Gluteus medius activation during running is a risk factor for season hamstring injuries in elite footballers

Abstract

Objectives: To investigate if size and activation of the gluteal muscles is a risk factor for hamstring injuries in elite AFL players.

Design: Prospective cohort study

Methods: Twenty-six elite male footballers from a professional Australian Football League (AFL) club participated in the study. At the beginning of the season bilateral gluteus medius (GMED) and gluteus maximus (GMAX) muscle volume was measured from magnetic resonance images and electromyographic recordings of the same muscles were obtained during running. History of hamstring injury in the pre-season and incidence of hamstring injury during the season were determined from club medical data.

Results: Nine players (35%) incurred a hamstring injury during the season. History of hamstring injury was comparable between those players who incurred a season hamstring injury (2/9 players; 22%) and those who did not (3/17 players; 18%). Higher GMED muscle activity during running was a risk factor for hamstring injury ($p = 0.03$, effect sizes 1.1-1.5). There were no statistically significant differences observed for GMED volume, GMAX volume and GMAX activation ($P > 0.05$).

Conclusions: This study identified higher activation of the GMED muscle during running in players who sustained a season hamstring injury. Whilst further research is required to understand the mechanism of altered muscle control, the results of this study contribute to the developing body of evidence that the lumbo-pelvic muscles may be important to consider in hamstring injury prevention and management.

Keywords: Electromyography; gait; magnetic resonance imaging; prospective studies.

Introduction

Over two decades of The Australian Football League (AFL) injury surveillance, hamstring strains have remained the most frequent and prevalent injury with approximately six new hamstring injuries per club per season (15% of all injuries)[1, 2]. Hamstring injuries are associated with a significant amount of time lost (20 missed matches per club per season) and high recurrence rates (26-34%)[1, 2]. This injury is not only problematic for professional athletes but is also the most common injury for amateur/community athletes[3]. The most consistent factors associated with hamstring injury are older age, previous history of hamstring injury, increased quadriceps strength, and a higher proportion of hamstring injuries are sustained during running activities than any other activity[4]. There is however little understanding of the relationship between the lumbo-pelvic musculature and hamstring injury.

Muscles of the lumbo-pelvic region control lumbar, pelvic and hip joint positions. The hamstring muscles attach directly to the ischial tuberosity of the pelvis and lateral lip of the femur[5], therefore, muscles controlling hip and pelvic position, such as gluteus maximus (GMAX) and gluteus medius (GMED), have the potential to influence hamstring muscle length and injury. This notion is supported by previous research that reported that the lumbo-pelvic muscles had the largest potential to influence hamstring stretch during running, where as muscles controlling knee position (e.g. vasti, gastrocnemius) exhibited very small potential[6]. Of note, the GMAX and internal/external oblique muscles had the greatest potential to decrease hamstring stretch during running[6]. The GMED and GMAX muscles are two important lumbo-pelvic muscles that provide a key link in load transfer between the trunk and lower limb[7, 8], therefore, it is important to investigate the relationship between these lumbo-pelvic muscles and hamstring injury.

Lower limb injury is associated with alterations in lumbo-pelvic muscle structure (size) and function (muscle activation). Hides et al[9] reported that smaller size of the lumbar multifidus was predictive of hamstring, quadriceps and adductor injuries in elite AFL players. Altered activation of the GMED and

GMAX muscles has been associated with lower limb injuries such as patellofemoral pain[10], exercise related leg pain[11], groin strain[12], Achilles tendinopathy[13, 14], post anterior cruciate ligament reconstruction[15] and early hip osteoarthritis[16]. With respect to hamstring injuries, no studies to date have investigated the size or activation of individual hip muscles such as the GMED and GMAX muscles. Sugiura et al[17] have previously reported that weakness during concentric action of the hip extensor muscles was associated with hamstring injuries in elite sprinters, however, this study was not able to discern whether deficits were of the hip extensors as a group or of individual muscles. Knowledge of the deficits in specific muscle size or function with hamstring injury can inform the design of effective prevention or rehabilitation strategies to minimise the risk and effects of hamstring injury.

Therefore the aim of this study was to evaluate if GMED and GMAX muscle size and activation during walking and running were risk factors for hamstring injury in elite male AFL players. We hypothesised that at baseline, players who went on to sustain a hamstring injury during the season would have altered muscle size and activation during gait compared to players who did not go on to sustain a hamstring injury.

Methods

Twenty-six elite male AFL players from one professional club participated in the study. The mean (SD) age, height and body mass of the participants was 22.2 (2.8) years, 189.7 (6.7) cm and 87.6 (8.9) kg. Professional AFL playing experience ranged from 1 to 11 years (mean 4 years). Participants provided written informed consent and all data collection procedures were approved by the institutional Human Research Ethics Committee. Prior to the AFL season, bilateral GMED and GMAX muscle volume was measured with magnetic resonance imaging (MRI) and electromyographic (EMG) recordings were obtained during treadmill gait (95 Ti Treadmill, Life Fitness, USA) at 6km/hr, 12km/hr and 15km/hr. These speeds related to the speed zones identified by the global positioning system used by the club during games. Participant characteristics obtained were age, height, weight, years played of professional AFL football and dominant kicking leg.

Bilateral muscle activation of the gluteal muscles was recorded using surface EMG recordings (Telemyo DTS; Noraxon, USA) during treadmill gait. Bipolar silver/silver chloride single differential surface electrodes (circular, 10mm diameter contact area, 20mm fixed inter-electrode distance, Noraxon, USA) were applied according to published recommendations for skin preparation procedures and electrode placement locations[18]. The EMG sensors had a baseline noise of < 1 uV, an input impedance of > 100 Mohm, a common mode rejection ratio of > 100 dB and base gain of 500. Prior to electrode placement skin was lightly abraded with a medical gel (Nuprep®, Weaver and Company, USA) and swabbed with alcohol. The GMED electrode was placed 50% of the distance along a line from the iliac crest to greater trochanter. The GMAX electrode was placed 50% of the distance along a line between the sacral vertebrae and greater trochanter. EMG data was sampled at 1500 Hz and band pass filtered between 10 and 1000 Hz. Standardised maximum voluntary isometric contractions (MVC) were recorded for EMG amplitude normalisation. For GMED the participant was positioned in sidelying with the test limb uppermost, the hip in neutral flexion/extension and the knee extended. Manual resistance was applied just proximal to the lateral malleolus while the participant abducted the uppermost limb. For GMAX the participant was positioned in prone lying with the hip in a neutral and the test limb in 90 degrees knee flexion. The participant extended the test limb hip against manual resistance applied to the distal posterior thigh. Standardized verbal encouragement was provided. Participants were instructed to increase muscle tension over 3 seconds, maintain tension for 5 seconds, and release tension over 3 seconds. Three contractions were recorded for each muscle. Treadmill gait was performed in participant’s usual running shoes. Five minutes was spent at each speed with data recorded during the final minute of each speed. Gait events were determined using foot switches (DTS; Noraxon, USA). Initial foot contact was identified manually using visual inspection of the analogue signal from the foot switch. EMG data were adjusted for direct current offset, full-wave rectified, filtered to remove low-frequency movement artifact using a fourth-order

Butterworth filter with a high-pass cutoff of 10Hz and amplitude normalised to the maximum value recorded during the MVCs. For each limb, ten consecutive strides were selected for analysis and time normalised to 100 data points (representing 0-100% of the stride). The average of the 10 strides was calculated for each limb and used for further analysis to obtain peak and average muscle activation for each speed.

MRI was used to measure bilateral volumes of the GMED and GMAX muscles[19, 20]. Participants were screened by a medical practitioner to identify contraindications to MRI. The participant was placed in a supine position with their hips and knees supported in a neutral position with sandbags. Transverse MRI images were captured at rest using a Siemens 3 Tesla Magnetom VERIO MR system (Siemens, Erlangen, Germany). A T2 weighted axial sequence from the top of the iliac crest to the inferior gluteal fold was obtained. The entire pelvis was included in this field of view, to allow simultaneous capture of images from both sides (repetition time = 7610 ms, echo time = 87 ms, flip angle = 120°, field of view 380mm, number of averages = 1, slice thickness = 5mm, inter-slice gap = 6mm). Images were saved to disk and measured on a computer using OsiriX imaging software (Version 5.7; Pixmeo SARL, Burnex, Switzerland). Using OsiriX, the muscle borders of GMED and GMAX were manually traced on each slice to calculate cross-sectional area (cm^2) for each muscle (Figure 1). The CSA measurements were multiplied by slice width to calculate slice volume (cm^3). Each slice volume was then added to determine total volume for each muscle.

Incidence of hamstring injury during the pre-season (prior to testing) and season (after testing) were determined from the club injury records kept by club medical staff. Hamstring injuries were diagnosed by club medical staff based on a combination of subjective reporting of hamstring pain or tightness following physical exertion and a clinical examination, and confirmed using MRI. In the pre-season, a hamstring injury was defined by whether it caused the player to miss the next full training session because of the injury, and this was used as a measure of recent history of hamstring injury. Hamstring injury incidence during the season was defined by whether it caused the player to miss a game.

Statistical analyses were performed using SPSS (Version 22, IBM Corp., NY, USA). Measurements of muscle volume and activation were averaged across side as preliminary analysis reported no difference between kicking and stance limbs ($p > 0.05$). Skewness and kurtosis values were obtained to ensure normal distribution of the data. The grouping variable was incidence of a hamstring injury during the season (yes/no). For all statistical tests a p value <0.05 was considered statistically significant. An independent t-test was performed to examine differences between groups on baseline characteristics of age, height, weight, and years playing professional football. A 2x2 crosstab with season hamstring injury (yes/no) and pre-season hamstring injury (yes/no) was generated to compare the proportion of players with and without a recent history of hamstring injury. To estimate between group differences in activation of GMED and GMAX, a linear mixed model with an autoregressive covariance matrix was used for each outcome measure. Least significant difference (LSD) tests were used to test whether there were significant differences between the speeds. The mean differences and 95% confidence intervals (95% CI) reported are predicted mean values from the model. To examine between group differences in muscle volume an independent t-test was conducted. Effect sizes (mean difference / pooled standard deviation) were calculated and classified as small 0.2-0.6, moderate 0.6-1.2, large >1.2[21]. Statistically significant variables from the linear mixed model and t-test, were then tested using receiver operating curve (ROC) analyses to identify the cut-off point that best predicted season hamstring injury. The optimal cut-point for each curve was obtained as the point where the true positive rate (sensitivity) was maximised and the false positive rate (1-specificity) was minimised.

Results

Nine players (34.6%) sustained a hamstring injury during the season (5 on kicking limb, 4 on stance limb). Running was the mechanism for 6/9 injuries and the remaining 3 injuries occurred while tackling. History of hamstring injury was similar between the two groups: 2/9 (22.2%) players injured in the season and 3/17 (17.6%) players uninjured during the season had a history of hamstring injury during the preseason. Due to the small numbers, recent history of hamstring injury could not be included as a factor in further analysis. Age, height, weight and years playing professional football were not different between groups ($p = 0.18, 0.48, 0.16, 0.17$ respectively).

GMED and GMAX muscle activity and volume is displayed in Table 1. For GMED activity there were significant main effects for group (peak $p = 0.023$, average $p = 0.014$) and speed (peak $p < 0.001$, average $p < 0.001$). There was a significant group by speed interaction effect for average GMED activity ($p = 0.001$), and a trend for peak GMED activity ($p = 0.06$). Post hoc comparisons indicated that players who sustained a hamstring injury during the season demonstrated higher average and peak GMED activity when running at 12km/hr and 15km/hr, but no difference was observed during walking at 6km/hr, see Figure 2. The effect size of these differences at 12km/hr and 15km/hr were moderate to large (1.1 to 1.5), see Table 1. For GMAX activity there was a significant main effect for speed (peak and average $p < 0.001$) but not group (peak $p = 0.185$, average $p = 0.111$) or group by speed (peak $p = 0.502$, average $p = 0.134$). There were no significant differences reported for GMED or GMAX volume between groups ($p = 0.087$ and $p = 0.170$ respectively).

ROC analyses indicated that for running at12km/hr the cut-offs that best predicted season hamstring injury were average GMED activity of 12.0% MVC (area under the curve 0.791, $p = 0.016$, sensitivity = 77.8%, specificity = 76.5%) and peak GMED activity of 78.9% MVC (area under the curve 0.752, $p = 0.038$, sensitivity = 77.8%, specificity = 70.6%). For running at 15km/hr, average GMED activity of 13.4 % MVC (area under the curve 0.824, $p = 0.008$, sensitivity = 77.8%, specificity = 82.4%) and peak GMED activity of 87.0% MVC (area under the curve 0.732, $p = 0.056$, sensitivity = 77.8%, specificity = 64.7%) best predicted season hamstring injury.

Discussion

The results of this study found that increased activation of GMED during running was a risk factor for hamstring injury during the playing season. There was no difference in GMED and GMAX muscle size or GMAX muscle activity between players who sustained a season hamstring injury and those who did not.

These findings likely reflect an increased role of GMED as an abductor and facilitator of pelvic stability during running[8]. Previous research has reported that increased GMED activity was associated with increased pelvic drop during running and that this resulted in metabolic inefficiencies[22]. We did not measure kinematics and therefore cannot determine if this occurred in our population. Increased GMED muscle activity has also been associated with strength deficits of the hip abductors and external rotators, suggesting that individuals are attempting to recruit a weak muscle[23, 24], however we did not measure hip strength in the current study. Interestingly, a pattern of higher GMED muscle activation, larger GMED volume and increased functional hip adduction has been previously reported with lower limb injury, specifically early/mild hip osteoarthritis[16, 20, 25]. Whilst the current study found no difference in GMED muscle size, it did find increased activity of this muscle. A possible explanation is that GMED may have been compensating for a deficit in other muscles involved in control of the hip and pelvis that we did not measure. Future studies could evaluate other lumbo-pelvic muscles as well as kinematics of the lower limb to provide further insight as to possible mechanisms for altered GMED activity.

Higher activation of the GMED during running (12k/hr and 15km/hr), but not walking, was related to season hamstring injuries (67% occurred during running). This highlights the importance of task specificity when assessing muscle function in the clinical setting. Whilst the underlying mechanism for the observed higher gluteus medius activity requires further investigation, several other studies have also reported alterations in activation of this muscle in lower limb injuries[11,12,13,15]. The results of our paper therefore contribute to this body of evidence to suggest that function of the GMED is very important for running related injuries. A major strength of the current study is the prospective design, which is able to establish that the altered GMED activity preceded the occurrence of hamstring strain. Despite the mechanisms for altered GMED activation, this may influence impact attenuation during landing and have implications for lower limb injury. Recent research has reported that bracing of another lumbo-pelvic muscle, the internal oblique, resulted in reduced knee and hip flexion and increased peak vertical ground reaction forces[26]. It is possible that control of the GMED muscle may have a role in hamstring screening/prevention programs; however further research is required to develop and evaluate this.

Interestingly, our results indicated that GMAX muscle size and activity was not statistically different between players who did and did not sustain a season hamstring injury. This was surprising given the shared role of the GMAX and hamstring muscles in decelerating the limb during late swing[7] and previous evidence that GMAX has the greatest potential to influence hamstring length during running[6]. It is possible that GMAX activity alone is not related to hamstring injury, but rather its activation relative to the hamstring muscle, however we did not examine hamstring muscle activation. Another possible explanation is the small sample size and insufficient cases to detect a statistically significant difference. Future studies are needed to repeat these investigations in a larger cohort and include the evaluation of hamstring muscle activation and size.

This is the first prospective study to investigate specific gluteal muscle activation and size as risk factors for hamstring injury, but should be considered in light of some limitations. This study consists of a small sample of male AFL players from one professional club, so it is possible that results may not be generalizable to female athletes and athletes of varying skill or sports. The lumbo-pelvic region is a complex area with many muscles contributing to control during running. We measured two primary muscles involved in hip/pelvic control but future studies could investigate other muscles of the lumbo-pelvic region, including the hamstring muscles. Whilst it is not possible to measure the strength of individual muscles, measurement of the strength of muscle groups such as the hip abductors and hip extensors and measurement of strength ratios could be investigated in future studies. Lower limb kinematics that have previously been associated to GMED activation[22, 27] - such as trunk shift, anterior/posterior pelvic rotation and lateral pelvic drop/raise - could also be included in future investigations, which may provide insight into the mechanisms underlying the higher GMED activity observed in the current study.

Conclusion

Results of this study suggest that higher activation of GMED during running is related to season hamstring injuries in elite male AFL players. There were no differences observed in GMED or GMAX volume and GMAX muscle activation. Further investigation is required to understand this alteration in GMED muscle activation, for example, prospective studies to evaluate other muscles of the lumbo-pelvic region, trunk/lower limb kinematics and measurements of muscle strength. Whilst larger studies replicating this preliminary finding are required, this study highlights the importance of considering lumbo-pelvic muscle function in prevention and management of hamstring injuries.

Practical implications

- Activation of the gluteus medius muscle was associated with AFL hamstring injuries
- Higher gluteus medius muscle activation was only observed during running, not walking, which highlights the importance of task specific assessment
- Neuromuscular control of the lumbo-pelvic region may be important in the prevention of hamstring injuries in AFL

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Tables

Table 1. Predicted group means (SD) and mean difference (95% CI) between groups

Variable	**No hamstring injury Mean (SD) (n = 17)**	**Hamstring injury Mean (SD) (n = 9)**	**Mean difference (95% CI)**	**P-value**	**Effect size**
GMED peak activity (%MVC)					
6km/hr	33.2 (23.7)	41.7 (23.7)	8.5 (-11.2 to 28.3)	0.388	0.4
12km/hr	73.02 (23.7)	99.1 (23.7)	26.1 (6.4 to 45.9)	0.011	1.1
15km/hr	80.09 (23.7)	107.3 (23.7)	27.2 (7.4 to 47.0)	0.008	1.1
GMED average activity (%MVC)					
6km/hr	5.4 (2.7)	6.3 (2.7)	0.9 (-1.3 to 3.2)	0.404	0.4
12km/hr	10.1 (2.7)	13.4 (2.7)	3.3 (1.0 to 5.6)	0.006	1.2
15km/hr	10.3 (2.7)	14.3 (2.7)	4.0 (1.8 to 6.3)	0.001	1.5
GMAX peak activity (%MVC)					
6km/hr	19.0 (16.7)	24.1 (16.7)	5.0 (-8.9 to 19.0)	0.470	0.3
12km/hr	42.6 (16.7)	52.6 (17.0)	11.0 (-3.1 to 25.0)	0.124	0.7
15km/hr	57.6 (16.7)	64.3 (16.7)	9.0 (-4.9 to 23.0)	0.198	0.5
GMAX average activity (%MVC)					
6km/hr	2.6 (2.4)	3.3 (2.4)	0.7 (-1.3 to 2.8)	0.462	0.3
12km/hr	6.5 (2.4)	8.2 (2.4)	1.8 (-0.2 to 3.9)	0.077	0.8
15km/hr	8.1 (2.4)	9.7 (2.4)	2.0 (0.1 to 4.0)	0.049	0.8
GMED volume (cm^3)					
	778.8 (117.0)	865.5 (119.8)	86.7 (-13.6 to 187.1)	0.087	0.7
GMAX volume (cm^3)					
	2337.2 (304.4)	2507.4 (265.0)	170.1 (-78.2 to 418.4)	0.170	0.6

Figure legends

Figure 1. Example of cross-sectional area measurement for GMED and GMAX on MRI.

Figure 2. Predicted mean +/- 95% confidence interval for average GMED activity illustrating significant differences in muscle activity during 12km/hr and 15km/hr but not 6km/hr.