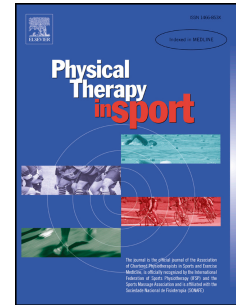


Accepted Manuscript

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Martyn J. Matthews, Kate Heron, Stefanie Todd, Andrew Tomlinson, Paul Jones, Anne Delextrat, Daniel D. Cohen



PII: S1466-853X(17)30046-9

DOI: [10.1016/j.ptsp.2017.01.006](https://doi.org/10.1016/j.ptsp.2017.01.006)

Reference: YPTSP 802

To appear in: *Physical Therapy in Sport*

Received Date: 8 February 2016

Revised Date: 26 January 2017

Accepted Date: 30 January 2017

Please cite this article as: Matthews, M.J., Heron, K., Todd, S., Tomlinson, A., Jones, P., Delextrat, A., Cohen, D.D., Strength and endurance training reduces the loss of eccentric hamstring torque observed after soccer specific fatigue, *Physical Therapy in Sports* (2017), doi: 10.1016/j.ptsp.2017.01.006.

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**Strength and endurance training reduces the loss of eccentric hamstring torque
observed after soccer specific fatigue**

Authors

Martyn J Matthews¹

Kate Heron¹

Stefanie Todd¹

Andrew Tomlinson¹

Paul Jones¹

Anne Delextrat²

Daniel D Cohen³

¹ School of Health Sciences, Centre for Health Sciences Research, University of Salford, Salford, United Kingdom, M66PU

² Faculty of Sport and Health Sciences, Oxford Brookes University, Oxford, UK

³ Instituto de Investigaciones, Escuela de Medicina, Universidad de Santander,, Bucaramanga, Santander, Colombia

Corresponding Author

Martyn Matthews

University of Salford

School of Health Sciences

Frederick Road

Salford

M6 6PU

UK

m.j.matthews@salford.ac.uk

44 7808 472229

**Strength and endurance training reduces the loss of eccentric hamstring torque
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Abstract

Objectives: *To investigate the effect of two hamstring training protocols on eccentric peak torque before and after soccer specific fatigue.*

Participants: *Twenty-two university male soccer players.*

Design: *Isokinetic strength tests were performed at 60°/s pre and post fatigue, before and after 2 different training interventions. A 45-minute soccer specific fatigue modified BEAST protocol (M-BEAST) was used to induce fatigue. Players were randomly assigned to a 4 week hamstrings conditioning intervention with either a maximum strength (STR) or a muscle endurance (END) emphasis.*

Main outcome measures: *The following parameters were evaluated:– Eccentric peak torque (EccPT), angle of peak torque (APT), and angle specific torques at knee joint angles of 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80° and 90°.*

Results: *There was a significant effect of the M-BEAST on the Eccentric torque angle profile before training as well as significant improvements in post-fatigue torque angle profile following the effects of both strength and muscle endurance interventions.*

Conclusions: *Forty-five minutes of simulated soccer activity leads to reduced eccentric hamstring torque at longer muscle lengths. Short-term conditioning programs (4-weeks) with*

either a maximum strength or a muscular endurance emphasis can equally reduce fatigue induced loss of strength over this time period.

Keywords: hamstring, fatigue, training, torque

ACCEPTED MANUSCRIPT

Introduction

Hamstring strain injuries (HSI) are one of the most common sporting injuries, accounting for 12% to 26% of all injuries that occur in sprint dominated sports (Lysholm et al., 1987; Woods et al., 2004; Small et al., 2009) and are a major cause of time lost to both training and competition (Bennell et al., 1998; Woods et al., 2004; Ekstrand et al., 2011). In soccer, the majority of HSI occur under conditions of fatigue (Woods et al., 2004; Small et al., 2009; Small et al., 2010), primarily in the latter periods of a game or half (Rahnama et al., 2003; Small et al., 2009), such that 47% of HSI are sustained during the final 15 minutes of match play (Woods et al., 2004). In intermittent sprint sports such as soccer, declines in hamstring peak torque are observed, not only after 90 minutes of real or simulated soccer (Cohen et al., 2015; Marshall et al., 2014; Small 2010), but also as early as half-time (45 minutes into play) or after 45 minutes of simulated soccer (Hoff et al., 2004; Marshall et al. 2014).

Moreover, soccer-specific fatigue appears to promote preferential strength loss at longer muscle lengths (Cohen et al., 2015), angles at which deficits are associated with injury. Cohen's study observed these changes to the torque angle profile after a 90 minute fatiguing protocol, however, it is unknown whether these changes might also occur sooner. Although there is an observed increase in injury risk at the end of a soccer half (Woods et al., 2004; Ekstrand et al 2011), and a previously observed decline in eccentric hamstring torque after 45

mins (Small et al 2010), it is unknown whether 45 minutes of soccer specific fatigue is also associated with a change in the torque angle profile.

With the changes to the eccentric torque and torque angle profile observed in the hamstrings under conditions of fatigue (Delextrat et al., 2010; Delextrat et al., 2013; Cohen et al., 2015), and the higher incidence of HSI observed under conditions of fatigue (Woods et al., 2004; Orchard et al., 2013), the training of muscular endurance, as well as maximum strength, of hamstrings may be helpful within an injury prevention program. Even with the previous success of strength training protocols for decreasing the incidence of HSI (Arnason et al., 2008; Mjolsnes et al., 2004; Van der Horst et al., 2014), it is not known whether these strength protocols have any influence on preserving eccentric muscle strength under conditions of fatigue. Moreover, it is also not known whether endurance based protocols will have any influence on eccentric muscle strength under conditions of fatigue. It therefore seems prudent to investigate the effects of both endurance training (low load/high repetition) as well as strength training (high load/low repetition) protocols on hamstring fatiguability.

The principle aims of this study were firstly to investigate the effect of a 45 minute soccer specific fatiguing protocol (M-BEAST) on the torque angle profile of competitive soccer players. Secondly, we aimed to compare the effects of a high load/low repetition (maximum strength emphasis) and a low load/high repetition (muscular endurance emphasis) hamstring conditioning training intervention on eccentric hamstring torque and torque decline following the M-BEAST.

We hypothesised that 45 minutes of soccer specific activity will result in a significant reduction in eccentric hamstring strength. In addition, we hypothesised that a 4 week hamstrings conditioning intervention with either a high load/low repetition, maximum strength, emphasis or a low load/high repetition, muscle endurance, emphasis will positively influence eccentric hamstring strength under conditions of soccer specific fatigue.

Methodology

Participants

Twenty-two volunteers from the University soccer teams participated in this study. Of these, twenty completed the study. Participants were pre-screened with a physical activity readiness questionnaire (University of Salford, Human Performance Laboratory, PARQ) for any previous or current injuries and medical conditions that would impede their participation and those with present injuries, major operations and muscle or tendon injuries within the past year were excluded. Ethical approval was gained prior to the study from the institution's RGECC.

Procedures

All testing took place in the human performance laboratory of the University. Subjects participated in two testing days separated by a four week training block. On each occasion, players were assessed before and after a modified 45-minute soccer-specific fatiguing protocol (M-BEAST) that is based on the Ball-sport Endurance And Sprint Test (BEAST90) (Williams et al., 2010) (Figure 1). In order to optimise the range during which true isokinetic measures are collected and allow for more repeatable measures across a range of joint angles (Baltzopoulos, 2008), the KinCom isokinetic dynamometer was set to 60°/s (type, 125 AP, Chattanooga, TN, USA). The following parameters were evaluated:– Eccentric peak torque

(EccPT), angle of peak torque (APT), and angle specific torques at knee joint angles of 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80° and 90°. After the first testing session, participants were randomly allocated (using a systematic random sample based on alphabetical order of names) to either a strength training group (STR) (n=11) or a muscle endurance training group (END) (n=11). Two participants from the END group did not complete the experiment. Anthropometric data for both groups of are as follows. END (n=9; 21.8 ± 2.8 years, 179.4 ± 6.5 cm and 79.3 ± 11.8 kg). STR (n=11; 23.2 ± 3.8 years, 184.8 ± 8.4cm and 82.5 ± 8.8 kg).

Participants were asked to avoid eating two hours prior to testing and to avoid any strenuous activity in the 48 hours prior to assessment. Prior to the isokinetic test, a seven-minute continuous dynamic warm up was performed on the track in the human performance lab of the University. Testing was conducted on the dominant leg, defined as the leg most commonly used for kicking. Each participant was seated on the isokinetic dynamometer in 90° hip flexion and 90° knee flexion, with the range of 90° to 0° of knee extension set (Askling et al., 2003; Brockett et al., 2004). The lever arm was aligned with the knee joint line (parallel to lateral epicondyle) and the shin pad attached above the malleoli. The dynamometer was adjusted according to the participant's limb length, to ensure that their knee was overhanging the seat by two inches. Shorts were worn to aid visibility. Each participant's thigh, waist and torso were strapped to eliminate extraneous movement. To ensure consistency between tests the lever arm length (cm) and dynamometer settings were recorded for each participant and gravity correction was applied. Angular velocity was set at 60°/s. The participant was instructed to give maximal effort for three repetitions. All isokinetic testing was conducted by the same researcher who was trained and familiar with the equipment and blinded to the allocation of groups.

Reliability

Prior to the initial test session, all participants attended a familiarisation session with the isokinetic dynamometer, after which the repeatability of EccPT and APT was determined using intra-class correlation coefficient (model 2,1). The comparison of first and second measurements indicated a strong correlation between the two measures of .92 ($p<0.01$) (EccPT) and .94 ($p<0.01$) (APT). For the angle specific ICCs there was a strong correlation shown at 10° (.92; $p<0.01$), 20° (.91; $p<0.01$), 30° (.88; $p<0.01$), 40° (.90; $p<0.01$), 50° (.89; $p<0.01$), 60° (.91; $p<0.01$), 70° (.92; $p<0.01$), and 80° (.91; $p<0.01$).

Selection of exercise

Rehabilitation programs and training sessions that work on eccentric loading via Nordic Hamstring Curls (NHC) appear to have a positive effect in reducing both the risk and recurrence of HSI (Arnason et al., 2008; Petersen et al., 2011; Thorborg et al., 2012; Mjølsnes et al., 2004; Häkkinen et al., 1985 Brito et al., 2010), with typical training protocols structured to bring about an improvement in eccentric strength, particularly at longer muscle lengths (Brockett et al., 2004; Arnason et al., 2008; Askling et al., 2003; Gabbe et al., 2006; Petersen et al., 2011).

However, although NHC appear to have a positive effect on muscle strength (Brito et al., 2010), and can decrease hamstring strains (Arnason et al., 2008; Mjølsnes et al., 2004), many athletes simply do not have enough strength to perform NHC to full range of motion under

control, reaching a “break point” well before the angles at which hamstring injuries occur. In order to reach beyond these ranges, many trainers prescribe a form of “assisted” NHC involving the use of an elastic band to support the athlete and provide assistance during the most demanding phase of the exercise, enabling them to complete full NHC and allow them to condition the hamstrings at longer lengths (Matthews et al., 2015).

Using the assisted NHC method described above, it is also possible to decrease muscle load, and target muscular endurance training by allowing the athlete to complete a higher number of repetitions.

Strength Protocol

The STR group performed a typical strength training protocol involving 5 sets of 4 NHC with a two minute rest between each set. The load selected corresponded to each participant’s 4 repetition maximum (4RM), a load that allowed just 4 repetitions to be performed to an angle of 45° or beyond. If participants could already perform 5 repetitions of the NHC, a weighted vest was worn. This allowed additional load to be added in .5kg increments and ensured the load and repetitions remained in the 4RM range. As participants progressed, the load was adjusted to the new 4RM. This protocol was performed twice a week for four weeks. (Pic 1).

Endurance Protocol

The END group performed a typical muscle endurance training protocol, starting at 5 sets of 12 assisted NHC, using a large rubber band secured around the participant’s chest, with the load adjusted by the trainer to allow the performance of just 12 full-range repetitions. This protocol was also performed twice a week for four weeks. (Pic 2).

Both training protocols were administered and supervised individually by the authors who are either qualified strength and conditioning coaches or registered independent clinical healthcare providers.

Statistical Analysis

Data were analysed using statistical software, SPSS v 16.0 for Windows (Chicago, Ill). A multi-factorial analysis of variance (ANOVA) was carried out to determine the effects of fatigue, time, or group. To determine where potential differences occurred, in the event of a significant F ratio, post hoc comparisons were made using paired T-tests. To account for multiple tests and the increased probability of a type I error, a Bonferroni correction was applied. The alpha level was set a priori at $p = 0.05$.

The calculation of effect sizes give a good indication of the adaption to the temporal dynamics of training (Rhea 2004; Frohlich et al 2009). As such effect sizes were calculated using the means and standard deviations method.

Results

Twenty participants completed the exercise intervention (STR, n=11; END, n=9). Two participants dropped out due to time commitments, giving a 91% completion rate.

Effect of fatigue - pre intervention

For all 20 participants: hamstring EccPT decreased significantly pre- vs post-fatigue

($p < 0.001$; $d = .71$, $r = .33$), while hamstring eccentric APT showed no significant difference; angle specific hamstring eccentric torque decreased significantly pre- vs post-fatigue at 60 ($p < 0.001$; $d = .43$, $r = .21$), 50 ($p < 0.001$; $d = .76$, $r = .35$), 40 ($p < 0.001$; $d = .95$, $r = .43$), 30 ($p < 0.001$; $d = .96$, $r = .43$), 20 ($p < 0.001$; $d = 1.16$, $r = .50$) and 10 ($p < 0.001$; $d = 1.12$, $r = .49$) degrees. (Figure 2).

Effect of fatigue - post intervention

Post intervention END Pre vs Post Fatigue

For the END group, post-intervention: hamstring EccPT and APT showed no significant difference pre- vs post-fatigue; angle specific hamstring eccentric torque showed no significant differences pre- vs post-fatigue at all angles. (*Figure 3*)

Post intervention STR Pre vs Post Fatigue

For the STR group, post-intervention: hamstring EccPT and APT showed no significant differences pre- to post-fatigue; angle specific hamstring eccentric torque showed no significant differences post-fatigue at all angles. (*Figure 4*)

Effect of Intervention

Pre-Fatigue Eccentric END

For the END group, Pre-Fatigue: hamstring EccPT and APT showed no significant differences pre vs post intervention; angle-specific hamstring eccentric torque increased significantly pre vs post-intervention at joint angles of 60° degrees ($p < 0.01$; $d = .66$, $r = .31$) and 20° ($p < 0.05$; $d = 1.04$, $r = .46$), but showed no significant difference at all other angles. (Figure 5).

Post-Fatigue Eccentric END

For the END group, Post-Fatigue: hamstring EccPT increased significantly pre vs post-intervention ($p < 0.001$; $d = 1.29$, $r = .54$). APT showed no significant difference; angle specific hamstring eccentric torque increased significantly pre vs post-intervention for the Endurance trained group at 70° ($p < 0.05$; $d = 0.60$, $r = .29$), 60° ($p < 0.05$; $d = .54$, $r = .26$), 50° ($p < 0.001$; $d = 0.94$, $r = 0.42$), 40° ($p < 0.001$; $d = 1.26$, $r = .53$), 30° ($p < 0.001$; $d = 1.27$, $r = .54$), 20° ($p < 0.001$; $d = 1.53$, $r = .61$), and 10° ($p < 0.01$; $d = 1.56$, $r = .62$) degrees. (Figure 6).

Pre-Fatigue Eccentric STR

For the STR group, Pre-Fatigue: hamstring EccPT and APT showed no significant difference pre vs post intervention; angle specific hamstring eccentric torque increased significantly pre vs post-intervention at 30 degrees ($p < 0.05$; $d = .75$, $r = .35$) but showed no significant difference at all other angles. (Figure 7).

Post-Fatigue Eccentric STR

For the STR group, Post-Fatigue: hamstring EccPT increased significantly pre- vs post-intervention ($p < 0.001$; $d = 1.24$, $r = 0.53$). APT showed no significant difference; angle specific hamstring eccentric torque increased significantly pre vs post intervention at 60° ($p < 0.05$; $d = .57$, $r = .28$), 50° ($p < 0.001$; $d = .83$, $r = .38$), 40° ($p < 0.001$; $d = 1.16$, $r = .50$), 30° ($p < 0.001$; $d = 1.44$, $r = .59$), 20° ($p < 0.01$; $d = 1.56$, $r = .62$), and 10° ($p < 0.01$; $d = 1.66$, $r = .64$) degrees.

(Figure 8).

Between group comparisons

No differences were observed for all variables of interest pre- to post- intervention between the END and STR groups.

Discussion

The aim of this study was to investigate the effect of a 45-minute fatiguing protocol on the torque angle profile of competitive soccer players and then to investigate two separate hamstring training protocols to determine which was most effective at mitigating the decline in eccentric hamstring strength previously observed with fatigue (Cohen et al., 2015). These were: a typical strength training protocol - high load/low repetitions – and a typical muscle endurance training protocol - low load/high repetitions.

Results showed a reduction in EccPT and a shift in the torque angle profile following fatigue, whereby torque at the longer muscle lengths declined more than the shorter lengths. The reduction in EccPT with fatigue observed in this study has previously been observed by Hoff Jan & Helgerud Jan., (2004), Small et al. (2010), and Cohen et al., (2015) although it should be noted that this study took place at an angular velocity of 60°/s, not 120°/s as used in other

studies (Cohen et al., 2015; Small et al., 2010; Lorde et al., 1992; Delextrax et al., 2010). The effect sizes reported (Cohen's $d = .71$) for the fatigue induced changes in EccPT indicate a medium to large effect size. For the torque angle profile, the effect size rises from .45 at 60°, .76 at 50°, .95 at 40°, .96 at 30°, 1.16 at 20° and 1.12 at 10° indicating that, at the longer muscle lengths, the effect of fatigue is greater. The angle specific changes in torque observed after a 45 minute fatigue protocol appear to mimic results previously observed after 90 minutes (Cohen et al., 2015). These observed changes in angle specific torque, and the reduction in EccPT observed by this study and Small et al (2010), after only 45 mins of soccer specific fatigue, may provide an explanation for the increase in HSI observed towards the end of 45 minutes of play (Woods et al., 2004; Ekstrand et al 2011).

Following the 4 week intervention period, both STR and END conditions showed significant improvements post-fatigue for EccPT and a shift in the torque angle profile, whereby the athletes were able to maintain higher eccentric hamstring torque at the longer lengths associated with injury. Between group comparisons revealed no differences in the effectiveness of the intervention between the STR and END groups. These results suggest that short-term hamstring conditioning programs (4 weeks), with either a maximum strength or a muscular endurance emphasis can significantly reduce the fatigue induced loss of EccPT and the preferential loss of eccentric hamstring strength observed at longer muscle lengths. This is relevant for the clinician as NHC are often difficult for some athletes to perform, imposing eccentric loads that are at or near maximum, and resulting in the performance of either partial or incomplete repetitions and often leading to delayed onset muscle soreness following the initial workouts (Sebelien et al., 2014). The END protocol used in this study, encompassing the assisted NHC exercise, provides an accessible alternative to traditional

NHC and allows a more endurance focussed protocol (higher repetition/lower load training) to be used. The assisted NHC may therefore provide a more suitable introduction to NHC, particularly if a NHC training intervention is introduced during a competitive season, where muscle soreness can impact performance. Moreover, the full range achieved through every repetition of an assisted NHC allows the muscles to be trained over a greater range and possibly strengthen ranges that some in the STR group could not have reached. This may partly explain why the END protocol in this study appears to be equally effective in mitigating the loss of eccentric strength with fatigue when compared to STR.

Although changes in APT were not significant for either group, there does appear to be a trend following the intervention. Both the END and STR groups appear to shift the APT towards a more extended knee position, which has previously been suggested to be advantageous in terms of injury prevention (Brockett et al., 2004; Proske et al., 2004).

Whilst NHC training has previously been reported to increase eccentric hamstring strength (Mjølsnes et al., 2004; Anastasi et al., 2011), these results suggest that both strength and muscle endurance training protocols are effective in maintaining eccentric hamstring strength in the post-fatigue condition, particularly at the longer muscle length associated with HSI. With HSI occurring in the final 15 minutes of a each half or towards the end of a game (Rahnama et al., 2003; Woods et al., 2004; Small et al., 2009), it is possible that the maintenance of eccentric strength under conditions of fatigue, observed in this study, may reduce the risk fatigue induced HSI.

We did not specifically control for training volume between the two groups and recognise that the endurance group were likely performing a higher training volume than the strength group. Whilst we acknowledge this as a potential limitation, the aim of this research was to apply typical training protocols that are designed to increase strength (5 sets x 4 repetition x 4RM) or endurance (5 sets x 12 repetitions x 12RM) in the real world. We also acknowledge that the training intervention was conducted on males. As such, we advise caution when extrapolating these results to females.

It is interesting to note that the 4-week training period appears to be sufficient to positively change torque angle profile, which may in turn contribute to a lower risk of HSIs. Previous research has focussed on longer intervention periods of up to 10 weeks (Mjølsnes et al., 2004; Anastasi et al., 2011). Whilst it is possible that the magnitude of change would have been higher if the study was carried out for longer, the significant improvements observed after 4 weeks suggests that a NHC training programme can be easily incorporated into a typical pre-season training phase.

Conclusion

This study appears to show that 45 minutes of soccer specific fatigue is enough to show reductions in EccPT and changes in the torque angle profile, with greater effect sizes observed at the longer muscle lengths. Moreover, both strength and muscle endurance training protocols appear to produce positive changes to the torque angle profile of the

hamstring muscles, particularly under conditions of fatigue, and may both be useful tools to mitigate the risk of HSI in the future.

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Pic 1: Strength Training Protocol



Pic 2: Endurance Training Protocol

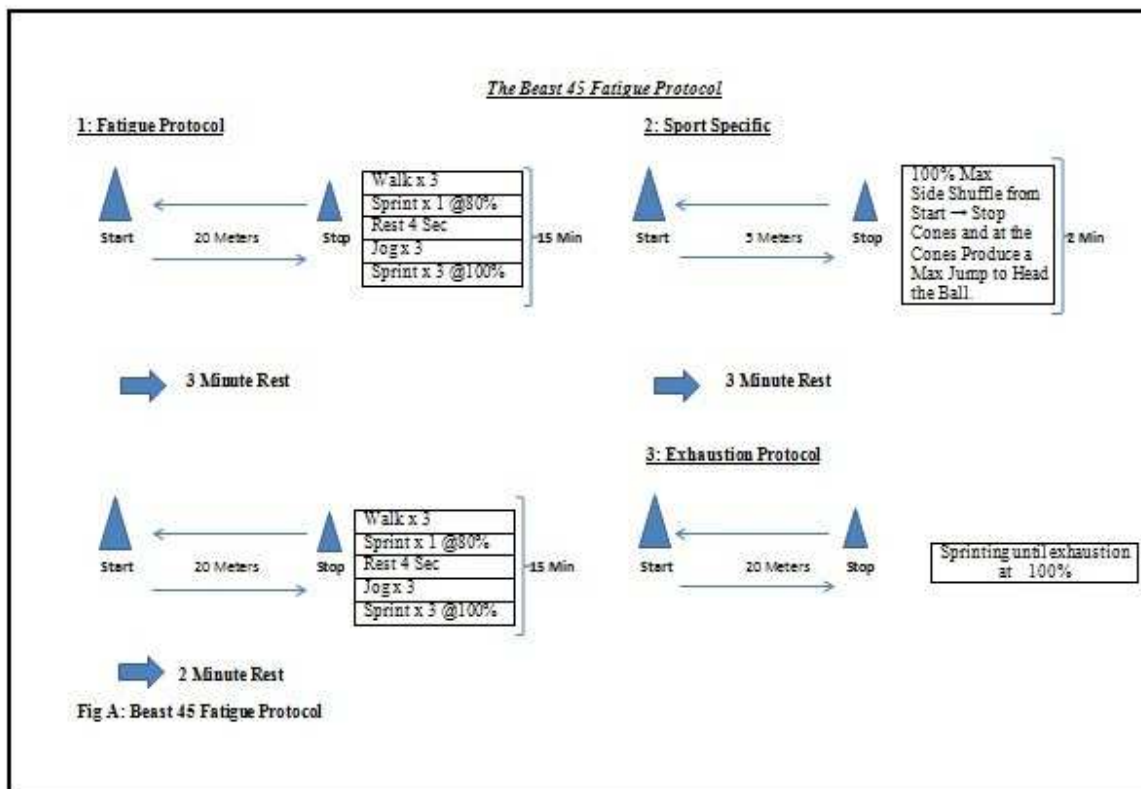


Fig 1. The 45-minute fatigue protocol

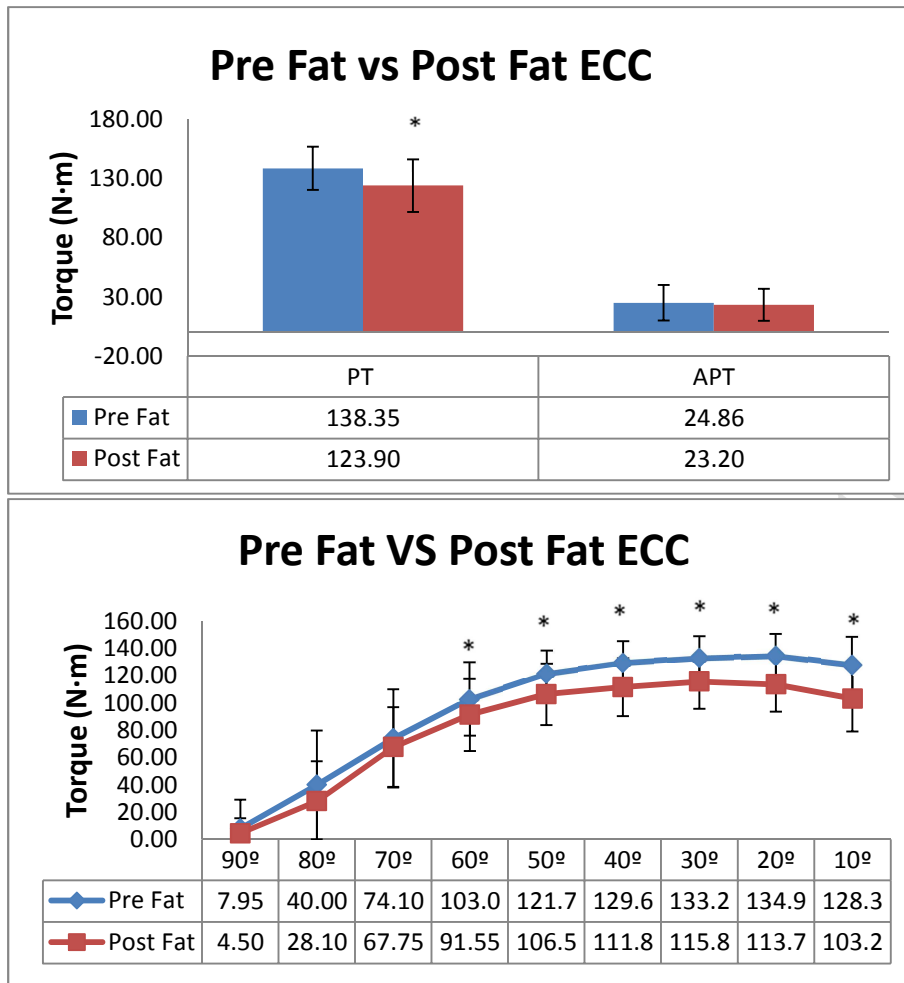


Fig 2: Pre-intervention results for eccentric PT, APT and Torque at nine specific angles, before and after fatigue for all participants. An Asterisk (*) denotes a significant difference ($p < 0.005$).

Graphs for Endurance Group Post Intervention/ Before and After Fatigue

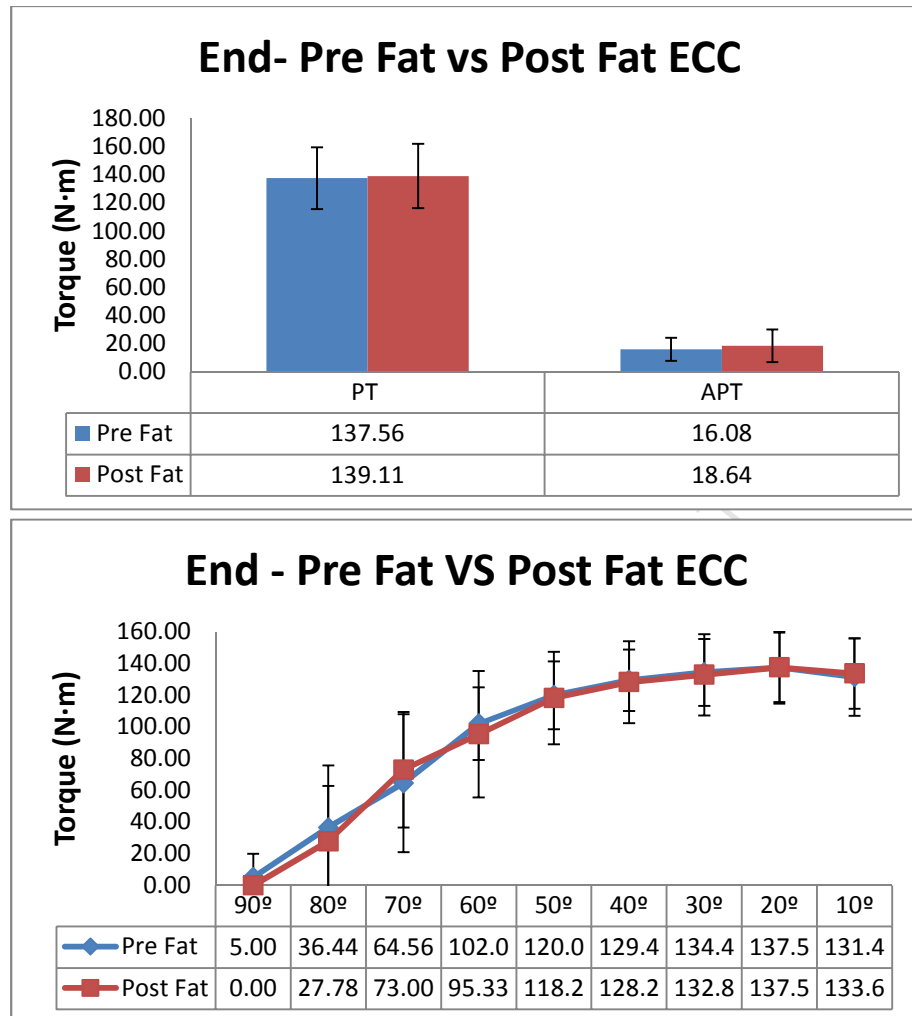


Fig.3: Post-intervention results for eccentric PT, APT and Torque at nine specific angles, before and after fatigue for the Endurance Group. An Asterisk (*) denotes a significant difference ($p < 0.005$).

Graphs for Strength Group Post Intervention/ Before and After Fatigue

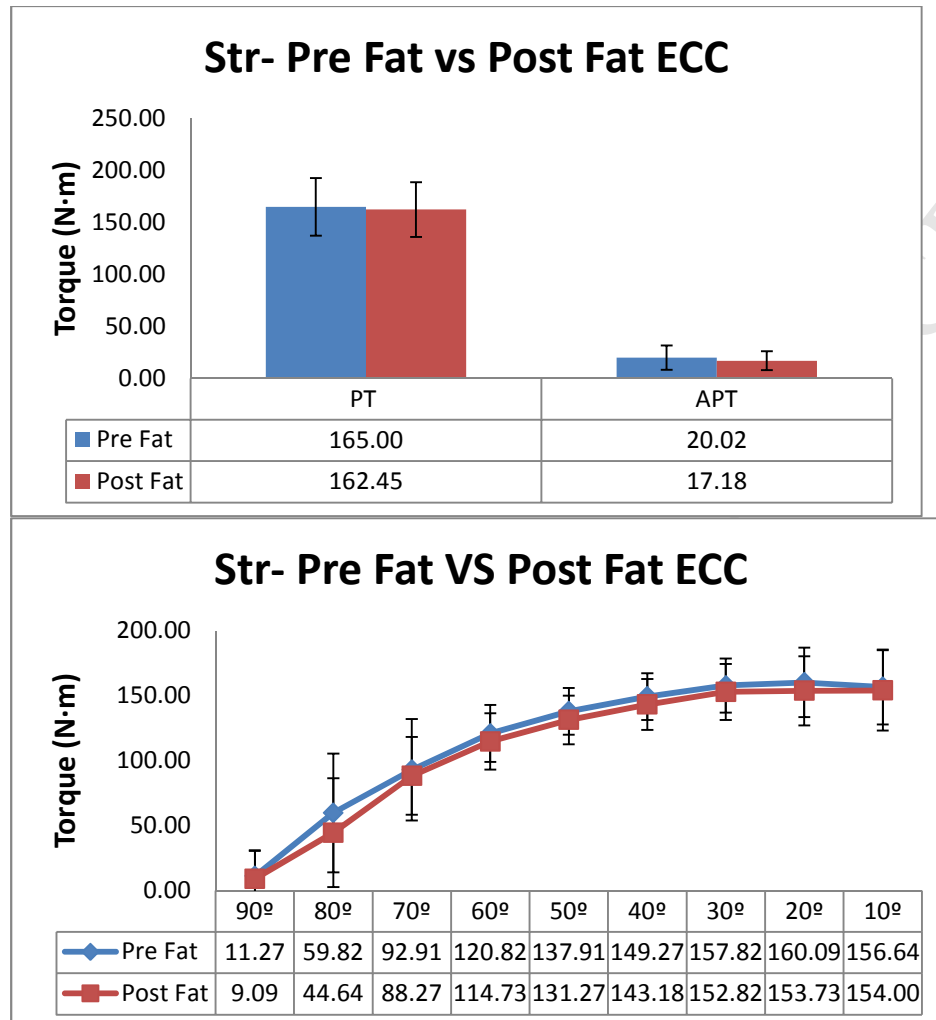


Fig.4: Post-intervention results for eccentric PT, APT and Torque at nine specific angles, before and after fatigue for the Strength Group. An Asterisk (*) denotes a significant difference ($p < 0.005$).

Effects of Intervention of Endurance Pre Fatigue Graphs

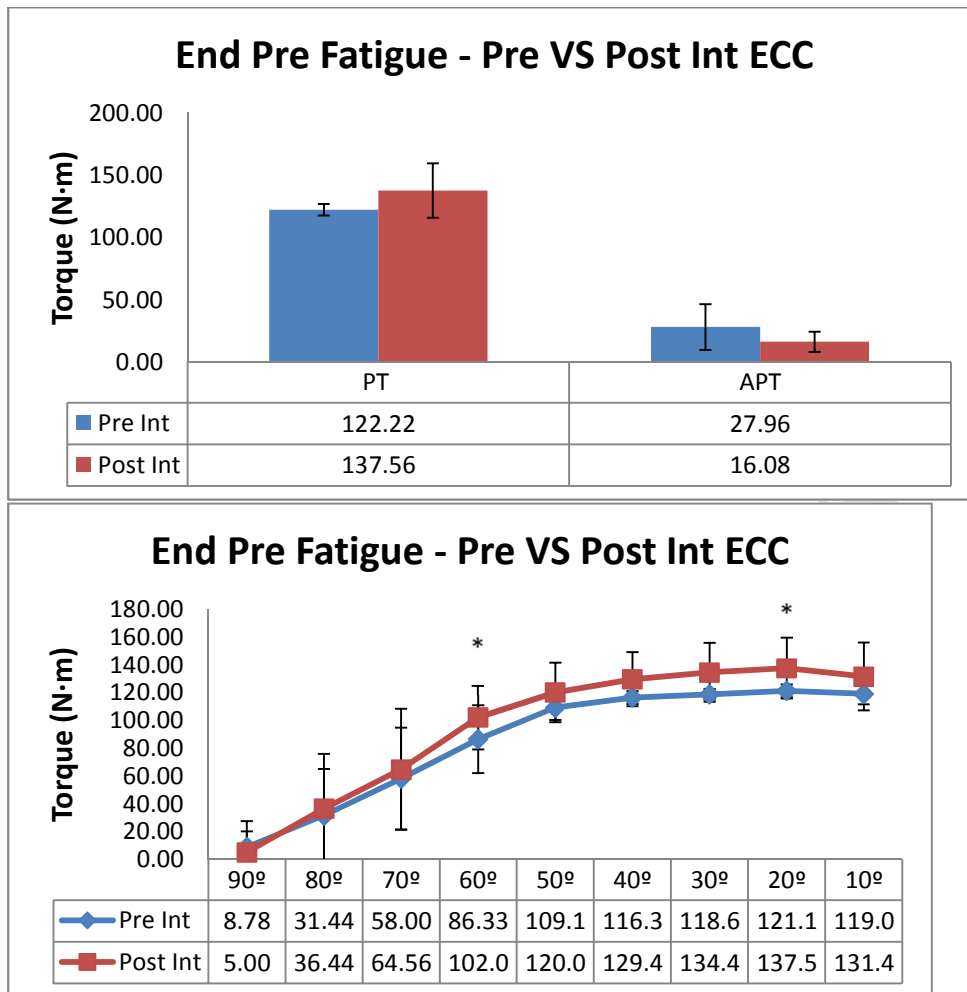


Fig 5: Pre-fatigue results for eccentric PT, APT and Torque at nine specific angles, before and after intervention for the Endurance Group. An Asterisk (*) denotes a significant difference ($p < 0.005$).

Effects of Intervention of Endurance Post Fatigue Graphs

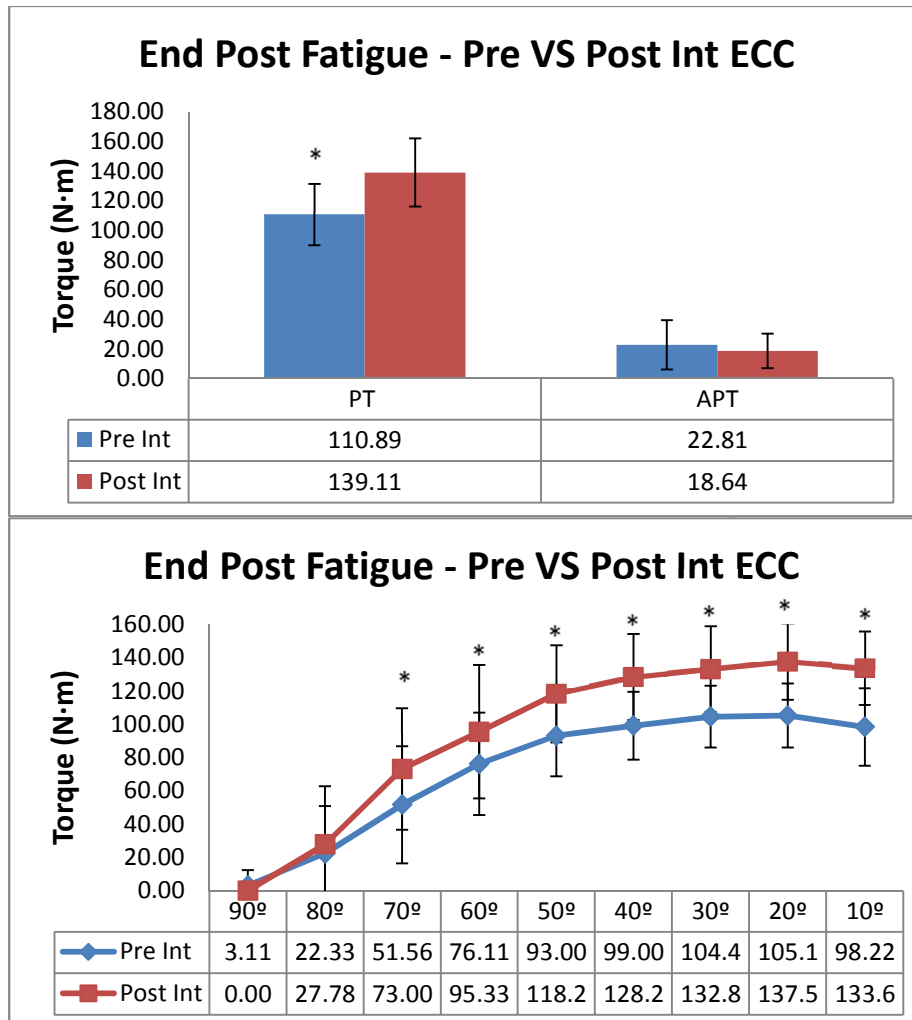


Fig 6: Post-fatigue results for eccentric PT, APT and Torque at nine specific angles, before and after intervention for the Endurance Group. An Asterisk (*) denotes a significant difference ($p < 0.005$).

Effects of Intervention of Strength Pre Fatigue Graphs

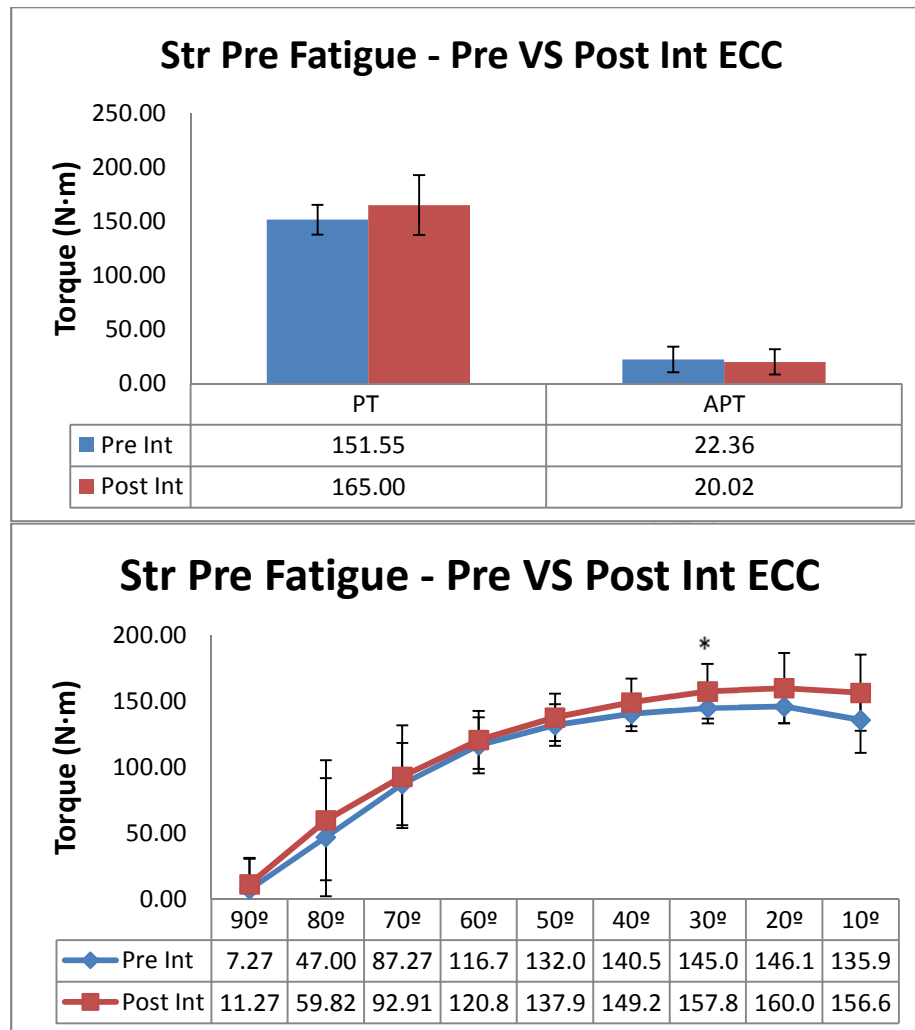


Fig 7: Pre-fatigue results for eccentric PT, APT and Torque at nine specific angles, before and after intervention for the Strength Group. An Asterisk (*) denotes a significant difference ($p < 0.005$).

Effects of Intervention of Strength Post Fatigue Graphs

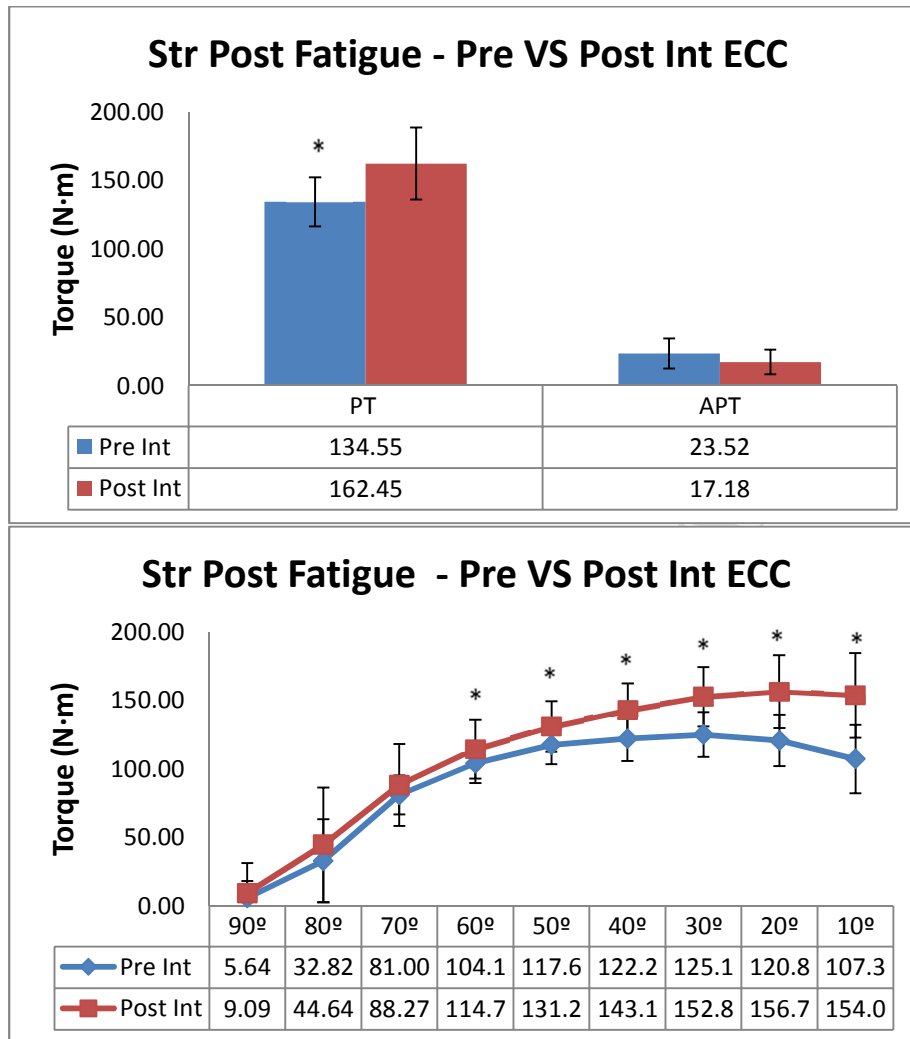


Fig 8: Post-fatigue results for eccentric PT, APT and Torque at nine specific angles, before and after intervention for the Strength Group. An Asterisk (*) denotes a significant difference ($p < 0.005$).

Acknowledgements

**Strength and endurance training reduces the loss of eccentric hamstring torque
observed after soccer specific fatigue**

Additional individuals who helped in the completion of this study.

Steve Horton and Laura Smith from the University of Salford human Performance laboratory
for providing the equipment.

Highlights – Hamstring Torque Angle

Forty-five minutes of simulated soccer activity leads to reduced eccentric hamstring torque.

Eccentric hamstring torque declined preferentially at longer muscle lengths

Strength or muscular endurance training reduces fatigue-induced loss of strength over this time period.

Ethical Statement

**Strength and endurance training reduces the loss of eccentric hamstring torque
observed after soccer specific fatigue**

Ethical Approval for the above title was gained from the Research Governance and Ethics Committee (RGEC): College of Health and Social Care, University of Salford – approval number 1314-260

Martyn Matthews

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors

ACCEPTED MANUSCRIPT