Note. This article will be published in a forthcoming issue of the *International Journal of Sports Physiology and Performance*. The article appears here in its accepted, peer-reviewed form, as it was provided by the submitting author. It has not been copyedited, proofread, or formatted by the publisher.

Section: Original Investigation

Article Title: Neuromuscular Fatigue Monitoring in Team Sport Athletes Using a Cycle Ergometer Test

Authors: George Wehbe[1], Tim Gabett[1], Dan Dwyer[2], Christopher McLellan[3], and Sam Coad[3]

Affiliations: [1]School of Exercise Science, Australian Catholic University, Brisbane, QLD, Australia. [2]School of Exercise and Nutrition Sciences, Deakin University, Geelong, VIC, Australia. [3]Faculty of Health Sciences and Medicine, Bond University, Gold Coast, QLD, Australia.

Journal: *International Journal of Sports Physiology and Performance*

Acceptance Date: July 30, 2014

DOI: http://dx.doi.org/10.1123/ijspp.2014-0217

ABSTRACT

Purpose: The purpose of this study was to compare a novel sprint test on a cycle ergometer to a countermovement jump test for monitoring neuromuscular fatigue following Australian rules football match-play. **Methods:** Twelve elite under 18 Australian rules football players (mean ± SD age = 17.5 ± 0.6 years; stature = 184.7 ± 8.8 cm; body mass = 75.3 ± 7.8 kg) from an Australian Football League club's Academy program performed a short sprint test on a cycle ergometer, along with a single countermovement jump test, at 1 h pre-match, and 1 h, 24 h, and 48 h post-match. The cycle ergometer sprint test involved a standardised warm-up, a maximal 6 s sprint, a 1-minute active recovery, and a second maximal 6 s sprint, with the highest power output of the two sprints recorded as peak power. **Results:** There were small to moderate differences between post-match changes in cycle ergometer peak power and countermovement jump peak power at 1 h (ES = 0.49), 24 h (ES = -0.85) and 48 h post-match (ES = 0.44). There was a substantial reduction in cycle ergometer peak power at 24 h post-match (ES = -0.40) compared with 1 h pre-match. **Conclusions:** The cycle ergometer sprint test described in this study offers a novel method of neuromuscular fatigue monitoring in team sport athletes, and specifically quantifies the concentric component of the fatigue-induced decrement of force production in muscle, which may be overlooked by a countermovement jump test.

KEY WORDS: Exercise test; Post-match fatigue; Team sports; Football; Athletic performance

INTRODUCTION

Athletes involved in team sports such as soccer, rugby league, and Australian rules football, are required to perform high intensity activities during matches,[1-3] and the demanding physical nature of such rigorous activities results in players experiencing physical[4-6] and perceptual fatigue.[7] Coaches and conditioning staff should understand and efficiently manage the fatigue-recovery process in order to maximise the potential of team performance on a weekly basis. Objectively quantifying fatigue, along with perceptual measures of physical and psychological well-being on a regular basis, can provide meaningful information on the preparedness of team sport athletes to train and compete, which may be beneficial for overall season performance.[7,8]

It has been proposed that applied tests to monitor neuromuscular fatigue (NMF) in an elite sport environment should be objective, quick and easy to administer, highly reliable, practical for use in a field setting, require minimal technology, and not be so overly strenuous that training is compromised.[9] Consequently, short maximal effort performance tests, in particular countermovement jump (CMJ) tests, have recently been examined in team sports such as soccer,[10,11] rugby league[5,8,12] and Australian rules football,[6,13,14] and are now often utilised to monitor NMF. The similarities in neuromuscular function between a CMJ and running suggest that the assessment of CMJ performance may be suitable for NMF monitoring in running-based sports.[15] In support, evidence has emerged suggesting that a CMJ test may be a useful tool to monitor NMF in Australian rules football,[6] and that reduced CMJ performance may compromise Australian rules football match performance.[13,14]

Recently, a novel approach has been proposed to monitor responses to training and match demands in team sport athletes. Peak power output, measured using a short cycle ergometer sprint test, was examined regularly throughout a Division I women's collegiate soccer season.[16] McLean et al.[16] found that regular starters, who experienced higher weekly training and match loads than non-starters, showed decreased cycle ergometer peak power during the second half of the season. Given the cycle ergometer test is highly reliable and sensitive to changes in training and match stresses, it was concluded that peak power offered a useful performance variable in monitoring NMF.[16] Moreover, a peak power cycle ergometer test for monitoring team sport NMF might be advantageous over a CMJ test. Firstly, cycle ergometer peak power, derived from short (up to 6 s) sprint tests, has greater test-retest reliability (CV = 2.8–3.3%)[17-19] than previously reported CMJ variables of peak power (CV = 3.5%), peak force (CV = 3.5%), and flight time:contraction time (CV = 6.1%).[20] Secondly, cycle ergometry provides an accurate power measurement that is independent of an imposed body mass load,[18] which presents a favourable option for coaches seeking to limit weight-bearing activity. Thirdly, eccentric muscle activity is experienced during a CMJ test, but not during cycling ergometry.[21] Eccentric muscle contractions are known to cause more muscle damage than concentric contractions,[22] and may increase the risk of muscle injury particularly in athletes with pre-existing match-related, microscopic muscle damage.[23] Finally, a single tester can use multiple cycle ergometers to test several athletes simultaneously, which may not be feasible using a CMJ test. Although cycling may not resemble team-sport specific movement patterns, such as running and jumping, as closely as a CMJ, if a cycle ergometer sprint test is able to detect a meaningful reduction in power output, then it may be reasonable to deduce that NMF is present, given that the force-production capacity of muscle is compromised in a fatigued state.[24,25]

The investigation of a performance measure to monitor NMF in team sports, other than a CMJ test, is warranted given that a 'gold standard' field test is yet to be established. While McLean et al.[16] monitored NMF in soccer players using peak power derived from a modified Monark cycle ergometer (Power Cycle, Austin, TX, USA), the use of a commercially available cycle ergometer to monitor NMF in team sport athletes has not been examined. Therefore, the aims of this study were to (1) compare pre- to post-match changes in peak power derived from a short sprint test protocol on a commercially available cycle ergometer with pre- to post-match changes in CMJ test variables in Australian rules football players; and (2) determine the sensitivity of a short sprint test protocol on a cycle ergometer to detect meaningful changes in peak power in response to an Australian rules football match.

METHODS

Subjects

Twelve elite under 18 Australian rules football players (mean ± SD age = 17.5 ± 0.6 years; stature = 184.7 ± 8.8 cm; body mass = 75.3 ± 7.8 kg) from the same team in an Australian Football League (AFL) club's Academy program participated in this study. Written informed consent was obtained from all players and their parents/guardians, and the Human Research Ethics Committee of the Australian Catholic University approved all experimental procedures.

Design

In this within-subject repeated measures design, players performed a short sprint test protocol on a cycle ergometer, along with a single CMJ test protocol, at various time points before and after an intra-club trial match in the pre-season. Testing was conducted 24 h and 1 h pre-match, and 1 h, 24 h, and 48 h post-match. Cycle ergometer and CMJ measures were expressed as a percentage of 1 h pre-match values; 24 h and 1 h pre-match values were used to determine reliability statistics for each test measure. Players were familiarised with all testing procedures on two separate occasions prior to the commencement of the study. Players were randomly assigned to either complete the cycle ergometer sprint test first, or to complete the CMJ test first, with 5 min of passive rest separating each test. The order in which the tests were completed remained consistent for each player across all testing sessions.

Methodology

The cycle ergometer sprint test was performed on a factory-calibrated Wattbike cycle ergometer (Wattbike Pro, Nottingham, UK), which operates with both air- and magnetically-braked systems. A lever regulates the flow of air through the flywheel to control air-braked resistance ('gear' levels 1–10), and a turn dial adjusts the magnetically-braked resistance ('climb control' levels 1–7). Players performed their testing on the same ergometer for each testing session. The ergometer computers were cleared of memory and 'zeroed' to restore their factory settings prior to testing, as recommended by the manufacturer. The reliability of the Wattbike cycle ergometer has previously been reported.[26-28] We found in this study, between 24 h and 1 h pre-match values, that the coefficient of variation (CV) and intraclass correlation coefficient (ICC) for Wattbike peak power during 6 s sprint efforts was 2.4% (90% confidence intervals [CI] = 1.8–3.9%) and 0.97 (90% CI = 0.91–0.99), respectively. Additionally the CV and ICC for Wattbike peak power in elite adult AFL players was 3.0% (90% CI = 2.5–3.8) and 0.96 (90% CI = 0.91–0.98), respectively (pilot data from our laboratory).

Each cycle ergometer sprint test commenced with a 2-minute warm-up on the Wattbike, whereby players were instructed to perform a steady state 'easy spin' at a self-selected cadence with the air- and magnetically-braked resistances fixed at the lowest settings (level 1 and 1, respectively). Players were then instructed to cease pedaling and adjust the air- and magnetically-braked resistance settings to level 10 and 4, respectively. On the tester's command, a 6 s maximal sprint was performed from a static starting position. Immediately following, a 1-minute active recovery 'easy spin' at a self-selected cadence was performed with both resistance settings returned to level 1. After the active recovery, an additional 6 s maximal sprint was again performed from a static starting position with the same resistance settings as the previous sprint. Similar test protocols for the assessment of peak power on other cycle ergometers have been described previously.[17-19] Peak power and peak cadence were recorded on the Wattbike performance computer as the highest power output and cadence of the two sprint cycle efforts, respectively. Players wore cycling shoes for testing and were required to remain in their seats for the duration of the protocol. Apart from verbal encouragement no other instructions were provided. Seat and handlebar positions were determined for each player prior to the first test and remained consistent across all subsequent testing sessions. The sprint cycle protocol was selected to elicit absolute maximal power output, and at the same time be practical and time-efficient in an elite team sport environment.

The CMJ test protocol comprised a 2-minute dynamic warm-up consisting of jogging, skipping, high knees, heel flicks and leg swings, followed by 3 practice jumps prior to the test jump. Players were instructed to jump as high as possible while keeping their hands held on the hips. Countermovement depth was self-selected. All CMJ testing was performed on a commercially available, portable force platform (Kistler 9290AD Force Platform, Kistler, USA). As a result of the reliability of measures between 24 h and 1 h pre-match values, the following CMJ variables were selected for comparison with cycle ergometer peak power: CMJ peak power (CV = 4.3% [90% CI = 3.2–7.0%], ICC = 0.89 [90% CI = 0.71–0.96]); CMJ mean power (CV = 5.2% [90% CI = 3.8–8.5%], ICC = 0.84 [90% CI = 0.60–0.95]); and CMJ flight time (CV = 2.8% [90% CI = 2.0–4.5%], ICC = 0.62 [90% CI = 0.16 – 0.85]).

The intra-club Australian rules football match was scheduled during the pre-season as a means of assisting coaches in making final team selections, However, players were informed prior to the match that team selection would not be influenced by the outcome of this study. The intra-club match comprised 4 x 15-minute quarters, and was played on a floodlit grass oval at 18:00. During the match, players were fitted with 10 Hz GPS tracking units (MinimaxX S5, Catapult Innovations, Melbourne, Australia) to quantify match activity profiles. Only time spent on the field was included for activity profile analysis; time spent on the bench and during inter-quarter breaks was omitted.

Statistical Analysis

Data were analysed using SPSS Statistics software version 22 (Chicago, IL) and expressed as mean ± SD. Data were checked for normality using the Shapiro-Wilk test. Changes in cycle ergometer peak power were compared to each selected CMJ variable over time using a two-way (test x time) ANOVA with repeated measures. Where significant differences were detected, a Scheffe's *post-hoc* test was used to detect the source(s) of those differences. Statistical significance was set at $P<0.05$. To determine the magnitude of main effects and interactions in ANOVA, partial eta squared (n^2) effect size statistics were adopted, and values of 0.01–0.06, 0.06–0.15, and >0.15 were considered small, moderate, and large, respectively.[29] To assess the real-world relevance of the data, Cohen's effect size (ES) statistic was calculated to determine: (1) the magnitude of pairwise differences between cycle ergometer peak power and CMJ variables at each time point; and (2) the magnitude of change of each test variable from 1 h pre-match. Effect sizes of 0.20–0.60, 0.61–1.20, and >1.20 were considered small, moderate, and large, respectively.[30] In addition, the smallest worthwhile change (SWC) was calculated as 0.2 x SD, and the probability that the true value of the effect was greater than the SWC was calculated and interpreted qualitatively according to the following: <1%, almost certainly not; <5%, very unlikely; <25%, unlikely; <50%, possibly not; >50%, possibly; >75%, likely; >95%, very likely; >99% almost certain.[31] A substantial increase or decrease was regarded as a ≥75% chance of the effect being equal to or greater than the SWC.[31] Effects that were less certain were described as trivial and in cases where the 90% CI of the ES crossed -0.2 and 0.2 the magnitude was described as unclear.[31]

RESULTS

On-field match time was 58.6 ± 3.5 min, which equated to 96.7 ± 5.8% of total match time (range = 80.7–100%). Players covered a total distance of 7627 ± 708 m during the match, of which 2122 ± 346 m was covered at high speeds (>15 $km.h^{-1}$). Relative total distance was 130 ± 13 $m.min^{-1}$ and relative high-speed distance was 35 ± 6 $m.min^{-1}$.

Results for ANOVA are presented in Table 1. There were small to moderate differences between cycle ergometer peak power and CMJ peak power at 1 h (ES = 0.49 ± 0.99; possibly, 69%), 24 h (ES = -0.85 ± 1.70; possibly, 60%) and 48 h post-match (ES = 0.44 ± 1.42; possibly, 56%); small to moderate differences between cycle ergometer peak power and CMJ mean power at 1 h (ES = -0.72 ± 0.86; likely, 82%), 24 h (ES = -1.16 ± 1.00; likely, 90%) and 48 h post-match (ES = 0.27 ± 1.21; possibly not, 48%); and a small difference between cycle ergometer peak power and CMJ flight time at 24 h post-match (ES = 0.49 ± 0.57; likely, 85%) (Figure 1). Post-match changes in test variables from 1 h pre-match are presented in Table 2.

DISCUSSION

This is the first study to examine acute post-match changes in cycle ergometer peak power in running-based team sport athletes. We found that pre- to post-match changes in cycle ergometer peak power in Australian rules football players were practically meaningful (Table 2), and in line with some, but not all CMJ variables (Figure 1) commonly used to monitor NMF.[5,8]

We found a substantial decrease in CMJ mean power and flight time at 1 h post-match, yet cycle ergometer peak power and CMJ peak power changes were not as definitive (Table 2). Together, these results support and oppose previous work. Young male soccer players showed no changes in both CMJ peak power and mean power immediately post-match compared to the non-fatigued control (measured 3-5 days post-match), despite an overall reduction in rapid force capacity of the lower limbs indicated by decreases in isometric strength and contractile rate of force development.[11] Conversely in rugby league players, CMJ peak power and peak force (not measured in this study) decreased at 30 min post-match.[5] In another study, CMJ peak power remained unchanged immediately post-match in Australian rules football players, and any further changes in CMJ peak power at subsequent post-match time points were not investigated on the premise of this outcome.[6] However, Cormack et al. did find a substantial decrease in CMJ mean power and flight time in Australian rules football players immediately post-match,[6] which accords with our results.

In this study, there was a substantial decrease in cycle ergometer peak power, and CMJ peak power, mean power and flight time at 24 h post-match when compared to 1 h pre-match, with all but CMJ flight time returning to near pre-match values by 48 h post-match (Table 2). In comparison, similar reductions in CMJ flight time were reported at 24 h post-match in Australian rules football[6] and rugby league[8] players, although measures were not taken at 48 h post-match. While substantial reductions in CMJ mean power have also been reported for Australian rules football players at 24 h post-match,[6] CMJ mean power remained below pre-match values at 72 h post-match.[6] In rugby league players, reductions in CMJ peak power were reported at 12 h, 24 h, and 36 h post-match,[5.12] and returned to pre-match values at 48 h post-match.[5]

Our results suggest that the cycle ergometer sprint test described in this study may be used to monitor NMF status in running-based team sport athletes. The dissimilarity in inter-muscular coordination of the lower limbs between cycling actions and running-based, team-sport specific activities may question the efficacy of using a cycle ergometer test to monitor NMF induced by team sport match-play. However, there are similarities between cycle ergometer short sprint performance and the ability to perform short, explosive running efforts from stationary starts.[32] For example, Chelly et al.[32] found significant positive associations between cycle ergometer peak power and both the velocity and acceleration during the first 5 m of a sprint in soccer players. Furthermore, cycle ergometer tests can accurately quantify lower limb force-production capacity,[18] and are highly reliable to detect worthwhile changes in power output,[17-19] making them a potentially valuable NMF-monitoring tool. While the use of a CMJ test to monitor NMF is generally accepted, many CMJ variables have been reported with contrasting results.[5,6,11] It is well recognised that the force-production capacity of muscle is compromised in a fatigued state,[11,24,25] yet studies have shown that CMJ performance can be maintained following fatigue-inducing activities.[6,11]

Although there are similarities in neuromuscular function between a CMJ and running,[15] the time course of recovery between sprint performance and CMJ performance can vary.[10] This may present difficulties in determining the state of preparedness of athletes to perform running-based team sport activities based on CMJ performance alone. Indeed, compromised CMJ performance may be indicative of impairment of the stretch-shortening cycle (SSC) in muscle. Furthermore, the SSC is an important component of running performance in team sports such as soccer, rugby league, and Australian rules football.[1-3] However, a CMJ performance test may not necessarily be adequate for determining the overall force-production decrement of muscle. Outcomes of CMJ performance are not always dictated by lower limb muscle strength or contractile rate of force development.[10,11] In addition, a recent study found no correlations between CMJ performance and both the velocity and acceleration during the first 5 m of a sprint,[32] which is an important aspect of team sport performance.[32] There is limited involvement of the SSC during the first few steps of acceleration over short distances, where propulsive forces greatly supersede eccentric braking forces during ground contact, and the main need is for concentric contraction to generate force and power.[32] The involvement of the SSC increases when sprints are prolonged to distances greater than 30 m and reach higher velocities.[32] In this context, it is important to consider other components of the force-generating capacity of muscle in conjunction with the SSC for overall performance of running-based team sport activities, such as explosive actions, accelerations, and tackles, which are often largely dependent on forceful concentric muscle contractions. Therefore, understanding the mechanism for reduction in the force-production of muscle beyond the SSC component may be beneficial for the assessment of team sport NMF.

In the present study, there were small to moderate differences between cycle ergometer peak power and both CMJ peak power and CMJ mean power at 1 h, 24 h, and 48 h post-match, as well as a small difference between cycle ergometer peak power and CMJ flight time at 24 h post-match (Figure 1). These differences may be explained by the capacity of each test to measure the specific components of force production in muscle, which may be disproportionally affected by NMF.[11] Peak power derived from a cycle ergometer is generated almost exclusively from concentric muscle contractions, whereas CMJ performance is reliant on the eccentric, concentric, and SSC components of muscle force production. Therefore, a cycle ergometer peak power test may be more useful to determine the decrements in muscle force production related to deficiencies in concentric contraction, whereas a CMJ test may provide insight into the impairments of the SSC mechanism.

PRACTICAL APPLICATIONS

The cycle ergometer sprint test protocol described in this study is a practical and highly reliable field-based test that can be implemented with minimal disruption to training. Furthermore, cycle ergometer peak power is a practically meaningful performance measure for monitoring NMF status in running-based team sport athletes. In conjunction with perceptual well-being measures, and other short performance tests such as a CMJ test, the cycle ergometer sprint test protocol can provide meaningful information on the preparedness of athletes to train and compete.

This is the first study to examine the use of a short sprint test on a cycle ergometer as a fatigue-monitoring tool in running-based team sport athletes. Therefore, to address the requirements of the "clinimetrics" approach proposed by Impellizzeri and Marcora,[33] further studies are needed to build a body of evidence to support the development and application of the cycle ergometer sprint test used in this study. Specifically, future research could focus on: the validity, reliability, and sensitivity of the cycle ergometer sprint test; applications for NMF monitoring in other team sports such as soccer and the rugby codes; and the investigation of longitudinal changes in peak power (e.g. across a season).

CONCLUSION

The results of the present study demonstrate that cycle ergometer peak power can be used to assess match-related NMF induced by running-based team sport activity. We found that cycle ergometer peak power was substantially reduced at 24 h following Australian rules football match-play, which coincided with CMJ measures commonly used to quantify NMF. Small to moderate differences between post-match changes in cycle ergometer peak power and CMJ peak power highlight the difference in fatigue-recovery response between different mechanisms of force-production in muscle.

ACKNOWLEDGEMENTS

The authors thank the Academy players who participated in the study, and the Academy staff for their support and collaboration, particularly Luke Curran, Scott Borlace and Christopher Brennan. The results of the present study do not constitute endorsement of the product by the authors or the journal. No financial assistance was provided for this study.

REFERENCES

1. Wehbe GM, Hartwig TB, Duncan CS. Movement analysis of Australian national league soccer players using global positioning system technology. *J Strength Cond Res.* 2014;28:834-842.

2. Gabbett TJ, Jenkins DG, Abernethy B. Physical demands of professional rugby league training and competition using microtechnology. *J Sci Med Sport.* 2012;15:80-86.

3. Wisbey B, Montgomery PG, Pyne DB, Rattray B. Quantifying movement demands of AFL football using GPS traking. *J Sci Med Sport.* 2010;13:531-536.

4. Rampinini E, Bosio A, Ferraresi I, Petruolo A, Morelli A, Sassi A. Match-related fatigue in soccer players. *Med Sci Sports Exerc.* 2011;43:2161-2170.

5. McLellan CP, Lovell DI, Gass GC. Markers of postmatch fatigue in professional rugby league players. *J Strength Cond Res.* 2011;24:1030-1039.

6. Cormack SJ, Newton RU, McGuigan MR. Neuromuscular and endocrine responses of elite players to an Australian rules football match. *Int J Sports Physiol Perform.* 2008;3:359-374.

7. Gastin PB, Meyer D, Robinson D. Perceptions of wellness to monitor adaptive responses to training and competition in elite Australian football. *J Strength Cond Res.* 2013;27:2518-2526.

8. McLean BD, Coutts AJ, Kelly V, McGuigan MR, Cormack SJ. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *Int J Sports Physiol Perform.* 2010;5:367-383.

9. Fowles JR. Technical issues in quantifying low-frequency fatigue in athletes. *Int J Sports Physiol Perform.* 2006;1:169-171.

10. Andersson H, Raastad T, Nilsson J, Paulsen G, Garthe I, Kadi F. Neuromuscular fatigue and recovery in elite female soccer: Effects of active recovery. *Med Sci Sports Exerc.* 2008;40:372-380.

11. Thorlund JB, Aagaard P, Madsen K. Rapid muscle force capacity changes after soccer match play. *Int J Sports Med.* 2009;30:273-278.

12. Johnston RD, Gibson NV, Twist C, Gabbett TJ, MacNay SA, MacFarlane NG. Physiological responses to an intensified period of rugby league competition. *J Strength Cond Res.* 2013;27:643-654.

13. Mooney MG, Cormack SJ, O'Brien BJ, Morgan WM, McGuigan M. Impact of neuromuscular fatigue on match exercise intensity and performance in elite Australian football. *J Strength Cond Res* 2013; 27(1):166-173.

14. Cormack SJ, Mooney MG, Morgan W, McGuigan MR. Influence of neuromuscular fatigue on accelerometer load in elite Australian football players. *Int J Sports Physiol Perform.* 2013;8:373-378.

15. Bosco C, Montanari G, Ribacchi R et al. Relationship between the efficiency of muscular work during jumping and the energetics of running. *Eur J Appl Physiol.* 1987;56:138-143.

16. McLean BD, Petrucelli C, Coyle EF. Maximal power output and perceptual fatigue responses during a Division I female collegiate soccer season. *J Strength Cond Res.* 2012;26:3189-3196.

17. Fernández-Peña E, Lucertini F, Ditroilo M. A maximal isokinetic exercise for EMG normalization in cycling. *J Electromyogr Kinesiol.* 2009;19:e162-170.

18. Martin JC, Wagner BM, Coyle EF. Inertial-load method determines maximal cycling power in a single exercise bout. *Med Sci Sports Exerc.* 1997;29:1505-1512.

19. Mendez-Villanueva A, Bishop D, Hamer P. Reproducibility of a 6-s maximal cycling sprint test. *J Sci Med Sport.* 2007;10:323-326.

20. Cormack SJ, Newton RU, McGuigan MR, Doyle TLA. Reliability of measures obtained during single and repeated countermovement jumps. *Int J Sports Physiol Perform.* 2008;3:131-144.

21. So RCH, Ng JKF, Ng, GYF. Muscle recruitment pattern in cycling: a review. *Phys Ther Sport.* 2005;6:89-96.

22. Gleeson M, Blannin AK, Zhu B, Brooks S, Cave R . Cardiorespiratory, hormonal and haematological responses to submaximal cycling performed 2 days after eccentric or concentric exercise bouts. *J Sports Sci.* 1995;13:471-479.

23. Brockett CL, Morgan DL, Proske U. Predicting hamstring strain injury in elite athletes. *Med Sci Sports Exerc.* 2004;36:379-387.

24. Abbiss CR, Laursen PB. Models to explain fatigue during prolonged endurance cycling. *Sports Med.* 2005;35:865-898.

25. Kay D, Marino FE, Cannon J, Gibson ASC, Lambert MI, Noakes TD. Evidence for neuromuscular fatigue during high-intensity cycling in warm, humid conditions. *Eur J Appl Physiol.* 2001;84:115-121.

26. Hopker J, Myers S, Jobson SA, Bruce W, Passfield L. Validity and reliability of the Wattbike cycle ergometer. *Int J Sports Med.* 2010;31:731-736.

27. Driller MW, Argus CK, Shing CM. The reliability of a 30 second sprint test on the Wattbike cycle ergometer. *Int J Sports Physiol Perform.* 2013;8:379-383.

28. Driller MW, Argus CK, Bartram JC et al. The reliability of a two-bout exercise test on a Wattbike cycle ergometer. *Int J Sports Physiol Perform.* 2014;9:340-345.

29. Cohen J. *Statistical power analysis for the behavioural sciences,* Hillsdale, NJ, Lawrence Erlbaum Associates, 1988.

30. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009;41:3-13.

31. Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes. *Int J Sports Physiol Perform.* 2006;1:50-57.

32. Chelly MS, Chérif N, Amar MB et al. Relationships of peak leg power, 1 maximal repetition half back squat, and leg muscle volume to 5-m sprint performance of junior soccer players. *J Strength Cond Res.* 2010;24:266-271.

33. Impellizzeri FM, Marcora SM. Test validation in sport physiology: lessons learned from clinimetrics. *Int J Sports Physiol Perform.* 2009;4:269-277.

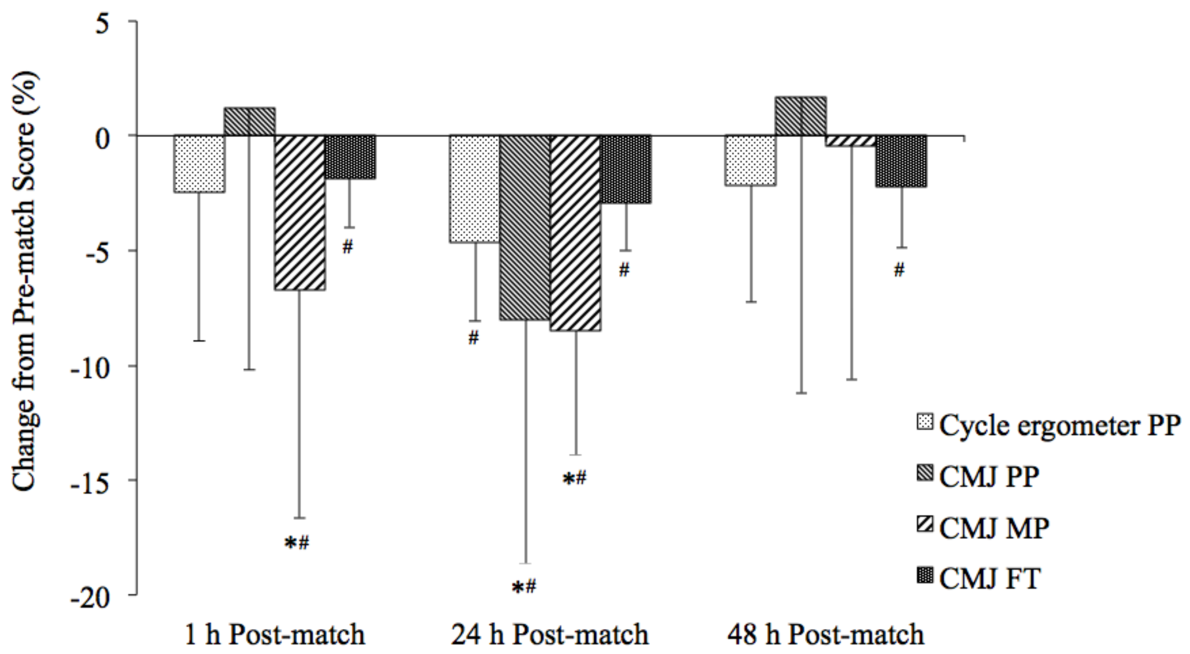

Figure 1 – Mean ± SD percentage changes in cycle ergometer peak power and countermovement jump variables from 1 h pre-match to post-match values. *Moderate effect size difference (0.61–1.20) compared with cycle ergometer peak power. #Substantial decrease (≥75% chance of the effect being equal to or greater than the smallest worthwhile change) from 1 h pre-match.

CMJ – countermovement jump

FT – flight time

MP – mean power

PP – peak power

"Neuromuscular Fatigue Monitoring in Team Sport Athletes Using a Cycle Ergometer Test" by Wehbe G et al.
International Journal of Sports Physiology and Performance

Table 1: Results of two-way (test x time) ANOVA with repeated measures comparing 1 h, 24 h, and 48 h post-match changes from 1 h pre-match in cycle ergometer peak power with countermovement jump variables.

Test variables	Effect	F value	Greenhouse-Geisser df	*P* value	Effect size statistic n^2	Magnitude of effect
Cycle ergometer PP & CMJ PP	Test	0.149	1, 11	0.707	0.013	Small
	Time	4.475	1.469, 16.158	0.023	0.289	Large
	Test x time	4.332	1.711, 18.821	0.026	0.283	Large
Cycle ergometer PP & CMJ MP	Test	0.707	1, 11	0.418	0.060	Small
	Time	3.723	1.324, 14.569	0.064	0.253	Large
	Test x time	3.025	1.744, 19.179	0.069	0.216	Large
Cycle ergometer PP & CMJ FT	Test	0.500	1, 11	0.494	0.043	Small
	Time	1.834	1.575, 17.321	0.183	0.143	Moderate
	Test x time	0.662	1.425, 15.679	0.526	0.057	Small

CMJ – countermovement jump

FT – flight time

MP – mean power

PP – peak power

Table 2: Changes from 1 h pre-match in cycle ergometer and CMJ test variables in response to an Australian rules football match. Data are Cohen's effect size statistic (± 90% confidence interval), qualitative descriptor of magnitude of change, and percentage change from 1 h pre-match score.

	1 h Post	24 h Post	48 h Post
Cycle ergometer PP	-0.33 ± 0.41 Trivial (70%) -2.49%	-0.40 ± 0.41 Substantial decrease (80%) -4.62%	-0.27 ± 0.32 Trivial (65%) -2.18%
CMJ PP	0.04 ± 0.45 Unclear +1.18%	-0.57 ± 0.43 Substantial decrease (93%) -8.01%	0.00 ± 0.45 Unclear +1.67%
CMJ MP	-0.67 ± 0.52 Substantial decrease (93%) -6.74%	-0.60 ± 0.40 Substantial decrease (95%) -8.50%	-0.10 ± 0.47 Unclear -0.44%
CMJ FT	-0.45 ± 0.27 Substantial decrease (93%) -1.85%	-0.70 ± 0.39 Substantial decrease (98%) -2.92%	-0.54 ± 0.33 Substantial decrease (95%) -2.25%

CMJ – countermovement jump

FT – flight time

MP – mean power

PP – peak power