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Rhodes, David ORCID: 0000-0002-4224-1959, Alexander, Jill ORCID: 0000-0002-6492-1621 and Greig, Matt (2020) The Temporal Pattern of Recovery in Eccentric Hamstring Strength Post-Localised Fatigue. Journal of Health, 4 (1).

SCIREA Journal of Health

http://www.scirea.org/journal/PMH

March 10, 2020

Volume 4, Issue 1, February 2020

The Temporal Pattern of Recovery in Eccentric Hamstring Strength Post-Localised Fatigue

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ABSTRACT

BACKGROUND

Eccentric hamstring training is a contemporary approach to reducing injury risk in elite footballers. Understanding the temporal pattern of recovery would inform training design.

METHODS

20 male professional football players completed baseline assessments of eccentric hamstring strength at isokinetic speeds of 60, 150 and $300°\cdot s^{-1}$. Post-exercise assessments were repeated immediately, +24hrs, +48hrs and +72hrs. Main effects for recovery time and testing speed in average torque (AvT), peak torque (PT) and the corresponding angle (Θ) were supplemented by regression modelling to describe the temporal pattern of recovery.

RESULTS

A main effect for recovery time highlighted greater strength pre exercise, with a quadratic pattern to temporal recovery highlighting minima attained at 35.2 – 41.0 hrs.

CONCLUSIONS

Strength parameters are not fully recovered until 82 hrs post localised fatigue, with the angle of peak torque at high speeds recovering at a much slower rate, with implications for training design.

KEYWORDS: Training, Soccer, Injury, Knee.

Introduction

Current evidenced based approaches have highlighted the importance of eccentric loading and its success in reducing hamstring injury in athletes1. Research has highlighted that there has been no reduction in hamstring injuries over the last decade, with literature indicating they are on the rise[2,3]. It has been documented that incorporation of eccentric training protocols within footballers training, most notably the Nordic hamstring exercise (NHE), reduced the incidence of hamstring injury by 51%[4]. Training and game schedules accompanied with contrasting opinions from the multi-disciplinary performance team can impede regular implementation of eccentric loading in the hamstring, due to the fear of increasing the risk of injury in the athlete. Emphasising a contemporary concern for conditioners within elite sport despite conclusive evidence that reduced eccentric strength of the hamstring muscle group has been identified as a primary aetiological risk factor for hamstring injuries[5]. Further evidence also highlights that poor hamstring function is associated with injury occurrence in the knee[6,7].

Evidently, muscle damage occurs as a result of exposing the athlete to high velocity, high load eccentric loading[8,9]. The effect of the speed of contraction has been debated however, with research highlighting that faster velocity eccentric contractions cause greater muscle damage than slow[10]. Exercise induced muscle damage initiates a training response and optimal periods of recovery between similarly loaded sessions provide a positive training response[11]. Consideration therefore needs to be given to exposure of the hamstrings to high velocity, high load eccentric work within the periodised training week, particularly in periods of fixture congestion where injury risk is increased[2,12,13]. Current literature does not highlight the fatigue response of the hamstrings in isolation. Exposing the hamstrings to high velocity eccentric fatigue and understanding the temporal pattern of recovery post fatigue, would inform training design.

Despite advancements in sports medicine and associated disciplines, the incidence of musculoskeletal injury located at the hamstring and knee has not been reduced[6,14]. The bi-articular function of the hamstring musculature has implications for injury aetiology at the local muscular level and knee joint, with hamstring strains and knee ligamentous injuries consistently reported as being most prevalent in football. Aetiological research in football has often cited fatigue as a risk factor, with reductions in eccentric hamstring strength and modifications in the angle of peak strength expression[5,15,16,17]. Previous research however, has typically only considered the acute and immediate effects[15,16]. Interestingly, sports science and medicine practitioners will commonly expose the hamstrings to localised training, without quantifying effect. Thus, providing debate concerning the optimal timing for subsequent high velocity, high load training.

Previous experimental paradigms fail to consider the context of elite football, where demand is placed on the frequency and subsequent congestion of training and match play, where the hamstrings would be potentially at their most vulnerable. Fixture congestion is a contemporary concern within soccer,[18](Carling et al., 2015) with implications for both performance[18,19] and hamstring injury risk[2,12]. Research has suggested that periods of fixture congestion increase the chance of players sustaining non-contact musculoskeletal injury[2,13]. It is common within football for players to be exposed to three games in a week, with as little as 72 hours between games. The periodisation of training micro-cycles and design of optimum recovery strategies may be enhanced by a greater understanding of the influence of local fatigue beyond the immediate post-exercise response. The aim of the current study is therefore to quantify the temporal pattern of recovery in eccentric hamstring strength for 72 hrs after exercise.

Materials and Methods

Participants

Twenty male professional football players completed the present study, with a mean age of (21.5 ± 3.09 years, 181.98 ± 5.43 cm, 77.7 ± 5.06 kg). All participants provided written informed consent in accordance with Department and Faculty Research Ethics committees at the host University, and in accordance with the Helsinki Declaration.

Experimental Design

Participants completed a familiarisation trial to negate potential learning effects[21], with all testing completed between 13:00 and 17:00 hrs to account for the effects of circadian rhythm and in accordance with regular competition times[22]. All trials were completed on the dominant lower limb, identified by their favoured kicking foot, based on non-contact musculoskeletal injury epidemiology[23].

All testing was completed on the same isokinetic dynamometer (System 3, Biodex Medical Systems, Shirley, NY, USA) at speeds of 60, 150, and 300°·s^{-1}. Participants were asked to complete a warm up on the cycle ergometer maintaining a speed of 70-watts for a period of ten minutes. Post completion participants were supervised through a series of dynamic stretches, which included the hamstrings, quadriceps, adductors, abductors and gastrocnemius. Familiarisation trials were then completed on the IKD. This consisted of 3 x 5 sets of eccentric hamstring work, which was followed by passive movement back in to knee flexion guided by the IKD at 10°·s^{-1}. Participants were seated in the IKD and straps were applied across the chest, pelvis and mid-thigh to minimize extraneous body movements during muscle contractions. The rotational axis of the dynamometer was aligned to the lateral femoral epicondyle and the tibial strap placed distally at three-quarters of the length of the tibia. Participant's arms were positioned across the chest to isolate the hamstrings during torque production[24] . The seat position and set up of the IKD was subject specific and once comfortable within the IKD the position of the athlete was noted and completed to the exact same specifications throughout the testing period. Set one was completed at 150°·s^{-1}, set two at 300°·s^{-1} and set 3 at 60°·s^{-1}. The settings were consistent with previous research as they analysed slow eccentric to fast eccentric contractions in a random order, which replicated the unpredictable demands of game play, but also stopped participants putting emphasis of importance on the last set (Greig, 2008). These testing speeds have been shown to have good reliability with ICC's ranging from 0.76 – 0.78 (Greig, 2008). Each participant was instructed to complete each repetition throughout every set to their maximum and were encouraged to do so throughout with verbal and visual feedback[25]. Each repetition completed was observed by the researcher and was smooth with consistent effort exerted, which was monitored through the athlete's performance.

Baseline measures on the IKD at each testing speed were taken for each participant prior to them completing the localised fatigue protocol. This protocol consisted of a succession of eccentric isokinetic contractions at $300°\cdot s^{-1}$ of the hamstring on their dominant limb until they achieved a 30% drop in their eccentric hamstring peak torque[15,16], which was calculated from their baseline measurements prior to completion. Fast speeds of eccentric torque were selected, as this represented the loadings and mechanism[15,26] of injury associated with hamstring[1] and ACL injuries[14,23]. Continuous repeated sets of 15 repetitions were carried out until a 30% drop in eccentric hamstring peak torque had been achieved for a succession of three consecutive repetitions. Each eccentric repetition was followed by a return speed of $60°\cdot s^{-1}$ passively in to knee flexion to put the participant in position to complete the next repetition. During completion of the fatigue protocol Borg's 6-20 point scale (1970) was used to record the participant's subjective rating of perceived exertion and was recorded at rest and post each set of 15 repetitions on the IKD. In addition to this heart rate (HR) was also recorded every 15 repetitions during each trial of each fatigue protocol using a HR monitor (Polar, Team system, Finland). To monitor the temporal pattern of recovery of the athlete IKD measurements were taken immediately post fatigue, 24 hr, 48 hr and 72 hr post fatigue.

Statistical Analysis

The gravity corrected torque-angle curve was analysed for each testing speed, with analysis restricted to the isokinetic phase. The repetition eliciting the highest peak torque was identified for subsequent analysis. Peak torque (PT), the corresponding angle (Θ), and the average torque across the isokinetic phase (AvT) were identified for each player, at each testing speed. In subsequent sections the isokinetic data is distinguished across speeds using subscripted values, such as PT_{300} for the peak eccentric hamstring torque at $300°\cdot s^{-1}$.

Each isokinetic variable was determined pre-exercise, immediately post-exercise, and then at 24, 48 and 72 hours after exercise. Given the experimental design and range in isokinetic speeds, a two-way repeated measures ANOVA was used to investigate a within factors main effect for time, and for isokinetic speed. Interaction effects between time and speed were also examined. The assumptions associated with the statistical model were assessed to ensure model adequacy. To assess residual normality for each dependant variable, q-q plots were generated using stacked standardised residuals. Scatterplots of the stacked unstandardized and standardised residuals were also utilised to assess the error of variance associated with the residuals. Mauchly's test of sphericity was also completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. Where significant main effects were observed, post hoc pairwise comparisons with a Bonferonni correction factor were applied. Measures of significance were supplemented with partial eta squared (η^2) values calculated to estimate effect sizes for each dependant variable, and provide a measure of meaningfulness.

The temporal pattern of changes in each isokinetic variable over the 72 hr data collection period was examined using regression analyses. Linear and quadratic polynomial models were applied, with the optimum fit determined by the strength of the correlation coefficient (r). Where a quadratic regression analysis represented the best fit, the regression equation was differentiated with respect to time to elicit the time (post-exercise) at which the data reached maxima (or minima). All statistical analysis was completed using PASW Statistics Editor 22.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at $p \leq 0.05$, and all data are presented as mean ± standard deviation.

RESULTS

Peak Torque

Figure 1 summarises the effects of the exercise protocol and the temporal pattern of recovery on PT. There was a significant main effect for time post-exercise ($P < 0.001$, $\eta^2 = 0.177$), but no main effect for isokinetic testing speed ($P = 0.95$, $\eta^2 = 0.001$), and no speed *x* time interaction ($P = 0.94$, $\eta^2 = 0.010$).

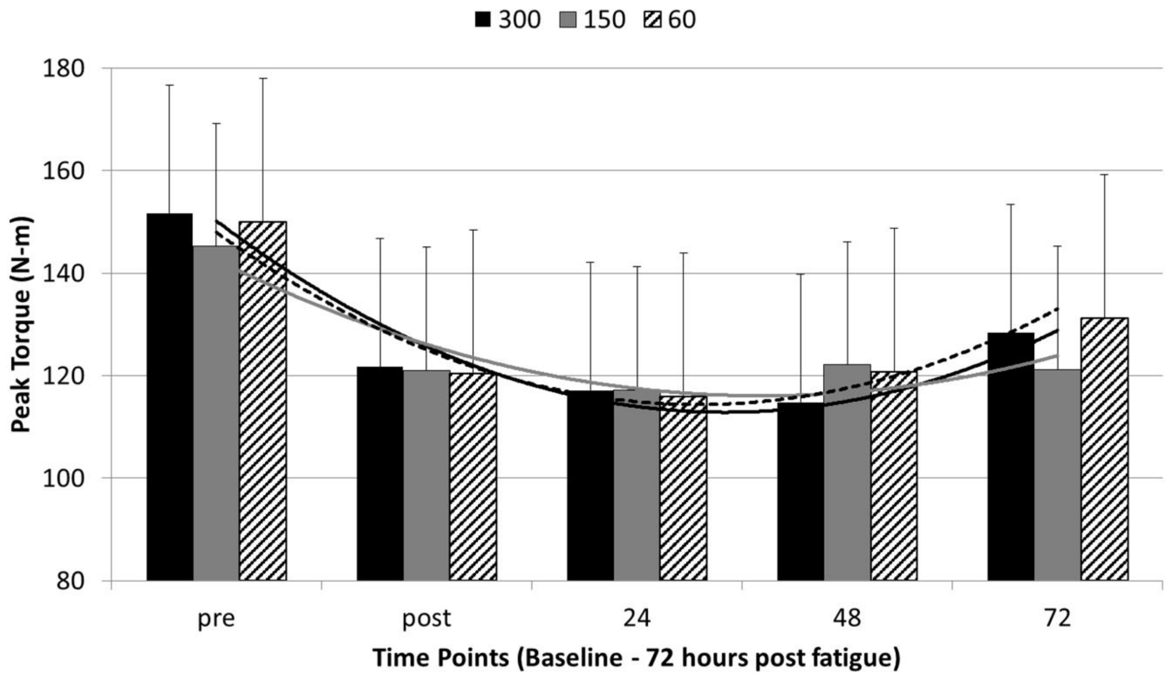

Figure 1. The temporal pattern of recovery in peak torque

PT displayed a significant main effect for time at all speeds (PT_{60} : $P = 0.005$, $\eta^2 = 0.142$; PT_{150} : $P = 0.002$, $\eta^2 = 0.165$; PT_{300} : $P < 0.001$, $\eta^2 = 0.244$). Post-hoc testing revealed that the pre-exercise PT was significantly higher ($P \leq 0.008$) than at all other time points, at all speeds. The quadratic regression revealed a strong correlation ($r \geq 0.91$) at each speed, with differentiated minima at between 35.2 hrs (PT_{150}) and 41.0 hrs (PT_{300}) post-exercise.

Average Peak Torque

The acute influence of the exercise protocol and the subsequent recovery in AvT is shown in Figure 2. There was a significant main effect for time post-exercise ($P < 0.001$, $\eta^2 = 0.209$), and for isokinetic testing speed ($P = 0.024$, $\eta^2 = 0.026$), but no speed *x* time interaction ($P = 0.855$, $\eta^2 = 0.014$). Post-hoc testing revealed that AvT was significantly greater at $300°\cdot s^{-1}$ than at $60°\cdot s^{-1}$ and $150°\cdot s^{-1}$ ($P \leq 0.02$), which were themselves no different ($P = 0.991$).

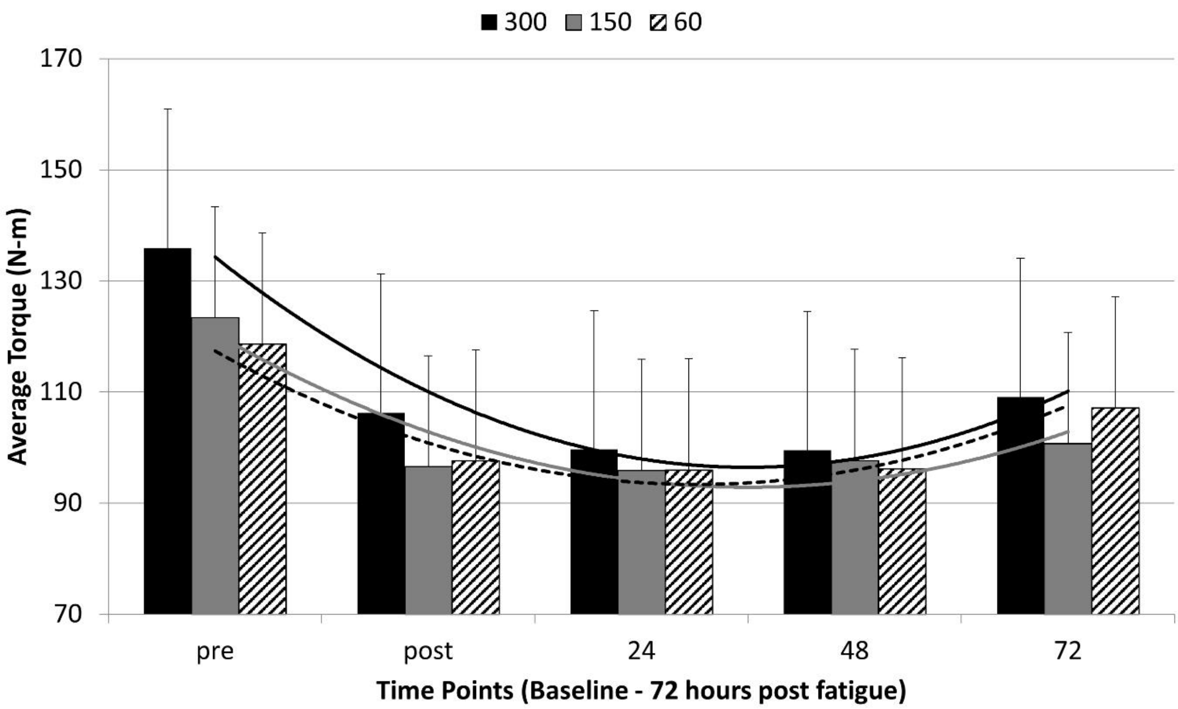

Figure 2. The temporal pattern of recovery in average torque

AvT displayed a significant main effect for time at all speeds (AvT_{60} : $P = 0.003$, $\eta^2 = 0.157$; AvT_{150} : $P < 0.001$, $\eta^2 = 0.227$; AvT_{300} : $P < 0.001$, $\eta^2 = 0.248$). Post-hoc testing revealed that the pre-exercise AvT was significantly higher ($P \leq 0.005$) than at all other time points, at all speeds. Strong quadratic correlation coefficients were established ($r \geq 0.96$) at each speed, with time histories reaching their minima at differentiated minima at between 38.4 hrs (PT_{150}) and 40.1 hrs (PT_{60}) post-exercise.

Angle of Peak Torque

Figure 3 summarises the temporal pattern of change in the angle of peak torque (Θ). There was a significant main effect for time post-exercise ($P < 0.001$, $\eta^2 = 0.087$), and for isokinetic testing speed ($P = 0.002$, $\eta^2 = 0.042$), but no speed *x* time interaction ($P = 0.269$, $\eta^2 = 0.034$). Post-hoc testing revealed that AvT was significantly greater at $150°\cdot s^{-1}$ than at $60°\cdot s^{-1}$ and $300°\cdot s^{-1}$ ($P \leq 0.006$), which were themselves no different ($P = 0.582$).

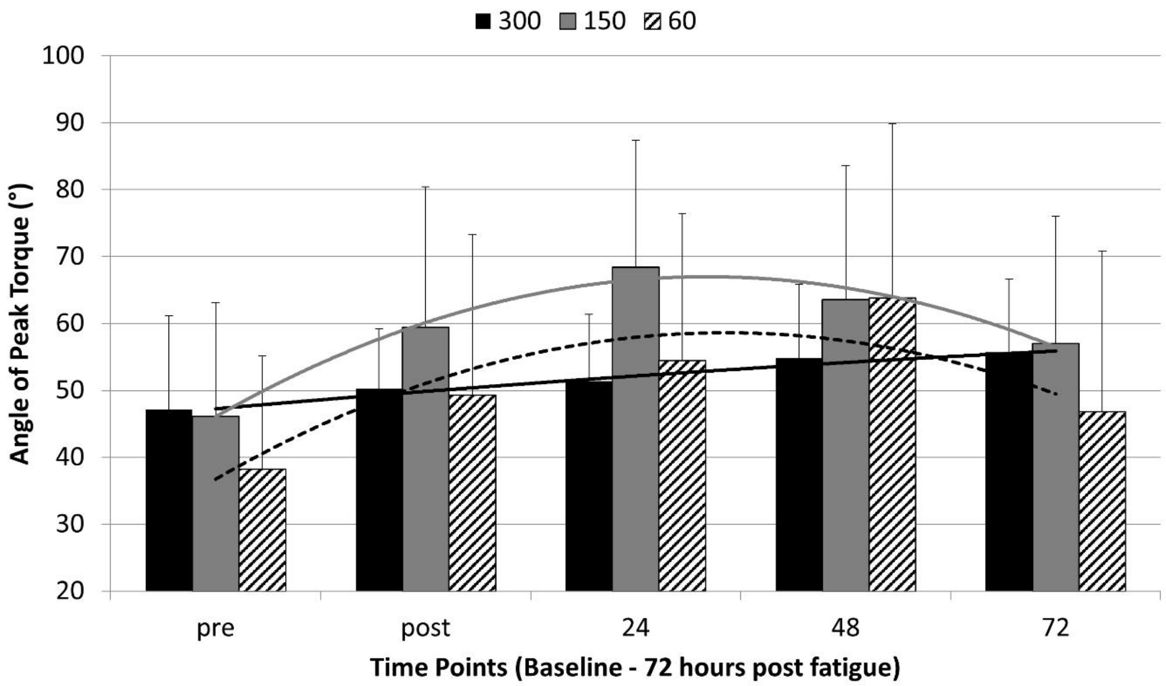

Figure 3. The temporal pattern of recovery in the angle of peak torque

There was a significant main effect for time on Θ_{60} (P = 0.029, η^2 = 0.106) and Θ_{150} (P = 0.006, η^2 = 0.139). However there was no main effect for time on Θ_{300} (P = 0.111, η^2 = 0.075). The pre-exercise value in Θ_{60} was significantly lower than at +24 (P = 0.049) and +48 hrs (P = 0.001). In Θ_{150} the pre-exercise value was significantly lower post-exercise (P = 0.035), +24 hrs (P < 0.001) and +48 hrs (P = 0.004). Quadratic correlation coefficients were strong at all speeds ($r \geq 0.90$), with maxima obtained between 34.1 hrs (Θ_{60}) and 80.2 hrs (Θ_{300}).

Discussion

The aim of the present study was to investigate the temporal pattern of knee flexor eccentric strength at speeds of $60°\cdot s^{-1}$, $150°\cdot s^{-1}$, $300°\cdot s^{-1}$ post localised hamstring fatigue. Recent research in the area is limited thus making direct comparisons to previous findings difficult. The main focus of previous research has been orientated around soccer specific fatigue and the effect of this on these parameters throughout game play, but not sustained over a time period post event[15,16] or not isolating the hamstring muscle group[17]. Isolation of the hamstring muscle determines the direct effect of fatigue on its function. This will provide the foundations for development of fatigue management and conditioning protocols guiding strategies to reduce the incidence of injury.

Although significant effects in angular velocity were exhibited for AvT and Θ, no significant main effect was observed for angular velocity in PT. Findings that are contradictory to previous research[15]. Interestingly, AvT exhibited greater values at the faster speeds. Accompanied with no changes in PT, in relation to angular velocity, these findings suggest that greater torque production is achieved through range, which some authors[28,29], have queried at high speeds. Despite no changes in angular velocity in relation to PT the findings in the present study advocate training at more than one speed and should be considered within training design. In addition to these findings no interaction was demonstrated for speed x time for any of the measured parameters.

Results displayed demonstrate a significant main effect for time in all isokinetic parameters measured. The immediate reductions in eccentric hamstring strength were consistent with previous research on soccer specific fatigue protocols[30,31]. Immediate effects of fatigue have indicated potential justification of why players are prone to sustaining non-contact musculoskeletal injuries such as hamstrings and ACL's during game play. The research listed does not consider the acute pattern of functional hamstring strength after fatiguing exercise, which may indicate a player's readiness for specific types of training. Previous research highlights the importance of increasing this knowledge to guide training recovery strategies implemented due to the impact of fixture congestion on injury[2,12,13]. Continued reductions in isokinetic parameters measured post fatigue are displayed through the 72 hr temporal pattern, suggesting that within this period athletes may be at an increased risk of sustaining injury. It is important to note the increase in Θ that occurs through the 72 hr temporal pattern, as it demonstrates that muscle architecture is inhibited because of fatigue.

The use of quadratic regression analysis as a predictor of recovery indicating minima and maxima of the curve for each calculated parameter could be a key tool utilised to inform optimal training design. Torque metrics were best modelled as negative quadratic equation, each isokinetic parameter displays a similar pattern of decreasing post exercise and subsequently recovering toward baseline. In Θ, the model was reversed with an increase being displayed post exercise and subsequent recovery towards the pre exercise angle. Calculations for AvT_{eccH}, PT_{eccH} and Θ_{eccH} indicate that detrimental changes to their function occur for 35 – 41 hrs and do not recover fully until 68 – 82 hrs post fatigue. Interesting differences in speed influence on muscle architecture are noted in the findings from the present study, with slowest speeds displaying the quickest recovery and high speeds predicting a peak at 82 hrs, with the predictive curve indicating a return to baseline at 160 hrs.

Highlighting force production recovery between 3-4 days post fatigue, but muscle architecture changes remaining at +6 days. Ultimately indicating that training ballistically in this period, where the muscle is stronger at greater angles, increases the risk of injury and decreases the functional support provided to the knee joint.

Recent research in football has shown that hamstring and ACL injuries are on the rise[6,14]. The common mechanisms for both of these injuries relate to linear motions either from a rapid acceleration/deceleration[1,32] or an excessive anterior force through the knee joint[6]. The findings in the current study highlight a potential cumulative fatigue effect that potentially could be a key aetiological factor contributing to the increase in these injuries. Reductions in eccentric strength and changes in Θ_{eccH} may suggest the muscle will be unable to resist required loading through performance or stabilisation of the knee will be reduced as a result of decreased functional strength. Taking this into consideration it is important to observe whether high velocity and high load training is appropriate in this period post fatigue, as the decrease in the muscles functionality potentially increases the chance of sustaining injury. Interestingly, if a predictive curve was applied to each player in relation to this aetiological marker of functional strength, would a reduction in non-contact musculoskeletal injuries, such as hamstring and ACL's be seen? Further research in this area should focus its attention on training design, with a focus on frequency and type of eccentric loading and readiness to train before the next session.

Conclusion

Eccentric hamstring AvT_{eccH}, PT_{eccH} and Θ_{eccH} were shown to deteriorate as a result of localised hamstring fatigue at all velocities. Monitoring functional changes in strength demonstrated that these deficits remained at the end of the 72 hr temporal testing period. Quadratic polynomial regression modelling highlighted minima at ~ 41 hrs in torque production, suggesting a return to baseline within + 82 hrs. This recovery time to baseline was influenced by movement speeds, with greatest deficits shown for each parameter measured at $300°\cdot s^{-1}$. Thus suggesting that certain high velocity/high load movements completed within this time-period could lead to potential injury. Furthermore, the angle of peak torque at the fastest speed was the slowest parameter to recover. Careful consideration needs to be given by coaches and trainers, to training design and recovery strategies between sessions.

What does this article add?

- Localised hamstring fatigue was induced to achieve a 30% reduction in peak torque, in line with match-play observations
- Greater deficits were experienced at fast isokinetic speeds, with quadratic analysis indicting a return to baseline at 82 hrs post fatigue
- Careful consideration must be given to training design and recovery strategies in relation to ballistic movements, as injury risk is heightened for up to 82 hrs post fatigue.

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