

1 **The effects of repeated-sprint training on field-based fitness measures: A meta-analysis of controlled and**
2 **non-controlled trials**

3

4 **Running title: Effects of repeated-sprint training on fitness**

5

6

7 Jonathan Taylor¹, Tom Macpherson¹, Iain Spears¹ and Matthew Weston¹

8

9

10

11

12 ¹Department of Sport and Exercise Sciences, School of Social Sciences, Business and Law, Teesside University,
13 Middlesbrough, UK.

14

15

16

17

18

19

20

21

22

23

24

25

26

27 Corresponding author:

28 Jonathan Taylor, Department of Sport & Exercise Sciences, School of Social Sciences, Business & Law,
29 Teesside University, Middlesbrough, UK

30

31 Email: Jonathan.Taylor@tees.ac.uk

32 Telephone: ++44(0) 1642 342326

33

34

35

1 **Key Points**

2 Repeated-sprint training offers an effective strategy to concurrently improve a range of fitness measures related
3 to team-sports performance.

4 In trained individuals repeated-sprint training can induce improvements in power, speed, repeated-sprint ability
5 and high-intensity running performance.

6 Further work to isolate the effects of manipulating repeated-sprint training variables, such as, sprint distance,
7 volume and work: rest, could lead to the optimisation of training programmes –specifically with regards to
8 achieving desired adaptations.

9

1 **Abstract**

2 *Background:* Repeated-sprint training appears to be an efficient and practical means for the simultaneous
3 development of different components of fitness relevant to team-sports.

4 *Objective:* Our objective was to systematically review the literature and meta-analyse the effect of repeated-
5 sprint training on a selection of field-based measures of athletic performance. These measures were counter-
6 movement jump, 10 m sprint, 20 m sprint, 30 m sprint, repeated-sprint ability and high-intensity intermittent
7 running performance.

8 *Data Sources:* Four databases (SPORTDiscus, PubMed, MEDLINE and Web of Science) were searched for
9 original research articles. Search terms included ‘repeated-sprint training’, ‘sprint training’ ‘aerobic endurance’,
10 ‘repeated-sprint ability’, ‘counter-movement jump’ and ‘sprint performance’.

11 *Study Selection:* Inclusion criteria were: intervention consisted of a series of ≤ 10 s sprints with ≤ 60 s recovery;
12 trained participants; intervention duration 2-12 weeks; field-based fitness measures; running or cycling based
13 intervention; published up to, and including February 2014.

14 *Data Extraction:* Our final dataset included 6 trials for counter-movement jump (2 controlled trials), 8 trials for
15 10 m sprint, 4 trials for 20 m sprint (3 controlled trials), 2 trials for 30 m sprint, 8 trials for repeated-sprint
16 ability and 3 trials for high-intensity intermittent running performance. Analyses were conducted using
17 comprehensive meta-analysis software. Uncertainty in the meta-analysed effect of repeated-sprint training was
18 expressed as 95% confidence limits (CL) along with the probability that the true value of the effect was trivial,
19 beneficial or harmful. Magnitude based inferences were based on standardised thresholds for small, moderate
20 and large changes of 0.2, 0.6 and 1.2 standard deviations, respectively.

21 *Results:* Repeated-sprint training had a likely small beneficial effect in non-controlled counter-movement jump
22 trials (effect size 0.33; 95% confidence limits ± 0.30), with a possibly moderate beneficial effect in controlled
23 trials (0.63; 95% CL ± 0.44). There was a very likely small beneficial effect on 10 m sprint time in non-
24 controlled trials (-0.42; 95% CL ± 0.24) with a possibly moderate beneficial effect on 20 m sprint time in non-
25 controlled (-0.49; 95% CL ± 0.46) and controlled trials (-0.65; 95% CL ± 0.61). Repeated-sprint training had a
26 possibly large beneficial effect on 30 m sprint performance in non-controlled trials (-1.01; 95% CL ± 0.93) with
27 possibly moderate beneficial effects on repeated-sprint ability (-0.62; 95% CL ± 0.25) and high-intensity
28 intermittent running performance (-0.61; 95% CL ± 0.54).

29 *Conclusions:* Repeated-sprint training can induce small to large improvements in power, speed, repeated-sprint
30 ability and endurance and may have relevance for training in team-sports.

31

32

1 **1 Introduction**

2 Team-sports are characterized by long periods of low-intensity activity, interspersed with isolated and repeated
3 bouts of high-intensity running and sprinting - the latter of which may precede crucial moments within matches
4 [1-7]. Other match activities and movements, such as turning, jumping, kicking, tackling, and
5 accelerating/decelerating, are influenced by the ability to exert force rapidly, suggesting that leg-power could
6 also be crucial to successful performance in team-sports [6, 8]. The activity profiles of team-sports necessitate
7 the development of power, acceleration, speed, and the ability to perform repeated high-intensity runs and
8 sprints. In short, team-sports require well-rounded athletes, with components of athletic fitness being assessed
9 via field-based tests [9].

10 Repeated-sprint training has received attention within the recent scientific literature [10-14] and is defined as “a
11 series of short sprints (3-7 s in duration), each separated by a short recovery period (< 60 s)” [15]. A bout of
12 repeated-sprinting can be described as three or more sprints with a work: rest of around 1: 3 [7], and the
13 physiological response to this type of activity shows a high degree of neuromuscular and metabolic stress, with
14 an increasing involvement of the aerobic system in proportion to an increasing number of sprints [16-20]. In a
15 very short period of time these training programmes can result in an improvement to the enzymatic activities of
16 the anaerobic and aerobic energetic pathways [21, 22]. Therefore, repeated-sprint training appears to be an
17 effective mode of multi-component training and is known to improve maximal oxygen uptake ($\dot{V}O_{2max}$) and
18 repeated-sprint ability [12].

19 The recent growth in this area of research [23-27] shows an increased awareness of this mode of training and the
20 potential benefits to fitness components other than $\dot{V}O_{2max}$ and repeated-sprint ability (e.g. sprinting speed and
21 power). However, the effects of repeated-sprint training on these other components of fitness have yet to be
22 meta-analysed. Therefore, our aim was to systematically review and meta-analyse the effect of repeated-sprint
23 training on field-based measures of fitness relevant to team-sports, namely power, acceleration, speed, repeated-
24 sprint ability and high-intensity intermittent running capacity.

25 **2 Methods**

26 **2.1 Literature Search**

27 This review was carried out in accordance with the ‘Preferred reporting items for systematic reviews and meta-
28 analyses’ (PRISMA) guidelines [28]. A search of four electronic databases (PubMed, SPORTDiscus,
29 MEDLINE and Web of Science) was conducted to identify original research in April 2014. Two authors [JT,
30 TM] performed the literature search, whereby journal articles were screened by title and abstract. The search
31 terms used as independent variables were; ‘repeated-sprint training’, ‘multiple sprint training’, ‘sprint training’,
32 ‘maximal sprint training’, ‘repeated-sprint’; whilst the dependent variable search terms were; ‘aerobic
33 endurance’, ‘repeated-sprint ability’, ‘sprint speed’, ‘fitness’, ‘agility’, ‘counter-movement jump’, ‘sprint
34 performance’ and ‘acceleration’. The dependent and independent variable terms were combined, giving a total
35 of 40 search combinations.

1 2.2 **Study Selection**

2 The review included original research articles only, published in peer-reviewed journals and available in full
3 English text. The following inclusion criteria were used to identify suitable studies; the study involved a
4 repeated-sprint training intervention consisting of a series of maximal sprints of ≤ 10 s in duration, with a
5 recovery ≤ 60 s (adapted from the definition provided by Buchheit and Laursen [15]); trained participants; an
6 intervention of 2 to 12 weeks in duration; field-based fitness measures only; a running or cycling intervention;
7 only research published up to and including February 2014 was included.

8 Following an initial search of the literature, articles deemed appropriate on screening of title and abstract were
9 obtained in full and screened by two authors [JT, TM] independently to ensure that they met the inclusion
10 criteria. Articles selected for inclusion in the analysis were agreed upon by both reviewers, with any
11 discrepancies resolved by discussion. Reference lists of the selected articles were also screened so that
12 additional repeated-sprint training studies could be identified.

13 A total of 100 articles were screened in full, after being recognised as potentially eligible following the initial
14 search by title and abstract (figure 1). From these articles a total of 13 were deemed suitable for inclusion within
15 the final analysis by both authors. The final dataset for counter-movement jump was 6 trials (2 controlled trials).
16 For sprint performance, the final dataset was 8 trials for 10 m sprint performance, 4 trials for 20 m sprint
17 performance (3 controlled trials), and 2 trials for 30 m sprint performance. For repeated-sprint ability and high-
18 intensity intermittent running performance [measured as Yo-Yo intermittent recovery level 1 test performance],
19 the final dataset was 8 and 3 trials, respectively.

20 2.3 **Data Extraction**

21 The study, testing and participant characteristics for the meta-analysed studies are displayed in Table 1.
22 Counter-movement jump, 10-30 m sprints and the Yo-Yo Intermittent recovery level 1 are field-based fitness
23 tests often used within the literature to assess leg-power, different aspects of speed (i.e. acceleration and
24 maximal sprint speed) and high-intensity intermittent running performance respectively [13, 29], hence their
25 inclusion within our analysis. Given the variety of repeated-sprint tests used within the literature, all data from a
26 ‘repeated-sprint test’ as defined by the authors of the respective papers were included for analysis. Only the data
27 for repeated-sprint mean (mean time of each sprint) were extracted and meta-analysed, as this is the most
28 reliable measure of those reported with respect to repeated-sprint ability [12, 30]. Although change of direction
29 ability represents a key fitness component within team-sports, only one study assessing the effects of repeated-
30 sprint training on change of direction ability met our exclusion criteria. The most popular research design was a
31 non-controlled pre-post trial, whereby the intervention was often integrated within the ‘normal’ program of the
32 participants. Where a control group was used, participants in this group maintained ‘regular’ training throughout
33 the intervention duration. All data were extracted directly from tables or within the text of the selected studies
34 where possible. A graph digitising software (DigitizeIt, Germany) was used to obtain data in studies where plots
35 only were published. Accuracy was confirmed via intra- and inter-individual reassessments of data extraction.

1 2.4 Data Analysis

2 Meta-analyses were conducted to determine the pooled effect size of repeated-sprint training on our field-based
3 measures of fitness [counter-movement jump, 10 m sprint, 20 m sprint, 30 m sprint, repeated-sprint ability, and
4 high-intensity intermittent running performance]. Analyses were conducted using comprehensive meta-analysis
5 software, version 2 for Windows (Biostat company, Englewood, NJ, USA) with random effects models.
6 Examination of funnel plots revealed no evidence of the asymmetrical scatter associated with publication bias in
7 all outcome measures. The uncertainty in the meta-analysed effect of repeated-sprint training on field-based
8 fitness measures was expressed as 95% confidence limits (CL) and also as probabilities that the true value of the
9 effect was trivial, beneficial or harmful in relation to threshold values for benefit and harm. Probabilities were
10 then used to make a qualitative probabilistic inference about the overall effect [31]. Given that improvements in
11 various field-based measures have clear practical application to team-sports [32], meta-analysed effects were
12 assessed clinically and therefore considered unclear if the chance of benefit (improved fitness) was high enough
13 to warrant use of the intervention but with an unacceptable risk of harm (reduced fitness). An odds ratio of
14 benefit to harm of <66 was used to identify such unclear effects. Inferences were then subsequently based on
15 standardised thresholds for small, moderate and large changes of 0.2, 0.6 and 1.2 standard deviations,
16 respectively [31]. The chance of the true effect being trivial, beneficial or harmful was then interpreted using the
17 following scale: 25-75%, possibly; 75-95%, likely; 95-99.5%, very likely; $>99.5\%$, most likely [31].
18 Heterogeneity was determined by the I^2 value, with values of 25, 50 and 75 indicating low, moderate and high
19 heterogeneity, respectively [33].

20 3 Results

21 The meta-analysed effect of repeated-sprint training on counter-movement jump was a likely small beneficial
22 effect in non-controlled trials (effect size 0.33; 95% confidence limits ± 0.30 ; $I^2 = 33.3$) (figure 2) and a possibly
23 moderate beneficial effect in controlled trials (0.63; 95% CL ± 0.44 ; $I^2 = 0.0$). There was a very likely small
24 beneficial effect for repeated-sprint training on 10 m sprint performance in non-controlled trials (-0.42 ; 95% CL
25 ± 0.24 ; $I^2 = 0.0$) (figure 3) and a possibly moderate effect for repeated-sprint training on 20 m sprint performance
26 in non-controlled (-0.49 ; 95% CL ± 0.46 ; $I^2 = 61.6$) (figure 4) and controlled trials (-0.65 ; 95% CL ± 0.61 ; $I^2 =$
27 43.0). In non-controlled trials, there was a possibly large effect for repeated-sprint training on 30 m sprint
28 performance (-1.01 ; 95% CL ± 0.93 ; $I^2 = 47.9$), a possibly moderate effect on repeated-sprint ability (-0.62 ; 95%
29 CL ± 0.25 ; $I^2 = 0.5$) and a possibly moderate effect on high-intensity intermittent running performance (-0.61 ;
30 95% CL ± 0.54 ; $I^2 = 56.2$) (figures 5, 6, and 7, respectively).

31 4 Discussion

32 The physical demands of team-sports necessitate the development of well-rounded athletes, capable of
33 producing repeated bursts of power and speed over prolonged periods. Power, speed and endurance are
34 traditionally trained in separate domains, but there is a recognised need for more time-efficient strategies.
35 Emerging evidence indicates that repeated-sprint training may have the potential to elicit a range of fitness
36 benefits relevant to team-sports match play and this is the first meta-analysis of the pooled effects of this
37 training mode. We found clear beneficial effects on measures of counter-movement jump height, sprint times

1 (10 m, 20m and 30m), repeated-sprint ability and high-intensity intermittent running performance, all of which
2 are highly relevant to team-sports performance. Given the time restrictions facing coaches and strength and
3 conditioning practitioners, an optimised version of this pragmatic approach to training could have broad appeal
4 [6, 38-39].

5 The physiological and metabolic stresses placed on the body during repeated bouts of high-intensity exercise
6 and the beneficial effect of this training on aerobic fitness and repeated-sprint ability have been previously
7 documented [12, 40-41]. The 17.1% pooled improvement for the high-intensity intermittent running
8 performance reported here provide further indication that repeated-sprint training can translate into potentially
9 meaningful improvements in aerobic match performance. Although we acknowledge that this is not a cause and
10 effect relationship, the strong association between high-intensity intermittent running performance and match
11 high-intensity running distances suggests that this may be the case [9, 42]. Our results also support the findings
12 of Bishop et al. [12] with respect to the moderate beneficial effect we observed on repeated-sprint ability in non-
13 controlled trials. The previously reported relationship between repeated-sprint performance and match distance
14 covered at very high-intensity running speeds in soccer [43] highlight the importance of these findings to team-
15 sports players and practitioners. Two principal theories regarding development of repeated-sprint ability have
16 been suggested previously [12]. Firstly, that of training specificity, i.e. the most appropriate way to train
17 repeated-sprint ability is to perform repeated-sprint training; and secondly that of targeting the main factors
18 limiting repeated-sprint ability (i.e. limitations to energy supply and metabolite accumulation) through various
19 training modes (see Girard et al. [44] for a comprehensive review). It was beyond the scope of this review to
20 assess these theories, however it is worth noting that many of the repeated-sprint training protocols used within
21 the analysed studies were based on the repeated-sprint ability test by which participants were assessed. Given
22 that strong similarities between testing and training routines are more likely to induce training improvements
23 [45], the practical applications of these findings should be interpreted with caution [11, 13].

24 The effects on anaerobic fitness as opposed to aerobic fitness could be equally, if not more important for team-
25 sports, given the frequent occurrence of very high-intensity activity at crucial moments in competition [1].
26 Whilst Ferrari-Bravo et al. [14] suggested that repeated-sprint training had no effect on leg-power and speed, we
27 observed small to moderate beneficial effects on counter-movement jump performance, 10 m, 20 m and 30 m
28 sprint times. The mechanisms underpinning the improvements in speed and power are possibly due to muscular
29 adaptation, however the precise nature of these adaptations is not known. Notably, increases in muscle
30 metabolites (e.g. phosphocreatine and glycogen of ~32%, respectively) and enzymatic activity have been shown
31 previously to increase due to repeated-sprint training [46], and may have contributed to increases in jump
32 height and sprint times observed in this meta-analysis. In addition, it is possible that sprint training causes
33 beneficial changes in the patterns of muscular activity. Well-trained athletes adopt muscle activation patterns
34 which are energetically advantageous for a given task and repetitions of which will lead to improvements in
35 efficiency via neural pathways and reduced co-contractions [47]. It is also possible that sprint training methods,
36 such as repeated-sprint training may also increase the activity of relatively inactive muscle groups [48].
37 Electromyographical (EMG) data reveals that large and proximal muscles become the dominant agonists at
38 faster running speeds, with the gluteus maximus becoming the major contributor to hip extension in all-out
39 sprinting [49]. Similar trends are observed in sprint-cycling whereby EMG activity in this muscle reaches over

1 70% of its maximal level and remains at high-levels for more than half the crank cycle [50]. Regardless of
2 whether the sprints are on a cycle ergometer or in running, the increasing emphasis on joint speed will place a
3 greater emphasis on recruitment of the gluteus maximus muscle [48]. Furthermore, it seems likely that this
4 muscle is underused in elite team-sports athletes, with MRI revealing the gluteal muscle group of elite soccer
5 players to be no more hypertrophied than an age-matched non-active control group [51]. Given that this muscle
6 plays only a minor role in many other tasks, such as everyday walking, slow-running or even slow-cycling [48],
7 it is suggested that there is considerable scope for neuromuscular adaptation. While further speculation is
8 unwarranted at this stage, it should be noted that regardless of which specific mechanism of muscular adaptation
9 is taking place, the improvements in jump height and sprint speed are likely to have arisen from the general
10 improvements in the contractile properties of the leg extensor muscles and adapting to creating force during fast
11 movements [8, 38, 52-53]. Taking into consideration the practicalities and wide-ranging benefits, it seems that
12 repeated-sprint training should be utilized for team-sports training.

13 In terms of practical implications, it is clear that the repeated-sprint training, whether cycling or running, offers
14 potential biomechanical and physiological stimuli that are highly relevant to the training and match
15 requirements of team-sports. How these features can be optimised should form the focus of future research.
16 Considerable variation in the repeated-sprint training protocols employed, specifically with regards to sprint
17 distances (5 m through to 80 m), training frequency (1-6 times per week) and work: rest ratios (~1: 2 through to
18 ~1: 10) characterizes the literature in this area. The extent to which the disparity in the aforementioned
19 variables, effects the physiological adaptation achieved from a repeated-sprint training protocol may provide
20 some explanation for the varied findings of the research in this area [11, 13-14]. Furthermore, a greater
21 knowledge of how variables such as sprint volume, length of sprint, length of rest, and the work-rest ratio can
22 be manipulated to achieve desired outcomes in terms of power and/or endurance, have implications within the
23 optimisation of training programmes developed for team-sports athletes (possibly on an individual-level), and
24 could lead to an improved roundedness of these athletes. As an example, where improved sprint accelerations
25 are sought, it is possible to incorporate horizontal resistance into the sprint protocol, thus focussing on the
26 determinants of horizontal acceleration and sprinting performance over short distances [38, 53]. Alternatively
27 where improvements in maximal running speed are sought, it may be possible to increase sprint length (e.g. >40
28 m) thus facilitating training of the stretch-shortening response. At the other end of this spectrum, where
29 improvements to the relative anaerobic and aerobic energy contributions are being sought, it is possible to
30 manipulate the periods of rests or work-rest ratio. From a training frequency perspective it would also seem that
31 the optimal training dose of repeated-sprint training also requires attention in future research, whilst the transfer
32 between cycle repeated-sprint training and sprint running performance presented by Nebil et al. [23] also
33 warrants further exploration.

34 The findings of our meta-analysis lend support to the premise that repeated-sprint training offers an effective
35 strategy to concurrently improve a range of fitness measures related to team-sports performance. There are,
36 however, several important issues to consider when interpreting our findings. Firstly, the issue of heterogeneity
37 of studies included in a meta-analysis has been highlighted previously [54, 55]. We observed low to moderate
38 heterogeneity of the studies included; the fitness parameters displaying higher heterogeneity generally
39 comprised a smaller sample size. Furthermore, the small sample size within our meta-analysis may have
40 affected both the magnitude of the effects observed and the uncertainty of these effects (e.g. the width of our

1 confidence limits). Secondly, as many repeated-sprint training interventions are implemented ‘in-season’,
2 research investigating the effects of repeated-sprint training on performance utilised a design whereby repeated-
3 sprint training was either additional or replaced usual training. This makes it difficult to isolate the true effects
4 of repeated-sprint training in highly-trained individuals [45]. To fully quantify the effects of repeated-sprint
5 training on an athletic population, a design whereby participants complete no other training would be necessary;
6 however, this presents ethical issues in high-level athletes [56]. Thirdly, although the repeated-sprint training
7 literature demonstrates clear benefits for a wide range of fitness components and may have relevance for
8 training in team-sports, it should be noted that our meta-analysis did not examine the effects of other modes of
9 training and therefore we cannot compare directly the results with current best practice. For example, plyometric
10 training is currently considered to be the most effective strategy to increase leg-power [57] and is known to
11 improve counter-movement jump height by almost 10%, much greater than the improvement due to repeated-
12 sprint training (2.3%). However, improvements in sprint times following repeated-sprint training for 10 m were
13 similar to those for plyometric training (2.2%) and better for 20 m sprints (3.0% vs 1.5%) [57]. Finally, although
14 it was beyond the scope of this review to examine how repeated-sprint training can influence the likelihood of
15 injury, many team-sports athletes are considered to be at a high risk of hamstring injuries, with failure to
16 activate the gluteal muscles during fast running considered to be an important risk factor [58]. Understandably,
17 given the potential risks of introducing novel modes of maximal exercise within athlete training programs,
18 coaches may be cautious about introducing repeated-sprints into training. In the short-term it may be necessary
19 to perform these sprints on stationary bikes or by ensuring sprint distances are very short (<10 m) in order to
20 minimise eccentric forces in the muscles [45].

21 **5 Conclusions**

22 The effectiveness of repeated-sprint training has received increasing amounts of attention due to its potential to
23 train both strength/power and endurance in team-sports. The results of our meta-analysis show a clear beneficial
24 effect for this mode of training on key components of fitness relevant to team-sports. Further work to
25 manipulate the protocols in order to achieve desired outcomes in terms of power, speed and endurance is
26 recommended.

27

28 **Acknowledgements** No sources of funding were used to assist in the preparation of this review. The authors
29 have no conflicts of interest that are directly relevant to the content of this review.

30

31

1 **References**

- 2 1. Faude O, Koch T, Meyer T. Straight sprint is the most frequent action in goal situations in professional
3 football. *J Sports Sci.* 2012;30(7):625-31.
- 4 2. Póvoas S, Seabra A, Ascensão A, et al. Physical and physiological demands of elite team handball. *J*
5 *Strength Cond Res.* 2012;26(12):3365-75.
- 6 3. Austin DJ, Gabbett TJ, Jenkins DJ. Repeated high-intensity exercise in a professional rugby league. *J*
7 *Strength Cond Res.* 2011;25(7):1898-1904.
- 8 4. King T, Jenkins D, Gabbett T. A time-motion analysis of professional rugby league match-play. *J Sports*
9 *Sci.* 2009;27(3):213-19.
- 10 5. Deutsch MU, Kearney GA, Rehrer NJ. Time – motion analysis of professional rugby union players during
11 match-play. *J Sports Sci.* 2007;25(4):461-72.
- 12 6. Stølen T, Chamari K, Castagna C, et al. Physiology of soccer – an update. *Sports Med.* 2005;35(6):501-36.
- 13 7. Spencer M, Lawrence S, Rechichi C et al. Time-motion analysis of elite field hockey, with special
14 reference to repeated-sprint activity. *J Sports Sci.* 2004;22(9):843-50.
- 15 8. Markovic G, Jukic I, Milanovic D, et al. Effects of sprint and plyometric training on muscle function and
16 athletic performance. *J Strength Cond Res.* 2007;21(2):543-49.
- 17 9. Bangsbo J, Iaia FM, Krstrup P. The Yo-Yo intermittent recovery test. *Sports Med.* 2008;38(1):37-51
- 18 10. Hoffman JJ, Reed JP, Leitin K, et al. Repeated sprint, high-intensity interval training, small sided games:
19 Theory and application to field sports. *Int J Sports Physiol Perf.* 2014;9(2):352-57.
- 20 11. Fernandez-Fernandez J, Zimek R, Wiewelhove T, et al. High-intensity interval training vs. repeated-sprint
21 training in tennis. *J Strength Cond Res.* 2012;26(1):53-62.
- 22 12. Bishop D, Girard O, Mendez-Villanueva A. Repeated-Sprint Ability—Part II: Recommendations for
23 training. *Sports Med.* 2011;41(9):741-56.
- 24 13. Buchheit M, Mendez-Villanueva A, Delhomel G, et al. Improving repeated sprint ability in young elite
25 soccer players: repeated shuttle sprints vs. explosive strength training. *J Strength Cond Res.*
26 2010;24(10):2715-22.
- 27 14. Ferrari-Bravo D, Impellizzeri FM, Rampinini E, et al. Sprint vs. Interval training in football. *Int J Sports*
28 *Med.* 2008;29(8):668-74.
- 29 15. Buchheit, M, Laursen PB. High-intensity interval training, solutions to the programming puzzle – Part 1:
30 Cardiopulmonary emphasis. *Sports Med.* 2013;43(5):313-38.
- 31 16. Glaister M. Multiple-sprint work: Methodological, physiological and experimental issues. *Int J Sports*
32 *Physiol Perf.* 2008;3(1):107-12.
- 33 17. Spencer M, Bishop D, Dawson B, et al. Physiological and metabolic responses of repeated-sprint activities:
34 Specific to field-based team sports. *Sports Med,* 2005;35(12):1025-44.
- 35 18. Gaitanos GC, Williams C, Boobis LH, et al. Human muscle metabolism during intermittent maximal
36 exercise. *J Appl Physiol.* 1993;75(2):712-19
- 37 19. Balsom PD, Seger JY, Sjödin B, et al. Maximal-intensity intermittent exercise: effect of recovery duration.
38 *Int J Sports Med.* 1992; 13(7):528-33.
- 39 20. Balsom PD, Seger JY, Sjödin B, et al. Physiological responses to maximal intensity intermittent exercise.
40 *Eur J Appl Physiol Occup Physiol.* 1992;65(2):144-9.

- 1 21. Gibala MJ, Little JP, van Essen M, et al. Short-term sprint interval versus traditional endurance training:
2 similar initial adaptations in human skeletal muscle and exercise performance. *J Physiol.* 2006;15(575) (Pt
3 3): 901-11.
- 4 22. Burgomaster KA, Heigenhauser GJ, Gibala MJ. Effect of short-term sprint interval training on human
5 skeletal muscle carbohydrate metabolism during exercise and time-trial performance. *J Appl Physiol.*
6 2006;100(6): 2041-47.
- 7 23. Nebil G, Zouhair F, Hatem B, et al. Effect of optimal cycling repeated-sprint combined with classical
8 training on peak leg power in female soccer players. *Iso Exerc Sci.* 2014;22: 69-76
- 9 24. Suarez-Arrones L, Tous-Fajardo J, Nunez J, et al. Concurrent repeated-sprint and resistance training with
10 superimposed vibrations in rugby players. *Int J Sports Physiol Perf.* 2013;9(4):667-73.
- 11 25. Lockie RG, Murphy AJ, Callaghan SJ, et al. Effects of sprint and plyometrics training on field sport
12 acceleration technique. *J Strength Cond Res.* 2014;28(7):1790-1801
- 13 26. Lockie RG, Murphy AJ, Schultz AB, et al. The effects of different speed training protocols on sprint
14 acceleration kinematics and muscle strength and power in field sport athletes. *J Strength Cond Res.*
15 2012;26(6):1539-50.
- 16 27. Serpiello FR, McKenna MJ, Stepto NK, et al. Performance and physiological responses to repeated-sprint
17 exercise: a novel multiple-set approach. *Eur J Appl Physiol.* 2011;111(4):669-78.
- 18 28. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses:
19 the PRISMA statement. *PLoS Med.* 2009;6(7):1-6.
- 20 29. Krstrup P, Mohr M, Amstrup T, et al. The Yo-Yo intermittent recovery test: physiological response,
21 reliability, and validity. *Med Sci Sports Exerc.* 2003;35:697-705.
- 22 30. Impellizzeri FM, Rampinini E, Castagna C, et al. Validity of a repeated-sprint test for football. *Int J Sports*
23 *Med.* 2008;29(11):899-905.
- 24 31. Hopkins WG, Marshall SW, Batterham AM, et al. Progressive statistic for studies in sports medicine and
25 exercise science. *Med Sci Sports Exerc.* 2009;41(1):3-12.
- 26 32. Ingebrigtsen J, Brochmann M, Castagna C, et al. Relationship between field performance tests in high-level
27 soccer players. *J Strength Cond Res.* 2014;28(4):942-49.
- 28 33. Higgins JP, Thompson SG, Deek JJ, et al. Measuring inconsistency in meta-analyses. *Br Med J.* 2003;
29 327(7414):557-60.
- 30 34. Galvin HM, Cooke K, Sumners DP, et al. Repeated sprint training in normobaric hypoxia. *Br J Sports Med.*
31 2013;47:i74-i79.
- 32 35. Buchheit M, Millet G, Parisy A, et al. Supramaximal training and postexercise parasympathetic reactivation
33 in adolescents. *Med Sci Sports Exerc.* 2008;40(2):362-70.
- 34 36. Mohr M, Krstrup P, Nielsen JJ, et al. Effect of two different intense training regimens on skeletal muscle
35 ion transport proteins and fatigue development. *Am J Physiol Regul, Integr Comp Physiol.*
36 2007;292(4):R1594-1602.
- 37 37. Dawson B, Fitzsimons M, Green S, et al. Changes in performance, muscle metabolites, enzymes and fibre
38 types after short sprint training. *Eur J Appl Physiol Occup Physiol.* 1998;78(2):163-69.

- 1 38. Los Arcos A, Yanci J, Mendiguchia J, et al. Short-term training effects of vertically and horizontally
2 oriented exercises on neuromuscular performance in professional soccer players. *Int J Sports Physiol Perf.*
3 2014;9(3):480-88.
- 4 39. Hoff J, Helgerud J. Endurance and strength training for soccer players—physiological considerations.
5 *Sports Med.* 2004;34(3):165-180.
- 6 40. Macpherson T, Weston M. The effect of low-volume sprint interval training (SIT) on the development and
7 subsequent maintenance of aerobic fitness in soccer players. *Int J Sports Physiol Perf*
8 <http://dx.doi.org/10.1123/ijsp.2014-0075>.
- 9 41. Weston M, Taylor KL, Batterham AM, et al. Effects of low-volume high-intensity interval training (HIT)
10 on fitness in adults: A meta-analysis of controlled and non-controlled trials. *Sports Med.* 2014;44(7):1005-
11 17
- 12 42. Krstrup P, Mohr M, Ellingsgaard H, et al. Physical demands during an elite female soccer game:
13 Importance of training status. *Med Sci Sports Exerc.* 2005;37(7):1242-48.
- 14 43. Rampinini E, Bishop D, Marcora SM, et al. Validity of simple field tests as indicators of match-related
15 physical performance in top-level professional soccer players. *Int J Sports Med* 2007;28(3):228-235.
- 16 44. Girard O, Mendez-Villanueva A, Bishop D. Repeated-sprint ability – Part I: Factors contributing to fatigue.
17 *Sports Med.* 2011;41(8):673-94.
- 18 45. Buchheit M. Should we be recommending repeated sprints to improve repeated-sprint performance? *Sports*
19 *Med.* 2012;42(2):169-72.
- 20 46. Rodas G, Ventura JL, Cadefau JA, et al. A short training programme for the rapid improvement of both
21 aerobic and anaerobic metabolism. *Eur J Appl Physiol.* 2000; 82(5):480-86.
- 22 47. McGill SM, Chaimberg JD, Frost DM, et al. Evidence of a double peak in muscle activation to enhance
23 strike speed and force: an example with elite mixed martial arts fighters. *J Strength Cond Res.* 2010;24(2):
24 348-57.
- 25 48. Lieberman DE, Raichlen DA, Pontzer H, et al. The human gluteus maximus and its role in running. *J Exp*
26 *Biol.* 2006;209:2143-55
- 27 49. Bartlett JL, Sumner B, Ellis RG, et al. Activity and functions of the human gluteal muscles in walking
28 running, sprinting and climbing. *Am J Phys Anthropol.* 2014;153(1): 124-31.
- 29 50. Dorel S, Guilhem G, Couturier A, et al. Adjustment of muscle coordination during an all-out sprint cycling
30 task. *Med Sci Sports Exerc.* 2012;44(11):2154-64.
- 31 51. Sanchis-Moysi J, Idoate F, Izquierdo M, et al. Iliopsoas and gluteal muscles are asymmetric in tennis
32 players but not in soccer players. *PLoS One.* 2011;6(7):1-10.
- 33 52. Mero A, Komi PV, Gregor RJ. Biomechanics of sprint running - a review. *Sports Med.* 1992;13(6):376-92.
- 34 53. Morin J, Bourdin M, Edouard P, et al. Mechanical determinants of 100-m sprint running performance. *Eur J*
35 *Appl Physiol.* 2012;112(11):3921–30.
- 36 54. Pattyn N, Coeckelberghs E, Buys R, et al. Aerobic interval training vs. moderate continuous training in
37 coronary artery disease patients: A systematic review and meta-analysis. *Sports Med.* 2014;44(5):687-700.
- 38 55. Fagard RH, Staessen JA, Thijs L. Advantages and disadvantages of the meta-analysis approach. *J*
39 *Hypertens Suppl.* 1996;14(2):S9-12.

- 1 56. Atkinson G, Nevill AM. Selected issues in the design and analysis of sport performance research. *J Sports*
2 *Sci.* 2001;19(10):811-27.
- 3 57. Markovic G, Mikulic P. Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric
4 training. *Sports Med.* 2010;40(10):859-95.
- 5 58. Nagano Y, Higashihara A, Takahashi K, et al. Mechanics of the muscles crossing the hip joint during sprint
6 running. *J Sports Sci.* 2014;32(18):1722-28.

7

1	Figure Legend
2	Figure 1. Flow diagram of study selection. CL confidence limits
3	
4	Figure 2. Effects of repeated-sprint training on counter-movement jump performance in non-controlled trials.
5	CL confidence limits
6	
7	Figure 3. Effects of repeated-sprint training on 10 m sprint performance in non-controlled trials. CL confidence
8	limits
9	
10	Figure 4. Effects of repeated-sprint training on 20 m sprint performance in non-controlled trials. CL confidence
11	limits
12	
13	Figure 5. Effects of repeated-sprint training on 30 m sprint performance in non-controlled trials. CL confidence
14	limits
15	
16	Figure 6. Effects of repeated-sprint training on repeated-sprint ability in non-controlled trials. CL confidence
17	limits
18	
19	Figure 7. Effects of repeated-sprint training on high-intensity intermittent running performance in non-
20	controlled trials. CL confidence limits
21	