# The Temporal Pattern of Recovery in Eccentric Hamstring Strength Post-Soccer Specific Fatigue

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## ABSTRACT

**Background/Aim:** Eccentric hamstring strength is an aetiological risk factor for soccer injury. The temporal pattern of recovery post-exercise is critical in injury management.

**Methods:** 18 male professional soccer players completed baseline assessments of eccentric hamstring strength at isokinetic speeds of 60, 150 and 300°·s$^{-1}$. Post SAFT$^{90}$ measures 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 isokinetic testing speed was observed in PT and AvT. A main effect for recovery time highlighted greater strength pre-exercise, with a quadratic pattern to temporal recovery highlighting minima achieved at between 40-48 hrs.

**Conclusion:** Strength parameters are not fully recovered until 96 hrs post soccer specific fatigue, with implications for training design and injury management, particularly within fixture-congested periods.

## INTRODUCTION

Epidemiological research consistently highlights the incidence of hamstring muscular strain injury in soccer (e.g. Woods et al., 2004; Ekstrand et al., 2012). Aetiological risk factors associated with the risk of hamstring strain injury include poor eccentric muscular strength (Walden et al., 2011; Hewett et al., 2013; Kim et al., 2016), with subsequent implications for ipsilateral strength imbalances. The temporal pattern of hamstring injury during soccer match-play highlights fatigue as a risk factor for injury (Ekstrand et al., 2016), with the majority of injuries incurred during the latter stages of each half. Eccentric hamstring strength has been shown to be impaired by exercise including high-intensity cycling (Mercer et al., 2003), repeated maximal isokinetic contractions (Gleeson et al., 1995), and prolonged intermittent treadmill running (Rahnama et al., 2003; Greig, 2008). Spendiff et al. (2002) highlighted that the nature of muscle fatigue is likely to be specific to the movement pattern of the exercise protocol, with soccer characterised by an intermittent and multi-directional activity profile. A reduction in eccentric hamstring strength as a result of soccer-specific fatigue has been identified as a key contributory factor to non-contact musculoskeletal injury (Greig, 2008; Small et al., 2009; Delextrat et al., 2010; Opar et al., 2012).

Despite advancements in injury prevention approaches within sports medicine and associated disciplines, the incidence and temporal pattern of non-contact musculoskeletal injury in the hamstrings over the last decade has not changed (Woods et al., 2004; Arnason et al., 2008; Ekstrand et al., 2011, Ekstrand et al., 2016). Of note, previous research into the risk of soccer-specific fatigue has typically only considered the acute and immediate effects of a single simulated match. This experimental paradigm fails to consider the context of contemporary elite soccer, where demand is placed on the frequency and subsequent congestion of training and match-play. Fixture congestion is a contemporary concern within soccer, (Carling et al., 2015) with implications for both performance (Odetoyinbo et al., 2007; Carling et al., 2012; Rollo etal., 2014) and injury risk (Dupont et al., 2010; Ekstrand et al., 2011; Dellal et al., 2015). It is defined as a period where players are expected to compete in many matches in a short period, often represented by three games in a week (Dupont et al., 2010). Research has suggested that periods of fixture congestion increase the chance of players sustaining non-contact musculoskeletal injury (Dupont et al., 2010; Ekstrand et al., 2011; Dellal et al., 2015). It is common within soccer 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 would be enhanced by a greater understanding of the influence of 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 a simulated soccer specific fatigue protocol. It was hypothesised that eccentric hamstring strength measures would remain suppressed for 72 hrs post-exercise. Male professional soccer players are used in the current study, given the specific nature of the evidence base in regards to injury epidemiology and notation analysis used to develop the exercise protocol.

## METHODS

### Participants

Eighteen male professional soccer players completed the present study, with a mean age of (22.94±4.57 years, 185.38±4.22 cm, 75.91±6.38 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 7 days prior to testing to negate potential learning effects (Hinman, 2000), which included the Soccer Aerobic Field Test ($SAFT^{90}$) protocol (Lovell et al., 2008) and the isokinetic testing battery. Subsequently, the testing session also included elements of the $SAFT^{90}$ as part of the pre-exercise warm-up, and trial repetitions of the isokinetic tasks. 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 (Sedliak et al., 2011). All trials were completed on the dominant lower limb, identified by their favoured kicking foot, based on non-contact musculoskeletal injury epidemiology (Brophy et al., 2010).

All testing was completed on the same isokinetic dynamometer (System 3, Biodex Medical Systems, Shirley, NY, USA) at speeds of 60, 150, and $300°\cdot s^{-1}$. Participants were asked to complete ten minutes of the $SAFT^{90}$ protocol as a warm up followed by directed dynamic stretching focussed on the quadriceps, hamstrings, gluteals and gastrocnemius. The $SAFT^{90}$ was utilised within the study as it is a free running protocol that replicates the physiological and mechanical demands experienced during game play (Lovell et al., 2008). Over a 20m distance players move through a series of cones and poles, alternating between side steps, backwards running, accelerations and decelerations with varying intensities, which are prompted by audio cues. The 15 minute activity profile is repeated six times to formulate the 90 minutes, with players having a 15 minute half time break, where they are directed to sit, as they would in normal game play. The activity profile is performed in a randomised and intermittent fashion, and incorporates 1269 changes in speed and 1350 changes in direction over a 90-minute period (Small et al., 2009).

Pre-exercise, all players completed the isokinetic testing battery, which comprised 3 sets of 5 maximal eccentric knee flexor repetitions. Between eccentric contractions, passive knee flexion was conducted at $10°\cdot s^{-1}$ to return the test limb to the start position. Familiarisation testing identified that this process facilitated maximal eccentric efforts. In all experimental trials the participants were seated with restraints 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 (Hazdic et al., 2010). The seat position and set up was subject specific and established during familiarisation. Experimental trials were conducted in the standardised order of $150°\cdot s^{-1}$, $300°\cdot s^{-1}$ and $60°\cdot s^{-1}$ (Greig, 2008). Each participant was told to complete each repetition throughout every set to their maximum and were encouraged to do so throughout with verbal and visual feedback (Knicker et al., 2011).

The standardised isokinetic testing battery was completed immediately following completion of the $SAFT^{90}$. Additional trials were completed at +24hrs, +48hrs and +72hrs in order to monitor the temporal pattern of recovery in isokinetic performance. Between trials participants were reminded to refrain from exercise and to maintain a normal diet.

**Data 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 (Greig., 2008; Small et al., 2009). In subsequent sections the isokinetic data is distinguished across speeds using subscripted values, for example the peak eccentric hamstring torque at 300°·$s^{-1}$ is annotated as $PT_{300}$. Each isokinetic variable was determined pre-exercise, immediately post-exercise, and then at 24, 48 and 72 hours after exercise.

## Statistical Analysis

A univariate repeated measures general linear model was used to quantify main effects for recovery duration post-exercise and isokinetic testing speed. Interaction effects were also quantified, and significant main effects in recovery duration were explored using post hoc pairwise comparisons with a Bonferonni correction factor. 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. Partial eta squared ($\eta^2$) values were calculated to estimate effect sizes for all significant main effects and interactions. As recommended by Cohen (1988), partial eta squared was classified as small (0.01–0.059), moderate (0.06-0.137), and large (>0.138).

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 ($F = 10.01$, $P < 0.001$, $\eta^2 = 1.36$), with the pre-exercise value significantly higher ($P \leq 0.008$) than at all other time points. With the data set collapsed to consider each speed in isolation, PT displayed a significant main effect for time at all speeds ($PT_{60}$: $P = 0.02$, $\eta^2 = 0.124$; $PT_{150}$: $P = 0.008$, $\eta^2 = 0.148$; $PT_{300}$: $P = 0.007$, $\eta^2 = 0.132$). There was also a significant main effect for isokinetic testing speed ($F = 3.30$, $P = 0.04$, $\eta^2 = 0.25$), with $PT_{300}$ and $PT_{150}$ significantly greater than at $PT_{60}$ ($P \leq 0.035$). There was no speed *x* time interaction ($F = 0.33$, $P = 0.96$, $\eta^2 = 0.010$).

*** Insert Figure 1 near here ***

The relationship between PT and post-exercise recovery duration was best represented as a quadratic polynomial function at each speed ($r \geq 0.88$). The differentiated regression equations yielded minima in PT between 40.49 hrs ($PT_{300}$) to 47.69 hrs ($PT_{60}$) post-exercise and maxima between 80.99 hrs ($PT_{300}$) and 95.38 hrs ($PT_{60}$) post-exercise. This would result in a predicted return to baseline values of up to 95.38 hrs ($PT_{60}$) post-exercise.

**Average Peak Torque**

The temporal pattern of recovery in AvT is summarised in Figure 2. There was a significant main effect for time post-exercise ($F = 9.40$, $P < 0.001$, $\eta^2 = 0.129$), with pre-exercise AvT significantly higher ($P \leq 0.007$) than at all other time points. AvT displayed a significant main effect for time at all speeds ($AvT_{60}$ : $P = 0.006$, $\eta^2 = 0.154$; $AvT_{150}$ : $P = 0.007$, $\eta^2 = 0.150$; $AvT_{300}$ : $P = 0.031$, $\eta^2 = 0.116$) when considered in isolation. There was also a significant main effect for isokinetic testing speed ($F = 8.31$, $P < 0.001$, $\eta^2 = 0.061$). $AvT_{300}$ and $AvT_{150}$ were significantly greater than $AvT_{60}$ and were themselves no different ($P = 1.00$). There was no speed *x* time interaction ($F = 0.22$, $P = 0.99$, $\eta^2 = 0.07$).

*** Insert Figure 2 near here ***

The relationship between AvT and recovery duration was again best modelled as a quadratic function ($r \geq 0.87$) at each speed, with time histories reaching their differentiated minima at between 41.01 hrs ($AvT_{300}$) and 45.18 hrs ($AvT_{60}$) post-exercise post-exercise. Thus AvT would return to baseline at up to 90.37 hrs ($PT_{60}$).

## Angle of Peak Torque

Figure 3 summarises the temporal pattern of change in the angle of peak torque (ϴ). There was no significant main effect for recovery duration ($F = 1.45$, $P = 0.219$, $\eta^2 = 0.025$), or isokinetic testing speed ($F = 0.77$, $P = 0.465$, $\eta^2 = 0.006$). No speed *x* time interaction ($F = 0.83$, $P = 0.58$, $\eta^2 = 0.025$).

*** Insert Figure 3 near here ***

Quadratic correlation coefficients were strong at all speeds ($r \geq 0.87$), with differentiated minima between 3.07 hrs ($\Theta_{60}$) and 12.5 hrs ($\Theta_{300}$) and thus return to baseline between 12.52 hrs ($\Theta_{60}$) and 25.05 hrs ($\Theta_{300}$).

## DISCUSSION

The aim of the present study was to investigate the temporal pattern of knee flexor eccentric strength post soccer specific fatigue. Recent research in the area is limited in relation to injury management, and methodological differences exist in isokinetic testing speeds for example, thus making direct comparisons to previous findings difficult. The main focus of previous research has been orientated around the influence of soccer specific fatigue during and immediately following match-play simulations (Greig, 2008; Small et al., 2009), with little consideration of the subsequent recovery in strength and implications for injury management. Isolation of the hamstring muscle determines the direct effect of fatigue on its function. This will provide the foundations for development of injury prevention and rehabilitation protocols guiding strategies to reduce the incidence of injury.

Much of the previous research has considered only a single isokinetic testing velocity (e.g. Small et al., 2009), which limits interpretation of the data and a critical discussion of functional relevance to mechanism of hamstring strain injury. In the present study a range of test speeds were used, and significant main effects for test speed were observed, supporting previous research (Greig, 2008). These findings advocate the use of a range of speeds during isokinetic testing, contradicting previous research (Dvir., 1991; Ayala et al., 2012). Despite no changes in angular velocity in relation to ϴ the findings in the present study advocate testing at more than one speed and should be considered when utilising these measures with regards injury prevention strategies or rehabilitation outcome measures. Caution should be taken when directly comparing the findings reported with studies that have employed different testing speeds. In addition to these findings no interaction was demonstrated for speed x time for any of the measured parameters.

Results displayed show that there was a significant main effect for time in the isokinetic parameters of PT and AvT, but no effect for Θ. The immediate reductions in eccentric hamstring strength were consistent with previous research on soccer specific fatigue protocols (Willems et al., 2002; Sangnieer et al., 2007; Thomas et al., 2010). The present study emphasises the significance of time on eccentric strength parameters and could potentially indicate why players would be more prone to sustaining hamstring or ACL injury, particularly in periods of fixture congestion (Dupont et al., 2010; Ekstrand et al., 2011; Dellal et al., 2015; Bengtsson et al., 2017). Careful consideration must also be given to recovery strategies and rehabilitation post injury. The time effect post fatigue on strength parameters should be utilised as a key marker in preparation for training/game play or equally act as an outcome measure in a players return post injury. Reductions in isokinetic parameters post fatigue are displayed through the 72 hr temporal pattern, suggesting that an athletes fatigue resistance must be increased (Blanch et al., 2015; Hulin et al., 2015) or alternatively if they continue to train/play they will be at an increased risk of injury. Recent studies have considered the potential of elastic taping techniques during (Farquharson and Greig, 2017) and after (Boobphachart et al., 2017; Choi and Lee, 2018) exercise, with implications for a reduction in the immediate fatigue response and a change in the temporal pattern of recovery.

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 preventing injury. Functional hamstring strength has been highlighted in previous research as a key aetiological factor contributing to non-contact hamstring and ACL injury (Greig, 2008; Small et al., 2009; Hewett et al., 2013; Kim et al., 2016). Torque metrics within the present study were best modelled as negative quadratic equations, each isokinetic parameter displays a similar pattern of decreasing post exercise and subsequently recovering toward baseline. Calculations for eccentric hamstring AvT and PT indicate that detrimental changes to their function occur for 40.49 – 47.69 hrs and do not recover fully until 80.99 – 95.38 hrs post fatigue. The quadratic regression analysis indicates that these deficits exist for up to 4 days, with greatest recovery required in the slow and fast speeds. The minima of the curve and observations of mean scores in Figures 1 and 2 highlight a potential window to optimise the effectiveness of recovery strategies employed. Predictions of recovery for Θ displayed minimal effects of fatigue, therefore indicating that although strength deficits exist, the effect of fatigue on muscle architecture is minimal.

Recent research in soccer has shown that hamstring and ACL injuries are on the rise (Agel et al., 2005; Walden et al., 2011; Serpell et al., 2012). The common mechanisms for both of these injuries relate to linear motions either from a rapid acceleration/deceleration (Alentorn-Geli et al., 2009; Opar et al., 2012) or an excessive anterior force through the knee joint (Walden et al., 2011). The findings in the current research 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 could 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 consider 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 the replication of a fixture-congested period, where a bout of soccer specific fatigue is completed in succession with a 72 hr recovery period between each session. Consideration must also be given to analysing the effectiveness of intervention strategies and how they influence the quadratic curve and its return to baseline. Elastic taping techniques have been identified as a possible intervention during and post-exercise (Farquharson and Greig, 2017; Boobphachart et al., 2017; Choi and Lee, 2018). Of note and given the nature of the elite participant group, a 'control' trial where the players would complete multiple sets of isokinetic testing without the $SAFT^{90}$ exercise intervention was not conducted. Whilst 24 hours should provide sufficient time for recovery from the strength assessment, this is a consideration when interpreting the results of the current study. The use of elite male senior players in the current study should also be considered when attempting to generalise these findings. The strength characteristics of elite youth players (Peek et al., 2018) highlights that younger players might respond differently to soccer-specific exercise, and even within an elite sample the standard of the opponent has been shown to influence activity profile and fatigue development (Rago et al., 2018). Consideration of different populations warrants consideration, but the experimental paradigm should be informed by specific epidemiology data and exercise protocols.

## Conclusion

Eccentric hamstring torque metrics were shown to deteriorate as a result of soccer specific fatigue, with minimal changes identified in the angle of peak torque. Monitoring functional changes in strength demonstrated that these deficits remained at the end of the 72 hr temporal testing period. Quadratic polynomial regression modelling suggested a return to baseline strength within + 82 hrs. This recovery time to baseline was influenced by movement speeds, with implications for training prescription and injury management. Certain high velocity/high load (acceleration) or low velocity/high load (decelerations) movements, completed within this time-period could lead to potential injury. Careful consideration needs to be given by coaches and trainers, to training selection, recovery strategies and selection of players in periods of fixture congestion. In addition, structured development of fatigue monitoring should be incorporated in a players return to play post injury.

## Practical Implications

- Greater deficits were experienced at slow and fast isokinetic speeds, with quadratic analysis indicting a return to baseline at 82+ hrs post fatigue
- Key considerations must be given to a variety of isokinetic eccentric testing speeds when implementing in injury prevention or rehabilitation protocols
- Careful consideration must be given to training design and recovery strategies in relation to ballistic movements, as injury risk is heightened for up to 95.38 hrs post fatigue.

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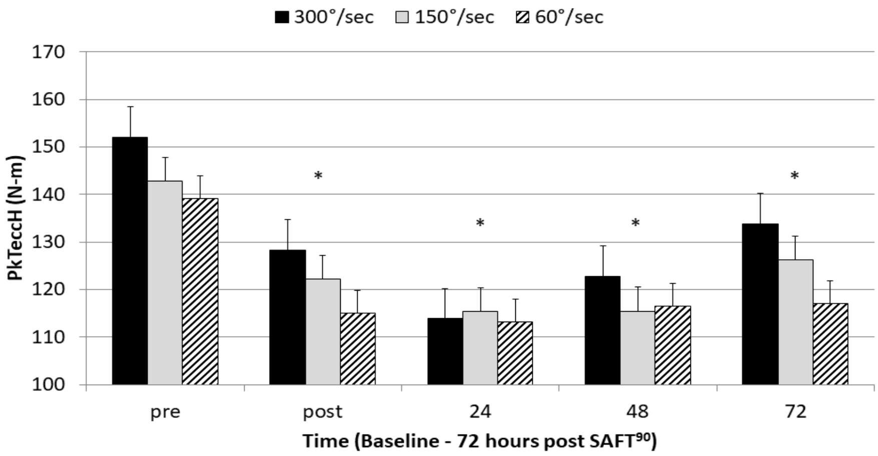


Figure 1. The temporal pattern of recovery in peak torque.  * denotes a significant main effect for time relative to pre-exercise values.

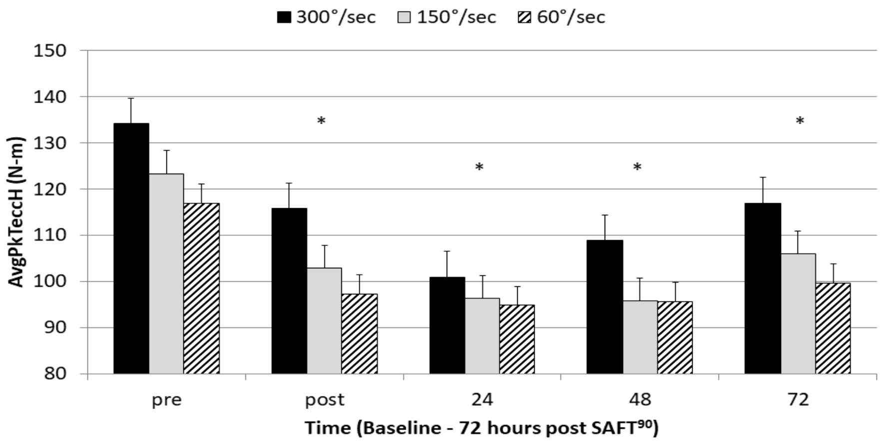


Figure 2. The temporal pattern of recovery in average torque. * denotes a significant main effect for time relative to pre-exercise values.

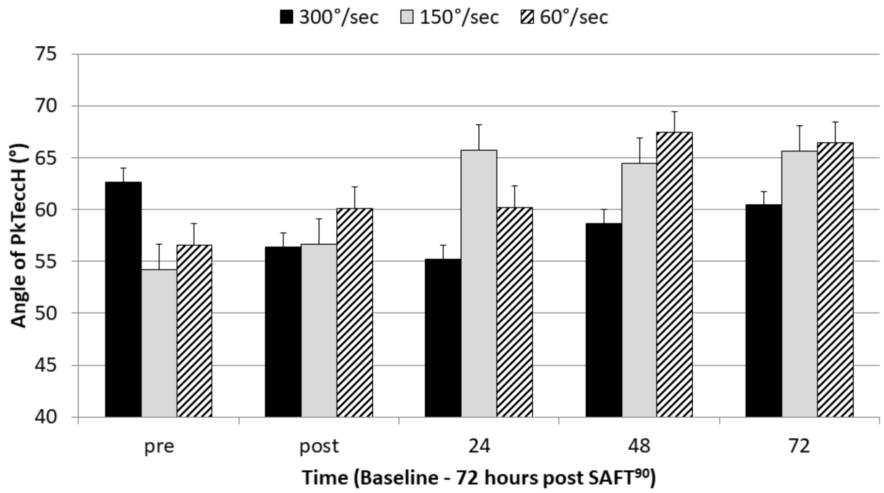


Figure 3. The temporal pattern of recovery in the angle of peak torque.