Original Article

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Article Title:

A novel method of assessment for monitoring neuromuscular fatigue within Australian rules football players.

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Abstract

Purpose: To compare the sensitivity of a submaximal run test (SRT) with a countermovement jump (CMJ) test to provide an alternate method of measuring neuromuscular fatigue (NMF) in high performance sport. **Methods:** 23 professional and semi-professional Australian rules football (ARF) players, performed a SRT and CMJ test, pre-match, 48- and 96-hours post-match. Variables from accelerometers recorded during the SRT were; player load 1D up ($PL1D_{up}$) (vertical vector); player load 1D side ($PL1D_{side}$) (medio-lateral vector); and player load 1D forward ($PL1D_{fwd}$) (anterio-posterior vector). Meaningful difference was examined through magnitude-based inferences (effect-size; ES), with reliability assessed as typical error of measurements expressed as coefficient of variance (CV). **Results:** A small decrease in CMJ_H; ES -0.43 ± 0.39 (likely) was observed 48 hours post-match before returning to baseline 96 hours post-match. This was accompanied by corresponding moderate decreases in the SRT variables; $PL1D_{up}$; ES -0.60 ± 0.51 (likely) and $PL1D_{side}$; ES -0.74 ± 0.57 (likely) 48 hours post-match before also returning to pre-match baseline. **Conclusion:** The results suggest that in the presence of NMF, players utilise an alternative running profile to produce the same external output (i.e. time). This supports changes in accelerometer variables during a SRT can be used as an alternate method of measuring NMF in high performance ARF and provides a flexible option for monitoring changes within the recovery phase post-match.

Keywords: activity profile, fatigue, GPS, movement strategy, monitoring

Introduction

Monitoring neuromuscular fatigue (NMF) in the sport-specific activity itself has been suggested as the most optimal method for monitoring NMF status [1]. Modified field tests of neuromuscular function have been implemented due to the impractical nature of simulating sports activity which can impede adaptation and induce undue fatigue during the recovery period [2]. Due to its robust nature in both reliability and validity [3, 4], the countermovement jump (CMJ) test has become accepted as the reference standard test for monitoring NMF status within high performance sport environments. However, evidence has emerged to suggest that the underlying mechanisms of fatigue are task specific [5]. Team sports, such as Australian rules football (ARF), involve high intensity repeat sprint efforts, numerous changes of direction, along with accelerations and decelerations, all interspersed with periods of moderate to low intensity running [6]. This has resulted in the analysis of the running profile to provide a greater task-specific method for the monitoring of NMF in field-based athletes [7-10].

Recently, a change in movement strategy has been observed in elite ARF players as evidenced by a reduction in the way load per minute (LPM) (the total of the triaxial vectors of vertical, anterio-posterior and medio-lateral) is accrued in match play in a fatigued state compared to a non-fatigued state [7, 9]. This was found to be specifically expressed in reductions in the vertical accelerometer vector to LPM (86% likely to exceed the smallest important value considered practically important), resulting in a greater accumulation of LPM at lower ends of the high-speed running bands, possibly due to acute NMF having a direct impact on the ability to sprint and/or accelerate and decelerate [7]. Although not measured within these studies [7, 9], the contribution of the vertical accelerometer vector has the potential to be related to changes in vertical stiffness [11], with reductions in vertical stiffness demonstrated to negatively influence stride characteristics such as forward running velocity, stride frequency, stride length, contact time and flight time [12]. Accompanying the change in contribution of the vertical accelerometer vector to LPM in elite ARF players, were greater accruement (75% likely to exceed the smallest important value considered practically important) in the anterio-posterior acceleration vector (forwards and backwards lean) [7]. The increases in the anterio-posterior acceleration vector contribution to LPM, provides further support for the concept that NMF results in a change of movement strategy of more running at a steady pace and/or lower ends of the high speed running bands rather than frequent acceleration and decelerations characterised by the non-fatigued state [7].

Detection of movement in three planes and the use of high-sample-rates (100 Hz) may allow devices, such as triaxial accelerometers, the capability of quantifying subtle changes in movement as a result of fatigue [7].

Subsequently, a change in movement strategy, evidenced by changes in the vector contributions to LPM [7, 9], can provide an alternate method of measuring NMF in high performance ARF. Currently, this has not been shown in a practical field setting for monitoring these changes within the recovery phase post-match. Therefore, the purpose of this study was to determine if outcome triaxial accelerometer variables from a submaximal run test (SRT) alter in the presence of post-match NMF in order to investigate an alternate method of measuring NMF in high performance ARF. It was hypothesised that in the presence of NMF, changes would occur in the running profile during the SRT in ARF players.

Methods

Subjects

The study involved twelve professional ARF players (age; 22.5 ± 4.2 years, body mass; 87.4 ± 6.8 kg, height; 190.1 ± 6.5 cm, years on an Australian Rules Football (AFL) list; 2.4 ± 2.9 years) from one AFL club, and eleven semi-professional ARF players from one South Australian National Football League club (age; 22.3 ± 2.9 years, body mass; 80.9 ± 6.2 kg, height; 184.4 ± 5.8 cm). All twenty-three participants performed testing as part of their normal training regime and were familiar with procedures prior to the study. To be eligible for inclusion, participants were required to be cleared as free from injury by the club's medical staff. Informed, written consent was obtained from all participants and the study was approved by the University of South Australia's Human Ethics Committee.

Design

In order to utilize a normal competition-phase recovery cycle within ARF, this study took place during a regular in-season microcycle following a bye in the playing schedule. This included a 4-day rest period leading into the baseline measure where the athletes were not required at the training facility. During both this rest period and the post-match recovery phase following the match, athletes were advised to rest and engage in normal recovery strategies (cold water immersion, compression garments, dynamic mobility exercises and stretching, nutrition) designed to limit the extent of NMF and enhance full recovery [8]. This was not controlled for other than requesting participants engaged within normal recovery strategy routines within this period. Measures were taken at three specific time points (TP): baseline, 24-hours pre-match (TP-1), 48-hours post-match (TP-2) and 96-hours post-match (TP-3).

Methodology

Countermovement Jump Test (CMJ)

The CMJ test was performed using previously established protocols [3] with the average of six CMJs used for analysis. The test involved the participants starting each jump in an erect position with a 400 g dowel rod positioned across their shoulders. Participants were instructed to jump for maximum height with each attempt, whilst keeping the rod firmly on their back and in a horizontal plane. Similar to previous procedures [3], subjects were encouraged to self-select the amplitude or rate of the countermovement with no attempts made to standardise these variables. CMJ height (CMJ_H) performance was obtained for analysis via an optical encoder (GymAware Power Tool, Kinetic Performance Technologies, Canberra, Australia) fixed to the ground and attached via a cable to the 400 g dowel rod.

It has previously been established that time of day can influence jump performance [13]. Therefore, the following standardised conditions were employed to minimise confounding factors: (1) all jumps and strides were performed at approximately the same time of day (between 4pm and 6pm); (2) athletes participated in a 10-min standardised warm-up prior to testing that consisted of various dynamic movements and running-based exercises of increasing intensity; (3) athletes were advised to maintain typical daily routines during the week of testing (e.g., similar food and fluid intake, caffeine consumption, recovery strategies, same clothing and footwear); and (4) the same sports science staff administered each protocol to ensure testing procedures remained consistent.

Submaximal Run Test (SRT and Match Outputs

The SRT involved three x 50 m runs, each completed in 8 s in a 30 s cycle. At 10 s before starting each run, subjects were asked to be ready, with a 3 s countdown given by one experimenter preceding each run. Subjects were instructed to perform the run in strictly 8 s with a time check at the 25 m halfway mark to help control for speed of the run. Average performance across the three trials was used as the criterion measure. The GPS-embedded triaxial accelerometers unit was worn in a specialized pocket in the training and match guernsey, located between the scapulae of the participant. For each run, the variables obtained for analysis were: player load 1D up ($PL1D_{up}$) (vertical vector); player load 1D side ($PL1D_{side}$) (medio-lateral vector); and player load 1D forward ($PL1D_{fwd}$) (anterio-posterior vector). The participants also wore the same GPS-embedded triaxial accelerometers units during a competitive ARF match and data were downloaded to spreadsheets post-match. Match characteristics were similar for both professional and amateur athletes with 4 x 20-minute quarters plus time on to allow for time occupied in stoppages (e.g., when the ball is out of bounds, injuries, goals etc.). Match outcome variables obtained from the GPS-embedded triaxial accelerometers included were; total distance, meters per minute ($m.min^{-1}$), PL per minute ($PL.min^{-1}$), high speed (HS) distance (>20 $km.h^{-1}$) and very high speed (VHS) distance (>25 $km.h^{-1}$). Rating of perceived exertion (RPE) was also included as it has been shown to be a valid subjective indicator of internal load in ARF [14].

All GPS-embedded triaxial accelerometer variables of the SRT and ARF match were derived using Catapult GPS units at a sampling frequency of 100 Hz (MinimaxX, Team 2.5, Catapult Innovations, Scoresby, Australia), and downloaded using Catapult software (Catapult Sprint v 5.1.5 software, Catapult Innovations, Melbourne, Australia). GPS data were discarded if any of the following criteria were met: 1) less than 8 satellites locked onto the GPS unit; 2) horizontal dilution of precision (HDOP) >2.0. GPS-embedded triaxial accelerometers have been shown to offer a reliable measure of physical activity in team sport athletes and have been reviewed elsewhere (for review [6, 7, 15]).

Analysing the Run

GPS-embedded triaxial accelerometer data were sampled at 100 Hz resulting in ~1000 data points for each run test. The initial 10 s of the run was used for analysis to allow full completion of the run including deceleration. To standardise the beginning of the run for each participant, the run was deemed to have begun once 1 $m.s^{-1}$ had been reached. Each set of GPS-embedded triaxial accelerometer data was then listed in a column next to the corresponding time point before being transferred into excel, where a 6-degree polynomial was fit. To find the starting plateau point, the derivative of the 6-degree polynomial was taken, then when the derivative was less than or equal to 0.7 $m.s^{-1}$, the plateau point was said to be at this time point. Similarly, to find the end of the plateau point, the time value used was when the derivative was less than or equal to -0.4 $m.s^{-1}$. Due to the nature of the running patterns both thresholds were chosen by the authors to standardise the analysis. An example of how the polynomial curve was fitted to the data points is illustrated in Figure 1. To standardise the acceleration and plateau length phases of each run test, maximal duration acceleration ($Stand_{accel}$) and plateau ($Stand_{plat}$) periods were calculated as the mean of all run tests, minus the standard deviation (SD) x 0.2 (Figure 1). This calculated the smallest worthwhile run length that captured all participants' profiles.

Insert Figure 1 here

Statistical Analysis

To analyse the sensitivity of a SRT, magnitude-based inferences (effect size (ES) statistic ± 90% confidence intervals (CI)) were calculated to determine the practical difference between the CMJ test and SRT variables throughout each time period (i.e., difference between TP-1 and TP-2, difference between TP-1 and TP-3 etc.). Furthermore, to quantify clear outcomes that represent the likelihood that the true value had the observed magnitude, a qualitative descriptor was included along with the ES ± 90% CI [16]. Thresholds for assigning the qualitative terms to chances of substantial difference were: <1%, almost certainly not; <5%, very unlikely; <25%, unlikely; 25-75%, possible; >75%, likely; >95%, very likely; and >99%, almost certain [16]. After log transformation to reduce bias due to non-uniformity error [17], differences were represented as ES ± 90% CI and classified as trivial (< 0.2), small (0.2 – 0.59), moderate (0.6 – 1.19), and large (1.2 – 1.99) and declared practically important were there was a >75% likelihood of exceeding the smallest important ES (0.2) [18]. Differences with less certainty (<75%) were classified as trivial [16], with the magnitude of the difference considered 'unclear' where the 90% CI simultaneously overlapped the smallest important ES (0.2) both positively and negatively [18]. For further analysis into the sensitivity of a submaximal run test, participants were then categorized into 'fatigued' (n = 9) and 'non-fatigued' (n = 14) groups based on the 8% coefficient of variance (CV) reported in the previous literature for CMJ_H [3, 7]. That is, samples with a score of <92% of baseline were considered 'fatigued', while the remaining samples considered to be 'non-fatigued' [3, 7]. Descriptive statistics are reported as mean ± SD. Typical error of measurements (TE) were calculated using all twenty-three participants, expressed as a CV (± 90% CI), were calculated to assess reliability for each variable [19]. The smallest worthwhile change (SWC) was calculated as 0.2 x SD.

Results

The match outcome variables (mean ± SD) as listed in Table 1. Mean values ± SD for TP-1, TP-2 and TP-3 along with differences in tests results between each time period, represented as ES ± 90% CI, are listed in Table 2 for the group overall, Table 3 for the 'fatigued' group and Table 4 for the 'non-fatigued'. The $Stand_{accel}$ phase was 1.87 s, and $Stand_{plat}$ phase 2.9 s. An example of the polynomial curve fitted to the data points of a 'fatigued' and 'non-fatigued' run is illustrated in Figure 2.

Neuromuscular responses to match-output:

Overall, a small decrease in CMJ_H; ES -0.43 ± 0.39 (likely) was observed at TP-2 before returning to baseline at TP-3. This was accompanied by moderate decreases in $PL1D_{up}$; ES -0.60 ± 0.51 (likely) and $PL1D_{side}$; ES -0.74 ± 0.57 (likely) at TP-2 compared to TP-1, before all returned to within pre-match levels at TP3.

When categorized into 'fatigued' (n = 9) and 'non-fatigued' (n = 14) groups based on the 8% coefficient of variance (CV), the 'fatigued' group (three professional and six semi-professional) saw a large reduction observed at TP-2 in CMJ_H; ES -1.42 ± 0.24 (almost certainly), from pre-match baseline. The nine participants then returned to within pre-match levels at TP3. At the same time point, moderate decreases were also detected in the $Stand_{accel}$ phase in $PL1D_{up}$; ES -0.94 ± 0.65 (very likely), $PL1D_{side}$; ES -0.93 ± 0.76 (likely) and $PL1D_{fwd}$; ES -0.60 ± 0.77 (likely). This was accompanied by a moderate decrease in $PL1D_{up}$; ES -0.67 ± 0.42 (very likely) and a small decrease in $PL1D_{side}$; ES -0.54 ± 0.43 (likely) in the $Stand_{plat}$ phase. Further in this group, small decreases were still evident at TP-3 in $PL1D_{up}$; ES -0.43 ± 0.38 (likely) and $PL1D_{side}$; ES -0.46 ± 0.39 (very likely) in the $Stand_{plat}$ phase, while all other variables returned to within pre-match levels. Small to moderate decreases in overall run $PL1D_{up}$; ES -0.63 ± 0.46 (likely) and $PL1D_{side}$; ES -0.58 ± 0.53 (likely) were also observed at TP-2 compared to TP-1, before returning to within pre-match levels at TP3. This was accompanied by a moderate increase at TP-2 compared to TP-1 in the overall plateau run length; ES 1.00 ± 0.61 (very likely) before both returned to pre-match levels.

In the 'non-fatigued' group, no change in CMJ_H; ES 0.30 ± 0.24 (possible) was observed at TP-2 or TP-3, however, small decreases in $PL1D_{up}$; ES -0.38 ± 0.36 (likely) and $PL1D_{side}$; ES -0.52 ± 0.50 (likely) were detected in the $Stand_{accel}$ phase, accompanied by small decreases in $PL1D_{up}$; ES -0.58 ± 0.46 (likely), $PL1D_{side}$; ES -0.45 ± 0.54 (likely) and $PL1D_{fwd}$; ES -0.34 ± 0.24 (likely) in the $Stand_{plat}$ phase. A large increase was also observed at TP-2 compared to TP-1 in the overall plateau run length; ES 1.75 ± 0.74 (almost certainly) and moderate decrease in overall acceleration run length; ES -0.63 ± 0.46 (likely) before both returned to pre-match levels.

Reliability:

Reliability statistics are shown in Table 5, with a small CV observed for CMJ_H. Moderate CVs were observed for $PL1D_{up}$, and $PL1D_{side}$ and $PL1D_{fwd}$ during the overall run and $Stand_{plat}$ phase. No variables displayed CVs smaller than the SWC.

Insert Table 1 here

Insert Figure 2 here

Insert Table 2 here

Insert Table 3 here

Insert Table 4 here

Insert Table 5 here

Discussion

The main purpose of this study was to ascertain if outcome triaxial accelerometer variables from a SRT alter in the presence of post-match NMF in high performance ARF. At the same time period post-match (TP-2), the results of the SRT suggested that changes in PL variables ($PL1D_{up}$, $PL1D_{side}$ and $PL1D_{fwd}$) are important indicators of NMF. The results of the current study support previous research [7, 9], and provides an alternate task specific method of measuring NMF within the recovery-phase in high performance ARF.

As in previous research [20], CMJ_H was used as the main criterion measure of NMF, although research has shown an altered movement strategy can be employed in the presence of NMF rather than just a reduced CMJ output [21]. The results of the current study, along with regular use within our professional setting, confirms jump height as a sensitive measure of NMF following ARF match play. These results are in line with previous research analysing the sensitivity of monitoring NMF via a CMJ test as a comparison method with running profiles [8, 20, 22].

From these results, a change in movement strategy, evidenced by changes in the PL variables from a SRT, can provide an alternate method of measuring NMF in high performance ARF. In support of previous research [7, 9], it is apparent that these changes can be expressed in a practical field setting for monitoring changes within the recovery phase post-match. Due to the versatility of accelerometers to be able to monitor in both outdoor and indoor locations, this can permit additional flexibility in implementation. Practitioners may then be able to glean information about NMF status from a large group of athletes, in a variety of different environments and settings and administered in only one and a half minutes. In comparison, the CMJ test can take a similar amount of time for a small number of players to be tested. Data collected from a SRT can be ‘downloaded’ in the same amount of time, and generally with, the training and/or match outcomes variables. This means post-test analysis of the SRT can be achieved in a similar amount of time to that of a CMJ test, especially when looking at the overall run. However, further analysis into an individual’s run (e.g. analysis of $Stand_{accel}$ and $Stand_{plat}$ phases) will take additional time. Nevertheless, this test provides the practitioner with a tool to minimise the impact upon the athletes already busy schedule and test within the normal training environment, such as the warm up.

Changes were observed in movement strategy due to the presence of NMF with reductions in $PL1D_{up}$, $PL1D_{side}$ and $PL1D_{fwd.}$ Previously it has been shown that the vertical accelerometer vector ($PL1D_{up}$) has the potential to be related to changes in vertical stiffness

[11]. Changes in vertical stiffness have been found to strongly influence stride characteristics such as forward running velocity, stride frequency, stride length, contact time and flight time [12]. Changes in $PL1D_{up}$ may be due to increased ground-contact time, resulting in reductions in elastic recoil and associated energy used for vertical displacement [23]. This may mean that, in a fatigued state, players adopt inefficient running characteristics, specifically that of increased knee flexion upon landing [7]. The increased knee flexion results in a progressive increase in ground contact time [24] which can manifest itself in the adoption of a 'Groucho' running pattern [24]. The 'Groucho' running pattern is characterised by reductions in vertical acceleration and is indicative of changes expected with reduced vertical stiffness [12]. This altered running pattern has been shown to require additional energy utilization at any given speed [24] and may be due to the loss of elastic energy, along with the additional muscle force required for propulsion [23]. It is thought to occur in order to preserve anatomical structures, as a high stiffness increases the stress induced by impact forces on the skeletal system [23]. Stiffness, being modulated solely by neuromuscular activation [23], gives evidence to the role group III and IV muscle afferents may provide in the prevention of peripheral fatigue to allow the sustainment of performance output, whist also minimising excessive muscle damage.

Along with NMF having an effect on the ability to sprint, decreases were observed within the medio-lateral vector ($PL1D_{side}$) and anterio-posterior vector ($PL1D_{fwd}$). This may mean that either directly, or due to modifications in vertical stiffness, NMF not only results in a reduced ability to sprint, but an accompanied reduced capacity to accelerate and decelerate. Reductions in these vectors are likely the result of a reduced sway during running (e.g. forwards and backwards lean), resulting in less aggressive acceleration and decelerations characterised by the non-fatigued state. This would further preserve anatomical structures from additional damage [23], resulting in a greater reliance on running at a steady pace and less changes of speed [7]. In further support of this, was the observed decrease in overall acceleration run duration and increase in overall plateau run duration in our study. As demonstrated in Figure 2, despite an ability to achieve the same output, it is done so with a more gradual acceleration, longer plateau run duration and a reduced deceleration at the end of the run. This suggests, along with the work done previously [7, 9], that NMF appears to limit the accruement in PL variables, which could be the result of the neuromuscular systems attempt to prevent peripheral fatigue to allow the sustainment of performance output, whist also minimising excessive muscle damage.

An interesting finding of this research was observed when participants were categorized into 'fatigued' and 'non-fatigued' groups based on the 8% coefficient of variance (CV) as done in previous research [7]. Small decreases were seen in PL variables and a large increase and moderate decrease in overall plateau and acceleration run durations in the 'non-fatigued' group at TP-2. This may imply that despite the CMJ test suggesting these players to have recovered from residual NMF, the results from the SRT suggests that some may not have fully recovered at this time point. Along with this, only nine participants (three professional and six semi-professional) were classified as exhibiting symptoms of NMF 48h post-match (TP-2). Despite CMJ_H returning to pre-match levels at TP-3, in this group, small reductions were still evident at this time point (TP-3) in some SRT variables. These observations could be due to the different effects NMF can have depending on the specificity of the testing task [25]. Due to the flexibility of the neural adjustments within muscle to meet the functional requirements of the peripheral system, central and peripheral activation changes may vary depending on the given task [25]. ARF being a predominantly running sport, may mean a running test could be more sensitive to changes in NMF status in this population than a jump test due to the greater task-specific nature. Adding further support to the notion that specificity of the task is fundamental to the capacity of the test to detect NMF.

The small CVs observed within the present study for CMJ_H, are comparable with previous findings in similar populations [4, 20]. Moderate CVs were also observed for $PL1D_{up}$, along with moderate CVs for $PL1D_{side}$ and $PL1D_{fwd}$ in the overall run and $Stand_{plat}$ phase. No variables displayed CVs smaller than the SWC signifying that no variables within this study were capable of detecting practically important changes in performance. Nevertheless, the reported values for the submaximal run variables are comparable to those previously reported within team sport athletes [11, 20], and the potential capacity of the test providing a task specific, within-individual NMF assessment, may overcome this limitation of moderate CVs greater than the SWC.

Practical Application

The results show selected outcome triaxial accelerometer variables of a SRT, can be used to assess NMF in high performance ARF. This can provide a submaximal alternative to the CMJ test that does not cause excessive fatigue, is easily administered as part of the warm-up, can be applied to a large group of athletes simultaneously and in a number of environments and settings (i.e. indoors and outdoors). There is also the potential application of this test in other field-based sports. Soccer, for example [26, 27], have observed similar changes in running profile as a result of a build-up of fatigue to that previously reported in ARF [7, 9]. The ability to be administered as part of the warm-up or immediately post-game, to a large group of athletes and in a range of environments and settings, can allow valuable information on recovery status which can be 'downloaded' as part of the training and/or match outcome variables. This would allow timely decisions in situations of multiple game per day and/or week, supporting decisions on rotations and recovery practices in the following games and rest periods.

Conclusion

Post-match NMF in high performance ARF players was aligned with changes in the running profile of a SRT. Specifically, this was manifested by reductions in the $PL1D_{up}$, $PL1D_{side}$, and $PL1D_{fwd}$. These findings suggest that in the presence of NMF, despite the ability to produce the same external output, an alternate running pattern is employed. Accordingly, routine monitoring of triaxial accelerometer metrics during a SRT provides an alternative to parameters from CMJ protocols in the assessment of NMF status in high performance ARF. Future research should look at replicating these findings and gaining a greater understanding of the time course changes within each SRT variable.

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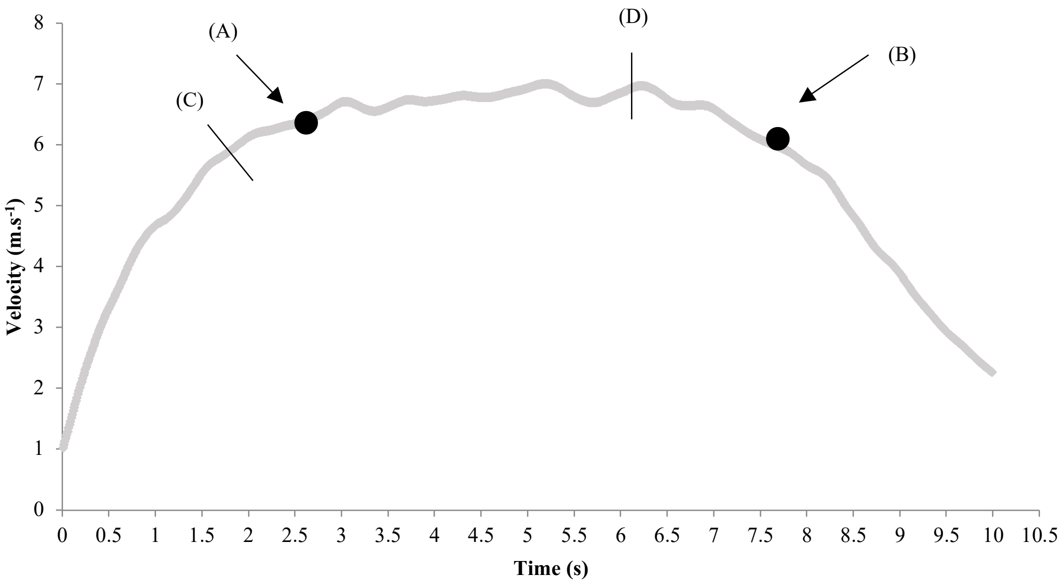

Figure 1. An example of how a 6-degree polynomial curve is fitted to the velocity data from an 8 s stride test. (A) represents the end of the acceleration phase and beginning of the plateau phase, quantified as a decrease of less than or equal to 0.7 m.s^{-1}. (B) represents the end of the plateau phase quantified as a decrease of less than or equal to -0.4 m.s^{-1}. Start of stride to (C) = standardised acceleration phase ($Stand_{accel}$). (A) to (D) = standardised plateau phase ($Stand_{plat}$).

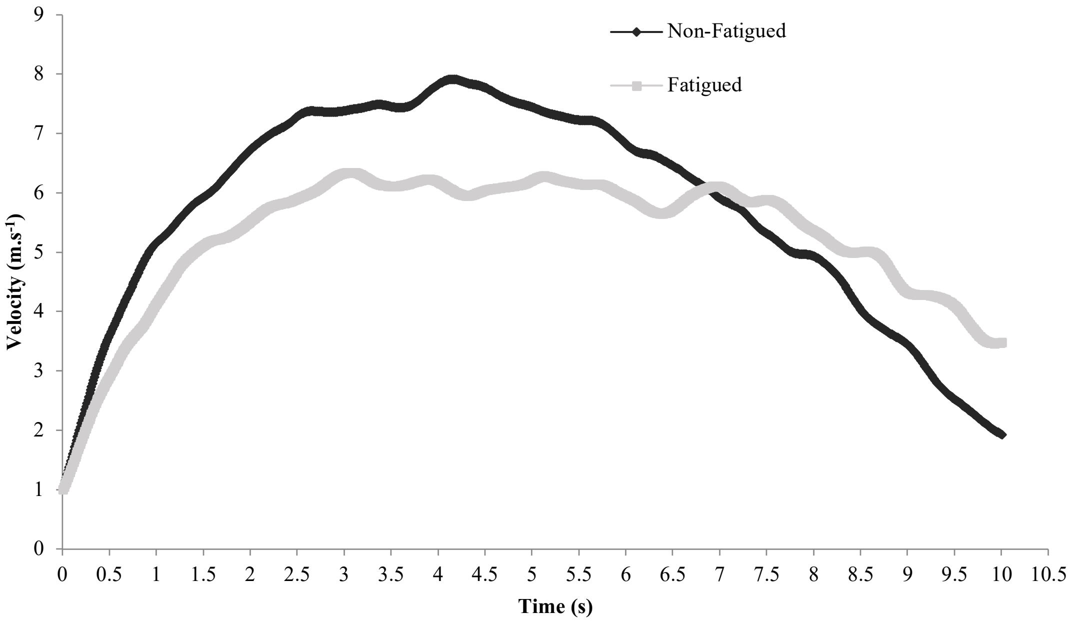

Figure 2. A player's stride profile in non-fatigued (dark) and fatigued (light) state.

	Professional ARF athletes	Semi-Professional ARF athletes
Total Distance (m)	12764.3 ± 1144.7	12414.1 ± 797.5
Maximal Velocity ($m.s^{-1}$)	8.2 ± 0.6	7.9 ± 0.4
$m.min^{-1}$	130.4 ± 9.9	137.0 ± 6.3
PL (AU)	1295.7 ± 116.3	1172.3 ± 138.9
$PL.min^{-1}$ (AU)	13.3 ± 1.4	12.9 ± 1.4
HS Distance (m)	943.7 ± 386.3	867.2 ± 402.7
VHS Distance (m)	143.9 ± 108.1	85.9 ± 86.8
RPE (AU)	8.9 ± 0.6	9.0 ± 0.5

Table 1. Match outcome variables obtained from the GPS-embedded triaxial accelerometers (mean ± SD) for professional ARF athletes (n = 12) and semi-professional ARF athletes (n = 11). Abbreviations: $m.min^{-1}$, meters per minute; PL, player load; $PL.min^{-1}$, PL per minute ($PL.min^{-1}$); HS Distance, high speed distance (>20 $km.h^{-1}$); VHS Distance, very high-speed distance (>25 $km.h^{-1}$); RPE, rating of perceived exertion; AU, arbitrary unit.

		Baseline	48hrs Post Game	96hrs Post Game	Baseline to 48 hrs *d* (± 90% CI)	Baseline to 96 hrs *d* (± 90% CI)
CMJ Performance	**Height (m)**	0.44 ± 0.5	0.37 ± 0.5	0.43 ± 0.5	-0.43 (-0.83;-0.04) **small ↓ (likely)**	-0.06 (-0.37;0.24) unclear
SRT	**$PL1D_{up}$ (AU)**	2.78 ± 0.51	2.43 ± 0.30	2.63 ± 0.38	-0.60 (-1.11;-0.09) **moderate ↓ (likely)**	-0.05 (-0.64;0.53) unclear
	$PL1D_{side}$ (AU)	1.87 ± 0.33	1.66 ± 0.27	1.80 ± 0.33	-0.74 (-1.30;-0.17) **moderate ↓ (likely)**	0.04 (-0.35;0.43) unclear
	$PL1D_{fwd}$ (AU)	2.15 ± 0.32	2.06 ± 0.33	2.11 ± 0.26	-0.34 (-0.83;0.14) trivial (possibly)	0.10 (-0.26;0.46) unclear

Table 2. Differences in tests results between baseline, 48 hours post game and 96 hours post game: represented as ES ± 90% CI and classified as *trivial* (< 0.2), *small* (0.2 – 0.59), *moderate* (0.6 – 1.19), and *large* (> 1.2). Where the 90% CI simultaneously overlapped the smallest important ES (0.2) the magnitude of the difference was considered "*unclear*", with a <75% likelihood of exceeding the smallest important ES (0.2) classified as trivial. Thresholds for qualitative terms to chances of substantial difference were: <1%, almost certainly not; <5%, very unlikely; <25%, unlikely; 25-75%, possible; >75%, likely; >95%, very likely; and >99%, almost certain. Abbreviations: SRT, submaximal run test; AU, arbitrary unit; PL, player load; Fwd, Forward.

		Baseline	48hrs Post Game	96hrs Post Game	Baseline to 48 hrs *d* (± 90% CI)	Baseline to 96 hrs *d* (± 90% CI)
CMJ Performance	**Height (m)**	0.44 ± 0.5	0.37 ± 0.5	0.43 ± 0.5	-1.42 (-1.66;-1.18) **large ↓ (almost certainly)**	-0.27 (-1.27;0.74) unclear
Stand$_{accel}$ Phase	**PL1D$_{up}$ (AU)**	0.52 ± 0.08	0.45 ± 0.07	0.52 ± 0.10	-0.94 (-1.60;-0.29) **moderate ↓ (very likely)**	-0.09 (-0.48;0.31) unclear
	PL1D$_{side}$ (AU)	0.42 ± 0.08	0.35 ± 0.07	0.45 ± 0.11	-0.93 (-1.69;-0.18) **moderate ↓ (likely)**	-0.16 (-0.25;0.57) unclear
	PL1D$_{fwd}$ (AU)	0.48 ± 0.11	0.42 ± 0.07	0.49 ± 0.13	-0.60 (-1.37;0.17) **moderate ↓ (likely)**	-0.04 (-0.28;0.36) unclear
Stand$_{plat}$ Phase	**PL1D$_{up}$ (AU)**	1.10 ± 0.28	0.91 ± 0.16	1.00 ± 0.17	-0.67 (-1.09;-0.25) **moderate ↓ (very likely)**	-0.43 (-0.71;-0.15) **small ↓ (likely)**
	PL1D$_{side}$ (AU)	0.74 ± 0.15	0.64 ± 0.09	0.68 ± 0.14	-0.54 (-0.97;-0.10) **small ↓ (likely)**	-0.46 (-0.85;-0.06) **small ↓ (likely)**
	PL1D$_{fwd}$ (AU)	0.85 ± 0.13	0.81 ± 0.16	0.81 ± 0.09	-0.30 (-0.97;0.36) unclear	-0.22 (-0.66;0.21) unclear
SRT (overall)	**PL1D$_{up}$ (AU)**	2.78 ± 0.51	2.43 ± 0.30	2.63 ± 0.38	-0.63 (-1.09;-0.17) **moderate ↓ (likely)**	-0.25 (-0.53;0.04) trivial (possibly)
	PL1D$_{side}$ (AU)	1.87 ± 0.33	1.66 ± 0.27	1.80 ± 0.33	-0.58 (-1.11;-0.04) **small ↓ (likely)**	-0.21 (-0.44;0.01) trivial (possibly)
	PL1D$_{fwd}$ (AU)	2.15 ± 0.32	2.06 ± 0.33	2.11 ± 0.26	-0.26 (-0.88;0.36) unclear	-0.08 (-0.51;0.36) unclear

Table 3. Differences in tests results between baseline, 48 hours post game and 96 hours post game for the 'fatigued' group (n = 9): represented as ES ± 90% CI and classified as *trivial* (< 0.2), *small* (0.2 – 0.59), *moderate* (0.6 – 1.19), and *large* (> 1.2). Where the 90% CI simultaneously overlapped the smallest important ES (0.2) the magnitude of the difference was considered "*unclear*", with a <75% likelihood of exceeding the smallest important ES (0.2) classified as trivial. Thresholds for qualitative terms to chances of substantial difference were: <1%, almost certainly not; <5%, very unlikely; <25%, unlikely; 25-75%, possible; >75%, likely; >95%, very likely; and >99%, almost certain. Abbreviations: SRT, submaximal run test; AU, arbitrary unit; PL, player load; Stand$_{accel}$, standardised maximal duration acceleration phase; Stand$_{accel}$, standardised maximal duration plateau phase; Fwd, Forward.

		Baseline	48hrs Post Game	96hrs Post Game	Baseline to 48 hrs *d* (90% CI)	Baseline to 96 hrs *d* (90% CI)
CMJ Performance	**Height (m)**	0.42 ± 0.4	0.43 ± 0.4	0.42 ± 0.4	0.30 (-0.03;0.62) trivial (possible)	0.09 (-0.35;0.54) unclear
Stand$_{accel}$ Phase	**PL1D$_{up}$ (AU)**	0.50 ± 0.10	0.46 ± 0.10	0.50 ± 0.14	-0.38 (-0.74;-0.02) **small ↓ (likely)**	-0.03 (-0.40;0.33) unclear
	PL1D$_{side}$ (AU)	0.42 ± 0.07	0.38 ± 0.09	0.42 ± 0.11	-0.52 (-1.02;-0.02) **small ↓ (likely)**	-0.04 (-0.64;0.55) unclear
	PL1D$_{fwd}$ (AU)	0.50 ± 0.09	0.50 ± 0.13	0.52 ± 0.15	-0.13 (-0.59;0.33) unclear	0.13 (-0.43;0.69) unclear
Stand$_{plat}$ Phase	**PL1D$_{up}$ (AU)**	1.07 ± 0.21	0.95 ± 0.23	1.02 ± 0.14	-0.58 (-1.04;-0.12) **small ↓ (likely)**	-0.17 (-0.54;0.20) trivial (possibly)
	PL1D$_{side}$ (AU)	0.71 ± 0.12	0.66 ± 0.18	0.72 ± 0.15	-0.45 (-1.00;0.09) **small ↓ (likely)**	0.05 (-0.22;0.32) unclear
	PL1D$_{fwd}$ (AU)	0.94 ± 0.21	0.86 ± 0.21	0.94 ± 0.24	-0.34 (-0.59;-0.09) **small ↓ (likely)**	-0.03 (-0.30;0.24) unclear
SRT (overall)	**PL1D$_{up}$ (AU)**	2.74 ± 0.43	2.53 ± 0.54	2.62 ± 0.36	-0.11 (-0.61;0.39) unclear	-0.07 (-0.66;0.52) unclear
	PL1D$_{side}$ (AU)	1.84 ± 0.25	1.72 ± 0.37	1.83 ± 0.26	-0.22 (-1.01;0.57) unclear	0.02 (-0.34;0.37) unclear
	PL1D$_{fwd}$ (AU)	2.37 ± 0.41	2.25 ± 0.52	2.39 ± 0.57	-0.13 (-0.47;0.21) unclear	0.06 (-0.35;0.47) unclear

Table 4. Differences in tests results between baseline, 48 hours post game and 96 hours post game for the 'non-fatigued' group (n = 14): represented as ES ± 90% CI and classified as *trivial* (< 0.2), *small* (0.2 – 0.59), *moderate* (0.6 – 1.19), and *large* (> 1.2). Where the 90% CI simultaneously overlapped the smallest important ES (0.2) the magnitude of the difference was considered "*unclear*", with a <75% likelihood of exceeding the smallest important ES (0.2) classified as trivial. Thresholds for qualitative terms to chances of substantial difference were: <1%, almost certainly not; <5%, very unlikely; <25%, unlikely; 25-75%, possible; >75%, likely; >95%, very likely; and >99%, almost certain. Abbreviations: SRT, submaximal run test; AU, arbitrary unit; PL, player load; Stand$_{accel}$, standardised maximal duration acceleration phase; Stand$_{accel}$, standardised maximal duration plateau phase; Fwd, Forward.

		N test comparison	Average ± SD	TE as a CV% (± 90% CI)	SWC%
CMJ Performance	**CMJ Height**	23	0.42 ± 0.04	8.5 (7.1;10.8)	1%
SRT (overall)	**PL1D$_{up}$ (AU)**	23	2.62 ± 0.42	11.2 (9.3:14.2)	7%
	PL1D$_{side}$ (AU)	23	1.79 ± 0.30	12.0 (10.0;15.4)	5%
	PL1D$_{fwd}$ (AU)	23	2.25 ± 0.44	9.6 (8.0;12.3)	8%
Stand$_{accel}$ Phase	**PL1D$_{up}$ (AU)**	23	0.49 ± 0.09	12.5 (10.4;15.9)	2%
	PL1D$_{side}$ (AU)	23	0.40 ± 0.07	16.3 (13.5;20.9)	1%
	PL1D$_{fwd}$ (AU)	23	0.49 ± 0.09	17.5 (14.5;22.5)	2%
Stand$_{plat}$ Phase	**PL1D$_{up}$ (AU)**	23	1.01 ± 0.17	12.5 (10.4;15.9)	3%
	PL1D$_{side}$ (AU)	23	0.69 ± 0.12	13.8 (11.4;17.6)	2%
	PL1D$_{fwd}$ (AU)	23	0.88 ± 0.18	11.2 (9.4;14.3)	4%

Table 5. Reliability of measures. Abbreviations: TE, typical error expressed as a coefficient of variation (± 90% CI); SWC, smallest worthwhile change; SRT, submaximal run test; AU, arbitrary unit; PL, player load; Stand$_{accel}$, standardised maximal duration acceleration phase; Stand$_{accel}$, standardised maximal duration plateau phase; Fwd, Forward.