TITLE
Comparing the use of a Countermovement jump and a Sprint protocol at monitoring fatigue in female football

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Comparing the use of a Countermovement jump and a Sprint protocol at monitoring fatigue in female football

This Research Project is submitted as partial fulfilment of the requirements for the degree of Master of Science, St Mary's University

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Abstract

Female football is capable of inducing many known fatigue based complications and negatively affecting subsequent performance. Monitoring player's recovery from match-induced fatigue is seen as one method of ensuring safe and effective training, leading to improved chronic performance. Performance testing, such as counter movement jumping, has become a well-supported method of monitoring this recovery process. The following study aims to: [1] indicate the ability of a simple sprint test protocol to monitor female footballers recovery from a fatiguing event, and [2] compare the efficacy of this protocol against the commonly used CMJ test.

Ten high-level female footballers from a single team (Age: 22.5yrs, Height: 1.70 ± 0.05 m, Weight: 55.61 ± 3.30 kg) performed 3 countermovement jumps and 3 x 25m sprints 24, 72 and 120-hours post match play following four separate matches.

Mean post match CMJ flight time and jump height scores were lower than baseline (FT Baseline: 457 ± 15.59ms CMJ Post match: 442 ± 4.86ms, $F_{(3,20)}=4.394$ $P<0.05$. JH Baseline 240 ± 5.02mm $F_{(2,20)}=4.20$ $P<0.05$) indicating an impact of match-induced fatigue. Sprint times were also lower than baseline (Baseline: 4.17 ± 0.21s, Post performance: 4.14 ± 0.04s), however they failed to achieve statistical significance ($F_{(3,20)}=0.875$ $P>0.05$). Sprint times were also highlighted as having weak negative correlations with both FT ($r^2=-0.484$, $P>0.05$) and JH ($r^2=-0.515$, $P>0.05$).

Both CMJ and Sprint data highlighted that match play had induced fatigue. Each performance test produced different recovery profiles and indicates the two tests recover from fatigue in a different manner. Coaches using these tests are advised to first understand the mechanisms behind the changes before implementing them into their athletes training programs.

Introduction

In Soccer, or Football, fatigue plays a large part in decreasing performance output both acutely and over various timeframes post-match play (35). Across various sports and various levels, coaches implement an array of tools to monitor athletic performance and by implication, fatigue (19, 35, 44, 49). For example, Global Positioning Systems (GPS) have outlined the distances covered (68) velocities achieved (35) and movement patterns used (55) during team sport match play. As a welcome bi-product, these systems are able to highlight how these data change over the course of a match (45) and thereby outlining the interaction of fatigue and performance (35, 75). Using this tool, female players have been recorded covering between 9-11km (21, 47, 69) using combinations of low intensity movements (standing 19%, Walking 42.8 % and low intensity running 27.7%), high intensity running (~6.0%) and sprinting (~1.2%)(55). In their review Hodun et al. (36) summarised that total distance values generated by GPS devices, such as those above, are valid and reliable indicators of physical load during match play. However, further research into match play analysis has been used to bolster the understanding of the performance characteristics and thereby fatigue inducing patterns of female match play (21, 36, 47, 64, 72). Female footballers specifically can perform between 1300-1400 different actions over a 90-minute period. This number is comprised of the above, basic loco-motor movements and more explosive, game specific actions such as headers, tackles, passes and shots at goal (47, 55). These actions hold a large influence not only on the outcome of matches but also the overall physical demand of match play (61). Football is capable of driving intra-match average heart rates of around 155-172 beats per minute (BPM) very often equating to 85% of the players maximum heart rates (MHR) (21, 24,64). These data indicate a high aerobic load during match play, equaling that of a many other high intensity, intermittent sports (66, 72, 73). Intermittent sports also classically involve a high anaerobic component, augmented by the persistent use of the aforementioned movement patterns i.e. tackles, headers, accelerations, sprints and rapid changes of direction (22, 32). Female football is no different with players producing average blood lactate concentrations of 6mmol.L^{-1} through the intermittent use of explosive muscular actions such as sprinting and jumping (18, 65,66). Players are capable of achieving peak velocities of 21.8-27.5 km_h over distances of 20-35m (36, 45, 71) allowing them to cover a 25m distance in around 3.27-4.13s. Sprint velocity and the number of maximum effort accelerations are believed to not only influence the outcome of matches but also separate playing levels (61, 74). Female footballers have been recorded achieving jump heights of between 26.1-51.0 cm dependent on age (21). Playing level has no impact on a female footballers CMJ performance however (21).

Sprinting and jumping are largely influenced by the neuromuscular systems ability to coordinate the rapid production of both concentric and eccentric forces to propel the body in a given direction (20, 21). Acute fatigue during football typically manifests as a reversible decrease in the capacity to generate force through muscular contractile impairment (25) that reduces the work capacity over time (44). Upstream triggers for this acute reduction in muscular force production are related to the central and peripheral nervous systems (63). Understanding this develops a clear rationale for impaired sprinting and jumping abilities. Further evidence supporting this rationale comes in the form of reduced performance, in various sprint and jump tests for a brief period immediately post performance (1, 2, 56, 70,76). Symptoms of fatigue can last up to 72 hours post exercise (62). The result is a long lasting reduction in mechanical capabilities accompanied by enhanced perceptions of pain, decreases to range of motion and feelings of psychological and physiological tiredness that reduce the performance output of the fatigued athlete. Knee extensor maximum voluntary contractions and EMG activity were noted as remaining reduced for 48-72 hours post match play (62). Peak power outputs were also decreased for both a cycling sprint test and counter movement-jump for 1, 24 and 48-h post performance (76). Research in this vein has encouraged coaches to use performance tests (Jump, sprint etc) to monitor alterations in neuromuscular fatigue between performance and subsequent training sessions and thereby developing recovery profiles (76). This has however been called into question by findings that sprint tests in particular may have a limited scope for accurately monitoring recovery profiles past a few hours as sprint ability can return to baseline levels in around 5-hours (2). This argument is supported by the findings that despite CMJ and Drop Jump (DJ) performance remaining reduced across all time points measured. Additionally match induced fatigue was shown to cause non-significant changes to squat jump as well as leaving sprint performance unchanged (59). Various Sprint and jump tests have been validated as suitable field tests for assessing neuromuscular function (30). Methodological differences within the research have elicited conflicting results in relation to the accuracy of these tests (12, 59). Despite these conflicts, the use of short sprint and Counter Movement Jump (CMJ) tests appears to be the most valid and reliable method of depicting fatigue related changes to neuromuscular function (30).

Research in this field is however lacking for non-elite and female footballers, with the majority being undertaken for higher-level males and general team sports athletes (59, 74). Although the similarities in performance, physiological loading and fatigue induction between football and other team sports have been shown (36) the benefit of monitoring fatigue recovery in female footballers is a less popular topic that should deliver some useful guidelines. Gender related differences in female footballers anthropometry and how they interact with their environment could place the female footballer at greater risks of injury than their male counterparts (4). Add in the conflict amateur, non-elite players face between recovery timeframes, pressures to return to training or playing and work commitments, a simple and easily implementable monitoring procedure may provide coaches with the tools to improve the training protocols of the non-elite, amateur female athlete.

Performance testing by definition is capable of highlighting athletic capability. However it is also postulated that these tests may be used to monitor recovery patterns for team sports athletes (1, 30, 76) through comparisons of change over time. The following study suggests using a simple 3x25m sprint test as a quick and effective method of developing the recovery profiles of non-elite female footballers. The following study aims to: [1] indicate the ability of a simple sprint test protocol to monitor female footballers recovery from a fatiguing event, and [2] compare the efficacy of this protocol against the commonly used CMJ test. It is hypothesized that changes in sprint test results will match the magnitude and pattern of CMJ changes and will also show concurrent improvements in performance over the selected time points.

Methods

Experimental Approach to the Problem

Match play descriptive information (GPS and RPE data) was used to outline the external physical load and the perceived internal load of the four selected matches. The matches spanned a four-month period (January to April) and were roughly one-month apart. During the typical team training sessions over the week following each assessed match, performance testing took place in a within-subject repeated measures design. Players completed three CMJ's followed by three 25m sprints (roughly 15 mins later) at each testing session. Data were then analyzed, in terms of means and standard deviations, for [1] their differences across the measured time points and [2] how well the data sets correlated.

Subjects

Fourteen adult females (Age: 21.9 years, Height: 1.71 ± 0.05 m, Weight 59.16 ±1 0.92 kg) from a single football team (Swansea City Ladies AFC) were recruited, following player consent and agreement from the head coach, to take part in a study spanning roughly half their competitive season. Additionally authorisation and ethical clearance were obtained from St Mary's University Ethics Committee prior to any data being recorded. Anthropometrical data were recorded using a set of weighing scales (PD750 Digital Scales Company, Flint, UK.) and a stadiometer (Seca 213, Seca, North America, CA, USA). Following familiarization, baseline scores for Counter Movement Jump (CMJ) and 25m sprints were collected. This was done prior to the first collection of match play data using Global Position Systems (GPS). GPS and RPE data were then collected for 4 separate matches across a 4-month period. Baseline testing consisted of 3 CMJ's and 3 x 25m, standing start, straight-line sprints prior to an ordinary training session, in the same manner to testing sessions during the data collection period. A standardized, repeated and familiar warm up consisting of 5-mins of cycling at a self determined intensity (Watt Bike Pro Trainer, Wattbike UK), static and dynamic stretching and light jogging was performed before baseline and each testing session. Players were also asked to perform 5-progressive speed runs over the same 25m-distance prior to Sprint testing.

Procedures

Each player was asked to wear a vest mounted Catapult Minimax S5 GPS Unit (http://www.catapultsports.com/media/3702/catapult-optimeye-s5.pdf Catapult Sports, Leeds, United Kingdom) under their playing shirt, collecting at 10hz. Units were positioned centrally on the upper back and players were given the freedom to opt out of wearing the unit or to take them off during play if they felt they were hampering performance. Data were recorded in meters for: total distance covered, average distance per minute (calculated from total distance divided by playing time) and distance covered using high intensity running (HIR). HIR was calculated by the amount of distance covered above 3.40 ms^{-1} or 12.24 km_h (23). This threshold was selected based on the work of Dwyer and Gabbett (23) who endeavored to find a standard sprinting threshold that was comparable across a range of field sports. The authors assessed a range of data from various male and female field sports. 3.40m_s^{-1} was outlined as being an acceptable sprint threshold for female soccer players. Rate of Perceived Exertion (RPE) scores were taken within 30mins of the matches ending. Players were shown the Borg 6-20 RPE scale (11, 48) and asked to rate the difficulty of the game. They were not given any verbal cues or encouragement by the researcher in-line with recommendations (11, 39). The original scale used here has the ability to capture the perceived exertion from central cardiovascular, respiratory and neuromuscular systems (11). Total distances covered (km), HIR distances (km) and meters covered per minute (M/min) were combined with RPE scores to indicate the physical load for a given match.

Counter movement jump tests

Following a standardized warm up, counter Movement Jumps were performed first, using a portable FSL electronic jump mat (FSL Jump mat, FSL Scoreboards, Northern Ireland). Players were given a self-selected start, initiating the jump with a controlled triple-flexion countermovement to a self-selected depth. Keeping their hands firmly placed on their hips and without pausing at 'full depth', they next triple-extended rapidly, jumping with maximal effort. No set rest period was given between jumps; instead players were instructed to perform subsequent jumps when comfortable and ready and to aim for maximum height possible. The current cohort was unfamiliar with this style of performance testing. Self selected timing allowed them to feel in control, collect themselves between jumps and encourage them to apply maximum effort each time. Each player performed three CMJ's per testing session: with the mean score of these jumps taken for data analysis. The mean jumps were taken in light of the coefficients of variance created during baseline testing. The players created a range of variances showing a spread of data that also differed between the two jump variables. Developing mean scores for these data created a lower CV (JH=6.95%, FT=3.41%) and therefore a more accurate representation of the populations jump data. Additionally, averaging a number of jumps per session across a variety of time points improves the reliability of data and repeatability of testing (67)

Sprint testing

Sprint testing took place on an artificial grass-playing surface with all players wearing football boots with rubber or plastic studs. Two light timing gates (Brower TC Timing System, Brower Timing Systems, Utah, USA.), positioned 25m in length, 1.5m apart in width and 1.1m tall, assessed sprint time. Players started 0.5m behind the 0m gate using a self-selected, static sprint start to eliminate any reaction time delay. Players were told to give maximum effort and aim for maximum velocity before the 25m gates. On completion of each sprint, players decelerated and walked back to the first gate to set up for the next sprint without performing any further actions or warm up. The average recovery period was 1.5-mins between sprints. Three sprints were performed in total per session with the mean sprint time recorded for data analysis to best indicate the overall sprint performance of each session. This decision was influenced by the CV spread data (CV=5.05%) collected during baseline testing and to maintain consistency across the variables.

Statistical analysis

Descriptive data were calculated and are reported in terms of their means and standard deviations to outline any basic patterns and differences that exist between the recorded data. All data were checked for normality using the Shapiro-Wilk test. Due to the same group repeating testing across three time points, within-subject repeated-measures analysis of variance (ANOVA) was used to discover the significance of the differences between the selected measures of player load across the four matches. Bonferroni adjustments were included for tests with multiple comparisons. The same process (within-subject repeated-measures ANOVA and relevant adjustments) was used to assess the significance between any differences in Jump Height, Flight Time and Sprint time across the measured time points, post match play. A Greenhouse-Geisser correction was used if at any point data violated the assumption of sphericity. Significance for all statistical tests was set at P=0.05 at the 95% confidence interval (CI). *Post hoc* analysis was used to highlight which time points created the significant differences. From this process a 'recovery profile' was generated and graphical data used to display the overall trends of this profile.

Two-tailed Pearson's correlation coefficients were developed to assess the relationship between the recovery profiles of FT and ST, JH and ST and finally JH and FT. As previously mentioned coefficients of variance (CV) were also calculated to highlight any changes to the variance in performance data for the three key variables.

Results

Due to the nature of competitive football, only 11 of the recruited players took part in all four assessed matches (average playing time = 85mins). Players, who completed less than 80mins, were removed from the data set. Additionally, Goal-keeper's data were removed due to the disparities in physical loading experienced by this position, leaving 10 players for analysis (Age: 22.5 years, Height: 1.70 ± 0.05m, Weight: 55.61 ± 3.30kg). For these players, baseline testing yielded a mean flight time (FT) of 452 ± 16.56ms with corresponding mean jump height (JH) of 251 ± 18.76mm. A group mean sprint time (ST) of 4.24 ± 0.33s was also recorded at base line testing sessions.

Match play

Match play analysis of the four matches, revealed the average distance covered by players to be 8.12 ± 1.07 km with a corresponding HIR distance of 2.00 ± 0.34 km and post-match mean RPE of 13.07 ± 0.22 (6-20scale). Players were then calculated at covering on average 86.22 ± 5.92 meters/minute across the four matches.

Inter-match analysis revealed the total distances covered by players (*Table 1*) to differ across the four matches ($F_{(3,6)}$=10.165, P<0.05). *Post hoc* analysis highlighted significant differences between matches one and two (P<0.05) and matches one and three (P<0.05). Conversely, data recorded for total distance covered using HIR ($F_{(1.544,3.088)}$=2.213, P=0.246) RPE ($F_{(39,3)}$=0.207, P=0.891) and meters covered per minute ($F_{(2.434,1.217)}$=7.861, P=0.861) did not differ across the four assessed matches.

Table1: Motion analysis data for the four assessed matches

Matches	1	2	3	4	Mean
Total distance (km)	7.67 ± 1.12	7.81 ± 0.91	9.1 ± 1.16	8.11 ± 0.64	8.18 ± 0.65
HIR (km)	1.73 ± 0.67	1.75 ± 0.51	2.44 ± 1.03	2.08 ± 0.46	2.00 ± 0.34
M/min (m)	81.52 ± 11.77	83.74 ± 9.53	94.86 ± 12.04	84.77 ± 3.13	86.22 ± 5.92
RPE	13.14 ± 1.41	13.14 ± 1.61	12.75 ± 1.28	13.25 ± 1.42	13.07 ± 0.22

Flight time

Mean post match play flight times were lower than that of mean baseline testing (Baseline: 457 ± 15.59ms Post match: 442 ± 4.86ms, $F_{(3,20)}$=4.394 P=0.038). (*Figure 1*) Shows the mean flight time and jump height profile across the measured time points. Mean CMJ flight time was 442 ± 4.86ms with times ranging from: 421ms to 450ms (CV=2.92%). Of the time points assessed, 72-hours post performance produced the largest flight time (445 ± 7ms $F_{(2,20)}$=3.739, P=0.042 η^2=0.272). *Post hoc* analysis using the Least Significant Difference (LSD) correction method revealed the largest difference to exist between 24-hours and 72-hours post performance (7ms; 95% likely range; -17.225- -1.866, P<0.05).

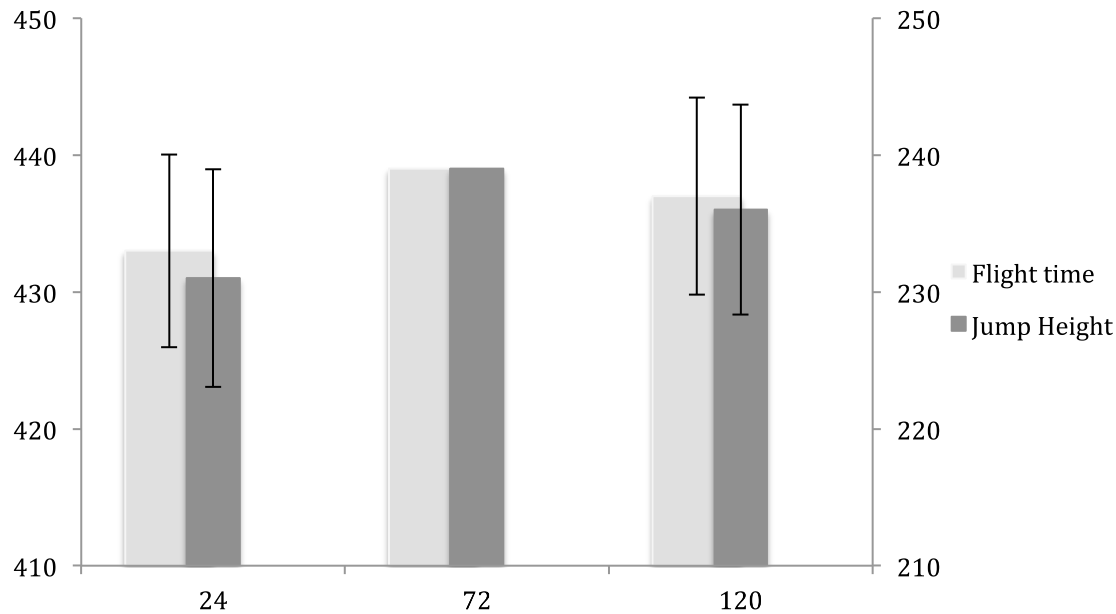

Figure 1: Mean Jump Height and Flight time across the three time points

Jump height

The mean post match jump height score was 240 ± 5.02mm with ranges in jump height of 219mm to 253mm seen across the group and time points. As is to be expected the JH recovery profile mimics that of FT with the greatest JH recorded 72-hours post performance (243 ± 8mm $F_{(2,20)}$=4.200 $P<0.05$ $\eta^2=0.296$). *Post hoc* analysis revealed significant changes to JH between 24 and 72 hours (8mm; 95% Likely range: 1.652-18.348, $P<0.05$) and between 24 and 120-hours (7mm; 95% Likely range: 1.051-14.949, $P<0.05$). Post match JH also however failed to equal that of baseline remaining lower by an average of 16mm (Baseline: 256 ± 17.75mm, Post match: 240 ± 5.02mm. $F_{(3,28)}$=4.274 P=<0.05).

Sprint time

Post performance mean sprint times (ST) appear to contradict the findings of FT and JH by not differing in comparison to those taken at baseline (Baseline: 4.17 ± 0.21s, Post performance: 4.14 ± 0.04s $F_{(3,20)}$=0.875 $P>0.05$). ST data recorded also shows a mean decrease of 0.07s across the 3 time points measured post-performance ($F_{(1.127,11.269)}$=1.414, $P>0.05$ $\eta^2=0.06$) indicating that ST remained similar, irrespective of the recovery time between testing sessions.

Correlation between sprint time, jump height and flight times

Table 1 displays the mean scores for selected variables over the four weeks. As is expected FT and JH have a very strong, positive correlation ($r^2=0.996$, P=0.004) showing that as Flight time alters, so too does Jump Height by a concurrent magnitude. Two-tailed Pearson's correlations of data from this study showed however that ST did not correlate well with either FT ($r^2=-0.484$, $P>0.05$) or JH ($r^2=-0.515$, $P>0.05$).

Discussion

This study aimed to elucidate the efficacy of a sprint test protocol at monitoring recovery from induced fatigue whilst also comparing this test to a CMJ protocol. All three variables tested (flight time, jump height and sprint time) decreased as a result of match play. However, sprint times were less affected across the measured time points when compared with jump data. The alternative hypothesis was that the two tests would experience concomitant changes across the measured time points due to their reliance on similar muscular capacities. This was not seen however, with sprint testing experiencing a smaller relative performance reduction, as well as smaller relative improvements over time, and an alternative pattern of change. This point was further supported by ST's achieving lower relative effect sizes (ST=0.124, FT=0.272, JH=0.296). Jump data may also point to the fatiguing impact of training sessions as peak jump scores were recorded prior to the mid week training session (72-hours post performance) and subsequent testing scores were lower (120-hours post performance). These scores however were not statistically different and therefore further research is required to discover whether this phenomenon truly exists. Sprint times did not follow this pattern but instead gradually improved as time progressed, potentially alluding to a longer lasting effect of fatigue on sprint performance.

Data produced during this research is in agreement with previous articles (2, 5, 36, 59, 76) around the impact of match-induced fatigue on performance variables over the days following a match. Recorded match play data indicated each match to be of equal stimulus or physical load for the players in question. However players failed to achieve reported total distances for their population (Current 8.12 ± 1.07 km Vs Population average 9.10-11.93km) (47, 69) or match that of simulated studies using soccer players (59). This could potentially indicate that players experienced a lessened physical load during this study than those used in previous research. The previous validation of total distance as a reliable measure of physical-load for female footballers (36, 43) further supports this hypothesis. However, measurements of total distance are thought to be more susceptible to the wider variables of football such as substitutions, opposition level and tactics than other measures collected via various forms of motion analysis such as GPS and notational analysis (23). Initially it seems logical to report that higher caliber players and more competitive matches would yield greater total distances in tandem with increased heart rates (6) and superior fatigue induced alterations (7). This would point to higher total distances coinciding with higher workloads. However, deeper analysis shows that distances covered at lower intensities do not vary greatly between playing levels (10). It is distance covered, and time spent performing high intensity actions that increases the physical load experienced (28, 29, 21). This indicates that players may cover similar total distances but experience different physical loads during match play. This is supported by findings that as the competitive level increases, female mid-field players utilize more HIR patterns than their teammates, with no difference in total distances (2). Higher level players can cover 28% and 24% more distance through HIR and sprinting respectively, averaging between 1.09 km and 1.68 km in this fashion (2, 21, 45, 46). With this information in mind players in this study did match these workloads, and therefore the fatigue experienced, for their population achieving 2.00 ± 0.34km using HIR.

Despite the disparities in monitoring procedures discussed, football performance has been consistently proven to induce fatigue lasting up to and beyond 72-hours (8, 28, 54, 62, 63, 71). Augmenting the fatigue developed via the above kinematics of football are the kinetic demands placed on the musculoskeletal system. Football's force-producing requirements involve: eccentric muscle loading, concentric contractions and combinations of the two applied in multiple directions and over various timeframes (68). The impact is an infringement on neuromuscular and metabolic systems of the body that in turn reduce work capacity both acutely (63) and over more chronic timeframes. Football performance has been repeatedly shown to reduce measures of muscular strength, power and sporting performance (25) through diminutions in neuromuscular function (2) that remain long after matches finish. Performance tests have become a staple when assessing the recovery of these fatigue-induced reductions (70). Measures such as sprint-cycling-derived peak power have been validated as being able to accurately assess fatigue and monitor recovery post football performance (76). Short cycle sprint performance has been highly correlated with the ability to perform the short, explosive sprints (13) regularly seen in football, accurately producing high, test-re-test variations of fewer than 3% (52). Cycle sprints are capable of such accuracy due to their basis in the development of peak power and the direct affect on peak power by the decreased neural drive and biochemical infractions produced through fatiguing performance (51). However, sprint cycling has a heavy concentric bias through the rotational motion of the pedals and the un-weighted cyclist not needing to absorb major landing forces. Although this allows the test to be less fatigue inducing and direct measures of sprint peak power can be obtained (76) it decreases the validity of these tests for sports or performances that themselves include a heavy eccentric bias.

Football has a heavy reliance on eccentric muscle contraction to absorb single leg landing forces and reapply them to create propulsive running forces through the stretch shortening cycle [SSC] (74). There is also a heavy reliance on this process during change of direction actions and to some extent kicking, tackling and shooting (76). The high utilization of the SSC during sprinting and the large impact of NMF on the SSC (58), creates a clear link to the use of typical running based sprint tests for performance testing in football. Additionally, provided the correct distances are chosen, sprint tests are directly relatable and applicable to the dominant actions of football performance (30). Furthermore, running sprint tests have been found to hold a higher degree of repeatability and therefore reliability over other tests such as drop jump and CMJ (30).

Recently however, countermovement jump tests have been proposed as more accurate and relatable to football performance through their use of eccentric contraction and the stretch shortening cycle (SSC) (15, 58). For example the key footballing movements of high velocity sprinting and change of direction each require high-force eccentric stabilization of the lower limbs prior to rapid, concentric reapplication of force (3) in a similar manner to a counter movement jump. CMJ's were also able to produce low test-retest variance of 3.5-6% (17). The current study is in accord with these figures finding mean coefficients of variance of between 2.92 and 5.76%. Changes to the accepted variance when selecting jump data for analysis could be a source of contention however (30). Some authors accept CV's of as high 10% while others have found various CMJ data to fluctuate by as little as 1.62% (30). Thorland, Aagaard and Madsen (68) supported the use of CMJ for assessing NMF with their findings that thigh muscle rate of force development decreased by around 9% post match play and attributing this result to decrements in power based performance. This result cannot be taken as solid evidence however due to the large interaction of other muscle groups when performing jumping motions. It simply stands to evidence the interaction between fatigued muscle and performance output.

In addition to assessing fatigue at a single time point, CMJ's have been used to show how performance recovers following fatigue accumulation. CMJ peak power showed concurrent reductions to that of flight time at the 24-hour mark matched by the current data set of this article. Similarly again, these measurements appear to improve at the 48 and 72-hour mark (74, 76) but do not return to baseline as can be seen within the current paper. When assessing the recovery profile between two matches, CMJ jump height experienced greater reductions than sprint times (4.4% and 3% respectively) and took ~69h to return to baseline readings (2)

More recently, CMJ performance was found to reduce in tandem with peak sprint speed (57). Peak sprint speed data from the (57) study does however appear to argue with the current data by achieving maximum reductions at the 48-hour mark and returning to baseline by the 72-hour mark. The disparities between that study and this are postulated to exist through this collection of peak data. Averaging data collected improves the probability of obtaining a true result (14) or detailing the 'real' response to an input, in this case fatigue (33, 60). A recent meta-analysis found average CMJ data to be more sensitive at detecting fatigue compared to peak or maximum scores (34). Comparing mean data from this paper with that of Nedelec and colleagues (60) yields two different profiles. The current study saw a gradual improvement in sprint times over the measured time points, whereas Nedelec and colleagues recorded their quickest sprint speeds at their middle time point (48-hours). However, the current study extends beyond 72-hours and did not take a measurement at 48-hours post fatigue. Combining the findings from the tow papers could draw the conclusion that sprint times take 48-hours to return to near-baseline. When eliminating this time point however, the two papers align more closely. However to improve the comparison between the two data sets, a 48-hour time point would be needed in the current research methodology.

In an attempt to further investigate the validity of the CMJ at monitoring fatigue recovery, Oliver, Armstrong and Williams (59) investigated the changes to other jump styles. The authors found that performance in all 3 jumps (squat, CMJ and drop jump) decreased as a result of fatigue. As is typical, CMJ's experienced the greatest decrease of ~3cm. However, force and muscle activity variables collected highlighted the drop jump as being most affected by fatigue. Only drop jumps presented significantly reduced total muscle activity and impact forces. This information points to the impact fatigue has on the stretch shortening cycle (SSC) and in particular the eccentric portion of this cycle (30). This finding has led some to believe that CMJ tests are less reliable than first thought. However, jump testing is highly concerned with profiling the neuromuscular changes caused by fatigue (16). By definition the CMJ must eccentrically control and stabilize the body and centre of mass before concentrically propelling said centre of mass upwards. This is a prime example of the SSC in practice (16) and suggests the interaction of the neuromuscular systems through the controlled firing and coordination of muscle groups. Typical CMJ testing however primarily concerns itself with the concentric phase of jumping (16, 18) with many opting to assess fatigue through flight times. Doing this may overlook the complex nature of how NMF affects muscle contractions and decrease the sensitivity of this test (44). This lack of sensitivity may be further questioned by findings that CMJ scores can be maintained even in a fatigued state (16, 68) especially when using Flight times and other non-direct measures of NMF.

With the disparities in CMJ becoming more apparent, the use of sprint testing becomes an attractive prospect. On the surface, sprint testing would seem a logical choice for testing NMF in football players due to the robust connection between sprinting and success in football (29). Given the already identified high physical load of football performance, its reliance on the SSC and the connections between a fatigued SSC and NMF (30, 58, 74, 76) sprint testing has a solid rationale behind its use for monitoring fatigue and recovery. Data produced by the current paper gives ambiguous support for this rationale however. The recovery profile generated agrees with the idea that as fatigue dissipates, SSC dictated performance (e.g. sprinting) should recover and return to near baseline levels. However the perceived reduction in sprint performance was not significantly great enough to stand as evidence that sprint times had been effected by the induced fatigue. Support for why this may be has basis in the understanding that the first 5m of sprinting are governed by the concentric force an athlete can produce (53) and the short ranges of motion during this phase could limit the involvement of the SSC (9). The result is further agreement with findings in this paper that short sprint performance does not correlate well with CMJ scores (13). In fact, sprint times have been found to return to that of pre-fatigue after as little as 5-hours (2). In this study, CMJ performance decreased by concurrent magnitudes to sprint times but remained decreased for longer. Hoffman et al (37) believed this difference to exist due to the differing impact of accumulating biochemical factors. It is thought that the increased reliance on eccentric contractions during CMJ's, increases perceptions of DOMS via muscle swelling and cell damage in the days following fatigue induction (63). However, as the first 5m of sprinting are predominantly concentric (53) and the remaining portions involve lower eccentric stresses than a CMJ, athletes may perceive lower feelings of pain or DOMS.

This idea that the muscular actions of the two tests (Sprint and CMJ) differ vastly is further supported by findings that peak knee extension and flexion torque each returned to normal before CMJ peak power does (2). In the referenced study sprint times returned to baseline before peak knee extension and flexion torque did. Amongst other changes, myofibrillar disruptions (26) and moderate CK and urea accumulation (2) are postulated at reducing the force generating capacity of muscles following intense, mutli-directional exercise (31) such as football. Due to the different muscular requirements of a CMJ and a sprint (40, 41, 42) sprinting may not require the same level of recovery from the aforementioned affects of fatigue and performance data would therefore return to baseline earlier. The current data set agrees in part with this theory, showing that sprint times did not differ greatly from baseline. A shorter recovery timeframe would stand to rationalize this difference.

Study limitations

Given the nature of the research design, there were a number of days between testing sessions. The activity of participants on these days was not accounted for and could have influenced their performance during testing sessions. Additionally the current design may have unwillingly created bias towards the sprint testing. The CMJ's may have primed the neuromuscular system leaving it in a beneficial activation state for the sprint tests. Future research is encouraged to apply a participant cross over design to eliminate this factor. Match play data was used to outline the external and perceived internal load of each of the matches. However, this does not directly outline the level of fatigue accumulated across a match. To further the current study design, performance testing would be performed immediately post match to give a direct measure of the impact fatigue has had on the performance during the tests.

Practical applications

The current data set agrees with much of the research in that sprint times do not experience the same recovery profile as some jump variables. Flight times and Jump heights improved as the week progressed with 72h post performance producing peak scores for both. Sprint times however produced a different profile as they gradually decreased over the week reaching peak quickest times at 120h post performance. This points to different optimal time points for performance in actions related to these tests i.e. jumping and short sprints. However due to a lack of clarity in the results obtained, further research is suggested into the reliability of these measures. The information garnered from further study may override some of the validity questions posed and more effectively guide the selection and use of these tests.

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Appendices A

Signed ethical approval for the undertaking of this project

St Mary's University Twickenham London

Approval Sheet

Name of applicant: Jack Spillets Name of supervisor: Stephen Patterson Programme of study: MSc. Strength and Conditioning Title of project: Using a performance test to monitor fatigue in high-level, non-elite female footballers

Supervisors, please complete section 1 or 2. If approved at level 1, please forward a copy of this Approval Sheet to the School Ethics Representative for their records.

SECTION 1 Approved at Level 1 Signature of supervisor (for student applications Date: 22/1/16
SECTION 2 Refer to School Ethics Representative for consideration at Level 2 or Level 3 Signature of supervisor... Date..
SECTION 3 To be completed by School Ethics Representative Approved at Level 2 Signature of School Ethics Representative: J Hill Date 07/12/2016

Participant information sheet given to all

Participant Information Sheet

I would like to invite you to participate in a research project. However, before you decide, it is important you understand what the research project is, why the research is being carried out and what you would need to do.

Title: "Using a performance test to monitor fatigue in high-level amateur female footballers".

What is the purpose of the research?
Following the completion of a match, the lasting effects of fatigue can increase the risk of injury to players in the subsequent training sessions. In order to minimise this risk and provide worthwhile opportunities for players to progress throughout the season, this research aims to outline and validate a method of monitoring the dissipation of fatigue over the days following match play.

Who is organising the project?
The research project will be organised by the principle researcher Jack Spillets (145425@live.smuc.ac.uk or jackspillets@scfccommunitytrust.co.uk) in collaboration with Dr Stephen Patterson from St Mary's University.

Why have I been invited?
Sixteen, female footballers, over the age of 18 are required for the research project to further the understanding of the impact fatigue has on this group.

Do I have to take part?
You do not have to take part; it is up to you. If you do decide to participate you will be given a consent form to sign. You are free to stop at any time and you don't have to have an excuse or reason to stop.

What is required of me if I participate?
You will be required to attend 3 testing sessions per week and one regular match. Two of the testing sessions will occur before your normal training session with one occurring on a separate day. You will be asked to perform 3 countermovement jumps, using only your legs to jump, and 3 20m sprints in each of the testing sessions. You will be required for a total of 4 weeks (4 matches and 12 testing sessions). Prior to the

testing phase beginning, you will be given opportunities to practice the movements and familiarise yourself with the test procedure. Each testing session will take no more than 1-hour including warm up and preparation for the tests.

What will I have to do?
You will be required to attend testing sessions and perform the test exercises to the best of your ability. No changes are to be made to your nutrition or lifestyle.

What are the possible disadvantages and risks of taking part?
The testing may at first be uncomfortable during the sessions close to match day however, the testing exercises have been specifically chosen to limit this discomfort and not put you at risk.

What are the possible benefits of taking part?
The project aims to develop a model of recovery for female footballers of your level. The information garnered will be used to better guide the training protocols used by your coaching staff and potentially decrease your injury risk and lead to improvements in your physical performance.

What if there is a problem?
If you have a problem with any part of the research project you can speak to the principle researcher Jack Spillets (145425@live.smuc.ac.uk or jackspillets@scfccommunitytrust.co.uk) who will do their best to answer your questions or concerns. You can ask to stop your participation at any time through out the research project with no need to provide a reason and this can be done by making contact with the principle researcher. If you would like to make a formal complaint this can be made to a member of the research project Jack Spillets (145425@live.smuc.ac.uk or jackspillets@scfccommunitytrust.co.uk)
Stephen Patterson (stephen.patterson@stmarys.ac.uk)

Will my details and data remain confidential?
All participant information will be safeguarded and remain confidential during and after the research project in line with the data protection act 1998. All data will be collected and stored on a password-protected computer known only by the researcher. All paper data will be in a locked cabinet in a locked office accessed only by the researcher. All data will be disposed securely after 3 years. If you withdraw from the research project all information and data collected will be destroyed.

What will happen to the results of the research project?
Participants will be provided with a summary document of their recovery profiles developed during the testing process. This will be accompanied by an explanation of what this means for their performance and the impact fatigue has on them post-match. St Mary's University will be provided with a complete summary of all participants' recovery data, critical analysis and overall conclusion from the research project. However no individual data (names, dates etc) will be shared. Further, proposed practical applications will be provided for future injury prevention programs and if the research results are accepted to be published in a peer reviewed research journal no identifying information will be released.

YOU WILL BE GIVEN A COPY OF THIS FORM TO KEEP TOGETHER WITH A COPY OF YOUR CONSENT FORM

Blank participant consent form, signed by all participants

St Mary's University Twickenham London

Participant Consent Form

Name of Participant: --

Title of the project: Using a performance test to monitor fatigue in high-level female footballers.

Main investigator and contact details: Jack Spillets
145425@live.smuc.ac.uk or jackspillets@scfccommunitytrust.co.uk

Members of the research team: Jack Spillets, Stephen Patterson

I agree to participate in this research project and that my participation is voluntary.
I am aware of what participation will involve and all my questions have been answered to my satisfaction.
I understand that I may withdraw from the research at any time, for any reason and without any judgement.
I have been informed that the confidentiality of the information I provide will be safeguarded
I am free to ask any questions at any time before and during the study.
I have been provided with a copy of this form and the Participant Information Sheet, which I understand.

Data protection: I agree to the University processing personal data, which I have supplied. I agree to the processing of such data for any purposes connected with the Research Project as outlined to me.

Name of participant
(print)…………………………..Signed……………..……………Date………………

Name of witness (print)……………………………..Signed……………..……………Date……………

If you wish to withdraw the participant from the research, please complete the form below and return to the main investigator named above.

Title of project: Using a performance test to monitor fatigue in high-level female footballers

I WISH TO WITHDRAW FROM THIS STUDY

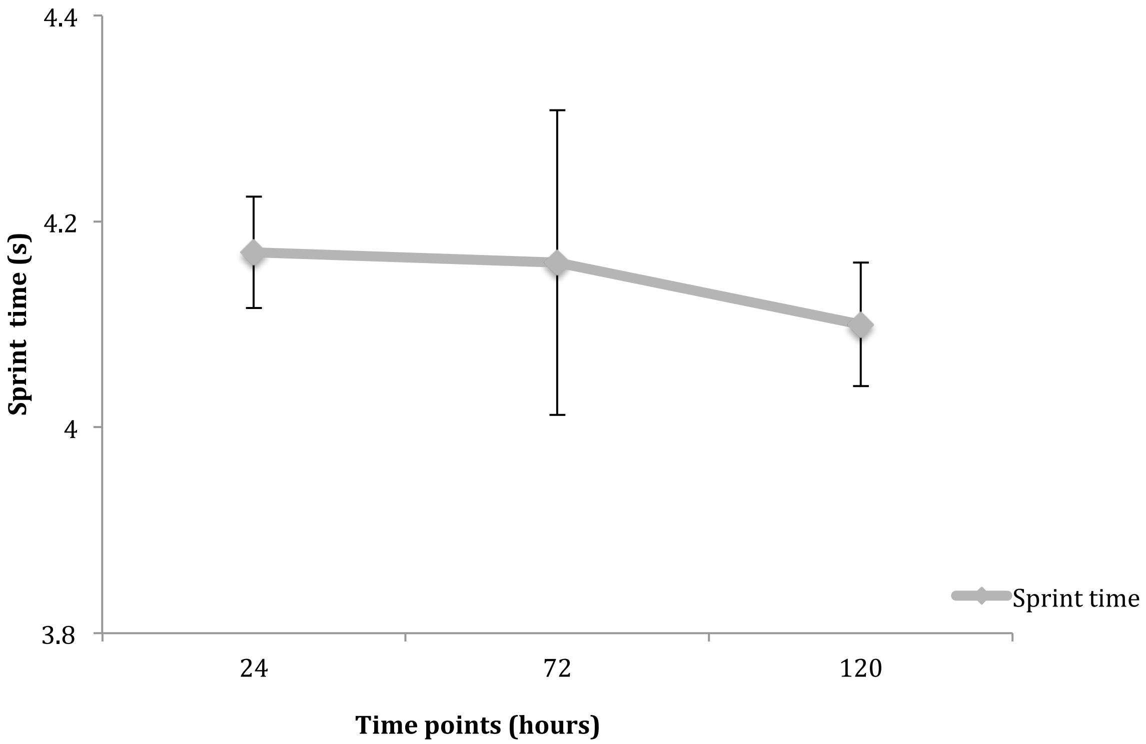
Name(print):……………….…………Signed……..……………………..Date………..

Appendices B

Mean data for Flight Time, Jump Height and Sprint Time

Week	Time post performance	Flight time (ms)			Jump Height (mm)			Sprint time (s)		
1	24	445	±	36	244	±	39	4.16	±	0.16
	72	447	±	30	245	±	33	4.12	±	0.11
	120	436	±	29	232	±	26	4.12	±	0.15
	Mean	443	±	32	241	±	32	4.14	±	0.14
2	24	441	±	27	239	±	27	4.15	±	0.11
	72	454	±	20	252	±	23	4.08	±	0.12
	120	437	±	28	234	±	25	4.12	±	0.15
	Mean	444	±	25	242	±	25	4.12	±	0.13
3	24	429	±	23	226	±	24	4.18	±	0.09
	72	436	±	27	234	±	30	4.11	±	0.12
	120	439	±	29	240	±	29	4.11	±	0.13
	Mean	435	±	27	233	±	28	4.13	±	0.11
4	24	436	±	22	233	±	22	4.18	±	0.10
	72	444	±	26	242	±	28	4.30	±	0.50
	120	458	±	31	260	±	36	4.06	±	0.14
	Mean	446	±	26	245	±	29	4.18	±	0.24

Mean changes to Sprint time across the three measured time points



Correlation data for mean Sprint time and Jump Height