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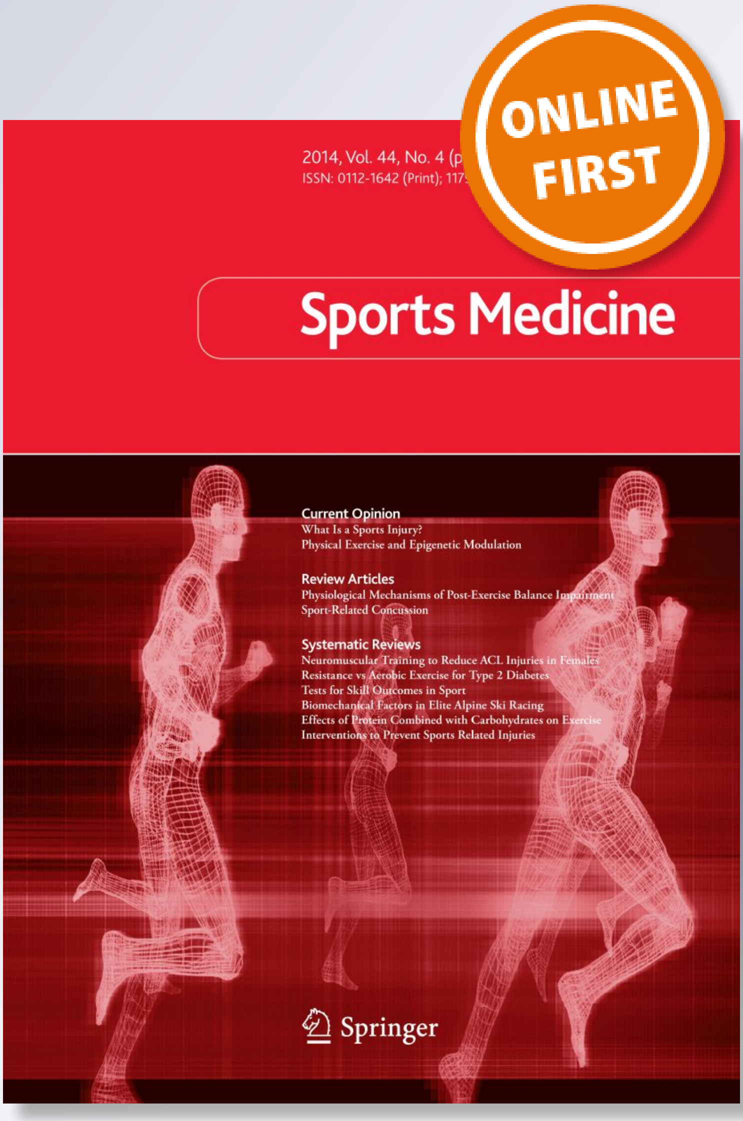
Sports Medicine

ISSN 0112-1642

Sports Med
DOI 10.1007/s40279-017-0752-9



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SYSTEMATIC REVIEW

Effects of Mindfulness Practice on Performance-Relevant Parameters and Performance Outcomes in Sports: A Meta-Analytical Review

Lucia Bühlmayer[1,2] · Daniel Birrer[1] · Philipp Röthlin[1] · Oliver Faude[2] · Lars Donath[2,3]

Abstract

Background Mindfulness as a present-oriented form of mental training affects cognitive processes and is increasingly considered meaningful for sport psychological training approaches. However, few intervention studies have examined the effects of mindfulness practice on physiological and psychological performance surrogates or on performance outcomes in sports.

Objective The aim of the present meta-analytical review was to examine the effects of mindfulness practice or mindfulness-based interventions on physiological and psychological performance surrogates and on performance outcomes in sports in athletes over 15 years of age.

Data Sources A structured literature search was conducted in six electronic databases (CINAHL, EMBASE, ISI Web of Knowledge, PsycINFO, MEDLINE and SPORTDiscus). The following search terms were used with Boolean conjunction: (mindful* OR meditat* OR yoga) AND (sport* OR train* OR exercis* OR intervent* OR perform* OR capacity OR skill*) AND (health* OR adult* OR athlete*).

Study Selection Randomized and non-randomized controlled studies that compared mindfulness practice techniques as an intervention with an inactive control or a control that followed another psychological training program in healthy sportive participants were screened for eligibility.

Data Extraction Eligibility and study quality [Physiotherapy Evidence Database (PEDro)] scales were independently assessed by two researchers. A third independent researcher was consulted to achieve final consensus in case of disagreement between both researchers. Standardized mean differences (SMDs) were calculated as weighted Hedges' g and served as the main outcomes in comparing mindfulness practice versus control. Statistical analyses were conducted using a random-effects inverse-variance model.

Results Nine trials of fair study quality (mean PEDro score 5.4, standard deviation 1.1) with 290 healthy sportive participants (athletics, cyclists, dart throwers, hammer throwers, hockey players, hurdlers, judo fighters, rugby players, middle-distance runners, long-distance runners, shooters, sprinters, volleyball players) were included. Intervention time varied from 4 weeks to over 2 years. The practice frequency lasted from twice daily to just once a week, and the mean session time covered 50–60 min. In favor of mindfulness practice compared with the control condition, large effects with narrow confidence limits and low heterogeneity were found for mindfulness scores [SMD 1.03, 90% confidence interval (CI) 0.67–1.40, $p < 0.001$, $I^2 = 17\%$]. Physiological performance indices depicted wide confidence limits accompanied with very large heterogeneity. However, the effect sizes remained very large, with confidence limits that did not overlap zero (SMD 3.62, 90% CI 0.03–7.21, $p = 0.10$, $I^2 = 98\%$). Moderate to large effects were observed for both psychological performance surrogates (SMD 0.72, 90% CI 0.46–0.98, $p < 0.001$, $I^2 = 14\%$) and performance outcomes in shooting and dart throwing (SMD 1.35, 90% CI 0.61–2.09, $p = 0.003$, $I^2 = 82\%$).

Conclusions Mindfulness practice consistently and beneficially modulates mindfulness scores. Furthermore,

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Published online: 29 June 2017

physiological and psychological surrogates improved to a meaningful extent following mindfulness practice, as well as performance outcomes in shooting and dart throwing. It seems reasonable to consider mindfulness practice strategies as a regular complementary mental skills training approach for athletes, at least in precision sports; however, more high-quality, randomized, controlled trials on mindfulness practice and performance improvements in diverse sport settings are needed.

Key Points

Mindfulness practice consistently and notably improves mindfulness scores among various sport disciplines.

Physiological and psychological performance surrogates improved to a meaningful extent following mindfulness practice.

Based on available evidence, mindfulness practice can be considered as a performance-enhancing complementary training approach in precision sport disciplines such as shooting and dart throwing.

More high-quality studies measuring the effect of mindfulness practice on performance in various sports should be conducted.

1 Introduction

Performance and success in sports rely on both physical and psychological capacity and readiness. For this purpose, athletes need to successfully deal with discipline-specific requirements and potential disturbances [1]. Various forms of mental training might contribute to physiological and psychological performance surrogates or to performance outcomes itself. One such form is psychological skills training (PST), which generally refers to cognitive behavioral techniques, including goal setting, imagery, mental rehearsal, arousal control, self-talk, and precompetitive routines [2].

The practice of mindfulness as another form of mental training is becoming increasingly popular with athletes. Defined by Kabat-Zinn, mindfulness is a structured mindset to being aware of the present-moment experience in an accepting, non-judging, and non-avoiding way [3], which can be understood as a state or trait [4]. Research shows that mindfulness is associated with several forms of mindfulness practice (e.g. different types of meditation or yoga) [5] or informal mindfulness practice in everyday life [6]. 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 [7]. In contrast to most forms of PST interventions that directly aim to change dysfunctional thoughts and emotions [8], interventional approaches that can be subsumed under the concept of mindfulness target altering the relationship to physiological and psychological states.

The first intervention of mindfulness in sport was indicated by Kabat-Zinn et al. in rowing in the early 1980s [9]. Following this introduction of mindfulness in the sporting world, only a few applications of mindfulness fostering meditation forms were applied before the turn of the century. Nevertheless, after many years of rapidly growing popularity of mindfulness in clinical psychology, an increasing interest of mindfulness-based interventions could also be observed in sports.

That growing popularity led to the development of two sport-specific and documented mindfulness-based intervention programs: the Mindfulness-Acceptance and Commitment approach (MAC) [10] and the Mindfulness Sport Enhancement Program (MSPE) [11]. Both are group interventions that consists of several session over several weeks. Participants in each program learn different forms of mindfulness practices and their benefits on and off the field. A good overview of all current mindfulness interventions in sport can be found in the Cambridge Handbook of Mindfulness and Performance [12].

Other interventions with athletes apply distinct exercises stemming from nonsport-specific mindfulness intervention programs. Aherne et al., for example, taught athletes several mindfulness exercises from Jon Kabat-Zinn's Mindfulness-Based Stress Reduction Program (MBSR) [13]. Their study showed that mindfulness practice improved performance, and, in addition, they reported elevated mindfulness and global flow scores. A systematic review of the efficacy of mindfulness-based interventions in sport was conducted by Sappington and Longshore [14], who evaluated single-case and qualitative studies as well as nonrandomized and randomized trials. As part of their findings, positive influences of mindfulness-based interventions on performance were reported in some of the studies.

Salutary effects of mindfulness practice for physical and psychological benefits have been impressively documented in nonclinical [15, 16] and clinical populations [17], as well as for physical stress parameters [18]. Comprehensive and systematically pooled findings derived from meta-analytical evaluations of mindfulness interventions on physiological and psychological surrogates, as well as performance outcomes in sports, are lacking. Thus, the present meta-analysis intended to examine whether, and to what extent, mindfulness-based interventions affect performance-relevant physiological and psychological surrogates or performance itself. Therefore, we examined the magnitude of pooled effects of mindfulness training on (1) mindfulness scores, (2) physiological performance surrogates, (3) psychological performance surrogates, and (4) performance outcomes. We hypothesized that mindfulness interventions lead to notable effects on relevant performance variables and sports performance.

2 Methods

2.1 Search Strategy and Study Selection

The present meta-analysis was performed along the lines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [19]. A literature search was independently conducted by two researchers (LB, LD), and six biomedical and psychological databases (CINAHL, EMBASE, ISI Web of Knowledge, PsycINFO, MEDLINE, and SPORTDiscus) were screened from inception to 22nd November 2016. Relevant search terms or operators were combined with Boolean conjunction (OR/AND) and applied on three search levels (Table 1).

Cited articles were tracked and hand searching of potentially relevant articles and review articles in the reference section was conducted. Duplicates were removed and the remaining studies underwent a detailed follow-up screening procedure by searching (1) titles, (2) abstracts and (3) full-texts. Irrelevant articles were excluded. A final decision over inclusion or exclusion was made based on the judgment of three independent researchers (LB, DB, and LD). The subsequent inclusion criteria based on the PICOS approach [population (P), intervention (I), comparators (C), main outcome (O), and study design (S)] were used:

- Full-text article published in English in a peer-reviewed journal.
- Participants were healthy and sportive (beginners, intermediates, and experts) adolescents and adults over the age of 15 years, without any clinical conditions, practicing a specific sport discipline (P).
- Mental practice approaches that focused on changes in the present-moment experience in an accepting and non-judging manner as defined by Kabat-Zinn [3] (i.e. mindfulness/acceptance/commitment (MAC); mindfulness/meditation/therapy (MMT); meditation-based yoga (Pranayama); Acem Meditation) served as the intervention strategy of interest (I).
- Passive inactive or (alternative active) control group (CON) that did not follow a mindfulness intervention as the comparator (C).
- Mindfulness (manipulation check), physiological performance surrogates (i.e. salivary cortisol level, immune response, resting heart rate, maximal oxygen uptake), psychological performance surrogates (performance-relevant parameters, i.e. flow, goal-directed energy, anxiety/apprehension, anxiety) and performance indices (i.e. shooting performance and scores, dart-throwing performance), served as outcome measures (O).
- Prospective, two-armed (randomized, non-randomized) controlled intervention studies with pre- and post-testing (S).

Table 1 Search levels and terms of the literature search

Search level	Search terms with Boolean operators
Search #1	Mindful* OR meditat* OR yoga
Search #2	#1 AND (sport* OR train* OR exercis* OR intervent* OR perform* OR capacity OR skill*)
Search #3	#2 AND (health* OR adult* OR athlete*)

The exclusion criteria were:

- (Pre-) pubescent children, older adults, and seniors with and without clinical constraints due to incomplete maturation and biological aging.
- Business people, coaches, teachers, soldiers, medical personnel, nonsportive people.
- No adequate control condition.
- Further mental training regimen (i.e. body-oriented yoga, acupuncture, massage, Aikido).
- Invalid target outcome (see inclusion criteria).
- Studies with alternative or lacking comparison group.

2.2 Assessment of Methodological Study Quality

Study quality of the included trials was assessed based on the Physiotherapy Evidence Database (PEDro) scale (http://www.pedro.org.au/english/downloads/pedro-scale), which contains 11 dichotomous items (yes or no) to characterize randomization, internal and external validity, and statistical information of the respective trials of interest. Studies were rated independently by two researchers (LB and DB), who both needed to obtain consensus on every item (Table 3). They were not blinded to study authors, place of publication, and results. In case of disagreement between both researchers, a third independent researcher (LD) was consulted to achieve final consensus.

2.3 Data Extraction

Mindfulness scores were analyzed as sum scores with means and standard deviations for the respective questionnaire. Physiological performance surrogates were extracted as original values, such as salivary cortisol level (nmol/L), immune response (cell count per unit), resting heart rate (beats per minute), and maximal oxygen uptake (L/min). Furthermore, psychological performance variables (i.e. flow, goal-directed energy, anxiety/apprehension, anxiety) were analyzed in the same way as mindfulness scores. Performance outcomes were extracted as shooting performance scores and dart-throwing performance. Data were scanned by two researchers (LB and LD) and transferred to an excel spreadsheet. Relevant study information regarding author, year, study design, number of participants, intervention characteristics (experimental and control group), training characteristics (volume, frequency, intensity, type) and outcome measures are reported in Table 2.

2.4 Statistical Analysis

Standardized mean differences [SMDs; with 90% confidence intervals (CIs)] were computed for each study using the adjusted Hedges' g (Eq. 1). This adjustment takes small sample biases into account. The Cochrane Review Manager Software (RevMan 5.3.5, Cochrane Collaboration, Oxford, UK) was used to compute the inverse-variance method according to Deeks and Higgins [20], and analyses were conducted using a random effects model [21]. Forest plots were generated for each outcome category (mindfulness, physiological performance surrogates and psychological variables, and performance outcomes in shooting and dart throwing). The magnitude of SMD was classified according to the following scale: 0–0.19, negligible effect; 0.20–0.49, small effect; 0.50–0.79, moderate effect; and $\geq$0.80, large effect [22]. Risk-of-bias assessment was performed by comparing weaker ($\leq$5) and stronger (>5) studies for each of the four funnel plots.

$$\mathrm{SMD}_i = \frac{m_{1i} - m_{2i}}{S_i}\left(1 - \frac{3}{4N_i - 9}\right). \quad (1)$$

3 Results

3.1 Trial Flow

After removing duplicates, 15,795 potentially relevant articles were identified (Fig. 1). These hits were then screened for irrelevant titles; however, if the researchers doing the screening were uncertain, the abstract was also checked. We only excluded hits with an irrelevant title, neglecting abstract screening if the title did not provide any relation to the topic. Thus, we also frequently checked the abstract for security reasons. As a consequence, 15,209 articles were removed. The abstracts of the remaining 586 potentially relevant articles were thoroughly studied. Overall, 502 abstracts did not meet the inclusion criteria (e.g. no intervention trial, not in the English language, no control condition, invalid target outcome). Eighty-four full-texts were further perused, of which 75 did not fulfill the inclusion criteria (i.e. no control, inappropriate age range and population, not the target outcome, unavailable articles). Finally, nine intervention trials were included in the meta-analysis.

3.2 Study Population and Quality

In total, 290 sportive and healthy participants aged over 15 years of age were involved in the nine trials included in this systematic review. These participants took part in cycling, dart throwing, hammer throwing, hockey, judo, rugby, running, shooting, tennis, track and field, or volleyball [13, 23–30]. The mean sample size was 34 participants per study, ranging from 12 [28] to 96 [24] participants. Trials contained two study arms: mindfulness practice (total number of participants = 147) and control conditions (total number of participants = 143). Three studies did not apply randomization for group allocation [23, 25, 27]. The mean study quality (PEDro score) was 5.4 (1.1), with a range between 4 and 7 (Table 3). None of the trials blinded the participants, supervisors, or testing personnel, except the study by Zhang et al. [30], where therapists were blinded. However, blinding within exercise intervention studies is generally considered difficult.

3.3 Risk-of-Bias Assessment

The funnel plots do not show a clear funnel-shape for mindfulness (Fig. 2a), physiological performance surrogates (Fig. 2b), and performance outcomes in shooting or dart throwing (Fig. 2d) because the underlying number of included study outcomes is low. Thus, studies with particularly higher standard errors and negative effect sizes are underreported (Fig. 2) and a publication bias cannot be ruled out. However, some analyses [e.g. psychological performance surrogates (Fig. 2c)] tend to show a funnel-like shape. Studies with very small sample sizes (higher standard errors) normally forming the basis of the funnel triangle are missing. The number of studies on the left and right side of the dashed SMD line are equally distributed on the left and right side from the dashed line for performance surrogates and performance outcomes in shooting and dart throwing (Fig. 2).

3.4 Mindfulness

We found large effects with narrow confidence limits for mindfulness (SMD 1.03, 90% CI 0.67–1.40, $p < 0.001$, $I^2 = 17\%$; Fig. 3) in favor of mindfulness practice

Table 2 Study overview

Reference (year)	Study design	Sample: population; sample size (n); age, [years (mean ± SD)]	Groups	Intervention	Training characteristics	Outcome measures	Study quality (PEDro)
Aherne et al. [13]	Randomized-controlled trial	Diverse athletes, competing at international or national level; n = 13; 21 ± 2	Experimental: $n = 6$ Control: $n = 7$	Mindfulness-training with four specific exercise domains in each session: Breathing Breathing and body Standing yoga Body scan	6 weeks 2 sessions/week Total session duration: 60 min Session distribution: 3×10 min (breathing, breathing and body, standing yoga) and 1×30 min (body scan)	Mindfulness Flow	6
Goodman et al. [23]	Controlled trial	NCAA division 1 athletic team; $n = 26$; 20 ± 2	Experimental: $n = 13$ (as treated analyses, $n = 8$) Control: $n = 13$	Mindfulness/Acceptance/Commitment (MAC)	5 weeks 8 total sessions 90-min MAC followed by 60-min Hatha Yoga	Mindfulness Goal-directed energy Anxiety/ apprehension	4
John et al. [24]	Randomized controlled trial	Elite pistol shooters; $n = 96$; 29 ± 4	Experimental: $n = 48$ Control: $n = 48$	MMT (Mindfulness Meditation Therapy)	5 weeks 6 days/week 20 min/session	Salivary cortisol level Shooting performance score	7
Raju et al. [25]	Controlled trial	Athletes competing at a national level; $n = 12$ Experimental: age, 17 ± 3 Control: age, 18 ± 2	Phase 2: Experimental: $n = 6$ Control: $n = 6$	Pranayama (breathing) and Shavasana (relaxation) in addition to physical workouts	Phase 2: 2 years Pranayama each morning for 48 min, plus Shavasana each morning for 12 min	Resting HR (beats/min)	5
Scott-Hamilton et al. [26]	Randomized controlled trial	Actively competing athletes (cyclists); $n = 47$; 40 ± 11	Experimental: $n = 27$ Control: $n = 20$	Mindfulness training program with regular weekly workshop sessions, home meditation training, group stationary cycle mindful-spinning sessions	8 weeks 15 min in class mindfulness practice followed by 20 min mindful cycling home-guided meditation two times for 15 min each day	Mindfulness Global flow Anxiety total	5
Solberg et al. [27]	Randomized controlled trial	Recreational athletes (runners); $n = 12$; range 27– 49	Experimental: $n = 6$ Control: $n = 6$	Acem Meditation	7 weeks 24 sessions in total 30 min/sessions at home	Maximum oxygen uptake Immune response	5
Solberg [28]	Controlled trial	Elite rifle shooters; $n = 25$; median 25 (range 18–46)	Experimental: $n = 13$ Control: $n = 12$	Acem Meditation	Learning meditation sessions: 1 session/week for 7 weeks Daily home-based 30-min sessions	Shooting score	4

Table 2 continued

Reference (year)	Study design	Sample: population; sample size (n); age, [years (mean ± SD)]	Groups	Intervention	Training characteristics	Outcome measures	Study quality (PEDro)
Solberg et al. [29]	Randomized controlled trial	Athletes (runners); $n = 21$; 39 ± 7	Experimental: $n = 11$ Control: $n = 10$	Acem Meditation	Learning meditation sessions: 1 session/week for 7 weeks 2.5 h/session followed by 30 min at home	Maximal oxygen uptake Anxiety	6
Zhang et al. [30]	Randomized controlled trial	Recreational athletes; $n = 43$; 19 ± 1	Experimental: $n = 22$ Control: $n = 21$	Mindfulness/Acceptance/Commitment (MAC)	7 weeks 3 times/week 80- to 90-min session duration	Mindfulness Flow Dart-throwing performance	7

SD, standard deviation; PEDro, Physiotherapy Evidence Database scale; NCAA, National Collegiate Athletic Association; HR, heart rate

compared with the control condition. Heterogeneity can be considered low ($I^2 = 17\%$). Risk-of-bias assessment revealed that weaker studies (PEDro ≤5; SMD 0.73, 90% CI 0.31–1.15) tended to attenuate the effect sizes ($p = 0.08$) compared with stronger studies (PEDro >5; SMD 1.43, 90% CI 0.93–1.93).

3.5 Physiological Performance Surrogates

Very large effects were found for physiological performance surrogates (SMD 3.62, 90% CI 0.03–7.21, $p < 0.10$, $I^2 = 98\%$; Fig. 4) in favor of mindfulness-based practice compared with the control condition. The confidence limits did not overlap zero; wide confidence limits with large heterogeneity were observed ($I^2 = 98\%$). Risk-of-bias assessment did not reveal that weaker studies (PEDro ≤5; SMD 2.73, 90% CI 1.34–4.11) notably attenuated the effect sizes ($p = 0.69$) compared with stronger studies (PEDro >5; SMD 3.93, 90% CI −0.80 to 8.65).

3.6 Psychological Performance Surrogates

Moderate effects with low heterogeneity were found for psychological performance surrogates (SMD 0.72, 90% CI 0.46–0.98, $p < 0.001$, $I^2 = 14\%$; Fig. 5) in favor of mindfulness or mindfulness-based practice compared with the control condition. Risk-of-bias assessment did not reveal that weaker studies (PEDro ≤5; SMD 0.61, 90% CI 0.32–0.91) attenuated the effect sizes ($p = 0.48$) compared with stronger studies (PEDro >5; SMD 0.92, 90% CI 0.28–1.55) to a meaningful extent.

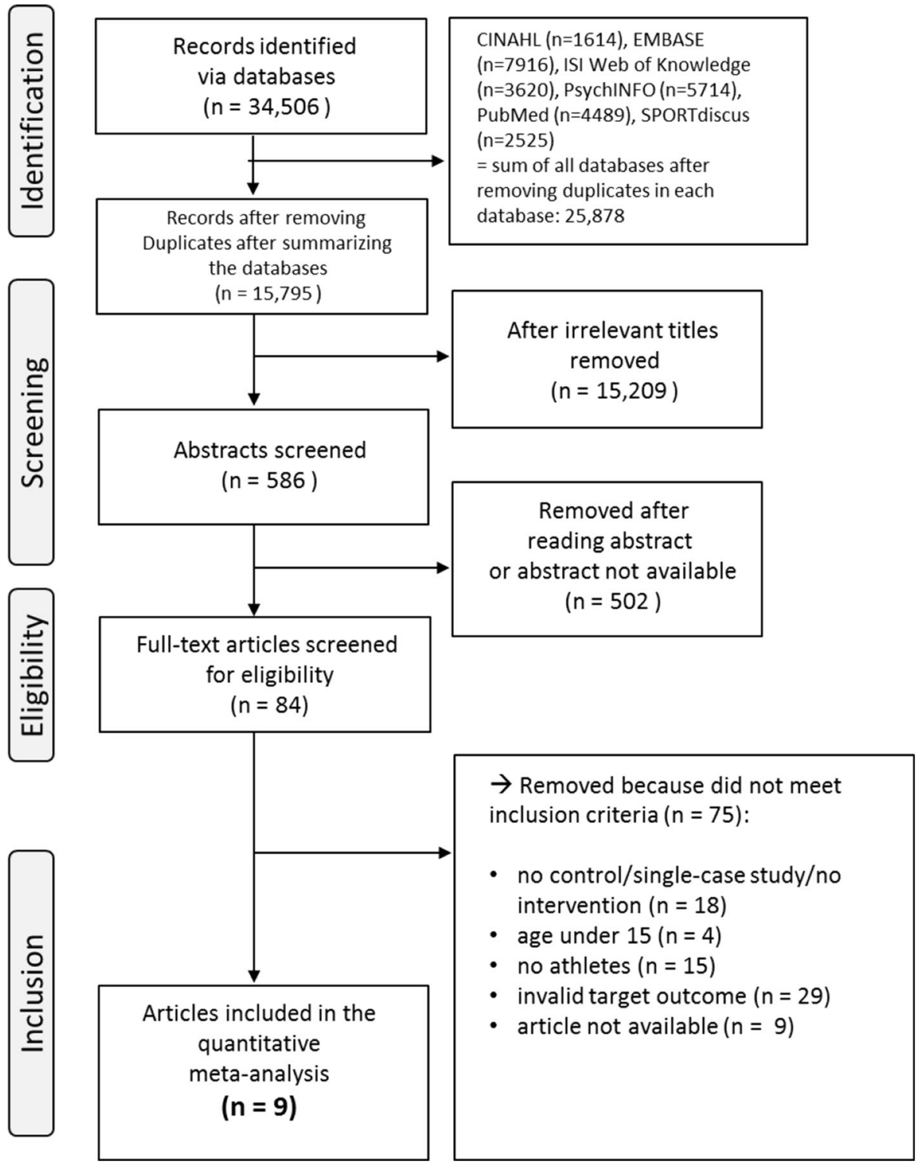
3.7 Performance Outcomes

A large effect was found for performance outcomes in the precision sports of shooting and dart throwing (SMD 1.35, 90% CI 0.61–2.09, $p = 0.003$, $I^2 = 82\%$; Fig. 6) in favor of mindfulness or mindfulness-based practice compared with the control condition. Risk-of-bias assessment did not reveal that weaker studies (PEDro ≤5; SMD 0.96, 90% CI 0.27–1.65) notably attenuated the effect sizes ($p = 0.46$) compared with stronger studies (PEDro >5; SMD 1.51, 90% CI 0.48–2.55).

4 Discussion

To the best of our knowledge, this is the first meta-analytical review that has pooled the effects of mindfulness practice on performance-relevant parameters in sports, as well as performance outcomes in sports. Mindfulness practice is considered to be an effective training component in sport psychological training. Our aim was to determine

Fig. 1 Study screening and selection process



whether an athlete's performance improves through mindfulness practice or mindfulness-based interventions. This meta-analysis is based on findings of nine intervention studies of overall sound quality. We found mainly large effects of mindfulness and mindfulness-related practice on (1) mindfulness scores, (2) physiological and psychological performance surrogates, and (3) performance indices. It is noteworthy that results on performance outcomes stemmed exclusively from the precision sports of shooting and dart throwing.

4.1 Changes in Mindfulness

Numerous mindfulness studies used self-report questionnaires and measured dispositional mindfulness scores [31]. Using such instruments, Block-Lerner and colleagues [32] referred to the difficulty in elucidating how an athlete performs mindfulness exercises and gains as behavioral changes. Furthermore, Birrer and colleagues [33] assumed that a mindfulness intervention changes behavior by helping individuals to mindfully experience emotional and cognitive processes. Being indulgent towards negative experiences, mindfulness-based interventions may lead to openness for negative thoughts, which consequently leads to positive coping with negative circumstances in performance situations and daily life [23]. Therefore, the evaluation of the present-moment experience seems to play a crucial role in successful mindfulness practice approaches. However, studies on mindfulness have not precisely evaluated potentially different effects of the mindfulness components, such as present-moment awareness, acceptance, and non-judgment, and research on the effects of

Table 3 PEDro scores and sum of the included studies

	Aherne et al. [13]	Goodman et al. [23]	John et al. [24]	Raju et al. [25]	Scott-Hamilton et al. [26]	Solberg et al. [27]	Solberg [28]	Solberg et al. [29]	Zhang et al. [30]
1. Eligibility specified	X	X	X	X	X	X	X	X	X
2. Subjects randomly allocated	X	–	X	–	X	X	–	X	X
3. Concealed allocation	–	–	X	–	–	–	–	–	–
4. Similar baseline values	X	X	X	X	X	–	X	X	X
5. Blinding of subjects	–	–	–	–	–	–	–	–	–
6. Blinding of therapist	–	–	–	–	–	–	–	–	X
7. Blinding of assessor	–	–	–	–	–	–	–	–	–
8. Dropout <15%	X	–	X	X	–	X	X	X	X
9. Received treatment as allocated	X	X	X	X	X	X	X	X	X
10. Statistical between-group comparison	X	X	X	X	X	X	X	X	X
11. Point measures and variability provided	X	X	X	X	X	X	–	X	X
Sum (items 2–11)	6	4	7	5	5	5	4	6	7

PEDro, Physiotherapy Evidence Database scale

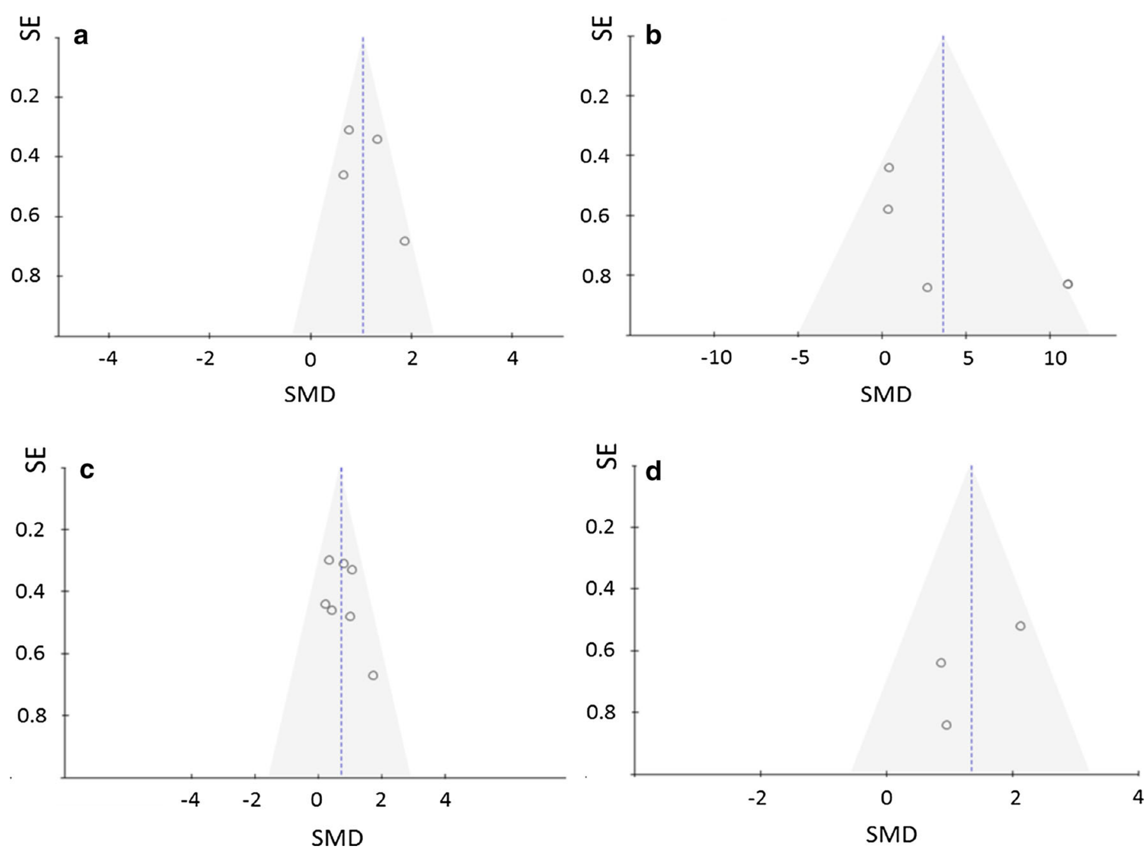


Fig. 2 Funnel plots for publication bias assessment on **a** mindfulness, **b** physiological performance surrogates, **c** psychological performance surrogates, and **d** performance outcomes in shooting and dart throwing. The *dashed line* indicates the mean SMD. SE, standard error; SMD, standardized mean difference

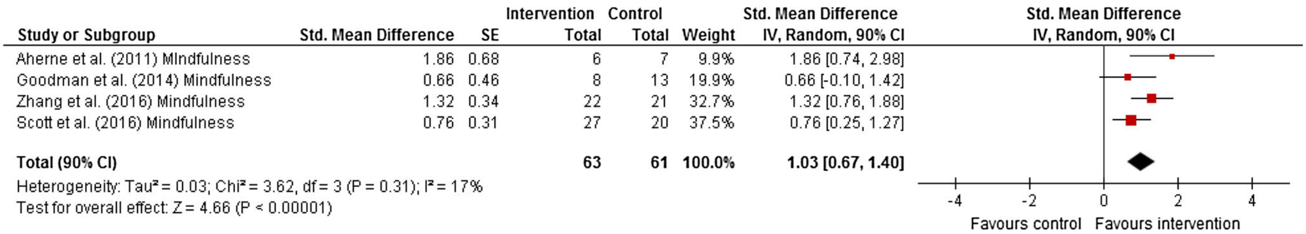


Fig. 3 Mindfulness outcomes for mindfulness practice interventions vs. control groups. SE, standard error; CI, confidence interval; Std., standardized; IV, independent variable; df, degrees of freedom

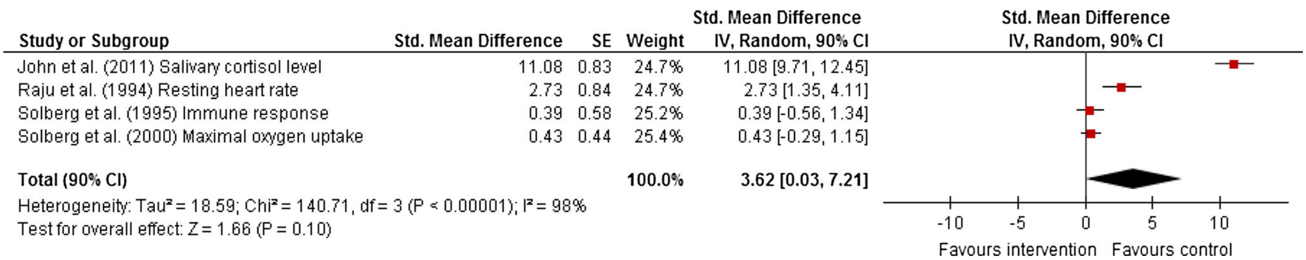


Fig. 4 Physiological performance surrogate variables for mindfulness-based practice interventions vs. control groups. SE, standard error; CI, confidence interval; Std., standardized; IV, independent variable; df, degrees of freedom

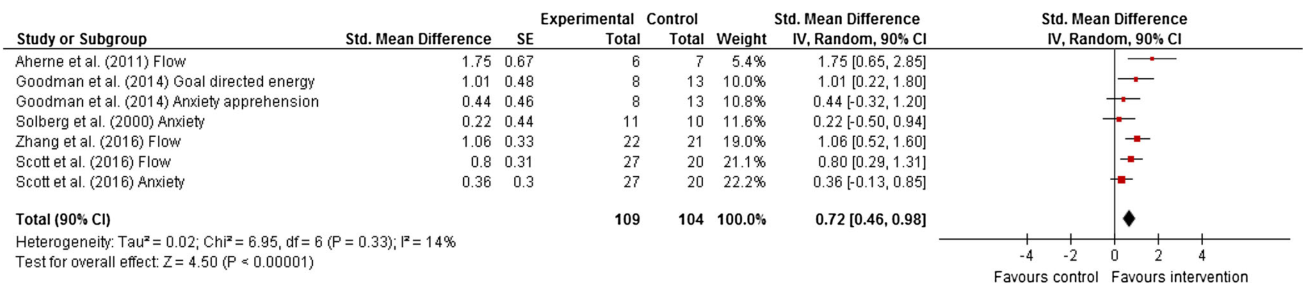


Fig. 5 Psychological performance surrogate variables for mindfulness or mindfulness-based practice interventions vs. control groups. SE, standard error; CI, confidence interval; Std., standardized; IV, independent variable; df, degrees of freedom

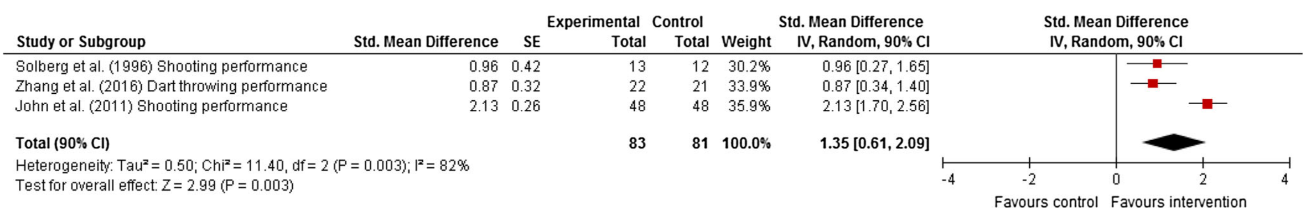


Fig. 6 Performance outcomes in shooting and dart throwing for mindfulness or mindfulness-based practice interventions vs. control groups. SE, standard error; CI, confidence interval; Std., standardized; IV, independent variable; df, degrees of freedom

different forms of mindfulness meditation and their effect on facets of mindfulness is still in its infancy [5, 6]. Future research might disentangle how these processes are functioning in athletes.

Kaufman and colleagues [9] discussed intervention continuance and recommended intervention periods of mindfulness practice longer than 4 weeks have a larger impact on an athlete's personal development compared with short-term approaches. Intervention periods of the included studies investigating the effects on mindfulness ranged between 5 [17] and 8 weeks [20], suggesting that a 5-week program might be sufficient to influence trait mindfulness in the short term. Additionally, the findings of Zhang and collaborators [30] showed a slight decrease in mindfulness scores after the follow-up-measurement. Furthermore, they remark that mindfulness practice is dependent on tenacity and engagement in the intervention. This statement is supported by research showing that levels of mindfulness are associated with continued practice in the present time, rather than with accumulated practice over years [5].

4.2 Changes in Physiological and Psychological Performance Surrogates

Since a variety of physiological and psychological surrogates contribute to sports performance, we also aimed to assess the impact of mindfulness practice on potential performance-relevant variables. In this respect, Raju and colleagues [25] pointed to the fact that physical training influences numerous hormonal and physiological subsystems. Thus, performance surrogates need to be considered in order to develop sports performance properly [34].

Despite not being conducted with athletes, mindfulness practice has been previously shown to gain notable physiological responses [18, 35]. In this line, the study by Solberg and coworkers [29] observed lowered lactate concentration after mindfulness practice, accompanied with unchanged levels of maximum oxygen uptake in athletes. They suggested that this decrease may be due to the reduction of noradrenaline. Thus, submaximal fitness parameters might be sensitive to physiological changes of mindfulness interventions. Raju and colleagues [25] found similar physiological changes in non-athlete volunteers when meditating, but the experimental group revealed larger changes in resting heart rate measures. Solberg and coworkers [27] considered that mindfulness-based meditation could have a beneficial effect on the immune response through the lower rise of CD8+ T cells. In this line, decreased salivary cortisol levels have been observed by John and colleagues [24], which confirms findings in healthy non-athletic adult populations [18]. A lower immune responsiveness upon mindfulness practice might also attenuate exercise-induced inflammation. Thus, it seems appropriate to apply mindfulness on a regular basis. A further side effect could be that recovery time could be reduced. However, further studies should evaluate whether mindfulness training approaches may serve as an appropriate complementary recovery strategy.

Furthermore, with regard to the results of this study, it can be expected that mindfulness practice enables athletes to realize their achievement potential in an efficient way. The discussed physiological markers seem to be linked with psychological variables, such as salivary cortisol level as a marker for stress [24]. Solberg and colleagues [29] confirmed that coping with stress is an important issue in sports; therefore, managing tension seems to have a meaningful influence on athletes' performances [28]. The results of their study show that Acem Meditation appears to be a beneficial technique to improve the present-moment awareness in an accepting and non-judging way (mindfulness). Other psychological variables, such as experiential acceptance and flow, might modulate disadvantageous stress levels [11].

Regarding return to sport after an injury, Mahony and Hanrahan [36] underlined that mindfulness through acceptance and commitment therapy (ACT) might help athletes, during the recovery period, to perform even better when they return to sport, due to a reduction in the fear of re-injury; mindfulness could even play an important role in injury prevention [37]. Corroboratively, John and colleagues [24] showed increasing performance scores in the experimental group accompanied by reduced anxiety levels upon mindfulness meditation. Furthermore, Acem Meditation led to lower muscle tightness, higher relaxation and peacefulness [28]. On the other hand, Scott-Hamilton and coworkers showed increasing scores of flow (moderate to large effects) by executing a mindfulness training program in cyclists [26]. Based on Nakamura and Csikszentmihalyi's [38] theory that a narrow focus beneficially improves flow, Kee and Wang [39] explained that their athletes showed higher scores in mindfulness and in the flow dimensions of 'clear goals' and 'sense of control'. In addition, Goodman and colleagues [23] measured a significant increase in athletes goal-directed energy after a mindfulness intervention. Nevertheless, Aherne and coworkers [13] were conservative regarding the influence of mindfulness on flow because there were no statistically significant effects in their study. Additionally, Gardner and Moore [40] explained that decreased anxiety and narrow focus are not necessarily the key factors for high performance because well-trained athletes can manage higher levels of arousal during performance. However, the interplay of all these variables in terms of sports performance is still unclear and multivariate analyses to elucidate this issue have been recommended [26]. It is also important to find more precise definitions of the different sports-performance requirements, and to adapt mindfulness practice and mindfulness-based interventions to sport-specific as well as individual needs.

4.3 Effects on Performance Outcomes in Shooting and Dart Throwing

Three studies [24, 28, 30] observed performance improvements upon mindfulness or mindfulness-based practice in pistol and rifle shooting, as well as dart throwing. All these sports can be categorized as precision sports. After a 2-week introduction 'period' of basic knowledge and skills in dart-throwing, Zhang and coworkers [30] found significant improvements in recreational dart throwers from pre- to post-testing. In line with Kee and Liu [41], these findings cannot elucidate whether mindfulness directly improves motor skill changes or psychological pathways that merely reduce negative impact on performance. Similar findings have been observed by John and colleagues [24], who found an increase of 2.6% in shooting performance score from baseline in the experimental group, while the control group showed a decrease of 0.9% from baseline. In line with Röthlin and coworkers [42], they showed that mindful athletes reported less performance anxiety and less performance-impairing effects of anxiety (both were associated with a better subjective performance under pressure). However, anxiety might be an insensitive psychological correlate because mindfulness training does not necessarily target the symptoms of anxiety, but rather the ability to skillfully relate to the presence of anxiety by being open and accepting, and then, taking charge of one's attention [42].

A similar argument holds true for flow. Although this ideal state is desirable, the pursuit of flow is not inherently a goal of mindfulness training, but rather awareness (and acceptance) of present-moment experience is the goal, combined with the ability to put attention where it needs to be put for the given task at hand. The latter can be considered a critical component for athletes. Thus, it seems plausible that the results for psychological correlates were only moderate. Perhaps a more sensitive psychological correlate might be measures of psychological flexibility combined with measuring aiming, sustaining, and regaining attention as a measure of attentional control. Corroboratively, Solberg [28] found improved shooting scores in elite rifle shooters as a result of mindfulness-based meditation compared with a control condition with no intervention. They questioned whether an overall good performance after mindfulness practice is caused by the low level of tension, or if feeling more relaxed is a result of successful performance. Other processes of change are possible (e.g. meta-cognitive awareness and acceptance). Furthermore, it is unclear whether the positive influence of mindfulness practice is limited to precision sports because mindfulness practice might affect performance directly in shooting and dart throwing than, for example, in running, where several physiological parameters have a direct influence on performance outcome. Thus, it might be easier to gain conclusive results in precision sports. Interestingly, Bernier and coworkers [43] showed that mindfulness practice and mindfulness-based interventions seem to improve performance outcomes in golf, as a precision sport, slightly superior than traditional PST. Looking at more body-oriented mental interventions (e.g. autogenic training and biofeedback), sports performance seems to also benefit from these approaches [29, 44]. Future research on the interrelation between mental training approaches and performance outcomes in sports should focus on underlying effects of performance improvement using high-quality, randomized, controlled trials in different sports, such as those Röthlin and colleagues are tracking in their study design [45].

4.4 Strengths and Limitations

The present meta-analytical review was performed in accordance with the PRISMA statement [19]. This is the first meta-analysis that has pooled effect sizes of specific mindfulness practice on sports performance using two-armed study designs. Even though there are few studies, the overall sample size ($n = 290$) is acceptable. Due to different study populations ranging from young to middle-aged adults, and different interventional procedures, notable heterogeneity is a limitation of our study. According to our inclusion criteria, we focused only on studies on mindfulness, or studies that are very closely related to a mindfulness regimen, such as the work by Raju and colleagues [25]. Despite a notable age range of included participants in our study, we did not include pubertal children. We were apprehensive that younger subjects might have limited abilities to successfully conduct a mindfulness program due to incomplete maturation. As another constraint, different scales and parameters were used for outcome measures. Nevertheless, effect sizes were clear and CIs were reasonably narrow. Three studies did not apply a randomization procedure for group allocation [23, 25, 28]. The remaining studies comprised mid-level to comparatively high PEDro scores ranging from 4 to 7. These data are noteworthy because blinding procedures in exercise-based intervention studies are difficult to apply. The intervention time differed a lot and lasted from 4 weeks up to 2 years. In line with Kaufman and colleagues [11], it might be reasonable to assume that longer intervention duration could lead to larger effects of mindfulness practice on physiological and/or psychological performance surrogates and performance outcomes, especially in precision sports; however, this assumption remains speculative and needs to be further elucidated. Nevertheless, our findings allow a comprehensive and quantitative view of current evidence on the effects of mindfulness and mindfulness-based practice on performance and performance-relevant parameters in several sports.

5 Conclusion and Future Implications

Mindfulness practice and mindfulness-based interventions in sport have the potential to notably improve relevant athletic outcome measures. This conclusion is particularly true for athletic and physical performance indices. Moreover, mindfulness practice indicated decreases in psychological stress parameters. Thus, low tension could lead athletes to more goal-oriented performance. In respect to the measurements of performance outcomes in beginners, as well as in high-level sportsmen, mindfulness might affect motor learning in several development stages. Whether mindfulness practice could improve performance outcomes in sports other than precision sports should be part of qualitative and quantitative research in the future. In conclusion, the application of the mindfulness intervention procedures may vary depending on the individual physiological and psychological needs of the target person or target group, as well as on the sport-specific performance requirements.

More research on mindfulness interventions in sport should be conducted to confirm and possibly extend the promising results of this systematic meta-analytical review. Studies with larger sample sizes and different performance requirements are needed to improve the application of the discussed intervention programs in the future. Additionally, which mindfulness practice (e.g. compassion meditation, informal mindfulness practice) influences specific mindfulness facets, physiological and psychological performance surrogates, and various kinds of sports performance, should be investigated.

Compliance with Ethical Standards

This article was written according to the ethical standards of scientific writing and publishing.

Funding No sources of funding were used to assist in the preparation of this article.

Conflicts of interest Lars Donath, Lucia Bühlmayer, Daniel Birrer, Philipp Röthlin and Oliver Faude declare that they have no conflicts of interest relevant to the content of this review.

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