

The effect of acute fatigue on countermovement jump performance in rugby union players during preseason

Rodney A. Kennedy,^{1*} David Drake,²

¹ School of Sport, Ulster University, Jordanstown, N. Ireland; ² Ulster Rugby, Kingspan Stadium, Belfast, N. Ireland

*Corresponding Author: Rodney A. Kennedy, School of Sport, Ulster University, Jordanstown, Shore Road, Newtownabbey, Co. Antrim, BT37 0QB, N. Ireland.
Email: r.kennedy@ulster.ac.uk

ABSTRACT

BACKGROUND: A countermovement jump (CMJ) is routinely used in many sporting settings to provide a functional measure of neuromuscular fatigue. However, the variables that are most sensitive to fatigue remain somewhat unclear. The purpose of this study was to determine the acute changes in neuromuscular fatigue in rugby union players during a period of preseason training.

METHODS: Nine male (age: 19.0 ± 1.5 years) academy rugby union players performed five CMJ trials on three occasions, at baseline, 24 hours and 48 hours post-baseline. The fatiguing protocol consisted of multiple high-intensity training sessions commensurate with the period of preparation and the sport. A total of 14 CMJ variables were derived from the force-time curve. Meaningful differences in CMJ performance were examined using the magnitude of change (effect sizes; ES) compared to baseline.

RESULTS: Most variables, 9 of the 14, showed substantial decreases at 24 hours post-baseline. Mean concentric power, peak velocity, jump height and force at zero velocity were impaired by the greatest magnitude (ES = -0.98 to -1.57). At 48 hours post-baseline, substantial increases in eccentric duration, concentric duration and total duration were first observed (ES = 0.48 to 0.61). Concomitantly, peak power, peak velocity and jump height, recovered to baseline levels.

CONCLUSION: During the late regeneration phase, neuromuscular fatigue can manifest itself as an altered movement strategy, rather than as a simple reduction in physical output such as jump height. Practitioners are therefore advised to incorporate a wide range of variables when trying to identify subtle changes in the bimodal recovery pattern associated with stretch-shortening cycle induced fatigue.

Keywords: exercise; fatigue; movement; workload

Introduction

Neuromuscular fatigue (NMF) is a complex phenomenon and is described as an exercise induced decrease in the maximal force capabilities of a muscle or muscle group, regardless of whether or not a given task can be maintained ¹. The cause of fatigue is regarded as multifactorial, with the proportion attributed to central and peripheral mechanisms being influenced heavily by the characteristics of the task ². The fatigue measure should be selected based upon the functional characteristics of the exercise bout completed, when trying to monitor fatigue in athletes ³. Although isolated forms of muscle action have commonly been used in many previous studies, possibly because of the perception that high levels of repeatability can be achieved ⁴, these measures don't reflect the natural occurring stretch-shortening cycle (SSC) used within most sports ^{5, 6}. This is however not to discount the vast amount of information that has been gleaned from such studies ⁵, but does suggest that a measure of SSC function, such as a countermovement jump (CMJ), may potentially provide a more suitable method to investigate NMF in athletic populations.

The CMJ has been used in many studies to monitor the post-exercise recovery process from both training and competition workloads ⁷. The analysis is typically limited to output related variables from the concentric portion of the movement, such as peak/average power or jump height ^{8, 9}. This type of approach largely ignores the mechanical variables that produce the jump and may help to explain, in part, why many CMJ derived variables are considered to lack the required sensitivity to detect fatigue induced changes in muscle function ^{4, 10, 11}. In addition, the bimodal nature of the recovery cycle from SSC activities further complicates the assessment process, with an immediate decline in muscle function that is restored after a number of hours, only to further decline 24-48 hours later, followed by a complete recovery in the days to follow ⁵. It is now therefore suggested that a CMJ analysis orientated toward NMF, should consider the movement strategy adopted and take into consideration the eccentric portion of the jump ¹⁰.

Rugby union is one of the most popular team sports in the world, with ever increasing participation figures. The game is composed of high intensity intermittent bouts of activities such as sprinting, jumping, rucking, mauling and tackling, with the inherent risk of injury considered to be substantial ¹². Although the incidence of injury is higher during competitive matches, the training environment is often viewed as a controllable environment that can be targeted for possible injury risk reductions ¹². In addition, like many team sports with a long

competition calendar, the preseason is viewed as a short period of intensification in the training load to sufficiently prepare for the season ahead^{13, 14}. Professional rugby union players typically train 5 days a week, with 2-4 sessions per day, resulting in a training load that may be between 2-4 times greater than completed in-season¹⁵. Such dramatic changes in the training load requires careful consideration, since insufficient recovery may lead to non-functional overreaching or an overtraining state¹³. Furthermore, the programming for professional rugby union players is often based on anecdotal information and non-specific literature¹⁵, highlighting the need for a practical, reliable and sensitive measure of NMF. Therefore, the purpose of the investigation was to determine the acute fatigue response to a typical training day during the preseason period in rugby union using a comprehensive range of CMJ variables.

Materials and Methods

Experimental Approach to the Problem

The present study was designed to examine the acute response to multiple daily training sessions, as typically used within preseason training in professional rugby. The dependent variable assessed was the NMF response to the training load; derived from a CMJ performed on a force platform. The proven relationship between training load and performance will naturally encourage progressively higher volumes of training in an attempt to realise the small, but often competition defining results¹⁶. Therefore, to ensure that the desired adaptations are occurring will require comprehensive monitoring of the individual response to the training load imposed.

Subjects

Nine elite male rugby union players, age 19.0 ± 1.5 years, height 188.3 ± 1.5 cm, and mass 95.0 ± 10.5 kg volunteered to take part in the study. The study was conducted at the start of week 5 of an 8 week preseason training block. The players took part in their normal team training as prescribed by their strength and conditioning coach. All the players were free from injury at the time of testing. Prior to the study commencing, the players attended a presentation to outline the purpose, benefits, risks and procedures involved in the study. Players provided written informed consent and were free to withdraw from the study at any

stage without penalty. The study was approved by the Ulster University Human Research Ethics Committee.

Procedures

A baseline measurement of CMJ performance was taken immediately before the start of training on day 1, at approximately 0700 hours (Table 1). Subjects were asked to refrain from strenuous exercise for 48 hours before baseline testing. Subsequent measures were taken under the same conditions at exactly the same time on the following 2 mornings. Training consisted of resistance training sessions (30 min: upper body, 3 sets of 4–6 RM, 3 min rest for 2 exercises; 45 min: lower body, 3 sets of 4–6 RM, 3 min rest for 3 exercises), speed training (30 min: 8 reps of 30m sprints, 3 min rest), and rugby specific training (45 min: defensive patterns and team plays), as previously described¹⁵. This daily training load equates to approximately 1000 Borg scale minutes, based on the method proposed by Foster¹⁶.

*****TABLE 1 NEAR HERE*****

Countermovement Jump Testing

The jump testing procedure was preceded by a 10 minute warm-up period that consisted of jogging, dynamic stretching, and the execution of 5 sub-maximal CMJ efforts of progressively increasing intensity. The CMJ trials were performed on a force plate (Kistler type 9286BA, Winterthur, Switzerland) that was connected to an A/D convertor (Kistler type 5691A1, Winterthur, Switzerland). Temporal and vertical ground reaction force (F_z) data were collected at a sampling frequency of 1000 Hz for 5 seconds using Bioware[®] software (Version 5.1, Type 2812A). The force plate was zeroed immediately before each trial and sampling began when the participant was standing still. After approximately 2 seconds, subjects were instructed to keep their hands on their hips and to jump as high as possible using a self-determined countermovement depth¹¹. Each participant completed 5 CMJ trials with 1 minute of rest in between, with the average used for further analysis.

Countermovement Variables

The F_z data were not filtered, as it has been reported as a potential source of error when determining jump height with the impulse method¹⁷. The subjects body weight was calculated as the average F_z during the first second of the sampling period. The first time the

F_z deviated above or below body weight by more than 1.75 times the peak residual found during the 1 second body weight averaging period was identified. A backward search of the F_z was then completed until the value passes through body weight, this time point was defined as the start of the jump. The take-off and landing time points were determined by finding the 0.4 second moving average with the smallest standard deviation F_z and then taking the peak residual during this phase as the threshold. Net impulse was obtained by integrating net F_z using the trapezoid method from the start of the jump and then dividing it by body mass to obtain vertical velocity. Vertical displacement was subsequently determined by integrating velocity. Power was calculated as the product of F_z and velocity.

An alternative start time calculation method has been proposed by Gathercole⁴ in an attempt to prevent any unnecessary distortion of the many CMJ variables due to premature triggering of a start point. Peak relative eccentric power and data points within a 10% range were identified on the power-time trace; the alternative start time was determined by completing a backward search of consecutive time points until the power change is $<0.15 \text{ W}\cdot\text{kg}^{-1}$ for more than 4 out of 5 consecutive pairs. The definition of all the CMJ variables used has been previously described in detail elsewhere⁴.

Statistical Analysis

All data were log-transformed to reduce bias due to non-uniformity of error. To improve the applicability of research to practice, the magnitude of change relative to the baseline time point was examined using the effect size (ES) statistic. ES was based on the within-individual variability at baseline testing, the difference between means divided by the individual standard deviation at baseline, a method that has previously been used¹⁸. The following magnitude thresholds were used: <0.3 = trivial, <0.9 = small, <1.6 = moderate, <2.5 = large, <4.0 = very large, and ≥ 4.0 = extremely large¹⁹. The practical utility of an effect was classified as substantial when there was a $>75\%$ likelihood that the $\pm 90\%$ confidence interval (CI) of the ES was equal to or greater than the trivial ($\text{ES} \pm 0.3$) reference value^{19,20}.

Results

At 24 h post-baseline, 9 of the 14 variables measured displayed substantial decreases, with mean concentric power (MP), peak velocity (PV), jump height (JH) and force at zero velocity (F @ 0V) decreasing by the greatest magnitude (Table 2). This pattern was replicated at 48 h

post-baseline, with the following exceptions. Peak power (PP), PV and JH had returned to baseline levels. Eccentric duration (EccDur), concentric duration (ConDur) and total duration (TotDur) all increased substantially and the ES for MP decreased from moderate to small (Table 2).

*****TABLE 2 NEAR HERE*****

Discussion

The present study is the first to document the effect of acute fatigue on a comprehensive range of CMJ variables in rugby union players after a typical preseason training day. The main finding of the study was that during the late regeneration phase (48 hours post-baseline), fatigued players may select a movement strategy to accomplish the output driven goal of jumping for height. The altered movement strategy adopted uses longer contraction time frames to achieve the required impulse values, in response primarily to the prolonged impairment in eccentric function that was induced by the SSC activities.

The training load completed by the subjects was commensurate with other professional players during the preseason period, such as rugby union¹⁵, rugby league²¹ and Australian rules football¹⁴, and represents a level of NMF that is experienced by many players from a variety of sports. The bimodal recovery pattern in function from SSC activities was first reported in humans by MacIntyre et al.,²² and may help explain the substantial decreases in 9 of the 14 CMJ variables at the 24 hour post-baseline time point. Although we did not test immediately post-exercise and are unable to discern any changes relative to baseline testing; it would be reasonable to infer that function had been impaired substantially at this time point. When considering the ensuing early recovery phase, partial or even full recovery is frequently observed after a number of hours⁵. This short-term recovery pattern seems to follow the production and clearance of metabolic markers, such as blood lactate, and markers of the development of an inflammatory reaction in response to muscle damage, such as interleukin 6²³. The subsequent phase of the recovery cycle is typically then characterised by a secondary longer lasting decline in function, as seen at the 24 hour post-baseline time point, the mechanisms responsible for such changes are associated with inflammatory, neural and remodelling processes^{4,23}. At the 24 hour post-baseline time point, MP, PV, JH and F @ 0V decreased by the greatest amount and are therefore considered the most sensitive to fatigue at this early stage in the recovery process. Fatiguing exercise elicits a variety of responses in CMJ derived variables, with increases, no changes, and decreases all being observed^{9,24,25}.

The divergent findings may be explained in the main by the fatiguing protocol used, the exact timing of post-exercise testing and the training status of the subjects used in previous studies^{4, 10}.

Skilled performers have higher movement variability that provides the required flexibility to adapt within a dynamic environment²⁶, so highlights a need to examine how movement occurs when fatigue is present⁴. The changes displayed in the time related variables (EccDur, ConDur and TotDur), in conjunction with a return to baseline for JH at 48 hours post-baseline, suggests that an alternative movement strategy was adopted to complete the task, albeit in a mechanical inefficient manner²⁷. Rodacki et al.²⁸ found no change in the movement strategy immediately after exercise but did suggest that a certain amount of time may be required for the neuromuscular system to re-optimize the neural input when performing a CMJ in a fatigued state. These results are aligned with the concept of dynamic systems theory²⁹, which proposes that the technique used to execute a movement can be altered in an attempt to achieve a constant task outcome, such as jump height. Several muscles and joints are involved during a CMJ²⁸ and therefore permit a diverse range of ways to coordinate the movement²⁶. In essence, subjects take more time to generate the necessary impulse parameters to maintain output¹⁷. Similar findings have been reported within the literature^{4, 10, 18, 30, 31} and seem to indicate that variables related to the mechanics of the jump must be considered when attempting to comprehensively measure NMF.

Although it may be contended that if the output related task is achieved, jump height in the current study, then the altered movement strategy is an issue that may not merit further consideration within performance sport⁴. However, Mooney et al.,³² reported that the movement pattern used by elite Australian Footballers to produce the same physical output is negatively altered in the presence of NMF. Load per minute (LPM) derived from triaxial accelerometers correlates very highly with the distance covered during competition and as such, is routinely used in many team sports to quantify player output³³. The changes noted by Mooney et al.,³² were also perceived by the sports coaches involved in the study and resulted in a greater proportion of the LPM being accumulated at the lower end of the high intensity running (HIR) threshold. HIR is an important performance variable within the sport³⁴ and any reductions would therefore be considered undesirable.

The typical 6-12 week preseason in rugby union offers an opportunity to develop the physical qualities that help tolerate the stress of the competitive season³⁵ and is usually

preceded by a 2-4 week transition phase. The incidence of injury is noted to be much higher during preseason³⁶ and has been associated with high training workloads²¹. These findings are equivocal, with recent evidence also demonstrating a protective effect from high training loads^{37, 38}. Contemporary evidence suggests it may be the management of the workloads during the annual cycle that ultimately influences the risk of injury³⁵. In the current study, testing was not completed after the 48 hour post-baseline time point, but based on previous literature; it is likely that at least 72 hours would be required to fully recover all CMJ variables after the high intensity training sessions conducted⁵. This acute response to fatigue, in conjunction with total weekly and monthly training loads, may help adjust the prescribed training for each individual player. It is recommended that only modest (5-10%) progressions in training volume be used in an effort to minimise the risk of injury³⁵. In addition, acute and chronic training loads can be compared (the rolling average of the most recent 3-6 weeks of training), with a range of 0.8 - 1.3 considered advisable when trying to avoid positive or negative spikes in the acute training load³⁹.

The assumption that the vertical velocity of the COM is zero prior to the start of the jump is fundamental to the correction application of the integration method. However, defining a clear threshold to reflect the initiation of the jump is not adequately described within the literature. Previous investigations have typically used a range of arbitrary absolute²⁵ and relative values¹¹ or some type of derived absolute value⁴⁰. The onset of negative power development does not always occur directly after these threshold derived time points, referred to as a mistrigger, stimulating the creation of a novel threshold based on continuous changes in power⁴. This comprehensive definition of the jump starting point has resulted in a more sensitive measure of NMF, as evidenced by the differing outcomes for the two flight time to contraction time measures (Table 2). It is therefore recommended that future studies consider using the Gathercole et al.,⁴ method when determining any duration dependent variables using a force plate.

Conclusions

A typical training day from the preseason training phase of rugby union players will induce substantial impairments in SSC function, as measured using a countermovement jump. It should be appreciated that during the late regeneration phase, neuromuscular fatigue can manifest itself as an altered movement strategy in an effort to attain the output driven goal of

jumping for height. Complete recovery from multiple daily training sessions will require at least 2 days and individual responses should be monitored to help plan both acute and chronic training loads.

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TABLE 1. The testing and training schedule on day 1.

TABLE 2. Effect sizes (mean \pm 90% CI) and inferences for the changes in CMJ variables at each post-baseline time point. Inferences are only shown if the effect is substantial.

TABLE 1

The testing and training schedule on day 1.

Time	AM					PM				
	7	8	9	10	11	12	1	2	3	
Activity	CJT		UR	SP		RS			LR	

Abbreviations: CJT = countermovement jump testing; UR = upper body resistance training; SP = speed training; RS = rugby specific training; LR= lower body resistance training.

TABLE 2

Effect sizes (mean \pm 90% CI) and inferences for the changes in CMJ variables at each post-baseline time point. Inferences are only shown if the effect is substantial.

Variable	24 hours Post-baseline	48 hours Post-baseline
PP ($W \cdot kg^{-1}$)	-0.83 \pm 0.59 [¶] Small	0.06 \pm 0.59
MP ($W \cdot kg^{-1}$)	-1.14 \pm 0.46 [¶] Moderate	-0.86 \pm 0.60 [¶] Small
PF ($N \cdot kg^{-1}$)	-0.52 \pm 0.77	-0.62 \pm 0.60 [¶] Small
MF ($N \cdot kg^{-1}$)	-0.54 \pm 0.30 [¶] Small	-0.66 \pm 0.43 [¶] Small
PV ($m \cdot s^{-1}$)	-1.57 \pm 0.85 [¶] Moderate	-0.20 \pm 0.75
JH (m)	-1.33 \pm 0.58 [¶] Moderate	-0.27 \pm 0.51
F @ 0V ($N \cdot kg^{-1}$)	-0.98 \pm 0.77 [¶] Moderate	-1.32 \pm 0.66 [¶] Moderate
FV-AUC ($N \cdot kg^{-1} \cdot m \cdot s^{-1}$)	-0.60 \pm 0.58 [¶] Small	-0.63 \pm 0.51 [¶] Small
EccDur (s)	0.30 \pm 0.47	0.57 \pm 0.22 [¶] Small
ConDur (s)	0.12 \pm 0.36	0.48 \pm 0.33 [¶] Small
TotDur (s)	0.28 \pm 0.43	0.61 \pm 0.21 [¶] Small
MEccConP ($W \cdot ms^{-1}$)	-0.58 \pm 0.44 [¶] Small	-0.78 \pm 0.25 [¶] Small
FT:CT	-0.39 \pm 0.31	-0.25 \pm 0.42
FT:CT _{ALT}	-0.48 \pm 0.36 [¶] Small	-0.53 \pm 0.26 [¶] Small

[¶]denotes a substantial change

Abbreviations: CMJ = countermovement jump; PP = peak power; MP = mean concentric power; PF = peak force; MF = mean concentric force; PV = peak velocity; JH = jump height; F @ 0V = force at zero velocity; FV-AUC = force-velocity area under the curve; EccDur = eccentric duration; ConDur = concentric duration; TotDur = total duration; MEccConP = mean eccentric and concentric power divided the time taken; FT:CT = ratio of flight time to contraction time; FT:CT_{ALT} = ratio of flight time to alternative contraction time.