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Effects of mindfulness practice on performance and factors related to performance in long-distance running: a systematic review

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Fatigue, boredom, pain, performance anxiety, and negative thoughts are challenges characteristic of competitive running. Psychological skills training (PST) has been suggested to help athletes to better deal with these challenges and to improve performance, but the empirical support for PST techniques is equivocal. One psychological technique that is gaining support and has been successfully implemented in sport is the practice of mindfulness. Where conventional psychological skills training interventions aim to change dysfunctional thoughts and emotions, mindfulness focuses on altering the relationship to physiological and psychological states. This could help in dealing with the demands of distance running but this has yet to be examined. The review was focused on reviewing mindfulness interventions on performance and performance based factors in long distance running, assessing (a) mindfulness scores; (b) physiological performance-related factors; (c) psychological performance-related factors and; (d) performance outcomes. A search of relevant electronic databases yielded seven studies which met the inclusion criteria. The review provided some tentative support for the use of mindfulness interventions regarding, reducing competitive anxiety, attenuating immune responses to high-intensity running and increasing state mindfulness. However, due to the methodological weakness of studies more research is required using high-quality RCT designs.

Keywords: mindfulness, running, applied sport psychology, systematic review

Introduction

In common with other sports, success in long-distance running requires both physical and mental training. Fatigue, boredom, pain, performance anxiety, and negative thoughts are challenges characteristic of competitive running (Tuffey, 2000). It has been suggested that psychological skills training can help athletes to better deal with these challenges to improve performance (American Psychological Association Division 47, 2016). In the field of sport psychology, interventions have typically been based upon traditional psychological skills training (PST) such as self-talk, goal setting and imagery which are grounded in cognitive-behavioral techniques (Gustafsson, Lundqvist, & Tod, 2017; Whelan, Mahoney, & Myers, 1991). Despite the support for PST there is still concern that athletes experience difficulty in effective implementation (Birrer et al., 2012). Moreover, until a recent meta-analysis suggesting PST could be beneficial for endurance athletes (McCormick, Meijen, & Marcora, 2015), the utility of psychological strategies for endurance performance has not received much attention. In a subsequent qualitative study, it was suggested that experimental research should be directed at examining the ability of psychological interventions to reduce the psychological demands of endurance sports (McCormick, Meijen, & Marcora, 2018).

The empirical support for PST techniques has been equivocal, with performance benefits suggested as limited (Moore, 2009). However, one psychological technique that is gaining support and has been successfully implemented in sport is the practice of mindfulness (Gardner & Moore, 2017). Mindfulness is defined as a structured mind set to being aware of the present-moment experience in an accepting, non-judging, and non-avoiding way (Kabat-Zinn, 1994). A classic study of world-class marathon runners showed that they adopted an associative strategy, engaging with the sensations of fatigue and the thought processes they experienced during

competition (Morgan & Pollock, 1977). This could suggest a possible link between a mindful approach to long-distance running and performance. Moreover, merging of action and awareness, and complete focus on the task at hand are elements of being mindful and also characteristics of flow, a state suggested to be optimal for performance (Jackson et al., 1998). Meta-analyses have consistently established that optimal performance in a range of sports is associated with internal experiences like mood (Beedie, Terry, & Lane, 2000), self-confidence (Craft, Magyar, Becker, & Feltz, 2003; Moritz, Feltz, Fahrbach, & Mack, 2000; Woodman & Hardy, 2003), and anxiety control (Jokela & Hanin, 1999), suggesting a potential benefit for mindfulness practice. Related research encompasses several forms of mindfulness practice (e.g. different types of meditation or yoga) (Bergomi et al., 2015) or informal mindfulness practice in everyday life (Cebolla et al., 2017). Mindfulness is considered to potentially influence physiological and psychological states through various processes, such as bare attention, experiential acceptance, non-attachment, or clarity about one's internal life (Moore, 2009). Most conventional psychological skills training interventions aim to change dysfunctional thoughts and emotions (Pineau et al., 2014). In contrast, mindfulness focuses on altering the relationship to physiological and psychological states.

The National Institute for Health and Clinical Excellence (NICE) recommend Mindfulness Based Cognitive Therapy as a treatment approach for individuals who have had three or more episodes of depression with it being found to be as found to be as effective as antidepressants in preventing relapse as antidepressants (Williams et al, 2014). Mindfulness has also been found to be an effective intervention with individuals who have long term health conditions. Carlson (2012) conducted a narrative review evaluating the evidence and found reductions in stress, anxiety and depression. A Parliamentary all-party group published the

Mindful Nation report (2015) outlining recommendations for the role of Mindfulness in health, education, the workplace and the criminal justice system. There has been a burgeoning increase in research into the effectiveness of mindfulness in recent years in affecting psychological health and growing interest how it may be used as an intervention in sport.

The first reported mindfulness intervention in sport was in the early 1980s in rowing (Kabat-Zinn et al., 1985). After this introduction of mindfulness in sport, only a few applications of mindfulness and meditation are reported before the turn of the century. After years of growing popularity in clinical psychology and psychotherapy (Chiesa & Serretti, 2010; Martin, 1997) an increasing interest in mindfulness-based interventions has been observed in sports.

This interest led to the development of two sport-specific mindfulness-based intervention programs: the Mindfulness-Acceptance and Commitment approach (MAC) (Gardner and Moore, 2004) and the Mindfulness Sport Enhancement Program (MSPE) (Kaufman et al., 2009). Both are group interventions comprising multiple sessions over several weeks. There has been some recent support for the MAC approach suggesting it is more effective for reducing emotion regulation difficulties in athletes compared to PST (Josefsson et al., 2019).

Other interventions with athletes have applied exercises stemming from non-sport-specific mindfulness intervention programs. For example, Aherne et al. (2011) taught university-standard athletes from a range of sports several mindfulness exercises from Kabat-Zinn's Mindfulness-Based Stress Reduction Program (MBSR). The results showed that mindfulness practice improved performance and increased mindfulness and global flow scores.

The first systematic review of mindfulness-based interventions in sport evaluated single-case and qualitative studies, as well as non-randomized and randomized trials (Sappington & Longshore, 2015). Positive influences of mindfulness-based interventions on performance were

reported in some of the studies. The effects of mindfulness practice on sports performance and related parameters has been examined using a meta analytic approach twice. One review concluded that practice in mindfulness improves mindfulness scores and enhances performance in precision sports such as shooting and darts (Buhlmayer et al., 2017). The other concluded that mindfulness versus no intervention produces large effect sizes for improvement in mindfulness, flow and performance, and reduces competition anxiety (Noetel et al., 2017). While both reviews include some studies on or containing long-distance runners, neither focusses on long-distance running specifically. As such, it is not possible to separate the effects of mindfulness training on performance or associated factors in long-distance running from the effects synthesized from a wide variety of team and individual sports. Therefore, the potential benefits of mindfulness practice for long-distance running from the available evidence are currently unknown.

This systematic review aims to synthesize the effects of mindfulness-based interventions on performance and performance-related factors in long-distance runners by examining the effects of mindfulness training and practice on: 1. mindfulness scores; 2. physiological performance-related factors; 3. psychological performance-related factors and; 4. performance outcomes.

Methods

Search Strategy and Study Selection

We conducted the review according to the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) guidelines (Hutton et al., 2015). The content of four databases (Web of Science, PsycINFO, MEDLINE, and SPORTDiscus) was searched from inception to February 13th 2019 by two researchers independently. The databases

were chosen due to comprehensive date coverage and their use in related meta analyses (Buhlmayer et al., 2017; Noetel et al., 2017). The following search terms were applied: Run* AND Performance AND Mindful* OR Meditation OR Present moment OR Acceptance-based OR MAC approach OR Acceptance and Commitment Therapy. The search was restricted to studies written in English. We included studies if they were available at any time before the date of the search.

Articles from the search were tracked and a further search of potentially relevant articles and review papers in the reference sections was conducted. Duplicates were removed and the remaining studies were further screened by title, abstract and full text. Irrelevant articles were excluded. Inclusion or exclusion decisions were based on the judgment of the two independent researchers. Any discrepancies were resolved through discussion, and a third author was consulted in cases where agreement could not be reached.

Inclusion criteria

In accordance with the PICOS approach [population (P), intervention (I), comparators (C), main outcome (O), and study design (S)], the following inclusion criteria were used:

- Participants were healthy (novice/recreational, intermediate or elite) adults or adolescents over 16 years of age with no clinical conditions who regularly undertook distance running (P).
- Interventions focused on mental practice that promote a structured mind set to being aware of the present-moment experience in an accepting, non-judging, and non-avoiding way as defined by Kabat-Zinn (1994) (i.e. mindfulness/acceptance/commitment/ meditation) (I).

- Passive-inactive or alternative-active control groups not receiving mindfulness interventions were acceptable controls in RCTs (C).
- Mindfulness, physiological performance surrogates (i.e. heart rate, maximal and submaximal oxygen uptake, lactate response, rating of perceived exertion, immune function), psychological performance surrogates (i.e. anxiety, confidence/self-efficacy, thoughts during running) and performance (i.e. objective and self-reported race times) constituted the outcome measures (O).

We chose not to limit the review to randomized controlled trials (RCTs). Studies of all design types were included because non-randomized trials and simple before–after and case-control designs have been suggested to still have value in systematic reviews for exploring unknown benefits and harms, and adding to evidence from RCTs (Sterne et al., 2016) (S).

Quality Assessment

Studies were evaluated using a modified Downs and Black tool due to its ability to assess both randomized and non-randomized designs (Downs & Black, 1998). Two independent researchers completed the risk of bias assessments. As with study inclusion, discrepancies were resolved through discussion, with a third researcher consulted to resolve disagreements.

Data Extraction

We extracted participant characteristics, study design, type and characteristics of intervention (if used), type of control/comparison group (if included), outcome measures, and effect sizes for post-intervention difference between intervention and control/comparison groups (RCT and non-randomized CT), or before-to-after intervention difference in cohort studies. For correlational analyses, we extracted *r* values for relationships between mindfulness outcomes and performance or psychological surrogates of performance.

Effect size was calculated as Cohen's *d* using the mean difference and pooled SD when reported. Where SD was not reported, it was calculated either from the reported exact *p* values or from *t* or *F* statistics using formulas provided in the Cochrane Handbook for Systematic Reviews of Interventions (Higgins & Green, 2011).

We extracted only composite scores from questionnaires with subscales, and where two or more variations of mindfulness intervention were delivered, effect size was calculated as the mean response of intervention groups combined compared to the control/comparison group mean.

Synthesis of Results

There were limited studies on the population of interest. Moreover, few shared similar designs, interventions, comparison groups or outcome measures. Therefore, quantitative synthesis via meta-analysis would not lead to meaningful results (Deeks, Higgins & Altman, 2008). As such, we created summary tables for primary outcomes and assessed the available evidence in light of the study quality assessment using the Downs and Black tool (Downs & Black, 1998).

Results

Study Selection

After removal of duplicates, 698 papers were screened by abstract, 88 full-text papers were reviewed and seven met the criteria for inclusion (Figure 1).

Figure 1, flow diagram of search results about here

Study Characteristics

There were 235 runners across the seven studies ranging in standard from recreational to USA collegiate division 1 with an average age of 34 years. Six studies evaluated the effects of a

mindfulness intervention. Of those, three were RCTs, two were non-randomized control trials and one was a cohort/before-after study. One RCT available in conference abstract form only, reported no data and was not considered in the synthesis of results. One of the non-randomized control trials, using a waiting-list group as a comparison, subsequently pooled data from the first group to receive the intervention and the waiting-list group after they had received the intervention, and so became a simple cohort study (De Petrillo et al., 2009). The cohort/before-after study of Thompson et al. (2011) included archers and golfers in addition to runners. Only outcomes that were reported for runners separately were used. There was one observational study using correlational analysis. Studies meeting inclusion criteria are summarized in table 1.

Table 1 summary of studies here

Quality Assessment

The two included RCTs (Solberg et al., 1995; Solberg et al., 2000) did not conceal group allocation, and failed to blind participants, therapists and researchers to the allocation. Moreover, Solberg et al. (1995) also failed to adjust for difference at baseline in the subsequent analysis. The remaining non-randomized control trials (De Petrillo et al., 2009; Pineau, 2014), cohort study (Thompson et al., 2011) and observational study (Hanneman, 2013) all had high risk of bias from non-random allocation, and lack of control for other confounds (see table 2).

Table 2 Downs and Black tool scores here

Evidence for Improving Mindfulness

Neither of the RCTs had mindfulness as an outcome. The remaining non-randomized control trials, which had high risks of bias, are summarized in table 3. Pineau (2014) reported a very small and non-significant effect of mindfulness training, and De Petrillo et al., (2009) reported no significant differences in either state or trait mindfulness between the intervention

and waiting-list control group, but reported no descriptive or inferential data for this. Post-workshop data for the initial intervention group and for the waiting-list group after they had completed the intervention were subsequently pooled by these authors and analysis was performed on the pre-post change in the pooled sample. There was a large increase in state mindfulness but only a small and non-significant increase in trait mindfulness. Thompson et al. (2011) did not report changes in mindfulness in runners separately from archers and golfers. The mixture of effect sizes, difference in tools used to measure mindfulness change, and the low quality of the available evidence suggests an uncertain effect of short-term mindfulness training for improving mindfulness in distance runners.

Table 3 here

Evidence for Reducing Competitive Anxiety

One RCT (Solberg et al., 2000), one non-randomized control trial (Pineau, 2014) and one before-after study (De Petrillo et al., 2009) explored the effect of mindfulness interventions on competitive anxiety (see table 4). Though scoring well on the quality assessment tool, the RCT did not specify allocation procedures, did not blind participants or researchers to the allocation, had evidence of baseline differences between groups and did not attempt to power the study for a predetermined effect size. These sources of bias should be considered when interpreting the small-to-moderate reductions observed in the intervention group compared to the two types of control. The non-randomized control trial reported a small increase in state anxiety in comparison to the waiting-list controls. The non-random allocation, and other confounds such as the intervention delivery setting (open concourse of a busy sports centre) should be considered in interpreting this effect. Finally, the before-after trial reported a significant, moderate reduction in state anxiety after the MSPE intervention period. Though two of the three studies suggest small

to moderate reductions in anxiety, bias in the designs means the quality of this evidence was judged to be low.

Table 4 here

Evidence for Improving Performance

The effects of mindfulness interventions on distance running performance were explored by three studies comprising one non-randomized control trial (Pineau, 2014) and two before-after trials (De Petrillo et al., 2009; Thompson et al., 2011) with the latter also including correlational analysis of before-after change in performance with change in trait mindfulness. The non-randomized trial reported a small (non-significant) decrease in performance on a standardized time trial of an unspecified distance between the intervention and waiting-list controls. In an unplanned before-after comparison of intervention and control groups combined, De Petrillo et al., (2009) reported no significant change in best mile time but failed to provide data from which effect size could be calculated. Thompson et al. (2011) was a follow up study of the participants used by De Petrillo et al. (2009) and examined changes in best mile time for runners that received the intervention and were willing to return one year after their baseline measurement from the 2009 study. A large reduction in best mile time was reported though it should be noted that the effect is confounded by among other things, the design and the duration between time trials. The correlation analysis showed a large-negative association between change in trait mindfulness and change in best mile time.

Overall, the few studies that have examined performance enhancement in distance running after mindfulness training are of low quality and show inconsistent effects.

Table 5 here

Other Outcomes

Five studies included other psychological or physiological outcomes possibly linked with performance (see table 6). One RCT showed large reductions in immune system response after a maximal-intensity treadmill run in the intervention group compared to no-treatment controls (Solberg et al., 1995) while another showed small and non-significant impairments in physiological measures of recovery from a maximal-intensity treadmill run.

Pineau's (2014) non-randomized control trial found no effect of mindfulness training on confidence, and the before-after analysis of De Petrillo et al., (2009) reported no change in thought disruption or perfectionism. Finally, there was evidence of a moderate association between a mindfulness measure and perceived exertion during a submaximal treadmill run in an observational study.

In summary, there is some evidence of improved immune function and reduced effort perception. While the quality of the evidence is low, these outcomes could be possible avenues for future research of better quality.

Table 6 here

Discussion

The aim of this systematic review was to synthesize the effects of mindfulness-based interventions on performance and performance-related factors in long-distance runners by examining the effects of mindfulness training and practice on mindfulness, physiological and psychological performance-related factors and distance-running performance outcomes.

There were a limited number of studies examining the effects of mindfulness on performance and factors linked to performance in distance runners. While there is some evidence for positive effects of mindfulness-type interventions, the evidence is currently of generally low quality.

Effects ranged from very small to large for improvements in state mindfulness; small/moderate for reductions in anxiety and none/small/moderate for improvements in running performance. For all outcomes, the high risks of bias reduce confidence in interpretations of benefit. Our review also found some preliminary evidence for positive effects of mindfulness on immune function and reduced perception of effort, the latter arising from a simple observational study.

Changes in Mindfulness

The limited evidence specific to distance runners suggests limited effects of mindfulness practice on mindfulness skill. Two intervention studies attempted to measure mindfulness as an outcome. Only the cohort study of De Petrillio et al. (2009) showed improvements, and only in state and not in trait mindfulness. The non-randomized trial of Pineau (2014) used a different tool and found no change in the intervention group. These findings are in contrast to the consistently large effects reported in previous systematic reviews encompassing other sports (Bulmayer et al., 2017; Noetel et al., 2017). The durations of interventions were similar in studies on runners and those on other sports (4-8 weeks) so exposure is unlikely to explain the limited effects seen in runners. It has been previously suggested that benefits of mindfulness practice depends on tenacity and engagement with the sessions (Zhang et al., 2016). Such engagement in the practice process is difficult to determine yet remains a possible reason for lack of improvement in the runners studied. However, the difference in effects on mindfulness in runners compared to the evidence in other sports is most likely due to the limited number and low quality of the studies specific to distance runners. The development of mindfulness skills in runners after mindfulness interventions needs further study with high-quality randomized trials.

Changes in Psychological and Physiological Surrogates of Performance

Our findings on anxiety reduction in runners after mindfulness practice are largely consistent with previous reviews of other sports (Sappington and Longshore, 2015; Bulmayer et al., 2017; Noetel et al., 2017), and are also commensurate with previous research in clinical populations (Hofmann et al., 2010), with moderate reductions found for state anxiety, albeit from studies of generally low quality. Mindfulness interventions have an intended key mechanism of change where creating a different relationship with thoughts reduces the rumination or worry that maintains negative mood states. This could be a mechanism underpinning anxiety reduction effects, though it could be argued to using mindfulness to target anxiety reduction is at odds with the cultivation of simple non-judgmental acceptance of the anxiety that is present. Studies designed to compare anxiety reduction strategies with acceptance interventions would allow exploration of this suggestion.

Since distance running success is underpinned to a large extent by physiological factors, we also explored the effects of mindfulness on physiological responses that could impact on performance. One RCT showed slightly slower recovery from a high-intensity treadmill run as indicated by heart rate and blood lactate responses in the intervention group (Solberg et al., 2000). No studies have explored the effects of mindfulness on physiological responses during running and it is worth noting that long distance races are not performed at the limit of oxygen uptake used by Solberg et al. (2000). Moreover, the observed association of reduced perception of effort in recreational runners during submaximal treadmill running at speeds similar to race paces, and self-reported mindfulness, suggest a potential benefit of mindful awareness during running and could be related to the key mindfulness attitudes encouraged in practice of acceptance, non-judgmental awareness and letting go. Well controlled randomized intervention

trials are required to explore this. However, a study (Schuker, Schmeing & Hageman, 2016) examining running economy, a powerful predictor of race performance (Bassett & Howley, 2000), showed worse economy with an associative task focus on breathing and stride rate in recreational runners. Early work by Morgan and Pollack (1977), showed elite marathon runners adopted an associative strategy. The potential benefits of mindfulness on physiological responses during running are far from clear. Nevertheless, RCT evidence does suggest a potential benefit on immune responsiveness to exercise in runners. Solberg et al. (1995) found a reduced rise in immune markers after an intense treadmill run in the mindfulness intervention group. Lower salivary cortisol has been previously reported in elite shooters (John, Verma & Khanna, 2011) and both results agree with findings in healthy non-athletic populations (Sanada et al., 2016). These findings suggest that regular mindfulness practice could serve to reduce post-exercise inflammation and enhance recovery from training sessions in runners. Further studies should evaluate this proposal.

Effects on Running Performance

Only three studies have explored the effects on mindfulness interventions on distance running performance with inconsistent and mixed effects from none to moderate improvements. Interpretations of the effects are confounded by the low quality of the studies and by large durations between performance measures where many other factors could explain changes. Reviews of other sports have also reported limited study numbers, weak quality of many studies and inconsistent effects (Noetel, et al., 2017). Of the few high-quality RCTs in other sports, there seems to be some benefits to performance in precision sports of darts and shooting (Bulmayer et al., 2017). Success in such sports lacks the heavy dependence on physiological parameters characteristic of other sports, particularly distance running. This could explain lack of and

inconsistent evidence for performance benefits, in addition to the general dearth of high-quality studies on the effects of mindfulness intervention in runners.

Mindfulness practice versus other PST interventions

While there were some positive effects of mindfulness, similar to PST approaches, the evidence in support of mindfulness interventions for endurance running also remains far from clear. Though the quality of evidence was generally weak, our review found moderate reductions in performance anxiety after MSPE interventions. This is similar to other mindfulness-based interventions in sport which show some effectiveness in improving performance-based wellbeing (Gardner & Moore, 2012; Sappington & Longshore, 2015). PST approaches have also been deemed effective at reducing anxiety specifically through imagery in footballers (see Maynard, Smith & Warwick-Evans, 1995) and self-talk in tennis players (see Hatzigeorgiadis, Zourbanos, Mpoumpaki, & Theodorakis, 2009). Interestingly, relaxation has garnered more support in anxiety reduction for sport performance with beneficial effects noted in swimming and football (Fletcher & Hanton, 2001; Maynard et al., 1995). However it should be noted that just like mindfulness interventions, there are very few studies that have examined PST and anxiety in the context of endurance sports, and even fewer in running.

Our review found that one study reported a small non-significant decrease in endurance performance in a standardized time-trial, however, as this finding is non-significant and the effect size very small, little practical inference can be drawn. In comparison, traditional PST approaches including goal setting, self-talk and imagery have been reported to improve endurance performance in runners (Blanchfield et al., 2014; Burhans, Richman & Bergey, 1988; Tenenbaum, Spence & Christensen, 1999). However, these studies are also not without limitations, with many acknowledging confounds pertaining to the ecological validity of time to

exhaustion protocols that are not representative of running performance (performance being time to complete a set distance), issues with placebo groups and the omission of a placebo group respectively. Finally, in a whole-body endurance systematic review, PST was found to improve performance in five out of the 25 included studies on practical psychological interventions (McCormick, Meijen & Marcora, 2015). Upon review and despite some evident advantages for mindfulness-based running interventions, it is apparent that the research is susceptible to the same limitations that are often observed in PST approaches. These limitations specifically pertain to the difficulty in measuring performance, lack of placebo controls, lack of double-blinding and the omission of key psychological mediating variables such as perception of effort and self-efficacy.

Strengths and Limitations of this Review

We performed this review in accordance with PRISMA guidelines (Hutton et al., 2015). To our knowledge, this is the first systematic review to synthesise the effects of mindfulness interventions from the available evidence in distance runners. There were a limited number of studies using different standards of runner, different tools for assessing study outcomes, a variety of mindfulness interventions and only two RCTs among the six included studies. These factors led us to avoid pooling effect sizes due to the many sources of heterogeneity, and is a limitation of our study. The overall quality of the included studies ranged from mid-level for RCTs to low for the non-randomised, cohort and observational studies. Nevertheless, the review represents the best available overview of currently available evidence on the topic of mindfulness effect on performance and psychological and physiological factors linked with performance in distance runners.

Conclusions and Future Recommendations

The evidence suggests tentatively that mindfulness interventions have potential to increase state mindfulness, reduce competitive anxiety and attenuate immune responses to high-intensity running. There is also some evidence that mindfulness skill could reduce perception of effort. Currently there is little evidence for direct benefits to running performance. All findings should be interpreted with caution in light of the limited range and generally weak quality of studies on this population. More research using high-quality RCT designs are required with distance-running participants to further explore the potential benefits we have identified. These studies should include recognized mindfulness interventions delivered by qualified practitioners and should investigate effects on mindfulness, physiological surrogates of performance during running at race intensities, and should attempt to assess engagement with the mindfulness practices prescribed.

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Table 1. Characteristics of studies meeting inclusion criteria.

Citation	Participant description, n, mean (SD)	Study type	Intervention description	Comparison	Outcome Measures
Solberg et al. (1995)	12 competitive male runners, (median age 47 years)	RCT	Acem meditation 7-week course, requested to complete 30-min daily at home.	No-treatment control group	CD2+, CD4+ and CD8+ T cells (immune function before and after a VO2max test)
Regan, Aitchison, and Grant (1998)*	28 runners aged 24.4 (4.8) years	RCT	Meditation, audio file, unclear dose, informal practice prescribed	No- treatment	Competitive anxiety (STAI Y1); exploratory outcomes (body tension, perceived exertion, incredibly short Profile of Mood States, respiratory output)
Solberg et al. (2000)	31 male runners aged 39 (36–42) years	RCT	Acem, group with experienced instructors, 7 × 150 min contact, informal practice prescribed	Autogenic training, problem solving	Competitive anxiety (STAI); exploratory outcomes (maximal and recovery oxygen uptake, stress induced lactate, resting and recovery heart rate)
Pineau (2014)	55 cross-country runners ,USA Div 1 (29 female; 26 male); 19-35 yrs old	Non-randomised CT	6 x 90 min MSPE or MSPE+SC, daily practice encouraged but not formally tracked	No-treatment control group	State and dispositional mindfulness (TMS, FFMQ); State and dispositional flow (FFS 2, DFS 2); Competitive anxiety (SAS, CSAI-2); Competitive race times; Eating Attitudes Test, Multidimensional Body Self Relations Questionnaire, Body Image Coping Strategies Inventory, (SCS, CSCI, Thoughts During Running Scale)
De Petrillo, Kaufman, Glass, and Arnkoff (2009)c	25 (15 female) runners aged 34.73 (18– 55) years from USA; 6.68 years experience	Non-randomised CT and before/after	MSPE, group with first author, 4 × 150–180 min contact, encouraged to listen to mindfulness CD	Waiting list no-treatment control	State and dispositional mindfulness (TMS, KIMS); competitive anxiety (SAS); competitive performance (self-reported best mile time); exploratory outcomes (MPS; TOQS)
Thompson et al. (2011)	11 archers, 21 golfers, 25 runners	Before/after and correlational	MSPE, group with first author, 4 × 150–180 min contact, encouraged to listen to mindfulness CD	none	Best mile time. Runners are merged with archers and golfers for other outcomes.
Hanneman (2013)	90 college students (recreational runners), (32 female; 58 male); 24.1(3.5) yrs	Correlational	none	none	Dispositional mindfulness (FFMQ); exploratory outcomes (Ratings of Perceived Exertion via treadmill test, Body Awareness Questionnaire, Exercise Self Efficacy Scale)

Notes: Interventions: ACEM = Meditation style taught at Academic Meditation School; MSPE = Mindfulness Sport Performance Enhancement; SC = Self Compassion. * abstract only, no data, not included in results. FFMQ = Five Facet Mindfulness Questionnaire; KIMS = Kentucky Inventory of Mindfulness Scale; TMS = Toronto Mindfulness Scale; STAI = State Trait Anxiety Inventory; SAS = Sport Anxiety Scale; CSAI-2 = Competitive State Anxiety Inventory; CSCI = Carolina Sport Confidence Inventory; MPS = Multidimensional Perfectionism Scale; TOQS = Though Occurrence Questionnaire for Sport; DFS 2 = Dispositional Flow Scale; FFS 2 = Flow State Scale.

Table 2. Downs and Black quality assessment.

Citation	hypoth/aim/objectives	Main outcome described	Participant characteristics	Confounds described	Main findings described	Random variability estimates	Actual p values given	Representative sample	No data dredging	Follow up time differences	Appropriate statistical tests	Valid and reliable outcome measures	Adjustment for confounds	Random allocation to intervention	Appropriately powered
Solberg et al. (1995)	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	U
Regan, Aitchison, and Grant (1998)	Y	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	U	Y	U
Solberg et al. (2000)	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	U
Pineau (2014)	Y	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y	N	N	U
De Petrillo et al. (2009)c	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	N	U
Thompson et al. (2011)	Y	Y	N	N	Y	N	Y	Y	Y	Y	Y	Y	N	N	U
Hanneman (2013)	Y	Y	Y	N	Y	Y	Y	N	Y	N	Y	Y	N	N	Y

Table 3. Effects of mindfulness interventions for improving mindfulness.

Citation	N	Standard	Intervention	Dose (hours)	Comparison	Measure	Mindfulness ES	Statistical significance
Non-randomised control trials								
Pineau (2014)	55	USA Collegiate Div. 1	MSPE±SC	9	No treatment	FFMQ	I > C; 0.07	N
Before-after trials								
De Petrillo et al. (2009)	25	Recreational	MSPE	10-12		KIMS (trait)	B<A; 0.32	N
						TMS (state)	B<A; 1.15	Y

Notes: Measures: FFMQ = Five Facet Mindfulness Questionnaire; KIMS = Kentucky Inventory of Mindfulness Scale; TMS = Toronto Mindfulness Scale. Interventions: MSPE = Mindfulness Sport Performance Enhancement; SC = Self Compassion. Statistical significance N = $p > 0.05$; Y = $p < 0.05$.

Table 4. Effects of mindfulness interventions for reducing competitive anxiety.

Citation	N	Standard	Intervention	Dose (hours)	Comparison	Measure	Anxiety ES	Statistical significance
Randomised control trials								
Solberg et al. (2000)	31	Recreational	Acem	18	Autogenic training;	STAI	I < C; -0.43	N
					problem solving		I < C; -0.21	N
Non-randomised control trials								
Pineau (2014)	55	USA Collegiate Div. 1	MSPE±SC	9	No treatment	SAS	I > C; 0.3	N
Before-after trials								
De Petrillo et al. (2009)	25	Recreational	MSPE	10-12		SAS	B > A; 0.62	Y

Notes: Interventions: ACEM = Meditation style taught at Academic Meditation School; MSPE = Mindfulness Sport Performance Enhancement; SC = Self Compassion: Measurements: STAI = State Trait Anxiety Inventory; Sport Anxiety Scale. I < C = Intervention reduced more than controls; I > C = controls reduced more than intervention; B > A = reduced from before to after intervention. Statistical significance N = $p > 0.05$; Y = $p < 0.05$.

Table 5. Effects of mindfulness interventions for improving distance running performance.

Citation	N	Standard	Intervention	Dose (hours)	Comparison	Measure	Performance ES	Statistical significance
Non-randomised control trials								
Pineau (2014)	55	USA Collegiate Div. 1	MSPE±SC	9	No treatment	Time trial	I > C; 0.23	N
Before-after trials								
De Petrillo et al. (2009)	22	Recreational	MSPE	10-12		Best mile time	-	N
Thompson et al. (2011)	10	Recreational	MSPE	11		Best mile time	B > A; 0.76	N
Correlational studies								
Thompson et al. (2011)	10	Recreational	MSPE	11		Change in best mile time v Change in trait mindfulness	*r* = -0.85	Y

Notes: Interventions: MSPE = Mindfulness Sport Performance Enhancement; SC = Self Compassion. I > C = intervention slower than control; B > A = faster time trial after intervention. Statistical significance N = $p > 0.05$; Y = $p < 0.05$.

Table 6. Effects of mindfulness on other psychological and physiological factors related to performance.

Citation	N	Standard	Intervention	Dose (hours)	Comparison	Measure	ES	Statistical significance
Randomised control trials								
Solberg et al., (1995)	12	Recreational	Acem	18	NT	CD2+	I < C; 1.23	N
						CD4+	I < C; 0.36	N
						CD8+	I < C; 1.37	Y
Solberg et al., (2000)	31	Recreational	Acem	18	Autogenic training; problem solving	Post-ex lactate	I > C; 0.24	N
						Post-ex10 lactate	I > C; 0.38	N
						Rec HR	I > C; 0.22	N
						Rec VO_2	I > C; 0.26	N
Non-randomised control trials								
Pineau (2014)	55	USA Collegiate Div. 1	MSPE±SC	9	No treatment	CSCI	I < C; 0.04	N
Before-after trials								
De Petrillo et al. (2009)	25	Recreational	MSPE	10-12		MPS	B > A; 0.3	N
						TOQS	B = A; <0.00	N
Correlational studies								
Hanneman (2013)	90	Recreational	-	-		FFMQ v treadmill RPE	r = -0.25	Y

Notes: Measures: CD2+, CD4+, CD8+ = immune system T cells; Post-ex lactate; Post-ex10 lactate = blood lactate immediately after and 10 minutes after a treadmill VO_{2max} test; Rec HR and Rec VO_2 = reduction in heart rate and VO_2 5 mins after VO_{max} treadmill test; CSCI = Carolina Sport Confidence Inventory; MPS = Multidimensional Perfectionism Scale; TOQS = Though Occurrence Questionnaire for Sport. Statistical significance N = $p > 0.05$; Y = $p < 0.05$.

Figure 1. Flow diagram of study selection process.