Section: Original Investigation

Article Title: Neuromuscular and Perceptual Fatigue Responses to Consecutive Tag Football Matches

Authors: Luke W. Hogarth, Brendan J. Burkett and Mark R. McKean

Affiliations: The authors are with the School of Health and Sport Sciences, Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Maroochydore, Australia.

Journal: *International Journal of Sports Physiology and Performance*

Acceptance Date: November 6, 2014

DOI: http://dx.doi.org/10.1123/ijspp.2014-0355

“Neuromuscular and Perceptual Fatigue Responses to Consecutive Tag Football Matches”
by Hogarth LW, Burkett BJ, McKean MR
International Journal of Sports Physiology and Performance

Original Investigation

Neuromuscular and Perceptual Fatigue Responses to Consecutive Tag Football Matches

Authors and Affiliations:

Luke W. Hogarth, Brendan J. Burkett and Mark R. McKean

School of Health and Sport Sciences, Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Maroochydore, Australia.

Corresponding Author:
Luke W. Hogarth
Telephone: +61 7 5456 5402
Fax: +61 7 5459 4600
Email: luke.hogarth@research.usc.edu.au
Postal Address: University of the Sunshine Coast, Locked Bag 4, Maroochydore DC, Queensland, Australia 4558

Preferred running head: Fatigue responses in tag football

Abstract word count: 228
Text-only word count: 3651
Number of figures: 1
Number of tables: 2

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

"Neuromuscular and Perceptual Fatigue Responses to Consecutive Tag Football Matches"
by Hogarth LW, Burkett BJ, McKean MR
International Journal of Sports Physiology and Performance

Abstract

Purpose: To examine the neuromuscular and perceptual fatigue responses to consecutive tag football matches played on the same day and determine the relationship between fatigue and match running performance. **Methods:** Neuromuscular and perceptual fatigue responses of fifteen national tag football players were assessed prior to and during the 2014 State of Origin tournament. Global positioning systems (GPS) provided data on players match running performance and a vertical jump test and subjective questionnaire was used to assess player's neuromuscular and perceptual fatigue, respectively. **Results:** There were small to moderate reductions in the majority of match running performance variables over consecutive matches, including distance (ES=-0.81), high-speed running (HSR) distance (ES=-0.51), HSR efforts (ES=-0.64) and maximal accelerations (ES=-0.76). Pre-match vertical jump was initially below baseline values before the first match (ES=0.68-0.88). There were no substantial reductions in vertical jump performance from baseline values over consecutive matches, although there was a small decline from post-match two to post-match three (3.3%; ES=-0.45±0.62). There were progressive reductions in perceived well-being scores following matches one (ES=-0.38), two (ES=-0.70) and three (ES=-1.14). There were small to moderate associations between changes in fatigue measures and match running performance. **Conclusions:** Perceptual fatigue accumulates over consecutive tag football matches although there were only marginal increases in neuromuscular fatigue. However, both neuromuscular and perceptual fatigue measures were found to contribute to reduced match running performance in the final match.

Keywords: Team sports; physical performance; match-activity profile; psychometric measures; GPS.

Introduction

Tag football is an international sport that has gained rapid popularity since its establishment in 1993. There are several variants of tag football played worldwide with sixteen nations competing in regular international competitions such as the triennial Tag Football World Cup. The game is best described as a modified version of rugby league where players aim to remove Velcro tags attached to each player's shorts rather than tackling their opponent. Modified contact and unlimited interchange laws promote a fast-paced running tempo that is characterised by frequent high-intensity running and change of direction activities.[1] Elite-level competition is typically played in tournament formats at state-, national- and international-representative levels. Teams play up to four matches on a single day which may impose considerable physiological demands and impact negatively on player performance in the latter stages of the tournament.

The use of non-invasive performance tests and subjective questionnaires are useful indicators of the fatigue-recovery cycle following intensive training and competition allowing practitioners to better understand and manage fatigue. Studies in rugby league suggest players experience suppressed neuromuscular function associated with skeletal muscle damage for up to 48 hours following matches.[2,3] In many cases suppressed neuromuscular function was accompanied by alterations in player's perceived fatigue and muscle soreness which may force athletes to down-regulate their exercise capacity.[4,5] High levels of neuromuscular fatigue, skeletal muscle damage and altered psychological states have the potential to compromise performance during subsequent competition and training.[6]

A number of recent studies have aimed to better understand changes in neuromuscular function and perceived fatigue levels during tournament competitions played over consecutive days. Montgomery et al.[7] showed junior basketball players experienced accumulated fatigue over a three day tournament resulting in substantial reductions in speed, agility and vertical jump performance. A more recent study by Johnston et al.[4] explored the relationship between changes in neuromuscular and perceived fatigue and decrements in match performance over a five day junior rugby league tournament. There were progressive decreases in countermovement jump performance and perceived well-being which showed small to large associations with reductions in important match activities during the final games of the tournament. The assessment of neuromuscular function and perceived fatigue may have important implications for managing player's fatigue and improving game readiness during consecutive days of competition.

Although studies have examined the neuromuscular and perceptual fatigue responses over consecutive days of sporting competition, there is limited research into the use of these fatigue measures over consecutive matches on a single day. Consequently, it is not known whether the sensitivity of these measures provide a useful assessment of players fatigue-recovery cycle over repeated game performances within several hours of one another. For sports such as tag football, identifying the fatigue response to consecutive matches may assist coaching staff to manage player's athletic state and identify strategies that improve team performance. The purpose of this study is to (1) examine the neuromuscular and perceptual fatigue responses to consecutive tag football matches played on the same day and (2) determine the relationship between fatigue measures and match running performance.

Methods

Subjects

Fifteen male, national tag football players participated in this study (age 23.0±2.5 years, height 180±6 cm, body mass 78.3±5.9 kg, estimated VO_{2max} 56.6±2.8 $ml.kg^{-1}.min^{-1}$). Participants were from the Queensland men's team selected to compete at the 2014 Annual State of Origin tournament which is a three-match test series contested by Queensland and

New South Wales. The State of Origin tournament is the highest standard of tag football competition in Australia and provides a pathway for international representation. Players were informed of the study requirements prior to the tournament and the entire team and coaching staff gave their informed consent to participate. All procedures were approved by the University of the Sunshine Coast's research ethics committee in the spirit of the Declaration of Helsinki.

Design

A prospective and observational study design was employed. Player activity profiles were determined using 10 Hz global positioning system (GPS) devices for three matches played on the same day against the same opposition. Matches were 40 minutes in duration and there was a 90 minute recovery period between each match. A vertical jump test and subjective well-being questionnaire was used to assess player fatigue levels prior to and during the tournament.

Methodology

Player characteristics and baseline vertical jump was assessed 5 days prior to the tournament before combined squad training. This date was selected for baseline testing as it followed a 2-day unloading phase and was the final combined squad training prior to short-haul air travel (~42 hours pre-tournament). Vertical jump performance was assessed as the jump height reached during three maximal attempts using a Swift apparatus (Swift Performance Equipment, Lismore, Australia). Players were instructed to perform a rapid countermovement jump from a standing start. Movement of arms was not restricted during the jump attempts and the depth of the countermovement action was self-selected. The vertical jump test was shown to have acceptable reliability in this study's participant cohort (CV=4.1%; ICC=0.88). Vertical jump performance was assessed on five occasions following baseline testing. This included 22 hours and 1 hour before the team's first match and 15-20 minutes following consecutive matches.

Perceptual well-being was assessed prior to the vertical jump test using a previously recommended questionnaire.[4,8] The questionnaire required players to rate their feelings of fatigue, sleep quality, general muscle soreness, stress and mood on a 5-point Likert scale. Players first recorded sleep quality score was used for each subsequent score when the questionnaire was used on multiple occasions on the same day. Players performed the vertical jump test immediately following the questionnaire in the same order for each test and values were expressed relative to player's baseline measure to account for individual variances.

Following matches players had a 90 minute recovery period before their next match. The team undertook an active recovery session involving low-intensity running patterns and dynamic stretching exercise immediately following matches before post-match perceptual well-being and vertical jump height was assessed. Players then had an approximated 40 minutes rest which was spent at the tournament venue before preparing for their next match. During this period, players consumed water and food ad libitum and were instructed by the coaching staff to avoid strenuous activity and sitting for prolonged periods of time. Players started to prepare for their next match approximately 40 minutes before kick-off at which time GPS devices were switched on and placed in the custom-made garment of each player. The team then performed a standardised warm-up before being ready to take the playing field approximately 5 minutes before the scheduled time for kick-off.

Time-motion data was sampled at 10 Hz using MinimaxX GPS devices (Catapult Sports, Melbourne, Australia). The GPS was worn in a small custom made vest in between the shoulder blades on the upper back of each player. Players were familiar with the GPS device and the custom made vest which they wore on numerous occasions prior to the tournament. The GPS device was switched on and locked to satellites prior to the team warm-up. Recorded data was compiled and analysed in Sprint 5.1 (Catapult Sports, Melbourne, Australia). Data was assigned to playing halves in addition to the entire match. The number of field rotations performed by each player was recorded for matches. A field rotation was defined as a time period spent on-field during match-play either before or following an interchange rest period. Periods of time where players were off the field, including interchanges and half-time periods, were excluded from data analysis. The mean (±SD) horizontal dilution of position (HDOP) and number of satellites locked to GPS devices during matches was 0.94±0.1 and 11.2±1.0, respectively.

This study categorised time-motion data into low-speed running (LSR = 0.4-14.0 km/h) and high-speed running (HSR = ≥14.1 km/h) as they have previously been recommended for tag football.[1] Low-to-high speed running ratios (low: high speed ratio) were calculated as the time spent above and below the HSR threshold (i.e. 14.1 km/h). Acceleration and deceleration efforts >2.78 $m.s^{-2}$ and lasting a minimum of 0.4 s were also recorded. The GPS device used in this study has been shown to have a typical error for distance covered at high-intensity running speeds (>4.17 $m.s^{-1}$ and >5.56 $m.s^{-1}$) of 4.7% to 10.5% and a percentage bias of -1.1% to -7.3% during intermittent shuttle runs.[9] Further, 10 Hz GPS has a typical error of 1.3% for total distance during team sport simulation circuits involving changes of direction activities.[9,10] The ability of 10 Hz GPS to detect instantaneous changes in velocity during acceleration against the criterion measure of a laser has a percentage bias of -3.6% to -2.1% and a typical error of 2.6% to 5.9%.[12] The occurrence of acceleration and deceleration efforts were only recorded if they lasted a minimum of 0.4 s as this method has been shown to improve the ecological validity of acceleration measures.[13]

Statistical Analysis

Data was log-transformed prior to statistical analysis to reduce non-uniformity of error and back transformed to attain descriptive statistics (mean ± SD). Standardised differences were calculated and the precision of estimates are indicated with 90% confidence limits (CL). The magnitude of difference was assessed as trivial (<0.2), small (0.21-0.6), moderate (0.61-1.2), large (1.21-2.0) and very large (>2.1) as per previously standardised criteria.[14] The effect was reported as unclear when the CL crossed the threshold for both substantially positive (0.2) and negative (-0.2) values. Pearson's correlation coefficients were calculated to examine the association between fatigue measures and match running performance and reported as small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9) and almost perfect (>0.9-1.0).[15]

Results

The Queensland team participating in this study levelled the first match (5-5) and lost the second (3-6) and third (2-5) matches to their opposition. The majority of activity profile variables showed small to moderate reductions (ES=0.51-0.81) from the first to final match, except for field time, peak running speed and maximal deceleration frequency (Table 1). Further, there were small reductions (ES=0.42-0.59) in distance, HSR distance, exercise-to-rest ratios and maximal accelerations in the second match.

Players' vertical jump height was 54.7±6.5 cm (baseline), 51.5±4.7 cm (22 hours pre-match), 52.5±5.5 cm (1 hour pre-match), 55.2±4.5 cm (post-match one), 55.0±4.6 cm (post-match two) and 53.4±5.6 cm (post-match three). Vertical jump height was expressed relative to player's baseline measure to account for individual variances (Figure 1A). Vertical jump height was initially below baseline levels 22 hours (ES=-0.88) and 1 hour (ES=-0.68) before the first match. Values returned to baseline following match one and there were no substantial reductions from baseline levels post-matches two and three. However, there was a small decline (ES=-0.45±0.62) in vertical jump height post-match three compared to post-match two values. Perceived well-being peaked 1 hour before the first match and then progressively declined following each match (Figure 1B). The most significant reductions in perceived well-being were following matches two (ES=-0.70; p=0.05) and three (ES=-1.14; p<0.01).

There were small to moderate associations between changes in vertical jump height and perceived well-being and reductions in selected performance variables (Table 2). Higher pre-match (1 hour) perceived well-being showed large associations with reduced maximal accelerations (r=-0.66) and decelerations (r=-0.53) from the first to final match. There were moderate to large correlations showing higher tournament averages for HSR efforts, maximal accelerations and maximal decelerations to be associated with greater decreases in vertical jump (r=-0.31 to -0.54) and perceived well-being (r=-0.39 to -0.54) over consecutive matches (i.e. ΔPost-match 1 vs. 3). Similarly, there were moderate to very large correlations showing increased distance (r=-0.50 to -0.81), HSR distance (r=-0.65 to -0.75), HSR efforts (r=-0.50 to -0.81), maximal accelerations (r=-0.57 to -0.58) and maximal decelerations (r=-0.48 to -0.58) in the first two matches to be associated with greater reductions in match work-rate in the final match (i.e. distance, HSR distance, HSR efforts, maximal accelerations and maximal decelerations).

Discussion

This study is the first to examine the neuromuscular and perceptual fatigue responses to consecutive matches played on the same day and identify the relationships between fatigue and match running performance in tag football. The main findings were: (1) pre-match vertical jump performance was associated with higher tournament averages for selected match running performance variables; (2) there were progressive declines in match running performance over consecutive tag football matches played on the same day; (3) players experienced progressive increases in perceptual fatigue over the tournament; although, there was only a marginal decrease in vertical jump performance following the final match and (4) there were a number of small to moderate associations between increases in neuromuscular and perceptual fatigue measures and reduced match running performance in the final match.

In the present study, players showed reduced vertical jump performance compared to baseline levels prior to the first match of the tournament (Figure 1A). The mechanisms responsible for suppressed neuromuscular function were not examined in the current study and could be owing to residual fatigue from prior training or due to the effects of short-haul air travel.[6,16] Regardless, it is an interesting finding particularly as pre-match vertical jump performance showed moderate correlations with tournament averages for HSR distance, HSR efforts and maximal accelerations (Table 2). These results suggest that suppressed neuromuscular function prior to tournament competition may impact negatively on match running performance in tag football players. Similarly, research in elite Australian rules football showed neuromuscular fatigue assessed using force-time derived measures 96 hours following the previous match had a negative impact on the relationship between players' match work-rate and their coaches performance rating.[6] The vertical jump test may provide a useful indication of player's athletic state as previously shown using force-time derived measures and may potentially be used to guide strategies that alleviate residual fatigue prior to tournament competition.

An important finding of this study was that tag football players experienced reductions in the majority of match running performance variables over consecutive matches (Table 1). Although these results may suggest that accumulated fatigue compromised match running performance, it is also possible that tactical changes and other match-related factors contributed to this finding. It is interesting to note that players interchange strategy appeared to change over consecutive matches as they were found to perform fewer, but longer, field rotations following the first match (Table 1). This may explain the reduction in HSR distance and maximal accelerations following the first match, as players had longer field rotations suggesting their substrate depletion may have been more severe. This is a perplexing finding considering player interchanges in tag football are self-managed and therefore it is logical to assume that players would be more likely to increase their interchange frequency to minimise the fatigue response.[17,18] An equally valid explanation may be that player's match work-rate influences their self-selected interchange frequency. For instance, changes in playing tactics or adopted pacing strategies may decrease player work-rates allowing them to spend greater amounts of time on-field during rotations.[19,20] Further research is warranted to examine the relationship between playing strategies, match running performance and the fatigue response and the influence of these factors on the match outcome in tag football.

There were no substantial decreases in vertical jump performance following matches suggesting that neuromuscular fatigue does not accumulate during consecutive tag football matches played on the same day. Player's vertical jump returned to baseline values following the first and second matches and only showed a small decline following the final match even though this did not deviate substantially from baseline levels (Figure 1A). The small reduction in vertical jump performance from post-match 2 to post-match 3 may suggest player's experienced increased neuromuscular fatigue, although this is perhaps dubious considering the magnitude of this difference (~3%; ES=-0.45±0.62) relative to the day-to-day variability in this study's participant cohort (CV=4.1%). Previous research in professional rugby league showed players experienced significant reductions in countermovement jump peak power and peak force indices 30 minutes and 24 hours post-match before returning to baseline levels 48 hours post-match.[2,21] It is likely that the lack of neuromuscular fatigue response in this study compared to those in rugby league is due to considerable differences in match demands.[1,22] Specifically, the shorter match durations, unlimited interchanges and modified contact laws may allow tag football players to better replenish phosphocreatine energy stores during match-play demonstrated by maintained vertical jump performance post-matches.[1,23] Additionally, given that the players in this study were selected based on their performance during previous tournament competition, it is possible that they exhibit certain physical or physiological qualities that positively influence the fatigue response to consecutive matches.[24] Further research may be warranted to examine the sensitivity of performance measures to identify subtle changes in neuromuscular fatigue during consecutive matches played on the same day.

Although there were no significant group effects showing reduced vertical jump performance from baseline values, there was a very large correlation showing reduced vertical jump performance over consecutive matches (i.e. Δpost-match 1 vs. 3) was associated with maximal deceleration frequency in the first match ($r=-0.71$; $p<0.01$).This suggests the fatigue response to consecutive tag football matches may be highly individual based on player’s positional demands and customisation to eccentric exercise.[1,8] Previous research in rugby league showed reduced countermovement jump performance during tournament competition to be characterised by changes in the force-velocity relationship associated with delayed onset muscle soreness and the inflammatory response.[4,8] Although this study did not examine the physiological mechanisms associated with increased neuromuscular fatigue, there was a moderate association ($r=0.46$) found between increases in subjective ratings of general muscle soreness and reduced vertical jump height following the final match. In conjunction with the association found between maximal decelerations in the first match and reduced vertical jump performance several hours after (~4 hours), these results suggest exercise-induced muscle damage may be the primary contributor to increased neuromuscular fatigue during consecutive tag football matches.

The progressive reduction in perceived well-being shows that players experience disturbed psychological states during consecutive tag football matches played on the same day. This is in agreement with research investigating perceptual fatigue measures over consecutive days and demonstrates the usefulness of cost-effective questionnaires to assess player's fatigue-recovery cycle during tournament competition.[4,7] It is interesting to note that higher perceived well-being scores prior to the tournament were associated with greater reductions in match running performance during the final match (Table 2). One explanation for this finding is that players with poor perceptions of well-being moderate their high-intensity activity in the earlier matches of the day to better maintain performance over the tournament. This is in agreement with research suggesting that disturbed psychological states or mental fatigue alter an athlete's sense of effort and may force them to down-regulate their exercise capacity.[3,25] Comparatively, players with higher pre-match perceived well-being increase their work-rate during the earlier matches resulting in greater increases in neuromuscular fatigue (r=-0.41 to -0.53) and decreased high-intensity activity in the final match.

There were small to moderate associations between increased neuromuscular and perceptual fatigue over consecutive matches and reductions in match running performance in the final match (Table 2). Managing accumulated neuromuscular and perceptual fatigue during consecutive tag football matches may have important implications on player performance. However, there were stronger correlations showing increased distance (r=-0.50 to -0.81), HSR distance (r=-0.65 to -0.75), HSR efforts (r=-0.79 to -0.87), maximal accelerations (r=-0.57 to -0.58) and maximal decelerations (r=-0.48 to -0.58) in the first two matches to be associated with greater reductions in work-rate in the final match. Although deploying a tactic or game strategy that reduces player work-rates may impact negatively on the match outcome, it may serve to improve team performance during subsequent matches where rankings are decided. For example, a team who is a lengthy margin in front of their opposition may wish to deploy a different match strategy in the second half to reduce player work-rates and hopefully minimise the fatigue response. While perhaps jeopardising their for-and-against, this may minimise player fatigue and improve the team’s potential to win their next match which may be of greater importance (e.g. grand final). Employing a strategy like this would be dependent on how a team is performing during the tournament (e.g. for/against standings) and on the match score line. Nevertheless, it may be a useful tactic to consider during tournament competitions, particularly during competitions played against several teams where it may not be so important to subject the opposition to higher work-rates in an attempt to elicit a greater fatigue response.

Whilst this study provided several interesting findings on the fatigue-response to consecutive tag football matches, there are several limitations that warrant discussion. Firstly, our sample size was relatively small and only included data from a single team. Therefore, the results of this study are unlikely to be generalizable to other tag football teams or varied tournament formats. We reconciled this with the knowledge that the participating team consisted of the best players from the state and was competing at the highest standard of tag football competition in Australia. However, further studies involving a greater number of participating teams and different tournament formats is warranted to establish the usefulness of cost-effective performance tests and subjective questionnaires in assessing the fatigue-response. Finally, in the current study we were unable to collect the activity-profiles of the opposition team due to a limited number of available GPS devices. Admittedly, this was out of the scope of the current study. Nevertheless, the activity profiles of the opposition team may have provided more conclusive insights into the relationship between the fatigue-response, match-running performance and match outcome during consecutive tag football matches.

Practical Application and Conclusion

This study showed non-invasive and cost-effective performance tests and subjective questionnaires provide a useful assessment of an athlete's fatigue-recovery cycle during consecutive matches played on the same day. Increases in neuromuscular and perceptual fatigue over consecutive tag football matches may have contributed to reduced match running performance in the final match. Interestingly however, player work-rate in the earlier matches showed the strongest correlation with reduced match running performance in the latter stages of the tournament. The findings of this study may also have important implications for other rugby codes that are played in similar tournament formats including rugby sevens, rugby nines and touch rugby.

Acknowledgements

This study was conducted as part of the PhD research project "Understanding and Enhancing the Performance of OzTag Players and Referees" funded by OzTag Queensland. The authors wish to thank the athletes and coaching staff of the Queensland men's team for participating in this study.

References

1. Hogarth LW, Burkett BJ, McKean MR. Movement patterns in tag football: Influence of playing position, representative selection and fatigue. *Int J Perform Anal Sport.* 2014;14:367-383.

2. McLellan CP, Lovell DI, Gass GC. Markers of postmatch fatigue in professional Rugby League players. *J Strength Cond Res.* 2011;25:1030-1039.

3. Twist C, Waldron M, Highton J et al. Neuromuscular, biochemical and perceptual post-match fatigue in professional rugby league forwards and backs. *J Sports Sci.* 2012;30:359-367.

4. Johnston RD, Gabbett TJ, Jenkins DG. Influence of an intensified competition on fatigue and match performance in junior rugby league players. *J Sci Med Sport.* 2013;16:460-465.

5. Twist C, Highton J. Monitoring Fatigue and Recovery in Rugby League Players. *Int J Sports Physiol Perform.* 2013;8:467-474.

6. Mooney MG, Cormack S, O'Brien BJ et al. Impact of neuromuscular fatigue on match exercise intensity and performance in elite Australian football. *J Strength Cond Res.* 2013;27:166-173.

7. Montgomery PG, Pyne DB, Hopkins WG et al. The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *J Sports Sci.* 2008;26:1135-1145.

8. Johnston RD, Gibson NV. Twist C et al. Physiological Responses to an Intensified Period of Rugby League Competition. *J Strength Cond Res.* 2013;27:643-654.

9. Rampinini E, Alberti G, Riggio M et al. Accuracy of GPS Devices for Measuring High-intensity Running in Field-based Team Sports. *Int J Sports Med*. 2014. doi: 10.1055/s-0034-1385866

10. Johnston RJ, Watsford ML, Kelly SJ et al. Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. *J Strength Cond Res.* 2014;28:1649-1655.

11. Johnston RJ, Watsford ML, Pine MJ et al. Assessment of 5 Hz and 10 Hz GPS units for measuring athlete movement demands. *Int J Perform Anal Sport.* 2013;13:262-274.

12. Varley MC, Fairweather IH, Aughey RJ. Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. *J Sports Sci*. 2012;30:121-127.

13. Akenhead R, French D, Thompson KG et al. The acceleration dependent validity and reliability of 10 Hz GPS. *J Sci Med Sport.* 2014;17:562-566.

14. Batterham AM, Hopkins WG. Making Meaningful Inferences About Magnitudes. *Int J Sports Physiol Perform.* 2006;1:50-57.

15. Hopkins WG, Marshall SW, Batterham AM et al. Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Med Sci Sport Exerc*. 2009;41:3-12.

16. Leatherwood WE, Dragoo JL. Effect of airline travel on performance: a review of the literature. *Br J Sports Med.* 2013;47:561-567.

17. Beaven R, Highton J, Thorpe C et al. The movement and physiological demands of international and regional men's touch rugby matches. *J Strength Cond Res*. 2014. doi: 10.1519/JSC.0000000000000535

18. Lythe J, Kilding A. The effect of substitution frequency on the physical and technical outputs of strikers during field hockey match play. *Int J Perform Anal Sport*. 2013;13:848-859.

19. Gabbett TJ. Physical, Technical and Tactical Factors Affect Final Ladder Position in Semi-Professional Rugby League. *Int J Sports Physiol Perform.* 2014;9:680-688.

20. Waldron M, Highton J, Daniels M et al. Preliminary Evidence of Transient Fatigue and Pacing During Interchanges in Rugby League. *Int J Sports Physiol Perform*. 2013;8:157-164.

21. McLean BD, Coutts AJ, Kelly V et al. 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.

22. 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.

23. 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;35:1025-1044.

24. Johnston RD, Gabbett TJ, Jenkins DG et al. Influence of physical qualities on post-match faituge in rugby league players. *J Sci Med Sport*. 2014. doi: 10.1016/j.jsams.2014.01.009

25. Marcora SM, Staiano W, Manning V. Mental fatigue impairs physical performance in humans. *J Appl Physiol.* 2009;106:857-864.

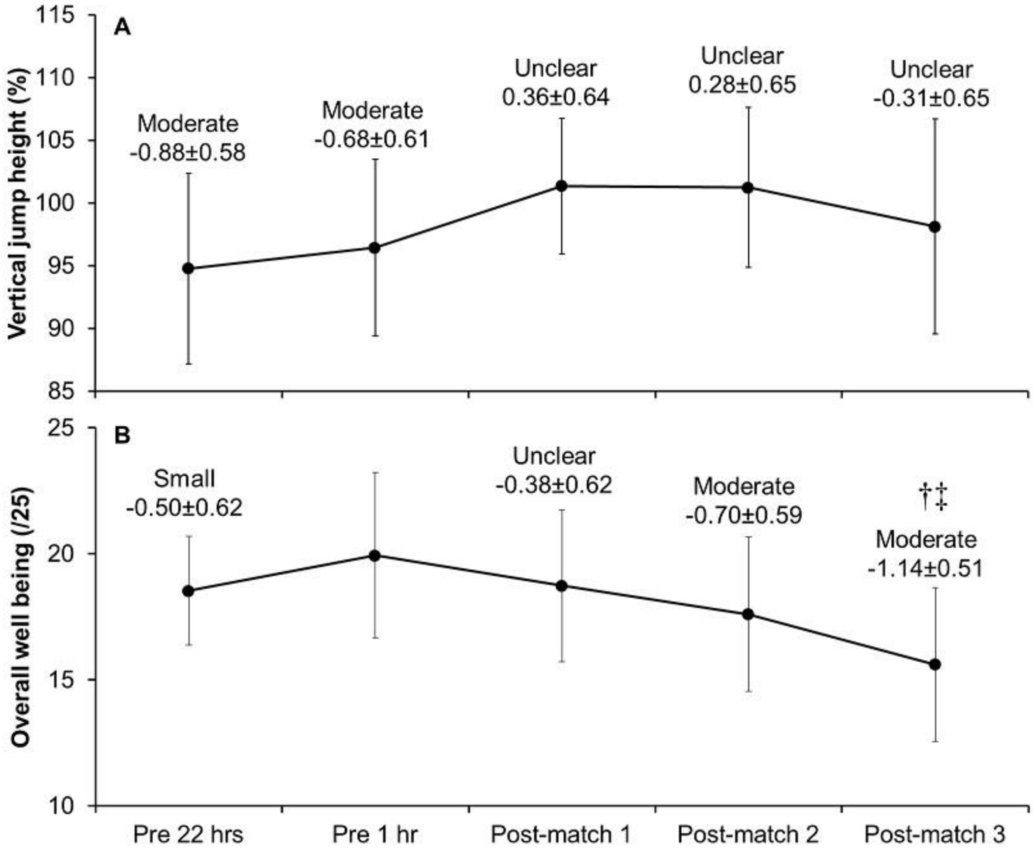

Figure 1. Changes in neuromuscular (A) and perceptual (B) fatigue measures over consecutive tag football matches. Vertical jump height is expressed as a percentage of baseline values. Standardised differences represent the magnitude of change from baseline vertical jump scores (i.e. 100%) and from well-being scores reported pre-match (1 hr). † Significantly different (P<0.01) to pre-match (1 hr) values. ‡ Significantly different (P<0.05) to post-match one.

“Neuromuscular and Perceptual Fatigue Responses to Consecutive Tag Football Matches”
by Hogarth LW, Burkett BJ, McKean MR
International Journal of Sports Physiology and Performance

Table 1. Changes in match running performance over consecutive tag football matches.

				Match 1 vs. 2		Match 2 vs. 3		Match 1 vs. 3	
Variable	**Match 1**	**Match 2**	**Match 3**	**ES±90% CL**	**QA**	**ES±90% CL**	**QA**	**ES±90% CL**	**QA**
Field time (min)	19.8 ± 1.9	19.9 ± 2.4	19.8 ± 2.6	0.01 ± 0.63	Unclear	-0.01 ± 0.63	Unclear	-0.01 ± 0.63	Unclear
Field rotations (no.)	5.6 ± 0.8	4.7 ± 0.8	4.6 ± 1.0	-0.98 ± 0.54	Moderate	-0.12 ± 0.62	Unclear	-0.99 ± 0.53	Moderate
Distance (m/min)	106.5 ± 10.3	101.2 ± 7.2	98.8 ± 6.9	-0.57 ± 0.61	Small	-0.35 ± 0.62	Unclear	-0.81 ± 0.58	Moderate
LSR distance (m/min)	84.1 ± 6.3	81.8 ± 5.9	79.8 ± 6.3	-0.38 ± 0.62	Unclear	-0.33 ± 0.62	Unclear	-0.66 ± 0.60	Moderate
HSR distance (m/min)	22.4 ± 7.6	19.4 ± 6.3	18.9 ± 5.3	-0.42 ± 0.62	Small	-0.08 ± 0.63	Unclear	-0.51 ± 0.61	Small
HSR efforts (/min)	1.73 ± 0.51	1.55 ± 0.41	1.46 ± 0.26	-0.39 ± 0.62	Unclear	-0.26 ± 0.63	Unclear	-0.64 ± 0.61	Moderate
Peak running speed (km/h)	26.5 ± 3.0	27.2 ± 3.7	26.7 ± 3.8	0.18 ± 0.63	Unclear	-0.12 ± 0.63	Unclear	0.05 ± 0.63	Unclear
Low: high speed ratio (x s: 1 s)	13.9 ± 5.6	16.8 ± 7.7	15.9 ± 4.6	0.42 ± 0.62	Unclear	0.15 ± 0.64	Unclear	0.37 ± 0.62	Unclear
Max accelerations.min^{-1}	1.07 ± 0.33	0.89 ± 0.26	0.83 ± 0.27	-0.59 ± 0.60	Small	-0.24 ± 0.63	Unclear	-0.76 ± 0.58	Moderate
Max decelerations.min^{-1}	1.10 ± 0.28	1.10 ± 0.30	0.99 ± 0.29	0.01 ± 0.63	Unclear	-0.37 ± 0.62	Unclear	-0.37 ± 0.62	Unclear

Data are reported as mean ± SD unless otherwise shown. CL = Confidence limits; HSR = high-speed running (≥14.1 km/h); LSR = low-speed running (≤14.0 km/h); QA = Qualitative assessment. Effects sizes (ES) are reported as small (0.21-0.60), moderate (0.61-1.20), large (1.21-2.0) and very large (>2.1) and reported as unclear when 90% CL surpass upper (0.2) and lower thresholds (-0.2) for a substantial difference.

Table 2. Relationship between neuromuscular and perceptual fatigue measures and selected match running performance variables.

	Vertical jump			Perceived well-being		
Variables	**Pre-match**	**ΔMatch 2 vs. 3**	**ΔMatch 1 vs. 3**	**Pre-match**	**ΔMatch 2 vs. 3**	**ΔMatch 1 vs. 3**
HSR distance						
Tournament	0.44	-0.01	-0.10	0.04	-0.22	-0.32
Match 1	0.40	-0.02	-0.07	-0.06	-0.20	-0.27
Match 2	0.44	0.07	-0.01	0.18	-0.23	-0.32
Match 3	0.19	-0.07	-0.19	-0.01	-0.08	-0.18
Δ match 1 vs. 3	-0.28	-0.03	-0.07	0.06	0.15	0.15
HSR efforts						
Tournament	0.48	-0.20	-0.31	0.18	-0.39	-0.44
Match 1	0.45	-0.22	-0.26	0.03	-0.27	-0.37
Match 2	0.40	0.03	-0.05	0.18	-0.29	-0.30
Match 3	0.25	-0.35	-0.57*	0.31	-0.45	-0.42
Δ match 1 vs. 3	-0.14	0.05	-0.03	0.13	0.05	0.17
Max. accelerations						
Tournament	0.44	-0.43	-0.45	0.11	-0.43	-0.34
Match 1	0.44	-0.50	-0.49	0.28	-0.17	-0.22
Match 2	0.28	-0.31	-0.33	0.18	-0.56*	-0.31
Match 3	0.29	-0.16	-0.20	-0.23	-0.34	-0.27
Δ match 1 vs. 3	-0.27	0.51	0.44	-0.66**	-0.15	-0.01
Max. decelerations						
Tournament	0.06	-0.50	-0.54*	0.06	-0.54*	-0.40
Match 1	0.12	-0.71**	-0.62*	0.21	-0.45	-0.37
Match 2	0.07	-0.13	-0.21	0.20	-0.49	-0.45
Match 3	0.08	-0.32	-0.42	-0.28	-0.30	-0.10
Δ match 1 vs. 3	-0.03	0.31	0.16	-0.53	0.11	0.39

Data are reported as Pearson product moment correlations (r), with 0.1-0.3 = small; 0.3-0.5 = moderate; 0.5-0.7 = large; >0.7 = very large. HSR = High-speed running. * Denotes a significant correlation ($p<0.05$); ** Denotes a significant correlation ($p<0.01$).