The Effects of Repeated-Sprint Training on Field-Based Fitness Measures: A Meta-Analysis of Controlled and Non-Controlled Trials

TAYLOR, Jonathan, MACPHERSON, Tom <http://orcid.org/0000-0002-6943-7302>, SPEARS, Iain and WESTON, Matthew

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

Running title: Effects of repeated-sprint training on fitness

Jonathan Taylor[1], Tom Macpherson[1], Iain Spears[1] and Matthew Weston[1]

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

Corresponding author:

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

Email: Jonathan.Taylor@tees.ac.uk

Telephone: ++44(0) 1642 342326

Key Points

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

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

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

Abstract

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

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

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

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

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

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

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

1 Introduction

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

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

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

2 Methods

2.1 Literature Search

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

2.2 Study Selection

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

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

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

2.3 Data Extraction

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

2.4 Data Analysis

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

3 Results

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

4 Discussion

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

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

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

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

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

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

The findings of our meta-analysis lend support to the premise that repeated-sprint training offers an effective strategy to concurrently improve a range of fitness measures related to team-sports performance. There are, however, several important issues to consider when interpreting our findings. Firstly, the issue of heterogeneity of studies included in a meta-analysis has been highlighted previously [54, 55]. We observed low to moderate heterogeneity of the studies included; the fitness parameters displaying higher heterogeneity generally comprised a smaller sample size. Furthermore, the small sample size within our meta-analysis may have affected both the magnitude of the effects observed and the uncertainty of these effects (e.g. the width of our confidence limits). Secondly, as many repeated-sprint training interventions are implemented ‘in-season’, research investigating the effects of repeated-sprint training on performance utilised a design whereby repeated-sprint training was either additional or replaced usual training. This makes it difficult to isolate the true effects of repeated-sprint training in highly-trained individuals [45]. To fully quantify the effects of repeated-sprint training on an athletic population, a design whereby participants complete no other training would be necessary; however, this presents ethical issues in high-level athletes [56]. Thirdly, although the repeated-sprint training literature demonstrates clear benefits for a wide range of fitness components and may have relevance for training in team-sports, it should be noted that our meta-analysis did not examine the effects of other modes of training and therefore we cannot compare directly the results with current best practice. For example, plyometric training is currently considered to be the most effective strategy to increase leg-power [57] and is known to improve counter-movement jump height by almost 10%, much greater than the improvement due to repeated-sprint training (2.3%). However, improvements in sprint times following repeated-sprint training for 10 m were similar to those for plyometric training (2.2%) and better for 20 m sprints (3.0% vs 1.5%) [57]. Finally, although it was beyond the scope of this review to examine how repeated-sprint training can influence the likelihood of injury, many team-sports athletes are considered to be at a high risk of hamstring injuries, with failure to activate the gluteal muscles during fast running considered to be an important risk factor [58]. Understandably, given the potential risks of introducing novel modes of maximal exercise within athlete training programs, coaches may be cautious about introducing repeated-sprints into training. In the short-term it may be necessary to perform these sprints on stationary bikes or by ensuring sprint distances are very short (<10 m) in order to minimise eccentric forces in the muscles [45].

5 Conclusions

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

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

References

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

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

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

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

Figure Legend

Figure 1. Flow diagram of study selection. CL confidence limits

Figure 2. Effects of repeated-sprint training on counter-movement jump performance in non-controlled trials. CL confidence limits

Figure 3. Effects of repeated-sprint training on 10 m sprint performance in non-controlled trials. CL confidence limits

Figure 4. Effects of repeated-sprint training on 20 m sprint performance in non-controlled trials. CL confidence limits

Figure 5. Effects of repeated-sprint training on 30 m sprint performance in non-controlled trials. CL confidence limits

Figure 6. Effects of repeated-sprint training on repeated-sprint ability in non-controlled trials. CL confidence limits

Figure 7. Effects of repeated-sprint training on high-intensity intermittent running performance in non-controlled trials. CL confidence limits