Behavior Change Techniques in Physical Activity Interventions for Adults With Substance Use Disorders

A Systematic Review

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Abstract

Objective: Increasing regular physical activity (PA) behaviour may be an effective adjunct intervention for substance use disorder (SUD) treatment. This systematic review aims to identify promising behaviour change techniques (BCTs), namely, BCTs present in the design of interventions evidencing significant short-term and/or long-term ($d \geq 0.15$ for objective measures and $d \geq 0.36$ for self-report measures) increase in PA and/or reduction of substance use, secondary psychological measures, and retention in the PA intervention.

Method: PRISMA guidelines were followed, and the search was performed on March 11, 2021 across databases including MEDLINE, PsycINFO, SPORTDiscus, Cochrane Library, CINAHL, ProQuest, Web of Science Core Collection, Google Scholar; Open Grey, and ProQuest Dissertations & Theses. Studies were included if they measured PA, included participants aged ≥18 years, were randomised control trials, and if participants were diagnosed with SUDs. The Cochrane RoB 2.0 Tool was used to assess risk of bias. BCTs from eligible studies were extracted, coded, and ranked according to their proportional presence across studies.

Results: The final synthesis included $k = 61$ studies with $N = 12,887$ participants. High heterogeneity across outcome measures, interventions and control conditions was found. In total, 477 applications of BCTs were identified. Instruction on how to perform the behaviour, social support (unspecified), behavioural practice/rehearsal, problem solving, pharmacological support, goal setting (behaviour), self-monitoring (behaviour), and biofeedback were the eight most frequently used promising BCTs across studies.

Conclusions: Incorporating the eight most promising BCTs identified in this review in future PA interventions in SUD populations may improve SUD outcomes.

Key words: *Physical activity, exercise, substance use disorders, behaviour change techniques, systematic review*

Public Health Significance Statement

This review found promising behaviour change techniques that should be incorporated in interventions using physical activity in the context of substance use disorder treatment. The application of these behaviour change techniques might reduce the use of substances, promote physical activity, improve secondary psychological outcomes like depression and anxiety, and foster treatment retention among people in treatment for substance use disorders.

Behaviour Change Techniques in Physical Activity Interventions for Adults with Substance Use Disorders: A Systematic Review

In 2017, substance use disorders (SUDs) were associated with 11.8 million global deaths (520,000 direct and 11.4 million indirect deaths through injuries or links to the development of various diseases). Estimates suggest that smoking tobacco accounts for 7.9% of global disease burden while alcohol use and use of other substances accounts for 4.2% and 1.3% of global disease burden, respectively (Degenhardt et al., 2018; Reitsma et al., 2021). The World Drug Report 2019 estimated 35 million people globally require SUD treatment (United Nations Office on Drugs and Crime, 2019). However, only around 7% of these people receive minimally effective treatment (Degenhardt et al., 2017). Current treatments for SUDs usually include a combination of in- and/or outpatient psychotherapeutic, psychosocial, or pharmacological interventions. However, high rates of attrition (Brorson et al., 2013), relapse (Brandon et al., 2007; Fleury et al., 2016), suicide (Poorolajal et al., 2016), and mental health co-morbidity (Bradizza et al., 2006; Wu & Blazer, 2014) limit the efficacy of these services. Identifying active components of interventions used in SUD treatment that positively affect outcomes is vital for the advancement of further treatment options.

Physical Activity Interventions for Substance Use Disorders

Physical activity (PA) might be a viable (adjunct) intervention that, if applied effectively, could successfully address some of these problems. Positive effects of PA range across physiological, psychological, and social domains (Bouchard et al., 2012). In terms of psychological outcomes, PA interventions may prevent relapse by increasing self-efficacy for changing substance use (Kadden & Litt, 2011), mitigate cravings and attentional biases (Van Rensburg et al., 2009, 2013), help with management of mental health problems and reduce

psychological distress (Paluska & Schwenk, 2000; Saxena et al., 2005), elicit social support in group settings (Abrantes & Blevins, 2019; Christensen et al., 2006), and increase self-esteem, prevention efficacy, and perceived physical health (Furzer et al., 2021). PA may activate the dopaminergic reward system and normalise dopaminergic signalling (Lynch et al., 2013) while also decreasing cravings through the production of endogenous opiates (Pareja-Galeano et al., 2013). Despite persuasive arguments (e.g., Read & Brown, 2003) for the potential positive effects of engaging in PA in SUD treatment, few methodologically rigorous studies have evaluated the efficacy of PA interventions for reducing substance use among individuals with SUDs, with evidence in support of these interventions being equivocal.

Past reviews and meta-analyses found PA to be a promising and potentially well-accepted adjunct intervention in SUD treatment. However, findings regarding its effects on substance use and psychological functioning were mixed (Colledge et al., 2018; Giménez-Meseguer et al., 2020; Linke & Ussher, 2015). These mixed results extend to reviews about the use of PA in the treatment of specific SUDs including alcohol use disorder (AUD; (Gür & Can Gür, 2020; Hallgren et al., 2017; Thompson et al., 2020) and tobacco use disorder (Klinsophon et al., 2017; Ussher et al., 2014; Zschucke et al., 2012). Further, there were high dropout rates (25-40%) across studies (e.g., Gür & Gür, 2020; Hallgren et al., 2017).

Reviews and meta-analyses have produced evidence in support of certain mental health benefits and increased physical fitness related to PA in SUD treatment. Nevertheless, the effect of PA on the reduction and/or abstinence of substance use remains inconclusive because high heterogeneity of primary data and study conditions and high risk of bias limit the generalisability of past findings.

Behaviour Change Techniques in Physical Activity Interventions for Substance Use Disorders

The application (or non-application) of certain effective components of behavioural interventions may account for some of the variance across study results. Michie et al. (2013) developed an interdisciplinary taxonomy of 91 observable and replicable single active components or techniques that are used in interventions to alter, redirect, or regulate behaviour (Michie & Johnston, 2011; Michie et al., 2011). These components are called behaviour change techniques (BCTs; Abraham & Michie, 2008). BCTs facilitate the description of typically complex interventions involving multiple interacting components (Craig et al., 2008; Michie et al., 2013). Identifying the use (or lack of) BCTs within interventions makes it possible to specify how interventions operate and which active components may be incorporated into future interventions to enhance their efficacy (Michie et al., 2015).

BCTs have been used for the reduction of alcohol use in AUD treatment. *Self-monitoring* was associated with largest effect sizes for reduced alcohol use in brief interventions (Michie et al., 2012). Several BCTs (e.g., *social support, reduce negative emotions,* and *problem solving*) have been found to be effective in preventing postpartum smoking relapse (Brown et al., 2019). In a systematic review of RCTs testing behavioural smoking cessation interventions, Black et al. (2020) found *prompting commitment, social reward,* and *identity associated with changed behaviour* to be predictive of higher smoking cessation rates. BCTs have also been used for the promotion of physical activity across different populations including pregnant women (Currie et al., 2013), people with dementia (Nyman et al., 2018), and older adults (French et al., 2014),with *self-monitoring* and *intention formation* being associated with the promotion of walking and cycling (Bird et al., 2013).

The Current Study

Notably, no review has assessed the effects of BCTs used in PA interventions for the promotion of PA and the reduction of substance use across different SUDs. Reporting of BCTs used in such interventions is generally inconsistent across studies. While only a few individual studies explicitly applied behavioural interventions or behavioural therapy using BCTs (e.g., Bernard et al., 2015; Brown et al., 2014), most studies have likely implicitly included BCTs in their interventions. Hence, the aims of this systematic review are to identify the most promising BCTs used in PA interventions associated with: (1) increased PA behaviour and reduced substance use across different SUDs and within individual SUDs, (2) positive secondary psychological outcomes (e.g., depression, anxiety, self-efficacy, motivation) across SUDs (high heterogeneity of outcome measures will likely render analysis for individual SUDs impossible), and (3) higher rates (≥70%) of retention in the PA intervention across SUDs and within individual SUDs. Thereby, we aim to identify active BCTs that are linked to positive substance use outcomes and may thus be incorporated into future PA interventions with SUD populations to enhance their efficacy.

Methods

The systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA-P) guidelines (Moher et al., 2015). The PICO framework (Richardson et al., 1995; Schardt et al., 2007) was used to develop the search strategy. Since heterogeneity of interventions, target behaviours, outcome measures and control conditions across studies did not warrant a meta-analysis, we conducted a systematic review of the literature. Prior to the commencement of the review, the study protocol was registered with *PROSPERO* (CRD42021231863) and the *Open Science Framework* (OSF; https://osf.io/xrgh6).

The initial search included papers that were published until March 11, 2021. Electronic databases (Gusenbauer & Haddaway, 2020), search terms and operators were identified in collaboration with a librarian and experts pursuant to the research questions. The following databases were searched: (1) MEDLINE, (2) PsycINFO, (3) SPORTDiscus (4) Cochrane Library, (5) CINAHL, (6) ProQuest, (7) Web of Science Core Collection, (8) Google Scholar; for grey literature: (9) Open Grey, (10) and ProQuest Dissertations & Theses. Results of the initial search were supplemented by suggestions from experts and scanning the references of retrieved articles. Eventually, the literature was imported into *EndNote X9*.

Transparency and Openness

The exact search strategy including a list of keywords used for respective databases and a list of eligible studies, a list of excluded studies detailing reasons for exclusion, extensive details of the studies that were included, all manipulations, all measures in the study, detailed tables of the BCTs that have been identified across all included studies, and a detailed risk of bias analysis are stored on the project OSF-page (https://osf.io/nc2fd/).

Eligibility Criteria

All published and non-published RCTs (including respective treatment manuals and study protocols) of any relevant PA treatment intervention for any SUD were considered. Studies were included if they involved (1) any type of PA as a primary component of an intervention, (2) participants aged 18 years or older, (3) had a RCT design, and (4) if participants were diagnosed with SUDs according to DSM-V (American Psychiatric Association, 2013) and/or ICD-10 (World Health Organization, 1993), or CCMD-3 (Chinese Classification of Mental Disorders; Chen, 2002) criteria (except for smoking cessation where participants did not need to meet criteria for nicotine use disorder). Studies were excluded if they (1) aimed to prevent the onset of

SUDs, (2) evaluated acute effects of exercise (i.e., measures taken immediately after a single bout of exercise), (3) evaluated exercise programs of less than 10 days duration, (4) the article was written in any language other than English or German, (5) the full-text was unavailable via institutional access or through direct correspondence with the author (i.e., two email requests/reminders, separated by two weeks), or (6) information required to compute an effect size for primary (i.e., promotion of PA or reduction of substance use) or secondary (i.e., psychological) outcomes was not sufficiently detailed in the full-text document and via direct requests made to the corresponding author, as per above.

Selection Process

Two independent reviewers (ST and LM) screened the retrieved literature. In a first step, the retrieved literature was imported into *Rayyan* (https://www.rayyan.ai/) for title and abstract screening. Good interrater reliability (Cicchetti & Sparrow, 1981) was reached ($\kappa = 0.763$). The second step consisted of a full-text review based on the eligibility criteria in which excellent interrater reliability (Cicchetti & Sparrow, 1981) was reached by the two reviewers ($\kappa = 0.934$). If consensus was not reached (i.e., sources were identified as suitable by one researcher but not the other), the suitability of the literature was discussed with the other co-authors until a consensus was reached.

Data Collection and Analysis

Pre-determined data from eligible studies including details on the type of the publication (e.g., journal article, dissertation, etc.), study design, participant characteristics, type and duration of interventions and control conditions, mode of delivery, primary and secondary outcome measures, and retention rates were extracted and recorded. Risk of bias of the studies was assessed using the Cochrane RoB 2.0 Tool (Sterne et al., 2019). Both reviewers completed an

online training for the application of BCTv1 (http://www.bct-taxonomy.com/) and identified

BCTs (using the coding principles from the BCTv1; Michie et al., 2013) that targeted the

promotion of PA and/or the reduction of substance use in the included studies. Frequency of

occurrence of BCTs across studies was calculated to define a list of promising BCTs for

interventions for SUDs. Brown et al. (2019) defined a BCT as 'promising' if it met one of two

criteria: its presence was identified in at least two interventions evidencing long-term (i.e., $p <$

0.05 reported at six-month follow-up) effects, or if it was present in more than 25% of all studies.

With regard to the first criterion, in our study a BCT was defined as 'promising' if it was present

in at least two interventions demonstrating efficacy for the reduction of substance use and/or the

promotion of PA. However, rather than p-values, measures of the magnitude of the experimental

effect (i.e., effect sizes based on formulae by Lipsey & Wilson, 2001) were used. An effect-size

of at least $d \geq 0.15$ was used as cut-off for objective measures and a medium effect size of $d \geq$

0.36 was used for self-report measures. Since determinants of behaviour may vary across

different phases of the behaviour change process, promising BCTs were recorded separately for

initial behaviour change (i.e., promising outcome after the intervention, referred to as 'short-term

effects') and for behaviour maintenance (i.e., promising results at $\geq$ three-month follow-up,

referred to as 'long-term effects'; Samdal et al., 2017). With regard to the second criterion by

Brown et al. (2019), BCTs were ranked according to their proportional presence across studies in

the absence of a 25% cut-off.

Deviations from Registered Protocol

While the pre-registration indicated that a small effect-size of at least $d \geq 0.20$ would be

used as cut-off for all studies, a small effect-size of at least $d \geq 0.15$ was eventually used as cut-

off for objective measures to account for potential inflation of published effects (i.e., publication

bias) in current studies (Schäfer & Schwarz, 2019) and a medium effect size of $d \geq 0.36$ was used for self-report measures (due to larger common method variance; Lovakov & Agadullina, 2021; Prince et al., 2020). A second deviation was that after a discussion with the librarian, we decided to omit searching the Database of Promoting Health Effectiveness Reviews (since it does not list RCTs) and Google Advanced Search (since potential adaptations of the search string were not straightforward). We further decided to also include SUDs diagnosed according to CCMD-3 criteria since criteria for psychiatric disorders are similar to the ICD and the DSM. Moreover, we only included studies that included PA as a primary component of an intervention. Lastly, we expanded our analysis to also include the most frequently used BCTs associated with high retetion rates to individual SUDs.

Results

The PRISMA 2020 guidelines (Page et al., 2021) have been followed for the reporting of the results. The initial search resulted in 43,937 hits. After removal of duplicates in *EndNote X9* (Bramer et al., 2016), 34,328 papers were included in the title and abstract review. A total of 155 articles were identified for further full-text analyses, of which 61 articles and 23 corresponding study protocols were included in the review (see Figure 1, Appendix 1). A list of excluded studies and respective reasons for exclusions can be found on the project OSF page.

Risk of Bias Analysis

The risk of bias analysis (see Figure 2, Appendix 2) indicated that most studies evidenced high risk of bias (50.8%) or at least some concern for bias (36.1%). More specifically, regarding the randomisation process, 9.8% of studies evidenced high risk of bias and 34.4% of studies evidenced some concern for bias. This bias resulted from the fact that six studies (Clark et al., 2005; Gary & Guthrie, 1972; Li et al., 2002; Marcus et al., 1991; Taylor et al., 1988; Zhang &

Zhu, 2020) did not provide enough information to determine if the allocation sequence was random. Further, in 24 studies (e.g., McKelvy et al., 1980; Smits et al., 2021; Zhu et al., 2018) the allocation sequence was not concealed until participants were enrolled and assigned to intervention or there was not enough information to determine concealment with certainty. Eventually, baseline differences suggesting a problem with the randomisation process, or not enough information about baseline measures, were found in ten studies (e.g., Marcus et al., 1995; Zhang & Zhu, 2020; Zhu et al., 2018). For bias due to deviations from intended interventions, 34.4% of studies showed high risk of bias and 4.9% of studies showed some concern. For missing outcome data, 27.9% of studies evidenced high risk of bias and 11.5% of studies showed some concern for bias. For bias due to outcome measures, 29.9% of studies showed high risk of bias and 36.1% of studies evidenced some concern. For biased selection of the reported results, 8.2% of studies evidenced high risk of bias and 59.0% of studies showed some concern.

Characteristics of Included Studies

The details of all included studies can be found in Table 1 (Supplemental materials). Most of the studies were research articles ($k = 59$) of which 41% ($k = 26$) were pre-registered. The majority of the studies targeted smoking cessation ($k = 37$). AUD ($k = 8$), stimulant use disorder ($k = 4$), methamphetamine use disorder ($k = 2$), cocaine use disorder ($k = 1$), opiate use disorder ($k = 2$), heroin use disorder ($k = 2$), and general SUD ($k = 5$) were targeted in the remaining studies. For the purposes of our analysis, it was decided to cluster studies targeting stimulants (i.e., general stimulant use disorder, cocaine use disorder, and methamphetamine use disorder; $k = 7$) and opioids (i.e., general opiate use disorder, heroin use disorder; $k = 3$). The total number of participants in all studies amounted to $n = 12,887$, ranging from $n = 14$ to $n = 2,318$ across studies. The duration of the interventions ranged from 10 days to 48 weeks, with

four to 360 total sessions. Group-based interventions were identified in 30 studies while 31 studies evaluated individual interventions. Interventions and control conditions, study populations, eligibility criteria, retention rates, and outcome measures evidenced high heterogeneity.

In sum, 56 studies included in this review evidenced promising BCTs. 1-28 different BCTs per study were found in the studies and study protocols (interrater reliability: $\kappa = 0.699$). *Instruction on how to perform the behaviour* ($k = 42$), *social support* (*unspecified)* ($k = 41$), and *behavioural practice/rehearsal* ($k = 32$) were the three most frequently used BCTs across studies. Likewise, the most frequently used promising BCTs across studies were *instruction on how to perform the behaviour* ($k = 40$), *social support* (*unspecified)* ($k = 37$), and *behavioural practice/rehearsal* ($k = 30$). Operational definitions and practical examples of these BCTs can be found in Table 2 (Appendix 3).

Most Promising BCTs for the Reduction of Substance Use across SUDs

Overall, 26 studies evidenced promising short-term effects for the reduction of substance use irrespective of the clinical target, with *social support (unspecified)* ($k = 20$), *instruction on how to perform the behaviour* ($k = 17$), and *behavioural practice/rehearsal* ($k = 16$) being the most frequently applied promising BCTs. Promising long-term effects for the reduction of substance use across SUDs were found in 16 studies with *social support (unspecified)* ($k = 13$), *instruction on how to perform the behaviour* ($k = 13$), and *problem solving* ($k = 12$) among the most frequently used BCTs with promising effects. Effect sizes in these studies ranged from $d = 0.18$ to $d = 1.30$ for objective measures and $d = 0.36$ to $d = 0.89$ for self-report measures.

Most Promising BCTs for the Promotion of PA across SUDs

Promising short-term effects for PA behaviour change across SUDs were identified in 21 studies. *Instruction on how to perform the behaviour* (k = 15), *social support (unspecified)* (k = 13), *biofeedback* (k = 10), and *behavioural practice/rehearsal* (k = 10) were the most frequently used promising BCTs in these studies. No study showed promising long-term effects for promotion of PA across SUDs. Effect sizes in these studies ranged from d = 0.15 to d = 3.78 for objective measures and d = 0.40 to d = 1.35 for self-report measures.

Most Promising BCTs for the Reduction of Substance Use in Specific SUDs

Promising short-term effects for the reduction of alcohol use were found in two studies with effect sizes ranging from d = 0.57 to d = 1.30 for objective measures and d = 0.52 for self-reported drinking. *Social support (unspecified)* (k = 2), *social support (emotional)* (k = 2), and *instruction on how to perform the behaviour* (k = 2) were the most frequently applied promising BCTs in these studies. Promising long-term effects for the reduction of alcohol use were identified in one study in which 17 different BCTs were used (d = 0.22). The reduction of opiate use was evident in two studies showing promising short-term effects. Participants showed reductions in self-reported substance use (d = 0.35 and d = 0.45, respectively), with *behavioural practice/rehearsal* being the most frequently used promising BCT. No study showed promising long-term effects for the reduction of opiate use. Promising short-term effects for the reduction of smoking behaviour was found in 19 studies, with *social support (unspecified)* (k = 16), *problem solving* (k =13), and *instruction on how to perform the behaviour* (k = 13) among the most frequently used BCTs with promising effects in these studies. Effect sizes ranged from d = 0.16 to d = 1.23 for objective measures and from d = 0.41 to d = 0.89 for self-reported measures. Promising long-term effects for the reduction of smoking behaviour was found in 14 studies with *social support (unspecified)* (k = 12), *problem solving* (k =11), and *instruction on how to perform*

the behaviour ($k = 11$) as most frequently used promising BCTs. Effect sizes ranged from $d = 0.18$ to $d = 0.69$ for objective measures and from $d = 0.57$ to $d = 0.85$ for self-reported measures. Substance use among people with stimulant use disorders was effectively reduced in the short-term in two studies, with *biofeedback* ($k = 2$), *social support (emotional)* ($k = 2$) and *adding objects to the environment* ($k = 2$) being the most frequently used promising BCTs. Effect sizes for objective measures ranged from $d = 0.27$ to $d = 0.36$. For self-report measures, effect sizes ranged from $d = 0.36$ to $d = 0.69$. Promising long-term effects were found in one study using *biofeedback*, *social support (emotional)*, *instruction on how to perform the behaviour*, and *adding objects to the environment.* Objective measures verified abstinence of methamphetamine three months ($d = -0.18$) and six months post treatment ($d = -0.23$). Promising short-term effects ($d = 0.50$) for the self-reported reduction of general substance use were found in one study with five different BCTs, while no study evidenced promising long-term effects.

Most Promising BCTs for the Promotion of PA in Specific SUDs

Promising short-term effects for the promotion of PA in AUD were found in five studies, with *social support (unspecified)* ($k = 4$) and *biofeedback* ($k = 3$), being the most frequently used BCTs with promising effects. Effect sizes for objective measures ranged from $d = 0.24$ to $d = 3.78$. For self-report measures, effect sizes ranged from $d = 0.80$ to $d = 1.35$. Short-term promotion of PA among people who use opioids was promising in two studies in which *behavioural practice/rehearsal* ($k = 2$) was the most frequently used promising BCT. One study objectively verified increases in in-session activity ($d = 1.87$) among the exercise group compared to controls. The other study reported self-report measures of increased PA ranging from $d = 0.41$ to $d = 0.99$. People who smoke effectively increased PA in the short-term in nine studies, with *problem solving* ($k = 8$), *social support (unspecified)* ($k = 8$), and *goal setting*

(behaviour) ($k = 7$) among the most frequently applied promising BCTs. Effect sizes ranged from $d = 0.15$ to $d = 0.98$ for objective measures and from $d = 0.40$ to $d = 0.88$ for self-reported measures. Three studies reported promising short-term effect for the promotion of PA in people with stimulant use disorders (objective measures ranged from $d = 0.17$ to $d = 0.62$) with *instruction on how to perform the behaviour* ($k = 3$) being the most frequently used promising BCT. Two studies evidenced increased PA among people with general SUD with *instruction on how to perform the behaviour* ($k = 2$) as the most frequently used BCT with promising effects. Effect sizes ranged from $d = 0.44$ to $d = 2.08$ for objective measures. As mentioned above, no study showed promising long-term effects for the promotion of PA.

Promising Secondary Outcomes Associated with Certain BCTs

Various promising short-term secondary outcomes were identified in 17 studies. In those studies, *instruction how to perform the behaviour* ($k = 11$), *behavioural practice/rehearsal* ($k = 10$), and *social support (unspecified)* ($k = 8$) were the most frequently applied promising BCTs. No objective measures were reported for secondary outcomes while subjective measures ranged from $d = 0.36$ to $d = 2.86$. Four studies evidenced promising short-term results for depression with effect sizes for objective measures ranging from $d = 0.36$ to $d = 0.95$. *Social support (unspecified)* ($k = 4$), *biofeedback* ($k = 3$), *instruction how to perform the behaviour* ($k = 3$), and *behavioural practice/rehearsal* ($k = 3$) were the most frequently used promising BCT. Likewise, four studies showed promising short-term effects for anxiety with effect sizes ranging from $d = 0.42$ to $d = 2.00$. *Instruction how to perform the behaviour* ($k = 4$), *social support (unspecified)* ($k = 2$), *demonstration of the behaviour* ($k = 2$), and *behavioural practice/rehearsal* ($k = 2$) were the most frequently applied promising BCTs in these studies. Only one study showed promising long-term effects for secondary outcomes. It included 12 different promising BCTs.

High PA Retention Rates Associated with Certain BCTs across SUDs

Retention rates refer to the percentage of participants that remained in the respective study condition (e.g., PA intervention or control; depending on the level of detail reported in the study) at the time of the data collection (i.e., end of treatment or follow-ups). Criteria for remaining in the PA intervention differed across studies. High retention rates equal to or more than 70% were found in 30 studies at the end of the treatment period. *Instruction how to perform the behaviour* ($k = 22$), *social support (unspecified)* ($k = 20$) and *behavioural practice/rehearsal* ($k = 20$) were the most frequently used promising BCTs in these studies. In three-month (or longer) follow-ups, four studies showed high retention rates for PA equal to or more than 70%. Among those, *instruction how to perform the behaviour* ($k = 4$), *social support (unspecified)* ($k = 3$), *behavioural practice/rehearsal* ($k = 3$) and *self-monitoring of behaviour* ($k = 3$) were the most frequently used BCTs with promising effects.

High PA Retention Rates Associated with Certain BCTs in Specific SUDs

High retention rates equal to or more than 70% were found in four studies with people with alcohol use disorder at the end of the treatment period. *Social support (unspecified)* ($k = 4$), *social support (emotional)* ($k = 3$), *instruction on how to perform the behaviour* ($k = 3$), and *behavioural practice/rehearsal* ($k = 3$) were the most frequently used BCTs with promising effects. In three-month (or longer) follow-ups, one study with 18 different promising BCTs showed high retention rates equal to or more than 70% for the PA intervention. High retention rates equal to or more than 70% were found in two studies with people who use opioids at the end of the treatment period. *Instruction on how to perform the behaviour* ($k = 2$) was the most frequently used promising BCT. High retention rates equal to or more than 70% were found in 17 studies with people who smoke, with *social support (unspecified)* ($k = 14$) and

pharmacological support ($k = 13$) among the most frequently applied promising BCTs. In three-month (or longer) follow-ups, high retention rates equal to or more than 70% were found in three studies with *instruction on how to perform the behaviour* ($k = 3$) being the most frequently used promising BCT. Three studies evidenced high retention rates equal to or more than 70% among people with stimulant use disorders at the end of the treatment period. *Instruction on how to perform the behaviour* ($k = 3$) and *behavioural practice/rehearsal* ($k = 2$) were the most frequently used BCT with promising effects. Four studies showed high retention rates equal to or more than 70% among people with SUDs at the end of the treatment period. *Instruction on how to perform the behaviour* ($k = 3$) and *behavioural practice/rehearsal* ($k = 3$) were the most frequently used BCT with promising effects. No high retention rates equal to or more than 70% in three-month (or longer) follow-ups were found in opiate use disorders, stimulant use disorders, and SUDs.

Discussion

This is the first systematic review identifying promising BCTs in PA interventions for people with SUDs. We identified 477 applications of BCTs in 61 studies amounting to an average of 7.8 BCTs per intervention. This is comparable to the review by Brown et al. (2019) who found on average 7.7 BCTs per intervention in studies to prevent postpartum smoking. As expected, interventions, comparators, study duration, mode of delivery, sample demographics, eligibility criteria, and outcome measures were heterogenous across studies. Similar observations have been reported in other reviews (Hallgren et al., 2017; Thompson et al., 2020).

The most promising BCTs across all reviewed studies, presented in order of frequency, were *instruction on how to perform the behaviour*, *social support* (*unspecified*), *behavioural practice/rehearsal, problem solving, pharmacological support, goal setting (behaviour),* and

self-monitoring (behaviour). Other BCTs were less represented. *Instruction on how to perform the behaviour* and *behavioural practice/rehearsal* are widely applied BCTs in behavioural interventions that serve the purpose of outlining, initiating, scheduling, and maintaining certain behaviours (Michie et al., 2013). Since most PA interventions include at least some instruction (for reasons of safety) and repetition, the prominence of these BCTs is not surprising. The importance of *social support* in SUD treatment (Polcin & Korcha, 2017), its negative relation with prevalence of substance use (Rapier et al., 2019), and its positive relation with PA across different populations (Resnick et al., 2016; Springer et al., 2006; Treiber et al., 1991) is well described. Further, mutual support or self-help groups offering social support are historically well-established (Kelly, 2003) and effective (Bekkering et al., 2016; Parkman et al., 2015) components of recovery from SUDs. *Social support (unspecified)*, however, differs from the social support described in the addiction and PA literature. Whereas *social support (unspecified)* according to Michie et al. (2013) includes broader concepts such as noncontingent praise, reward for performance of target behaviour, encouragement, or counselling directed at the target behaviour, social support as described above refers to being part of a supportive social network. Interestingly, *social support (emotional)* which also includes psychotherapeutic interventions like cognitive behaviour therapy (CBT) was rarely identified among the most frequently used promising BCTs. This could indicate that brief interventions (like brief counselling) in combination with PA might be more effective to reduce substance use and promote PA among the target population.

   Problem solving helps individuals manage stressful situations and develop alternative coping strategies integral to relapse prevention (Demirbas et al., 2012), with problem solving therapy being a widely used evidence-based SUD treatment (Preusse et al., 2020). *Problem*

solving and *social support (unspecified)* were also among the most frequently used promising BCTs identified by Brown et al. (2019) for the prevention of postpartum smoking relapse. Further, *self-monitoring* showed some effectiveness in the reduction of substance use (Gass et al., 2021) and the promotion of PA (Izawa et al., 2005; Noland, 2013). *Goal setting* has been effectively used as a motivational technique in PA interventions (Kyllo & Landers, 1995; McEwan et al., 2015) and by means of motivational interviewing (MI; Miller & Rollnick, 2013) in SUD treatment. Meanwhile, *pharmacological support* was most frequently used in smoking cessation interventions. This is not surprising as nicotine replacement therapy is one of the most common and most effective interventions used for smoking cessation (Hartmann-Boyce et al., 2018). Depending on the SUD, there may be effective pharmacological treatments available. Accordingly, *pharmacological support* for certain SUDs might show promising effects. A similar trend of frequently used promising BCTs was observed for individual SUDs and there was no striking difference between promising BCTs used in interventions that were effective for initial behaviour change and behaviour maintenance.

While the same BCTs were also among the most frequently applied BCTs in promising interventions for the reduction of substance use, *biofeedback* was widely used in addition to abovementioned BCTs in promising interventions for the promotion of PA. This may be because *biofeedback* is currently more easily applicable to PA than to substance use. However, the successful use of smart devices for ecological momentary assessment and assessment based on physiologic data in SUD treatment is increasing (Carreiro et al., 2020). Activity monitoring through technological devices in combination with *goal setting* and *self-monitoring* has been recommended to increase PA in SUD populations (Abrantes et al., 2019; Abrantes & Blevins, 2019). This is further supported by a meta-analysis by Howlett et al. (2019) that showed

significant association between effective PA interventions and *biofeedback*, *demonstration of the behaviour*, *behavioural practice/rehearsal*, and *graded tasks*. Hence, future PA interventions should aim to include *biofeedback*, among other effective BCTs, and ecological momentary assessment and physiologic data on substance use and other health related variables as means to increase PA (and other health-related behaviours) and decrease substance use.

Curiously, no study evidenced promising long-term effects for the promotion of PA. In part, this might be explained by the fact that few studies collected long-term PA data. However, this might also highlight that sustaining motivation for PA remains a common barrier among those with SUDs (Abrantes & Blevins, 2019). Maintaining PA over time seems to be especially challenging for this population and, evidently, no study has effectively applied strategies to foster long-term PA motivation. In comparison, *action planning, instruction on how to perform the behaviour, prompts/cues, behavioural practice/rehearsal, graded tasks*, and *self-reward* have been associated with long-term promotion of PA in non-SUD populations (Howlett et al., 2019). Interventions that include techniques that aim to increase motivation, like MI, might be of value for the promotion of PA maintenance in SUD populations. MI was shown to enhance exercise adherence (Anshel & Kang, 2008) and treatment adherence in patients with SUDs and comorbid mental disorders (Swanson et al., 1999). It may also increase self-efficacy and patient activation (Linden et al., 2010). A recent study (Hardcastle et al., 2017) has identified 16 of the 38 MI techniques proposed by Miller and Rollnick (2013) to match BCTs determined by Michie et al. (2013). Surprisingly, these BCTs were rarely applied in the studies included in this review. It is conceivable that these BCTs may be effective for the reduction of substance use, the promotion of PA, or to increase treatment adherence (and motivation). Future studies should develop interventions that specifically aim to foster motivation for PA maintenance in SUD populations.

Promising secondary outcome measures were quite heterogenous and included, among others, self-report measures of depression, anxiety, stress, self-efficacy, irritability, and craving. Unfortunately, the heterogeneity of the measures did not allow for a meaningful comparison of effect sizes across studies for measures except for depression and anxiety. Amongst studies showing promising short-term improvements for secondary outcomes *instruction on how to perform the behaviour*, *behavioural practice/rehearsal,* and *social support* (*unspecified)* were, again, the most frequently used promising BCTs. They were, however, closely followed by *biofeedback* which, as for promotion of PA, was linked to promising effects in secondary outcome measures, as well. For depression and anxiety, the most frequently used promising BCTs closely resemble those for overall secondary outcomes. Only a single study identified in the review showed promising long-term effects for secondary outcome measures. This is because it was the only study that reported follow-up measures for secondary outcomes.

Instruction on how to perform the behaviour, *behavioural practice/rehearsal,* and *social support* (*unspecified)* were the BCTs with promising effects most frequently used in studies showing short-term and long-term PA retention rates of equal to or more than 70%. They were closely followed by the other promising BCTs that were most frequently applied across studies. Intuitively, it makes sense that behavioural repetition and social support foster treatment adherence in PA interventions for SUD. Several authors have suggested that higher adherence rates may be achieved through improving social support (Abrantes & Blevins, 2019; Christensen et al., 2006; Marcus et al., 2005). In a systematic review of adherence to prescribed exercise in patients with persistent musculoskeletal pain, *social support, goal setting, instruction on how to perform the behaviour, demonstration of behaviour,* and *behavioural practice/rehearsal* were shown to improve exercise adherence (Meade et al., 2019). Overall, promising BCTs associated

with high retention rates for individual substance use disorders resemble those frequently used across studies. One remarkable exception to this is *social support (emotional)* among people with AUD. It may be the case that elaborate psychotherapeutic interventions (like CBT and MI) foster treatment retention in AUD treatment (see Swanson et al., 1999). *Pharmacological support* was another exception among smokers suggesting that it is a well-received intervention that may facilitate retention. Nevertheless, it is noteworthy that only 49% of the studies showed retention rates of ≥70%. This further supports the fact that treatment motivation remains an important issue in PA interventions in SUD populations. Low rates of treatment adherence may be approached through the involvement of participants' social networks, individually targeted exercise strategies and strategies to increase self-efficacy, psychological need satisfaction, and self-determined motivation (Ntoumanis et al., 2021; Roessler et al., 2017).

Limitations

Potential limitations of the reviewed empirical base include the heterogeneity of interventions, comparators, study duration, mode of delivery, sample demographics, eligibility criteria, and outcome measures. Hence, a meta-analysis was not possible. Other reviews (Brown et al., 2019; Campbell et al., 2018; Hallgren et al., 2017; Thompson et al., 2020) have remarked similar issues of substantial heterogeneity of the primary data, small sample sizes, heterogenous intervention (e.g., running, coordinative training, circuit training, yoga, weightlifting) and control conditions (e.g., standard care, group therapy, card games, group discussions, wellness groups, education groups), diverse objective (e.g., heart rate, blood pressure) and subjective (e.g., self-reported activity) measures of physical activity, a range of psychological outcomes (e.g., depression, mood, anxiety), and varying adherence rates. Therefore, PA interventions for SUD could not be combined and compared via effect size calculations. The risk of bias analysis

revealed a high risk of bias among most of the studies that were included, and consequently, confidence that the results of the included studies represent true treatment effects is low. Similar high risk of bias has been reported in other reviews (Thompson et al., 2020; Ussher et al., 2014). Almost all included studies were conducted in high income countries and generalisability of findings to low-and middle-income countries is thus limited.

In terms of limitations of our review, although study protocols were examined and authors were consulted, the level of detail necessary for BCT coding was not available in all publications. It is thus likely that some studies have applied more BCTs than were identified in our review. It was usually unfeasible to determine which BCTs targeted the reduction of substance use and which BCTs targeted the promotion of PA. Further, the frequency with which BCTs have been used within interventions was impossible to determine in most included studies. How well certain BCTs were applied or conveyed and if they were used with fidelity remains uncertain. These are common issues in BCT coding; imprecise descriptions of interventions have been criticised in the past (Michie et al., 2009). It is thus recommended that future publications offer detailed and well-specified descriptions of the interventions that are used in order to facilitate scientific evaluation and translational processes. Further, a causal relationship between the frequency with which promising BCTs are present across studies and promising effects for the reduction of substance use, the promotion of PA, secondary outcome measures or retention rates cannot be demonstrated. Future studies should investigate the optimal threshold for the number of promising BCTs that may be used within a single intervention.

Conclusion

In sum, the same BCTs were promising (with minor variations) across conditions in our study. Eight BCTs have repeatedly shown significant effects above our cut-off scores, namely

instruction on how to perform the behaviour, *social support* (*unspecified*), *behavioural practice/rehearsal, problem solving, pharmacological support, goal setting (behaviour), self-monitoring (behaviour),* and *biofeedback.* Although certain BCTs have evidenced greater effect sizes in individual studies, we believe that it may be advisable to incorporate the BCTs that have frequently evidenced links to significant effects as standard components in future PA interventions with people who have SUDs. Treatment motivation, PA motivation and PA retention remain important issues that should receive more consideration in future interventions. Improving the overall quality of evidence and the quality of reporting details of the delivery of interventions is essential to facilitate BCT coding for future studies.

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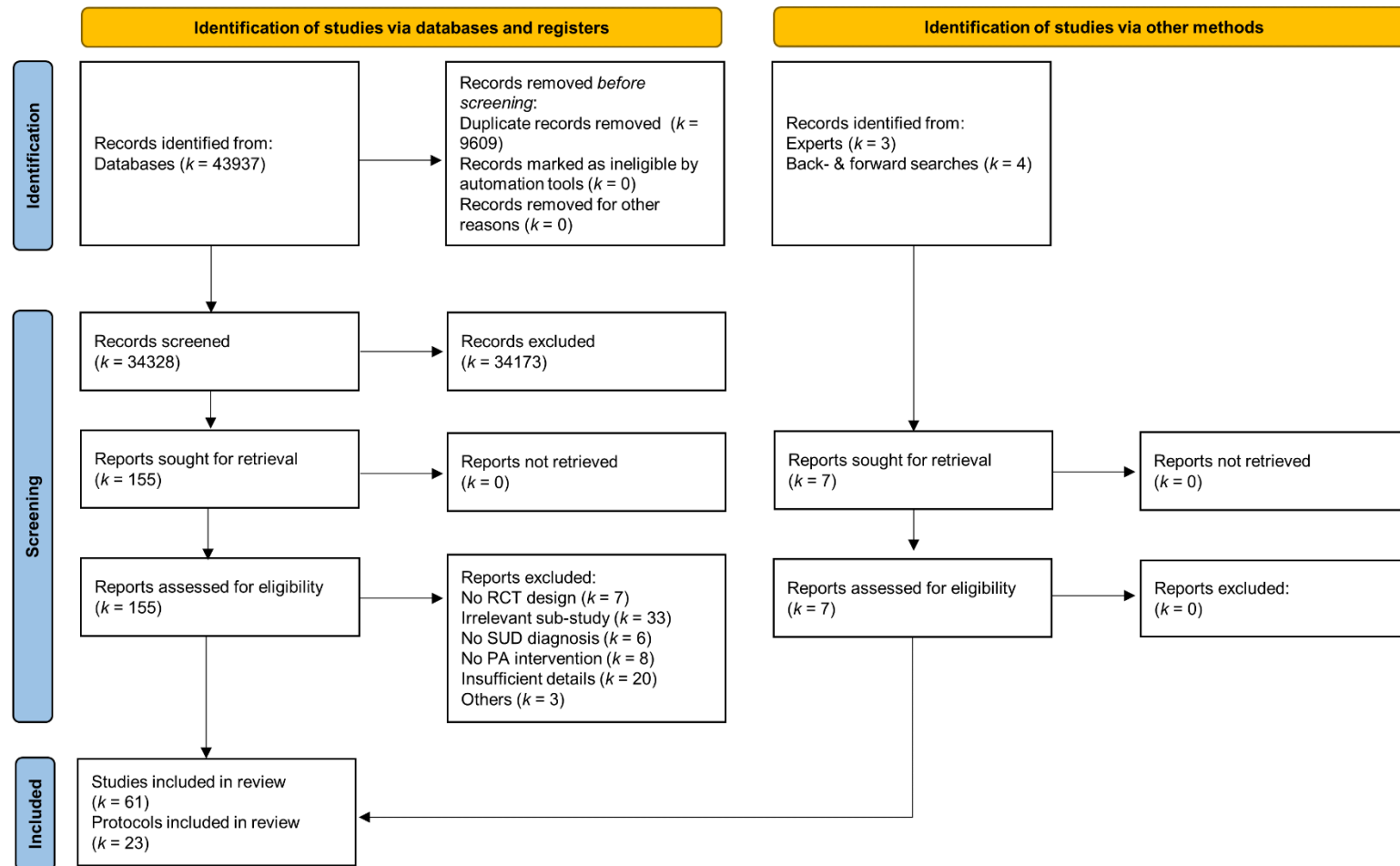and Sons Ltd. https://doi.org/10.1002/14651858.CD002295.pub5

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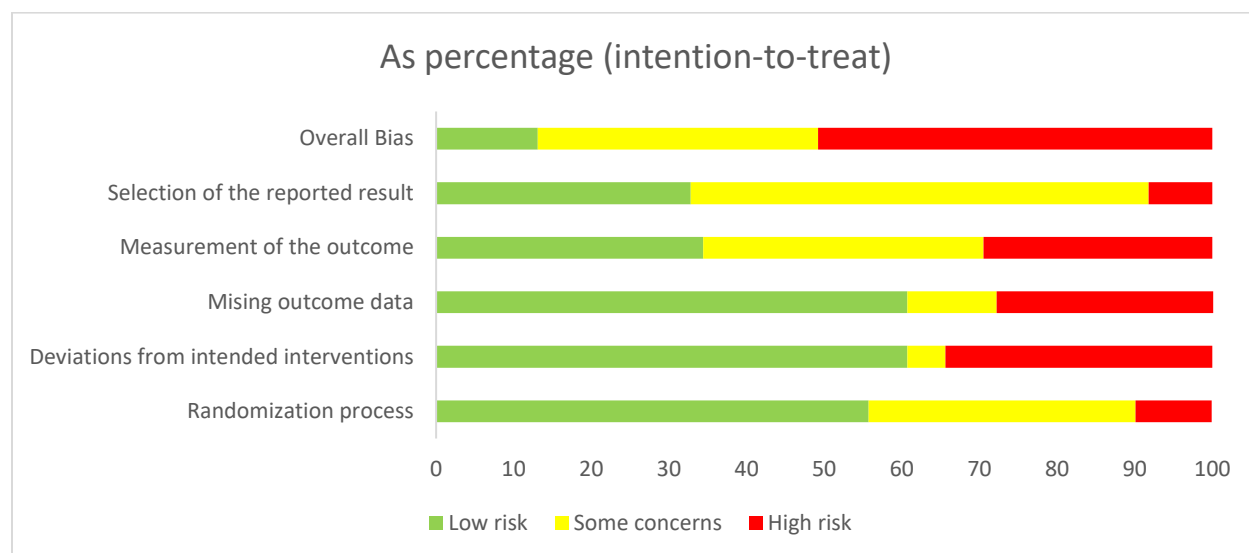
Appendices

Appendix 1

Figure 1

Prisma 2020 flow diagram

Identification of studies via databases and registers		**Identification of studies via other methods**	

Identification

Records identified from:
Databases (*k* = 43937)

→ Records removed *before screening*:
Duplicate records removed (*k* = 9609)
Records marked as ineligible by automation tools (*k* = 0)
Records removed for other reasons (*k* = 0)

Records identified from:
Experts (*k* = 3)
Back- & forward searches (*k* = 4)

Screening

Records screened
(*k* = 34328)

→ Records excluded
(*k* = 34173)

Reports sought for retrieval
(*k* = 155)

→ Reports not retrieved
(*k* = 0)

Reports sought for retrieval
(*k* = 7)

→ Reports not retrieved
(*k* = 0)

Reports assessed for eligibility
(*k* = 155)

→ Reports excluded:
No RCT design (*k* = 7)
Irrelevant sub-study (*k* = 33)
No SUD diagnosis (*k* = 6)
No PA intervention (*k* = 8)
Insufficient details (*k* = 20)
Others (*k* = 3)

Reports assessed for eligibility
(*k* = 7)

→ Reports excluded:
(*k* = 0)

Included

Studies included in review
(*k* = 61)
Protocols included in review
(*k* = 23)

Appendix 2

Figure 2

Risk of bias analysis[1]

As percentage (intention-to-treat)

| | Low risk | Some concerns | High risk |

Appendix 3

Table 2

Details of identified BCTs across studies

BCT	K	Operational Definition	Practical Example	Illustrative Application
4.1. Instruction on how to perform a behaviour	42	Advise or agree on how to perform the behaviour (includes 'Skills training')	Educate about the use of the patch prior to quit date	Abrantes et al., 2014
3.1. Social support (unspecified)	41	Advise on, arrange or provide social support (e.g., from friends, relatives, colleagues,' buddies' or staff) or noncontingent praise or reward for performance of the behaviour. It includes encouragement and counselling, but only when it is directed at the behaviour	Smoking cessation counselling	Ciccolo et al., 2011
8.1. Behavioural practice/rehearsal	32	Prompt practice or rehearsal of the performance of the behaviour one or more times in a context or at a time when the performance may not be necessary, in order to increase habit and skill	Participate in the circuit Monday through Friday for three weeks	Piorkowski & Axtell, 1976
1.2. Problem solving	31	Analyse, or prompt the person to analyse, factors influencing the behaviour and generate or select strategies that include overcoming barriers and/or increasing facilitators (includes 'Relapse Prevention' and 'Coping Planning')	Guidance on possible withdrawal symptoms and how to deal with them, identification of and coping plans for urges, cravings, and high-risk situations	Kinnunen et al., 2008
11.1. Pharmacological support	28	Provide, or encourage the use of or adherence to, drugs to facilitate behaviour change	Receive varenicline as pharmacological aid to smoking cessation	Oncken et al., 2020
1.1. Goal setting (behaviour)	24	Set or agree on a goal defined in terms of the behaviour to be achieved	Set a quit date for the morning of the week-6 group session	Clark et al., 2005

2.3. Self-monitoring of behaviour	24	Establish a method for the person to monitor and record their behaviour(s) as part of a behaviour change strategy	Instruct to measure heart rate during running	Jensen et al., 2019
2.6. Biofeedback	20	Provide feedback about the body (e.g., physiological, or biochemical state) using an external monitoring device as part of a behaviour change strategy	Give a pedometer to encourage physical activity, which is also used as a tool to monitor progress	Maddison et al., 2014
1.4. Action planning	18	Prompt detailed planning of performance of the behaviour (must include at least one of context, frequency, duration and intensity). Context may be environmental (physical or social) or internal (physical, emotional or cognitive) (includes 'Implementation Intentions')	Detailed planning of what the person will do including when, in which situation and/or where to act	Bernard et al., 2015
5.1. Information about health consequences	16	Provide information (e.g., written, verbal, visual) about health consequences of performing the behaviour	Provide information regarding the psychological and physical benefits of moderate intensity exercise	Brown et al., 2014
3.3. Social support (emotional)	15	Advise on, arrange, or provide emotional social support (e.g., from friends, relatives, colleagues, 'buddies' or staff) for performance of the behaviour	Receive Cognitive Behavioural Therapy	De la Garcia et al., 2016
6.1. Demonstration of the behaviour	11	Provide an observable sample of the performance of the behaviour, directly in person or indirectly e.g., via film, pictures, for the person to aspire to or imitate (includes 'Modelling')	Precise use of language, demonstration, and observation when teaching the technique	Bock et al., 2019
2.1. Monitoring of behaviour by others without feedback	10	Observe or record behaviour with the person's knowledge as part of a behaviour change strategy	Exercise specialist monitors physical activity participation during the supervised exercise sessions by using a physical activity log	Marcus et al., 2005
2.2. Feedback on behaviour	10	Monitor and provide informative or evaluative feedback on performance of the behaviour (e.g., form, frequency, duration, intensity)	Provide feedback on the current smoking status and progression on relevant psychological factors	Oenema et al., 2008
11.2. Reduce negative emotions	10	Advise on ways of reducing negative emotions to facilitate performance of the behaviour (includes 'Stress Management')	Emphasise how to manage negative affect	Nair et al., 2017

1.5. Review behaviour goal(s)	9	Review behaviour goal(s) jointly with the person and consider modifying goal(s) or behaviour change strategy in light of achievement. This may lead to re-setting the same goal, a small change in that goal or setting a new goal instead of (or in addition to) the first, or no change	Follow up on the smoking cessation goals that were made during the previous session	Hill, 1993
10.2. Material reward (behaviour)	9	Arrange for the delivery of money, vouchers or other valued objects if and only if there has been effort and/or progress in performing the behaviour (includes 'Positive reinforcement')	Get paid $15 for completing weeks 1–6, $25 for weeks 7–12, and $10 for the 6-month follow-up	Ciccolo et al., 2011
14.5. Rewarding completion	9	Build up behaviour by arranging reward following final component of the behaviour; gradually add the components of the behaviour that occur earlier in the behavioural sequence (includes 'Backward chaining')	Those completing moderate exercise up to three times a week earn a "bonus" draw	Islam, 2013
8.2. Behaviour substitution	6	Prompt substitution of the unwanted behaviour with a wanted or neutral behaviour	Do the 10s-E whenever craving or smoking urge is expected	Cheung et al., 2020
10.8. Incentive (outcome)	6	Inform that a reward will be delivered if and only if there has been effort and/or progress in achieving the behavioural outcome (includes 'Positive reinforcement')	Earn $700 if all study visits are completed	Cutter et al., 2014
12.5. Adding objects to the environment	6	Add objects to the environment in order to facilitate performance of the behaviour	Receive a free handgrip	Cheung et al., 2020
1.3. Goal setting (outcome)	5	Set or agree on a goal defined in terms of a positive outcome of wanted behaviour	Teach "SMART" principles (specificity, measurable, attainable, realistic, time-frame) of setting a goal	Prapevessis et al., 2016
1.8. Behavioural contract	5	Create a written specification of the behaviour to be performed, agreed on by the person, and witnessed by another	Set a quit date that involves a contract with fellow group members	Hill, 1993

2.4. Self-monitoring of outcome(s) of behaviour	5	Establish a method for the person to monitor and record the outcome(s) of their behaviour as part of a behaviour change strategy	Receive a heart rate monitor and instructions to measure heart rate during running	Jensen et al., 2019
2.5. Monitoring outcome(s) of behaviour by others without feedback	5	Observe or record outcomes of behaviour with the person's knowledge as part of a behaviour change strategy	Research staff obtains baseline measures (e.g., heart rate (HR), blood pressure (BP)) with ongoing monitoring throughout the treadmill session	Islam, 2013
2.7. Feedback on outcome(s) of behaviour	5	Monitor and provide feedback on the outcome of performance of the behaviour	Provide feedback with regard to the social, physical, and self-evaluative outcomes of quitting	Oenema et al., 2008
8.4. Habit reversal	5	Prompt rehearsal and repetition of an alternative behaviour to replace an unwanted habitual behaviour	Engage in a short bout of exercise each time a cigarette is craved	Linke et a., 2012
5.6. Information about emotional consequences	4	Provide information (e.g., written, verbal, visual) about emotional consequences of performing the behaviour	Provide detail about how exercise improves mood and reduces cigarette craving/withdrawal	Patten et al., 2017
10.1. Material incentive (behaviour)	4	Inform that money, vouchers or other valued objects will be delivered if and only if there has been effort and/or progress in performing the behaviour (includes 'Positive reinforcement')	Receive a sports T-shirt, and 100 Swiss francs as reward for participation	Colledge et al., 2017
10.3. Non-specific reward	4	Arrange delivery of a reward if and only if there has been effort and/or progress in performing the behaviour (includes 'Positive reinforcement')	Earn incentives in the form of token draws for prizes for each instance of observed treadmill walking during a scheduled exercise session	Islam, 2013
12.3. Avoidance/reducing exposure to cues for the behaviour	4	Advise on how to avoid exposure to specific social and contextual/physical cues for the behaviour, including changing daily or weekly routines	Break the link between environment and smoking behaviours	Thompson et al., 2016
5.5. Anticipated regret	3	Induce or raise awareness of expectations of future regret about performance of the unwanted behaviour	Focus on how the person will feel in the future and specifically whether they will feel regret or feel sorry that they did or did not take a different course of action	Bernard et al., 2015

7.1. Prompts/cues	3	Introduce or define environmental or social stimulus with the purpose of prompting or cueing the behaviour. The prompt or cue would normally occur at the time or place of performance	Receive a daily email reminding participants to login to the website in order to complete their daily records and read their daily lesson/handout	Linke et a., 2012
10.4. Social reward	3	Arrange verbal or non-verbal reward if and only if there has been effort and/or progress in performing the behaviour (includes 'Positive reinforcement')	Give praise or other rewards for the effort the smoker is making and if the smoker has engaged in activities such as correct use of cessation medication	Bernard et al., 2015
10.6. Non-specific incentive	3	Inform that a reward will be delivered if and only if there has been effort and/or progress in performing the behaviour (includes 'Positive reinforcement')	Every time a participant completes 30 minutes at a level, they receive an escalating number of prize draws	Islam, 2013
12.1. Restructuring the physical environment	3	Change, or advise to change the physical environment in order to facilitate performance of the wanted behaviour or create barriers to the unwanted behaviour (other than prompts/cues, rewards and punishments)	Advise on ways of changing the physical environment to minimise exposure to smoking cues	Bernard et al., 2015
13.2. Framing/reframing	3	Suggest the deliberate adoption of a perspective or new perspective on behaviour (e.g., its purpose) in order to change cognitions or emotions about performing the behaviour (includes 'Cognitive structuring')	Change the participant's perspective to exercise, from one of fitting exercise into their life to fitting their life around exercise	Maddison et al., 2014
13.5. Identity associated with changed behaviour	3	Advise the person to construct a new self-identity as someone who 'used to engage with the unwanted behaviour'	Receive their respective group t-shirt to reinforce group identity	Prapevessis et al., 2016
14.10. Remove punishment	3	Arrange for removal of an unpleasant consequence contingent on performance of the wanted behaviour (includes 'Negative reinforcement')	A $100 deposit is refunded upon completion of the final follow-up session	Marcus et al., 1999
3.2. Social support (practical)	2	Advise on, arrange, or provide practical help (e.g., from friends, relatives, colleagues, 'buddies' or staff) for performance of the behaviour	Enact the necessary procedures to ensure that the smoker gets his/her medication easily and without charge	Bernard et al., 2015
9.1. Credible source	2	Present verbal or visual communication from a credible source in favour of or against the behaviour	The exercise physiologist provides information regarding the psychological and	Brown et al., 2014

			physical benefits of moderate intensity exercise	
10.9. Self-reward	2	Prompt self-praise or self-reward if and only if there has been effort and/or progress in performing the behaviour	Generate personal rewards for accomplished exercise goals	Brown et al., 2014
11.3. Conserving mental resources	2	Advise on ways of minimising demands on mental resources to facilitate behaviour change	Advise on ways of minimising activities that require mental effort	Bernard et al., 2015
15.3. Focus on past success	2	Advise to think about or list previous successes in performing the behaviour (or parts of it)	Create a list of improvements seen or felt in participants since the beginning of the exercise program	Prapevessis et al., 2016)
15.4. Self-talk	2	Prompt positive self-talk (aloud or silently) before and during the behaviour	Utilise positive self-statements	Brown et al., 2014
1.7. Review outcome goal(s)	1	Review outcome goal(s) jointly with the person and consider modifying goal(s) in light of achievement. This may lead to resetting the same goal, a small change in that goal or setting a new goal instead of, or in addition to the first	Review or analysis of the extent to which previously set outcome goals were achieved	Bernard et al., 2015
1.9. Commitment	1	Ask the person to affirm or reaffirm statements indicating commitment to change the behaviour	Encourage the smoker to affirm or reaffirm a strong commitment to start, continue or restart the quit attempt	Bernard et al., 2015
5.3. Information about social and environmental consequences	1	Provide information (e.g. written, verbal, visual) about social and environmental consequences of performing the behaviour	Provide information about the benefits and social and environmental costs of action or inaction to the individual	Bernard et al., 2015
6.2. Social comparison	1	Draw attention to others' performance to allow comparison with the person's own performance	Offer normative information about others' behaviour and experiences	Thompson et al., 2016
6.3. Information about others' approval	1	Provide information about what other people think about the behaviour. The information clarifies whether others will like, approve or disapprove of what the person is doing or will do	Involves information about what other people think about the target person's behaviour	Bernard et al., 2015
7.3. Reduce prompts/cues	1	Withdraw gradually prompts to perform the behaviour (includes 'Fading')	Environmental planning that involves removing smoking-related cues	Hill, 1993

7.4. Remove access to the reward	1	Advise or arrange for the person to be separated from situations in which unwanted behaviour can be rewarded in order to reduce the behaviour (includes 'Time out')	If participants do not complete three exercise activities in a week, they earn a draw for each activity completed (if any) but forfeit the bonus draws	Weinstock et al., 2020
7.7. Exposure	1	Provide systematic confrontation with a feared stimulus to reduce the response to a later encounter	Exercise is introduced as a means of systematic interoceptive exposure	Smits et al., 2016
8.6. Generalisation of a target behaviour	1	Advise to perform the wanted behaviour, which is already performed in a particular situation, in another situation	Prompt generalisation of a target behaviour	Thompson et al., 2016
8.7. Graded tasks	1	Set easy-to-perform tasks, making them increasingly difficult, but achievable, until behaviour is performed	Set graded tasks (for example, take 1 hour/day at a time)	Ussher et al., 2015
9.2. Pros and cons	1	Advise the person to identify and compare reasons for wanting (pros) and not wanting to (cons) change the behaviour (includes 'Decisional balance')	Outline the pros and cons of cutting down	Thompson et al., 2016
9.3. Comparative imagining of future outcomes	1	Prompt or advise the imagining and comparing of future outcomes of changed versus unchanged behaviour	Enhance the motivation to quit by increasing smoker's expected positive outcome expectations of quitting	Oenema et al., 2008
10.10. Reward (outcome)	1	Arrange for the delivery of a reward if and only if there has been effort and/or progress in achieving the behavioural outcome (includes 'Positive reinforcement')	All subjects make a $25.00 deposit with the understanding that it would be refundable under the following conditions […]	Hill, 1985
13.1. Identification of self as role model	1	Inform that one's own behaviour may be an example to others	Instructors prompt identification as role model	Thompson et al., 2016
14.1. Behaviour cost	1	Arrange for withdrawal of something valued if and only if an unwanted behaviour is performed (includes 'Response cost')	Missed sessions or failure to complete 30 minutes of treadmill walking result in a reset of prize draws to baseline level	Islam, 2013
14.3. Remove reward	1	Arrange for discontinuation of contingent reward following performance of the unwanted behaviour (includes 'Extinction')	Reward is reduced by four francs for each session missed	Colledge et al., 2017

| 14.4. Reward approximation | 1 | Arrange for reward following any approximation to the target behaviour, gradually rewarding only performance closer to the wanted behaviour (includes 'Shaping') | Prompt rewards contingent on progress | Thompson et al., 2016 |
| 15.1. Verbal persuasion about capability | 1 | Tell the person that they can successfully perform the wanted behaviour, arguing against self-doubts and asserting that they can and will succeed | Positively influence the attitude towards physical activity and perception of how easy performing this behaviour will be | Bize et al., 2010 |

Note: Operational definitions used for this study have been adapted with permission from Michie, S., Richardson, M., Johnston, M., Abraham, C., Francis, J., Hardeman, W., ... & Wood, C. E. (2013). The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Annals of behavioral medicine, 46*(1), 81-95. The Society of Behavioral Medicine is the copyright holder of the material.

Supplemental Materials

Table 1

Details of included studies

Publication	SUD	Duration	Intervention (I)	Comparator (C)	N	Retention rates	Primary outcomes cohen's d	Secondary outcomes cohen's d	Follow-up
Brown et al., 2014	AUD	12 weeks	• Moderate intensity exercise + Group behavioural treatment + Incentives + CBT (n = 26)	• Control (n = 23)	49	All participants: • End of treatment: 90% • 6-month follow-up: 88%	End of treatment: • Drinking days: d = -0.57* • Heavy drinking days: d = -1.30* 6 month follow-up: • Drinking days: d = -0.22* • Heavy drinking days: d = 0.08	N/A	6-month
Gary & Guthrie, 1972	AUD	4 weeks	• Physical training program + Standard treatment (n = 10)	• Standard treatment (n = 10)	20	N/A	• Physical activity level - Recumbent pulse rate: d = -0.87* - Standing pulse rate: d = -1.04* - Exercise pulse rate: d = -1.64* - Time for exercise pulse rate to return to standing: d = -3.78*	• Body Cathexis: d = 0.48** • Self-Cathexis: d = 1.43** • Gough Adjective Check - Self-Acceptance: d = 0.15 - Self-Criticality: d = 0.06 - Masculinity: d = - 0.39 - Dependency: d = -0.2 - Aggression: d = 0.17 - Heterosexuality: d = -0.25	N/A
Hallgren et al., 2014	AUD	10 weeks	• Yoga + Standard treatment (n = 8)	• Treatment as usual (TAU; n = 6)	14	All participants: 77.7%	• Number of standard drinks per day: d = 0.13 • Number of standard drinks per week: d = 0.61 • Gamma-glutamyltransferas: d = 0.81 • Carbohydrate-deficienttransferrin: d = 0.77	• Short Alcohol Dependence Data (SADD): d = 0.33 • Hospital Anxiety and Depression (HAD) Scale: d = -0.44**	6-month
Jensen et al., 2019	AUD	24 weeks	• Treatment as usual (TAU) and supervised physical exercise in groups (GR ; n = 16) • TAU and physical exercise on an individual basis (IND; n = 19)	• TAU (n = 22):	105	All participants: 54.2%	• TAU + GR vs. TAU - BLmax: d = 0.36* - HRmax: d = 0.07 - RER: d = 0.53* - RPE: d = 0.55 - Tmax: d = 0.36* - VO2max: d = 0.34* - TLFB: d = -0.16 • TAU + IND vs. TAU - BLmax: d = 0.63* - HRmax: d = 0.07 - RER: d = 0.49* - RPE: d = -0.19 - Tmax: d = 0.53* - VO2max: d = 0.64* - TLFB: d = -0.34	N/A	N/A

Study	Disorder	Duration	Intervention	Control	N	Retention	Outcomes (Physical/Substance)	Outcomes (Psychological)	Follow-up
McKelvy et al., 1980	AUD	4 weeks	• Jogging (n = 31)	• Control (n = 17)	48	N/A	• RHR: d = -0.24* • HR1M: d = -0.72* • HR3M: d = -1.20*	N/A	N/A
Piorkowski & Axtell, 1976	AUD	3 weeks	• Exercise (n = 12)	• Non-exercise (n = 14)	26	• All participants: 63.4%	• Step cycles: d = 1.13* • RHR: d = -0.07	N/A	N/A
Roessler et al., 2017	AUD	24 weeks	• Supervised group exercise (GE) + treatment as usual (n = 62) • Supervised individual exercise (IE) + treatment as usual (n = 60)	• Treatment as usual (TAU; n = 53)	175	End of treatment: • All participants: 77.7% 12-month follow-up: • All participants: 57.1%	• GE vs. C: - Abstinence rate: d = 0.03 - NDD: d = N/A - DDD: d = -0.14 • IE vs. C: - Abstinence rate: d = -0.03 - NDD: d = N/A - DDD: d = -0.52**	N/A	12-month
Weinstock et al., 2019	AUD	16 weeks	• Motivational interviewing + Contingency management (n = 33)	• Gym membership only (n = 33)	66	End of treatment: • I: 87.9% • C: 87.9%	• Cardiorespiratory fitness: d = 0.46* • Weekly exercise frequency: d = 0.80** • Weekly exercise MET hours: d = 1.35** • Weekly total standard drinks: d = 0.29 • Weekly binge drinking episodes: d = 0.24	• I: - Short Index of Problems Score: d = 0.22 - CES-D: d = -0.36**	N/A
De La Garza et al., 2016	CUD	4 weeks	• Exercise + CBT (n = 17)	Contact control + CBT (n = 7)	24	N/A	• Runners vs. Walkers: - Cigarettes/last 24h: d = 0.50 • Runners vs. Sitters: - Cigarettes/last 24h: d = -0.15 • Walkers vs. Sitters: - Cigarettes/last 24h: d = -0.69**	• Runners vs. Walkers: - Cocaine craving: d = 0.15 • Runners vs. Sitters: - Cocaine craving: d = -0.32 • Walkers vs. Sitters: - Cocaine craving: d = -0.52**	N/A
Colledge et al., 2017	HUD	12 weeks	• Exercise (n = 13)	• Control (n = 12)	24	C(I): 38.5% C(C): 45.5% SC(I): 53.8% SC(C): 9.1% NC(I): 7.7% NC(C): 45.5% C: Missed <5/23 sessions SC: Missed 6-18/23 sessions NC: Missed >18/23 sessions	• Physical activity level - IPAQ – 1: d = 0.50** - IPAQ – 2: d = 0.41** - IPAQ – 3: d = 0.99** - IPAQ – 4: d = 0.19 - IPAQ – 5: d = 0.11 - IPAQ – 6: d = 0.62** • I: Substance Use - Days secondary drug consumption: d = -0.43** - Days illicit heroin consumption: d = 0.55 - Days illicit cocaine consumption: d = -0.45** - Days alcohol consumption: d = 0.34 - Days cigarette consumption: d = 0.45 - Days unprescribed medication consumption: d = -0.07	• ADS: d = -0.16 • BSCS: d = 0.25 • PSS: d = -0.36**	N/A

Study	Disorder	Duration	Intervention	Control	N	Adherence	Outcomes	Outcomes	Follow-up
Li et al., 2002	HUD	10 days	• Qigong treatment group (n = 34)	• Medication-treatment group (n = 26)	86	All participants: 100%	N/A	• Qigong vs. Medication - Hamilton anxiety scores: d = -2.00** • Qigong vs. Nontreatment - Hamilton anxiety scores: d = -0.51**	N/A
Rawson et al., 2015	MUD	8 weeks	• Supervised progressive endurance and resistance training + Standard treatment (n = 69)	• Health and wellness education session + Standard treatment (n = 66)	135	• All participants: 66.6%	1-month post treatment: • Biochemically positive for methamphetamine use: d = -0.27* 3-month post treatment: • Biochemically positive for methamphetamine use: d = -0.18* 6-month post treatment: • Biochemically positive for methamphetamine use: d = -0.23*	End of treatment: • BDI: d = -0.43** • BDA: d = -0.49**	1-month, 3-month & 6-month
Wang et al., 2017	MUD	12 weeks	• Aerobic exercise training (n = 32)	• Attentional control program (n = 31)	63	• I: 78.1% • C: 80.1%	N/A	• I: • Go RT: d = -0.81* • Go accuracy: d = 1.53* • Nogo accuracy: d = 2.86* • Go-N2: d = -1.77* • Nogo-N2: d = -2.40*	N/A
Cutter et al., 2014	OUD	8 weeks	• Exercise games + Standard treatment (n = 15)	• Video games + Standard treatment (n = 14)	29	N/A	• In session activity: d = 1.87* • Extra-session activity: d = 0.16 • All: Weekly Substance Use Inventory: d = 0.36** • All: Urine toxicology screens: d = 0.49*	N/A	N/A
Uebelacker et al., 2019	OUD	12 weeks	• Yoga (n = 20)	• Health education (n = 20)	40	• I: 90.0% • C: 90.0%	N/A	• Between arm difference I vs. C: - Sadness: d = -0.17 - Anxiety: d = -0.42** - Irritability: d = -0.11 - Fatigue: d = -0.21 - Pain: d = -0.58*	N/A
Abrantes et al., 2014	SC	12 weeks	• Exercise + Standard Smoking Protocol (n = 30)	• Contact control + Standard Smoking Protocol (n = 31)	61	End of treatment: • I: 80.0% • C: 62.9% 6-month follow-up: • I: 71.4% • C: 45.7% 12-month follow-up: • I: 45.7% • C: 37.1%	• 7-day point prevalence: - End of treatment: d = 0.46** - 6-month follow-up: d = 0.50** - 12-month follow-up: d = 0.50** • Continuous abstinence: - End of treatment: d = 0.11 - 6-month follow-up: d = 0.57** - 12-month follow-up: d = 0.85** • Minutes of MVPA per week: d = 0.62**	• CES-D: d = 0.95** • PANAS positive affect: d = 0.53** • PANAS negative affect: d = 0.59** • Withdrawal symptoms—negative affect: d = 1.05** • Withdrawal symptoms—craving: d = 0.29 • Withdrawal symptoms—sleep: d = 0.68** • Withdrawal symptoms—somatic: d = 0.65**	6-month & 12-month
Bernard et al., 2015	SC	8 weeks	• Exercise + Counselling + Standard treatment (n = 35)	• Contact control + Standard treatment (n = 35)	70	End of treatment: • I: Group sessions: 82%, Home-based exercise: 63% • C: 75%	• End of intervention (week 8): d = -0.51* • 12-week visit: d = -0.51* • 24-week visit: d = -0.26* • 52-week visit: d = -0.30*	End of intervention: • HADS-D: d = 0.14 • HADS-A: d = 0.13 • TCQ-12: d = -0.01 • SSQ-12: d = -0.46**	3-month, 6-month & 12-month

Bize et al., 2010	SC	9 weeks	• Physical activity + Smoking cessation treatment (n = 229)	• Health education + Smoking cessation treatment (n = 252)	481	• I: End of treatment: 88% • C: End of treatment: 89% • I: 12-month follow-up: 49% • C: 12-month follow-up: 55%	• End of treatment continuous smoking abstinence: d = 0.02 • 26th week continuous smoking abstinence: d = -0.02 • 52nd week continuous smoking abstinence: d = -0.05	Comparison baseline to end of treatment: • Wisconsin Smoking Withdrawal Scale: d = -0.14 • CES Depression Scale: d = -0.27 • 4-item Perceived Stress Scale: d = -0.10	6-month & 12-month
Bock et al., 2012	SC	8 weeks	• Yoga + CBT for smoking cessation (n = 32)	• Wellness program + CBT for smoking cessation (n = 23)	55	I: 76.2% of yoga classes, 82.6% of smoking cessation group sessions C: 67.1% of wellness sessions, 78.2% of smoking cessation group sessions	• 24-hour quit: - End of intervention (week 8): d = 0.79* - 3 months: d = 0.60* - 6 months: d = 0.35* • 7-day quit: - End of intervention (week 8): d = 0.84* - 3 months: d = 0.60* - 6 months: d = 0.24*	End of intervention: • CESD-10: d = 0.07 • STAIT: d = -0.17 • SST: d = 0.19	3-month & 6-month
Bock et al., 2019	SC	8 weeks	• Yoga + CBT for smoking cessation (n = 113)	• Wellness program + CBT for smoking cessation (n = 114)	227	All participants: 94.7%	• 7PPA - End of treatment: d = 0.17*	N/A	3-month & 6-month
Cheung et al., 2020	SC	24 weeks	• Exercise encouragement (n = 108)	• Control (n = 100)	208	• I: - 64% reported they had done 10s-E at least once in the past 2 months - 36% had done it when they had a craving - 28% had done it more than once a day in the first week - 18% had sustained 10s-E for more than one month	6-month follow-up: • Self-reported abstinence in past 4 weeks: d = -0.12 • Validated abstinence: d = -0.13 • Self-reported abstinence in past 7 days: d = -0.08	N/A	6-month
Ciccolo et al., 2011	SC	12 weeks	• Exercise (n = 13)	• Control (n = 12)	25	End of treatment: • I: 92% • C: 92% 3-month follow up: • I: 62% • C: 50%	End of treatment: • 7-day point prevalence abstinence (PPA): d = 0.81* • Prolonged abstinence: d = 0.38* 3-month follow-up: • 7-day point prevalence abstinence (PPA): d = 0.63* • Prolonged abstinence: d = 0.38*	N/A	3-month

Study		Length	Intervention	Control	n	Abstinence rates	Effect sizes (smoking)	Effect sizes (other)	Follow-up
Clark et al., 2005	SC	12 weeks	• Exercise instructions + CBT (n = 21)	• Group sessions for weight management (n = 20)	41	N/A	End of treatment: • 7-day point prevalence abstinence: d = 0.29* 3-month follow-up: • 7-day point prevalence abstinence: d = 0.04	N/A	3-month
Gaskins et al., 2015	SC	8 weeks	• Vinyasa yoga program + CBT (n = 23)	• Wellness program + CBT (n = 15)	38	I: 20.1% C: 75.8%	• Wellness vs. Yoga - End of treatment: d = 1.23* - 3-month follow-up: d = 0.48* - 6-month follow-up: d = 0.48*	N/A	3-month & 6-month
Hill, 1985	SC	5 weeks	• Physical activity + Group counselling (n = 18)	• Group counselling (n = 18)	36	N/A	• Smoking behaviour End of treatment: d = 0.46** • Smoking behaviour 1-month follow-up: d = 0.46** • Smoking behaviour 3-month follow-up: d = 0.24 • Smoking behaviour 6-month follow-up: d = 0.24	N/A	1-month, 3-month & 6-month
Hill et al., 1993	SC	12 weeks	• Behavioural training and exercise (n = 18)	• Behavioural training only (n = 22) • Exercise only (n = 22)	82	• Behavioural training only: 65% • Behavioural training and nicotine gum: 66% • Behavioural training and exercise: 57% • Exercise only: 53%	• Behavioural training and exercise vs. Behavioural training only - Abstinence End of treatment: d = -0.28 - Abstinence 1-month follow-up: d = 0.04 - Abstinence 3-month follow-up: d = -0.15 - Abstinence 6-month follow-up: d = -0.11 • Behavioural training and exercise vs. Behavioural training and nicotine gum - Abstinence End of treatment: d = -0.28 - Abstinence 1-month follow-up: d = -0.18 - Abstinence 3-month follow-up: d = -0.69 - Abstinence 6-month follow-up: d = -0.21 • Behavioural training and exercise vs. Exercise only - Abstinence End of treatment: d = 0.22 - Abstinence 1-month follow-up: d = 0.83 - Abstinence 3-month follow-up: d = 0.07 - Abstinence 6-month follow-up: d = 0.69*	N/A	1-month, 6-month & 12-month
Kinnunen et al., 2008	SC	19 weeks	• Supervised exercise + Standard treatment (n = 92)	• Equal contact control (CC; n = 56)	181	End of treatment: • I: 23.9% • CC: 23.2% • SCC: 14.7% 8-month follow up: • I: 9.8% • CC: 12.5% • SCC: 5.9%	End of treatment: • I vs. CC: d = 0.03 • I vs. SCC: d = 0.34* 8-month follow-up: • I vs. CC: d = -0.15 • I vs. SCC: d = 0.30*	N/A	8-month
Linke et al., 2012	SC	12 weeks	• Exercise + Web-based tutorial (n = 19)	• Web-based tutorial (n = 19)	38	• All participants: 60.5% • I: 57.9% • C: 63.2%	• Number of cigarettes/day: d = 0.55 • FTND: d = 0.23 • LTEQ: d = 0.64**	End of treatment: - CES-D: d = -0.29 - Exercise Self-Efficacy: d = 0.04 - Smoking Cessation Self-Efficacy: d = -0.34	N/A

Study	Type	Duration	Intervention	Control	N	Adherence	Outcomes		Follow-up
Maddison et al., 2014	SC	24 weeks	• Usual Care Smoking Cessation + Exercise (n = 455)	• Usual Care Smoking Cessation (n = 451)	906	• All participants: 92.3% • I: 52 % completed at least 7/10 of intervention calls	• I: - Number of cigarettes/day in past 7 days: d = -0.11 - Number of cigarettes/day since nominated quit date: d = -0.11 - Total walking: d = 0.04 - Total moderate physical activity: d = -0.02 - Total vigorous physical activity: adjusted d = 0.03	N/A	N/A
Marcus et al., 1991	SC	15 weeks	• Smoking cessation + Exercise (n =10)	• Smoking cessation (n = 10)	20	• I: 66% • C: 100%	• VO2max: d = 0.62*	N/A	N/A
Marcus et al., 1995	SC	15 weeks	• Smoking cessation + Exercise (n = 10)	• Smoking cessation + Contact time (n = 10)	20	• I: 100% • C: 80%	• VO2max: d = 0.13 • Abstinent for 24h: d = -0.45* • Abstinent for ≥7days: d = 0.76* • Abstinent at end of treatment: d = 0.74* • Abstinent at 12-month follow-up: d = 0.74*	N/A	12-month
Marcus et al., 1999	SC	12 weeks	• Group-based CBT smoking cessation treatment + Exercise (n = 134)	• Group-based CBT smoking cessation treatment + Contact time (n = 147)	281	• End of treatment: - I: 68.7% - C: 64.6% • 3-month follow-up: - I: 58.2% - C: 49.9% • 12-month follow-up: - I: 56.0% - C: 50.3%	• VO2max: d = 0.54* • 7-day point prevalence abstinence at end of treatment: d = 0.25* • 7-day point prevalence abstinence at 3-month follow-up: d = 0.40* • 7-day point prevalence abstinence at 12-month follow-up: d = 0.23* • Continual abstinence at end of treatment: d = 0.41* • Continual abstinence at 3-month follow-up: d = 0.43* • Continual abstinence at 12-month follow-up: d = 0.48*	N/A	3-month & 12-month
Marcus et al., 2005	SC	8 weeks	• Cognitive–behavioural smoking cessation treatment for women + supervised group and home-based moderate-intensity exercise (CBT+EX; n = 109)	• CBT plus equal contact time with staff (CBT; n = 108)	217	• End of treatment: - I: 54.1% - C: 58.9% • 3-month follow-up: - I: 39.4% - C: 42.1% • 12-month follow-up: - I: 24.8% - C: 31.8%	• I: - 7-day point prevalence abstinence at end of treatment: d = 0.06 - 7-day point prevalence abstinence at 3-month follow-up: d = 0.57* - 7-day point prevalence abstinence at 12-month follow-up: d = -0.08 - Continual abstinence at end of treatment: d = 0.18 - Continual abstinence at 3-month follow-up: d = 0.40* - Continual abstinence at 12-month follow-up: d = 0	N/A	3-month & 12-month

Martin et al., 1997	SC	12 weeks	• Behavioural counselling plus exercise (BEX; n = 72)	• Standard treatment (ST; n = 70) • Behavioural counselling plus nicotine gum (BNIC; n = 63)	205	N/A	• End of treatment: - BEX vs. BNCI: d = 0.18* - BEX vs. ST: d = 0.66* • Abstinence at 6-month: - BEX vs. BNCI: d = 0.06 - BEX vs. ST: d = 0.24*	N/A	6-month
McKay et al., 2008	SC	24 weeks	• Active Lives (n = 1159)	• QSN intervention condition (n = 1159)	2318	• 3 month: - All participants: 44.3% • 6-month: - All participants: 39.2%	• Abstinence at 3-month: d < -0.01 • Abstinence at 6-month: d = 0.03 • Moderate physical activity at 6-month: d = 0.09 • Vigorous physical activity at 6-month: d = -0.05	N/A	N/A
Nair et al., 2017	SC	8 weeks	• SUTQ counselling intervention group (n = 50)	• Standard smoking cessation counselling control group (n = 51)	101	N/A	• Self-reported abstinence: d = 0.11 • Steps per day: d = 0.97*	N/A	1-month
Oenema et al., 2008	SC	4 weeks	Intervention (n = 1080): • Tailored online information modules on saturated fat intake, PA, and smoking cessation	Control (n = 1079): • Delayed treatment	2159	• End of treatment: - I: 79% - C: 84%	• Self-rated PA level: d = 0.01	N/A	N/A
Oncken et al., 2020	SC	24 weeks	• Exercise (n = 150)	• Control (n = 151)	301	• Phase I: - I: 86% - C: 84% • Phase 2: - I: 60% - C: 51% • Phase 3: - I: 31% - C: 21%	End of treatment: • 4- week continuous abstinence rate (CO-verified): d = 0.21* 12-month follow up: • 4- week continuous abstinence rate (CO-verified): d = -0.10	N/A	3-month, 6-month, 9-month & 12-month
Patten et al., 2017	SC	12 weeks	• Exercise (EX) + Smoking Cessation Counselling and Pharmacotherapy (n = 15)	• Health Education + Smoking Cessation Counselling and Pharmacotherapy (n = 15)	30	End of treatment: • I: 87% • C: 87%	End of treatment: • Max VO2: d = 0.98* • Overall physical activity: d = 0.15* • Smoking abstinence: d = 0.88* 6-month follow-up: • Smoking abstinence: d = 0.29*	• End of treatment: - PHQ-9 score: d = 0.08	6-month
Prapavessis et al., 2007	SC	12 weeks	• Exercise (EX; n = 35) • Exercise + Nicotine Replacement Therapy (EX+NRT; n = 33)	• Cognitive Behavioural Therapy for Smoking Cessation (CBT; n = 27) • Cognitive Behavioural Therapy for Smoking Cessation + Nicotine Replacement Therapy (CBT+NRT; n = 26)	142	• End of treatment: - I: 77.4% - C: 79.2% • 3-month follow-up: - I: 70.6% - C: 73.5% • 12-month follow-up: - I: 60.3% - C: 77.4%	End of treatment: • EX vs. EX+NRT: d = -0.93 • EX vs. CBT: d = -0.45 • EX vs. CBT+NRT: d = -0.78 • EX+NRT vs. CBT: d = 0.49* • EX+NRT vs. CBT+NRT: d = 0.16* 3-month follow-up: • EX vs. EX+NRT: d = -0.40 • EX vs. CBT: d = -0.18 • EX vs. CBT+NRT: d = -0.22 • EX+NRT vs. CBT: d = 0.22* • EX+NRT vs. CBT+NRT: d = 0.18* 12-month follow-up:	N/A	3-month & 12-month

						• EX vs. EX+NRT: d = -0.56 • EX vs. CBT: d = -0.74 • EX vs. CBT+NRT: d = -0.70 • EX+NRT vs. CBT: d = -0.18 • EX+NRT vs. CBT+NRT: d = -0.14		
Prapavessis et al., 2016	SC	26 weeks	• Groups: exercise + smoking cessation maintenance (E+SCM; n = 108) • Exercise maintenance + contact control (EM+CC; n = 106) • Smoking cessation maintenance + contact control (SCM+CC; n = 100)	• Contact control (CC; n = 95)	413	End of treatment: • All: 59.7% 12-month follow-up: • All: 46.2%	End of treatment: • E+SCM vs. EM+CC: d = 0.12 • E+SCM vs. SCM+CC: d = 0.19* • E+SCM vs. CC: d = 0.30* • EM+CC vs. SCM+CC: d = 0.07 • EM+CC vs. CC: d = 0.18* • SCM+CC vs. CC: d = 0.11 • METS: d = 0.12 12-month follow-up: • E+SCM vs. EM+CC: d = 0.40* • E+SCM vs. SCM+CC: d = 0.14 • E+SCM vs. CC: d = 0.35* • EM+CC vs. SCM+CC: d = -0.27 • EM+CC vs. CC: d = -0.06 • SCM+CC vs. CC: d = 0.21 • METS: d = -0.08	N/A	12-month
Prochaska et al., 2008	SC	24 weeks	• Exercise (n = 159)	• Control (n = 240)	399	• All participants: 96.6%	PA vs. Control: • MVPA: d = 0.79*	N/A	12-month
Richardson et al., 2020	SC	8 weeks	• Supervised Resistance training (RT; n = 20)	• Control Group (n = 20):	40	• I: 55.5% • C: 90.1%	End of treatment: • Total cigarettes smoked: d = 0.14	End of treatment: • The smoking Abstinence self-Efficacy survey (SASE): d = 2.24** • The Mood and Physical Symptom Scale (MPSS): d = 0.03	N/A
Smits et al., 2016	SC	15 weeks	• Exercise + Standard smoking cessation treatment (n = 72):	• Wellness education + Standard smoking cessation treatment (n = 64):	136	End of treatment: • I: 51.4% • C: 68.8 4-month follow-up: • I: 47.2% • C: 54.7% 6-month follow-up: • I: 47.2% • C: 50.0%	• PPA at each of the major end points among persons with high anxiety sensitivity: - I vs C: d = -0.57* • PA at each of the major end points among persons with high anxiety sensitivity: - I vs. C: d = -0.70* • PPA at each of the major end points among persons with low anxiety sensitivity: - I vs. C: d = -0.26* • PA at each of the major end points among persons with low anxiety sensitivity: - I vs. C: d = -0.25*	N/A	4-month & 6-month

Study		Duration	Intervention	Control	N	Adherence	Smoking/Physical activity outcomes	Psychological outcomes	Follow-up
Smits et al., 2021	SC	15 weeks	• Standard smoking cessation treatment + 60–85% HRR exercise (n = 77)	• Standard smoking cessation treatment + 20–40% HRR exercise (n = 73)	150	• All participants: 78.8%	6-month follow-up: • PPA: d = 0.44*	N/A	6-month
Taylor et al., 1988	SC	26 weeks	• Training (n = 107)	• Control condition (n = 53)	160	• Training: 77.5%	• Cigarettes/day: d = -0.89**	N/A	N/A
Thompson et al., 2016	SC	16 weeks	• The Exercise Assisted Reduction then Stop smoking intervention + Usual care (n = 49)	• Usual care (n = 50)	99	• I: 62.0% • C: 62.0%	• Cigarettes/day: d = -0.46** • CO (ppm): d = -0.13 • Total minutes MVPA per week: d = 0.40** • Total minutes MVPA per day: d = 0.40** • Accelerometer total minutes MVPA per day: d = 0.13	N/A	N/A
Ussher et al., 2003	SC	7 weeks	• Smoking cessation program + Exercise (n = 154)	• Smoking cessation program + Contact time (n = 145)	299	N/A	• Only for those remaining abstinent from smoking throughout the study: - Hours of moderate or vigorous exercise in the previous week: d = 0.88** - Hours of vigorous exercise in the previous week: d = 0.16 - Daily METs: d = 0.42** - Days with 30 minutes of moderate or vigorous exercise in the previous week: d = 0.33	N/A	N/A
Ussher et al., 2015	SC	8 weeks	• Behavioural cessation support + Physical activity intervention (n = 391)	• Behavioural cessation support (n = 393)	789	End of treatment: • All participants: 88.8%	• Self-reported continuous abstinence at end of pregnancy with biochemical validation: d = 0.11 • Self-reported continuous abstinence 4 weeks post-quit day, with validation: d = -0.13 • Self-reported continuous abstinence 6 months after birth: d = 0.24	N/A	6 months after birth
Vickers et al., 2009	SC	10 weeks	• Exercise counselling + Smoking cessation counselling (n = 30)	• Health education + Smoking cessation counselling (n = 30)	60	End of treatment: • All participants: 65.0%	• Abstinence at end of treatment: d = -0.21 • VO2: d = -0.09	End of treatment: • Hamilton Rating Scale for Depression: d = 0.12 • PANAS positive: d = -0.08 • PANAS negative: d = 0.14 6-month follow-up: • Hamilton Rating Scale for Depression: d = -0.77** • PANAS positive: d = 0.36** • PANAS negative: d = -0.37**	6-month

Study	Type	Duration	Intervention	Comparison	N	Adherence/Retention	Substance Use Outcomes	Other Outcomes	Follow-up
Whiteley et al., 2012	SC	12 weeks	• Smoking cessation CBT + Exercise (n = 166)	• Smoking cessation CBT + Contact control (n = 164)	330	End of treatment: • All participants: 100% 3-month follow-up: • All participants: 89% 6-month follow-up: • All participants: 84% 12-month follow-up: • All participants: 78.5%	End of treatment: • 7-Day PPA: d < -0.01 • Continuous abstinence: d < -0.01 3-month follow-up: • 7-Day PPA: d = -0.03 • Continuous abstinence: d = -0.05 6-month follow-up: • 7-Day PPA: d = 0.05 • Continuous abstinence: d = 0.16 12-month follow-up: • 7-Day PPA: d = 0.11 • Continuous abstinence: d = 0.34	N/A	3-month, 6-month & 12-month
Williams et al., 2010	SC	8 weeks	• Smoking cessation treatment + Exercise (n = 30)	• Smoking cessation treatment + Wellness contact control (n = 30)	60	End of treatment: • All participants: 98.3%	End of treatment: • 7-Day PPA: d = 0.62** • Continuous abstinence: d = 0.41** 1-month follow-up: • 7-Day PPA: d = 0.29 • Continuous abstinence: d = 0.17	N/A	1-month
Trivedi et al., 2017	STUD	36 weeks	• Vigorous Intensity High Dose Exercise Augmentation (DEI) + Treatment as usual (n = 152)	• Health Education Intervention (HEI) + Treatment as usual (n = 150)	302	Week 1-12: • I: 69.0% • C: 75.0%	• Percent of stimulant abstinent days based on TLFB: d = -0.05	N/A	N/A
Yan-guang et al., 2021	STUD	48 weeks	• High-intensity Interval Training (HIIT; n = 60)	• Moderate-intensity Continuous Training (MICT; n = 60)	120	End of treatment: • I: 66.7% • C: 76.7%	• Hand grip: d = -0.07 • Push up: d = 0.31* • Sit-and-reach: d = 0.24* • One-leg stand with eyes closed: d = -0.26	N/A	N/A
Zhang & Zhu, 2020	STUD	24 weeks	• Taijiquan Intervention + Routine rehabilitation exercises (n = 38)	• Routine rehabilitation exercises (n = 38)	76	• I: 100% • C: 89.5%	• Grip strength: d = -0.27* • Standing on one foot: d = 0.51* • Body flexion: d = -0.17*	• BDI: d = -0.20 • S-AI: d = -0.35 • T-AI: d = -0.66**	N/A
Zhu et al., 2018	STUD	24 weeks	• Tai Chi (n = 42)	• Standard Care (n = 38)	80	• I: 88.1% • C: 31.6%	• Hand grip: d = 0.02 • Sit-and-reach: d = 0.33* • One-leg stand with eye closed: d = 0.62* • PACER: d = 0.78*	• Subjective sleep quality: d = 0.04 • PSQI score: d = -0.53** • Self-rated Depression Scale: d = -0.33	N/A
Brellenthin et al., 2019	SUD	6 weeks	• Supervised exercise + Intensive Outpatient Programs (n = 11)	• Intensive Outpatient Programs (n = 10)	21	I: 91% C: 83%	• Continuous abstinence rates: d = 0.50**	End of intervention: • self-efficacy to abstain from drug use: d = 0.41** • depression: d = 0.27 • anxiety: d = 0.11	N/A

Flemmen et al., 2014	SUD	8 weeks	• High intensity training group (TG) + Standard treatment (n = 9)	• Conventional rehabilitation control group (CG; Standard treatment; n = 7)	16	I: 75% C: 58.3%	• Physical activity level - VO2 (L·min−1): d = -0.44* - VO2 (ML·kg−1·min−1): d = -0.96* - VE (L·min−1): d = -1.06* - RER: d = -0.67* - HR max (beats·min−1): d = -0.98*	• Anxiety: d = 0.77 • Depression: d = 0.19 • Insomnia: d = -0.04	N/A
Islam, 2013	SUD	6 weeks	• Behavioural incentives for physical activity + Standard treatment (n = 10)	• Standard treatment without incentives (n = 7)	17	End of treatment: • I: 41.2% • C: 40.0% 1-month follow-up: • I: 25.0% • C: 20.0%	N/A	• QIDS-SR: d = -0.11 • Levels of Craving for Cocaine: d = 0.49 • Sticking to it scale: d = 0.33 • Making time to exercise: d = 1.11**	1-month
Wimberly et al., 2018	SUD	12 weeks	• Treatment as usual + Yoga (n = 37)	• Treatment as usual (n = 36)	73	End of treatment: • I: 78% • C: 92%	• Substance use days: d = -0.31	N/A	N/A
Zhu et al., 2020	SUD	24 weeks	• Mind-Body Exercises (MBE; n = 50)	• Conventional exercise (n = 50):	100	• I: 88.0% • C: 86.0%	• Sit-and-reach: d = 0.48* • One-leg stand with eye closed: d = 0.47* • PACER: d = 1.48* • Running heart rate: d = -2.08*	• QOL-DA: d = 1.09**	N/A

* Promising effects size $d \geq 0.15$ for objective measures
** Promising effect size $d \geq 0.36$ for self-reported measures
AUD = Alcohol use disorder
CUD = Cocaine use disorder
HUD = Heroin use disorder
MUD = Methamphetamine use disorder
OUD = Opiate use disorder
SC = Smoking cessation
STUD = Stimulant use disorder
SUD = Substance use disorder

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