# Biomechanics of kicking in the AFL with respect to the development of quadriceps strains

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# Preface

## AIMS

The aims of this study were to determine, through the analysis of the dynamics of kicking and quadriceps muscle function, the likely mechanism of injury for the rectus femoris muscle, and to measure the rate of quadriceps strains in games under varying ground conditions (as measured by Penetrometer readings) and under varying ball conditions (direct pressure and weight measurements), to determine whether ground hardness and/or ball pressure contribute to risk of injury.

## Lay summary: Biomechanics of Quadriceps Strains

Quadriceps strains affect the muscles at the front of the thigh and are the fourth most common injury in the AFL, extracting a heavy toll on a club's injury list. Although it was previously understood that quadriceps strains have been related to kicking and occur on the kicking leg side, the exact mechanism during kicking has not been understood.

This study has found that it is very likely that a quadriceps strain during a running kick is related to a deceleration movement performed by the kicking leg in the final step before the backswing, and *not* due to contact with the ball during the kick. The evidence suggesting that this is the case includes the following:

1. The risk of a quadriceps strain for a type of kick is proportional to the running speed of the approach, rather than the distance kicked. A long kick from a standing start (such as from a free kick, or a kick out from goal) is far less likely to cause a quadriceps strain than a short, fast running kick. Similarly a running pass kick in soccer is a greater risk than a standing punt kick in American football or a kick for goal in rugby. This study has shown that stretch of the quadriceps is greater in a running kick than a standing kick or in regular sprinting, which makes a strain injury more likely.
2. Quadriceps strains may occur during running when the player is trying to slow down, and video analysis of these injuries reveals that the mechanics of the leg movement during slowing down movements are very similar to the final step before kicking a running drop punt in which an injury has occurred.
3. The study has shown that impact forces to the leg from the ball mainly depend on how wet the ball is. Impact forces from ball contact are therefore greater on wet days. However, injury survey data reveals that quadriceps strains are more likely in dry weather. This strongly suggests that ground conditions, more than ball conditions, affect the risk of quadriceps strain. Furthermore, there was no relation shown between measured ball pressures and risk of quadriceps injury.

Other risks for quadriceps strains include that they are more common in players with a past history of quadriceps strain, players returning from a hamstring strain and in shorter players (who presumably are more likely to make fast, running kicks than long kicks from a stoppage). Quadriceps strains are also more common in teams based out of Melbourne, although like many other injuries that are more common in warmer climates, there is a poor correlation with Penetrometer readings. This suggests that ground traction is more of a risk than hardness. In contrast to most other injuries quadriceps strains are almost as likely during training sessions as they are in matches. There is some evidence that fatigue and overuse may be implicated in causing quadriceps strains.

The findings of this study pinpoint a set of circumstances in which a quadriceps strain is highly likely. Long training sessions on dry grounds where repetitive running kicks are performed under pressure, particularly by players with a history of hamstring or quadriceps injury, are the most likely circumstances to result in a quadriceps strain. These circumstances should be avoided by teams in their efforts to prevent injury.

**Abstract/scientific summary**

This study reports that rectus femoris strains in Australian football are related to the final step or backswing of the kicking motion rather than ball contact. This conclusion is made based on a combination of video evidence, kinematic and strain data during running kicks and measures of ball-foot impact forces. From previous anecdotal and direct video evidence, it is known that gastrocnemius (calf) strains often occur during a single-leg support phase of push-off movements with the body weight far in front of the calf. The exact moment of hamstring strains has not been proven, but recent video evidence suggests that hamstrings often occur due to over-striding when at fast speed. Under-striding when trying to slow down is the likely mechanism of rectus femoris strains that occur during running, and also during the running drop punt kick in Australian football. The deceleration component of the final step of the kicking leg before ball contact is very similar to the mechanics observed in a deceleration movement in which a quadriceps strain can occur whilst running. It is therefore highly probable that deceleration movements, whether occurring during running or a running kick, are highly likely to result in a quadriceps strain compared to other movements. This combination of under-striding when trying to slow down causes the body to lean backwards and the leg to move farther behind the body than normal, which places extra stress and strain on the rectus femoris. This study shows greater strain on the rectus femoris during a running kick compared to a standing kick and sprinting. It is not established whether strain injury actually occurs during the back-swing phase (when the muscle is at greater length) or the ground contact phase (when there is greater stress on the muscle from external forces), but it is considered very unlikely that the quadriceps strains during ball contact. Wet weather (resulting in heavier balls, which cause greater ball-foot impact forces) is not risk factor, nor is ball inflation pressure. Fatigue, lack of warm-up and decreased strength of a muscle group probably contributes to muscle failure, as quadriceps fatigue, weakness or dysfunction may contribute to an under-stride (by failing to progress the leg fully during the preceding swing phase). The risk of a quadriceps strain for a type of kick is proportional to the running speed of the approach, rather than the distance kicked. A long kick from a standing start (such as from a free kick, or a kick out from goal) is less likely to cause a quadriceps strain than a short, fast running kick. Other data previously established regarding quadriceps strains include that they are more common in players with a past history of quadriceps strain, players returning from a hamstring strain and in shorter

players (who presumably are more likely to make fast, running kicks than long kicks from a stoppage). They are also more common in teams based out of Melbourne, and they are almost as likely during training sessions as they are in matches. Although dry ground conditions relate to risk of quadriceps strain, Penetrometer readings do not, suggesting the most important ground characteristic is shoe-surface traction. There is some evidence that fatigue and overuse may be implicated in causing quadriceps strains. The findings of this study pinpoint a set of circumstances in which a quadriceps strain is highly likely, which teams should try to avoid in preventing these injuries. Long training sessions on dry grounds where repetitive running kicks are performed under pressure, particularly by players with a history of muscle strain injury, are the most likely circumstances to result in a quadriceps strain.

# 1 – A review of biomechanics of Quadriceps strains and AFL injury database

## 1.1 Introduction – Biomechanics of muscle strains

Muscle strain injuries are often cited as the most frequent injury in sport [1-6]. This is not surprising given that skeletal muscle constitutes the largest tissue mass in the body, comprising up to 45% of the total body weight [7]. The most common strains are to the long muscles of the lower limb, particularly the hamstring muscle group, the rectus femoris (quadriceps group) and gastrocnemius (calf group) [8, 9]. Despite their frequency, little is known about the risk factors [9]. The assessment of risk factors is best made through a combination of epidemiological studies and biomechanical analysis.

It is known that strain injury is the result of excessive forces (which can be either externally applied or passive internal forces, due to strain). In the laboratory external forces and strain can be created and measured for an isolated muscle [10-13]. The forces (moments) affecting individual joints during the gait cycle *in vivo* can be estimated using well established models [14-16]. There are also models which can estimate muscle length during sprinting gait [17-20]. However there is no established model to determine the external force (or stress) that individual muscle groups or muscle fibres are subject to at any given time of the gait cycle, making it very hard to assess why strain injury actually occurs.

Gastrocnemius muscle strains are known to commonly occur late during single-leg stance phase of a push-off manoeuvre. Clinical and anecdotal evidence is in agreement with direct video evidence that has recently been reported [21]. Although hamstring muscle strains are a more common injury, authors have disagreed about whether strains occur during late swing or early stance during sprinting [21-23]. Rectus femoris (quadriceps) strains are known to commonly occur during kicking in Australian football and soccer, but no previous study has addressed the question of whether they primarily occur during ball contact, back swing, or ground contact during the step before kicking [9].

Clinical sports medicine teaching asserts that two-joint muscles strain during sprint activities when undergoing eccentric contractions, which is well summarized in the works of Garrett [8, 24]. However, Garrett admits in these reviews that he is merely summarizing popular opinion of the clinical sports medicine literature rather than stating proven fact, for example "most clinicians would agree that muscle strain injuries occur when the muscle is either stretched passively or activated during stretch.[25-27]" [8]. This paradigm suggests that hamstring muscles are prone to strain injury in late swing phase (eccentric phase) rather than early ground contact (when the hamstring contraction is concentric) [22]. This model would also suggest that the rectus femoris is prone to strain in the early swing phase of sprinting and early backswing of the kicking motion. These phases are when the rectus femoris is eccentrically contracting [28, 29].

Change of movement (angular velocity) of a joint is determined by a sum of the forces (moments) acting on the joint. These forces can be divided into the net moment generated by muscles acting on the joint ('muscle moment') and the net moment generated by external forces ('external moment'), such as ground reaction forces and gravity. It is quite complicated to consider these forces for a single joint, such as the knee, and it is extremely complicated to consider how these forces interact for two joint muscles such as the hamstrings and rectus femoris.

The first author to measure muscle moments during sprinting and declare a period in the gait cycle where the hamstrings were prone to tear was Ralph Mann [14, 30]. He measured muscle moments for hip, knee and ankle during sprinting and found that knee flexion moment and hip extension moment were both highest in the early ground phase of sprinting [14, 30]. This establishes that the hamstring muscle group is generating the most force during this phase of gait (initial ground contact), and Mann concluded from this that hamstring strains are most likely to occur at this time. Mann's theory is most plausible if it is considered that the hamstring group is able to generate maximum joint moments during the initial contact phase because it is being stressed by a net external moment in the opposite direction. When publishing muscle moments, Mann and other authors have not generally published the external moments, although during the initial contact phase of sprinting these will tend to reflect the muscle moments. Angular velocity of the hip and knee are not changing rapidly during this phase [31], from which the conclusion can be made that the muscle and external moments are acting in opposite directions and are tending to neutralize each other. That is, during the initial contact phase of maximal sprinting there is a high hip extensor muscle moment counterbalancing a hip flexor external moment, with the converse occurring at the knee. Complicating this explanation is the fact that other muscles, such as the vasti and gastrocnemius, are also actively contracting during the initial ground contact phase [28], although as mentioned the net muscle moment at the knee is one of flexion. The hamstring muscle is also very active during the late swing phase [22, 28] but in this phase it acts against relatively little external force, so its action results in a much greater change of angular velocity at the hip (which changes from flexing to extending during this phase) and knee (which changes from extending to flexing). Even though the hamstring contracts at least as much during the early ground contact phase, there is less resulting change in joint angular velocity due to the resisting external forces.

To summarise, in real life activities such as sprinting and kicking, the greatest lengths (stretches or strains) of the hamstring and rectus femoris muscles occur during swing phases. However, maximum external joint moments (forces which oppose muscle action) and consequent stress on muscles occurs during ground phases. Clinical teaching that stretch (strain) is most responsible for muscle strain injuries [8], suggests that the hamstring and rectus femoris muscles are most prone to failure when most stretched which is when they are contracting eccentrically during the swing phases.

A human muscle strain injury model can be simulated in the laboratory [10, 11] by over-stretch of *isolated* animal muscle (i.e. *not* animal muscle during a running activity). Injury generally occurs at the musculo-tendinous junction (as seen in human *in vivo* strains) although can sometimes occur in the muscle belly [8, 12].

Almost all laboratory simulated muscle strain injury experiments have found that strain (amount of lengthening of the muscle or muscle fibre, expressed in units of mm/mm) is the property that correlates most with muscle damage. Strain has been shown to have a greater correlation with muscle damage than muscle force [10], velocity [13], strain rate [12] and contraction status of the muscle [32]. These findings suggest that amount of strain (muscle length) should be the property that correlates most with risk of muscle strain injury *in vivo*.

Unfortunately with respect to real life human activities, strain alone does not explain why muscles sustain injury. The greatest strain (displacement) that a muscle can undertake is a movement from being fully shortened to fully lengthening, for example during a slow muscle stretching exercise, yet a slow stretch rarely if ever results in a muscle strain injury. As a muscle is stretched towards its maximum length, it passively resists the stretch [33]. In activities that typically cause muscle strain injuries (e.g. hamstring strains during sprinting) maximal range of motion of muscle groups (and hence maximal strain) is not nearly reached, yet a muscle strain injury can result. This implies that one or more of stress (tension), velocity, strain rate and/or contraction status are also relevant to creating a muscle strain injury in real life.

The laboratory studies, in showing that amount of strain is an important factor, suggest that muscles probably need to be in a relatively stretched state in order to create a strain injury. Certainly this is the case during a calf strain in the push-off manoeuvre described earlier. They also suggests that muscles are unlikely to be injured in a shortened state, irrespective of the forces involved, such as the rectus femoris muscle during ball contact in kicking.

The biomechanical milieu during gastrocnemius strain injuries can be summarised more easily than the other muscle strains, as the time of occurrence of the common gastrocnemius strain in the gait cycle is well established. ‘Tennis leg’ in which the gastrocnemius suffers strain injury during the push-off movement after a tennis serve, was described over 30 years ago [34]. A video has recently been published which reveals a gastrocnemius strain at the exact moment of occurrence captured on a cricket ‘Stump Cam’ [21]. In this case, the muscle strain injury occurs during the commencement of the second step of take-off (single leg support) towards the end of ground contact cycle. The gastrocnemius muscle is close to, but probably not at, maximum length. It is also presumably contracting quite strongly as it appears likely that ground reaction forces are tending to dorsi-flex the ankle and extend the knee. It is difficult to determine whether the muscle is undergoing any change in length at the time of the strain injury [21]. The muscle-tendon unit appears to be almost isometric.

A recent study has shown that the muscle and tendon components of a muscle-tendon unit are not necessarily moving in the same direction [35]. When the gastrocnemius changes length during jumping, that there is a phase after eccentric contraction where musculo-tendinous unit as a whole appears to be isometric. However, real time ultrasound reveals that during this phase the muscle component is contracting while the tendon component continues to lengthen, with the overall appearance of no change in length of the muscle-tendon unit [35].

Video analysis of hamstring strains, whilst not revealing the time of injury during the gait cycle, shows that they are likely to occur during overstriding when close to maximum speed and trying to maintain speed. During this type of movement, the hamstring muscles are relatively more stretched than during a stride of normal length at maximum speed, although they do not reach maximum muscle length. As mentioned previously, authors have disagreed about whether the actual muscle injury occurs during late swing or early stance during sprinting [21-23]. This is because the external forces and consequent muscle stress are greater during the ground phase, whereas the maximum length (muscle strain) is in the swing phase.

## 1.2 Rectus femoris strains

The quadriceps femoris, the largest muscle of the body, is the main extensor of the knee joint and has four parts: rectus femoris and the three vastus muscles- lateralis, intermedius and medialis. Ryan, over 30 years ago, described the seriousness of quadriceps muscle strain injury [1]. A previous radiological study found that the rectus femoris was the location of clinical quadriceps strains [36] confirming clinical suspicion [24]. There have been multiple papers presenting a series of quadriceps muscle strain injuries, all describing rectus femoris injuries, which are the most common and serious of quadriceps strains [37-39].

The location of rectus femoris strain has been shown to occur in either the distal musculotendinous junction or in the mid-muscle belly as a lesion of the intramuscular indirect head tendon [38, 39].

Quadriceps strains are particularly common injury in Australian football [5] and soccer [6]. A relatively high proportion of these injuries occur during training [5].

## 1.3 Descriptive data regarding quadriceps strains in the AFL

Analysis of the AFL injury database [5] revealed that of 411 quadriceps strains that caused matches to be missed, 216 of these definitely occurred during matches whereas 159 occurred during training, with the onset of the remainder uncertain or gradual. Of the common injuries in the AFL, this is the injury type with the highest proportion of occurrence during training sessions. When a specific quarter of a match was nominated as the time of injury, this was most likely to be the second quarter, with a distribution across the four quarters of first – 19; second – 30; third – 26; last – 16.

Figure 1 shows the incidence and prevalence of quadriceps strains in the AFL over the past ten seasons (to the end of 2001). This shows a trend towards a recent decrease of quadriceps strains in the AFL. A possible contributing explanation may be that club training methods have improved over the past few years. A further explanation may be that quadriceps strains appear to have followed the trend of other lower limb injuries such as ACL tears of the knee and groin strains that also decreased over the period 1997-2001, due partially to their relationship with ground conditions.

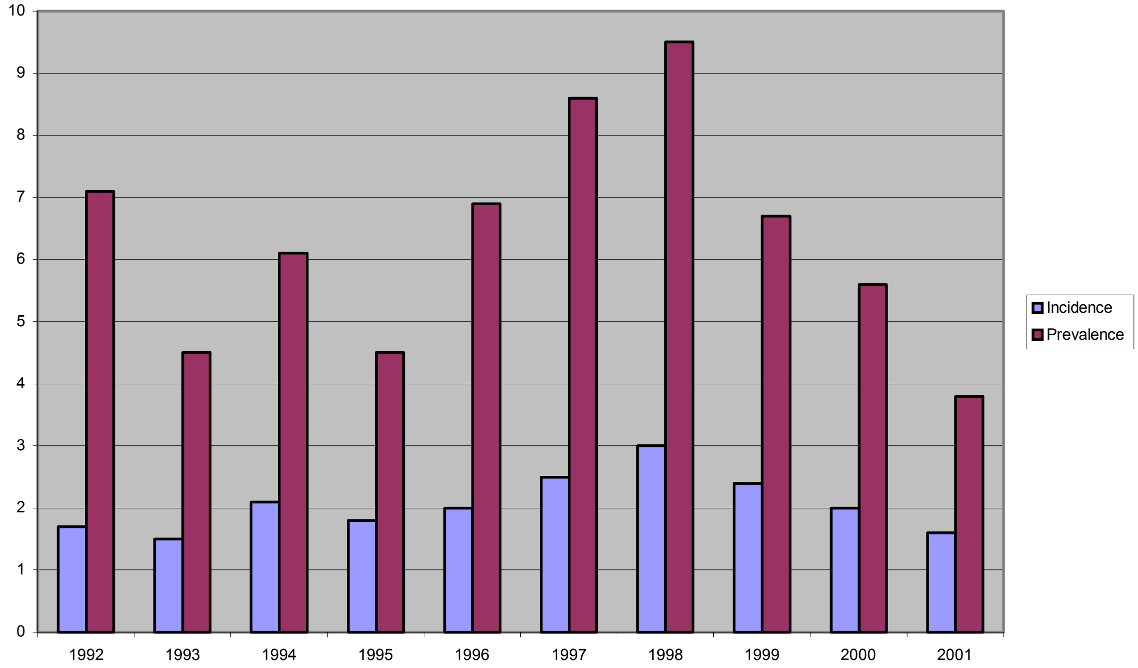


**Figure 1.1 - Incidence and prevalence of quadriceps strains in AFL 1992-2001 (injuries per club per season and matches missed per club per season).**

A consistent anecdotal observation is that the speed of the run-up, rather than the distance the ball is kicked, is associated with a greater risk of quadriceps strain. In Australian football, quadriceps strains are extremely rare on long kick-outs from goal or kicking after a mark. By contrast, rectus femoris strain injuries often occur during short kicks when the player is running at high speed. The amount of foot-ball impact force is roughly proportional to the distance that the ball travels, yet because long kicks with a slow run-up do not tend to cause rectus femoris strain, it is unlikely that ball contact impact forces are the mechanism for quadriceps strain.

Players who were injured during training could sometimes nominate a specific kick in which they felt they were injured. Usually this was during a kicking drill from a kick ‘on the run’. Sometimes this was during a shot at goal after practising many shots in a row. Players injured at training sometimes felt that fatigue or repetition was a factor as the injury occurred towards the end of a long session with many kicks, although some players strained a quadriceps muscle early in a session.

Players who were injured during matches were generally *unable* to nominate a specific kick when they felt an injury occur. The most common description was that the player felt a gradual onset of pain during running and kicking in the dominant leg quadriceps muscle that did not force him to leave the field. This is in contrast to hamstring and calf strains which generally occur during a running motion and in which the time of injury can generally be pinpointed by the player or seen on video.

Sometimes players mentioned that they felt a quadriceps strain was caused by a recent cork thigh to the quadriceps, or contributed to by a recent hamstring strain or tightness. Many players were unsure about the exact timing of a quadriceps strain during a kicking motion, although a few players felt the strain occurred during ball contact. One player felt specifically that he felt his quadriceps had strained during a kick motion in the back swing before ball contact.

## 1.4 Descriptive data regarding quadriceps strains in other sports

Quadriceps strains in rugby league players are much more likely to occur during running than kicking. Examination of the primary author's database of injuries during 5 years of working with an NRL team [40] revealed 29 quadriceps strains, including 11 which caused matches to be missed. Only 3 of these injuries involved a kicking mechanism, and by comparison these injuries were minor (missing 0, 1 and 2 matches respectively). All other injuries occurred during running. There was one documented occasion of a specialist goal-kicker sustaining a quadriceps strain in his kicking leg with a running mechanism, who claimed that the mechanism of goal kicking placed less stress on his leg than running during general play. Kicking in rugby league is generally of two types: goal kicking, which is a set shot at goal from a standing start, and field kicking, which is usually performed by a player whilst running at slow speed within 3-4 steps of receiving the ball.

An ex-AFL player who had moved to a career as a punter in the NFL was interviewed, and he declared that quadriceps strains were a very rare injury in punters in the NFL, and were far more common in kicking in Australian football [41]. Punters in the NFL kick off one to two steps, as they must complete the kicking task in a very brief time period, but must kick the ball very hard for maximum height and distance. Although a comparison is not made in this study, it could be assumed that an

American football style punt would have similar or greater ball-foot impact forces to Australian football, but lower ground reaction forces.

## 1.5 Risk factor data regarding quadriceps strains

Quadriceps strains in football players are more common in dominant kicking leg (RR 2.13, 95% CI 1.59-28.6), whereas hamstring and calf injuries are fairly evenly distributed [9]. Previous muscle strain injury is a strong risk factor for future strain injury to the same muscle group (and in some cases other muscles). Calf and hamstring (but not quadriceps) strains are more common in older players [9]. Quadriceps strains are more common in matches where there has been low rainfall over the previous week, which suggests a ground contact rather than a ball contact mechanism [9]. This is because that if quadriceps strains occurred during ball contact, it would be expected that these injuries would be more common on wet days, when the ball may be heavier. Quadriceps strains are also more likely after a recent hamstring strain [9]. These findings are detailed in Tables 1.1 and 1.2.

| Injury | Variable | B | S.E | Risk ratio | 95% CI |
|---|---|---|---|---|---|
| Quadriceps injury | Quadriceps injury within previous 8 weeks | 2.75 | 0.21 | 15.61 | 10.27-23.74 |
| | Previous quadriceps injury (more than 8 weeks ago) | 1.30 | 0.18 | 3.67 | 2.60-5.19 |
| | Hamstring injury within previous 8 weeks | 0.73 | 0.32 | 2.08 | 1.12-3.86 |
| | Low rainfall at match venue in previous 7 days | 0.37 | 0.18 | 1.45 | 1.01-2.08 |
| | Shorter player (<=182 cm) | 0.39 | 0.16 | 1.48 | 1.09-2.02 |

**Table 1.1 – Analysis of significant variables in logistic regression equations [9]. B = regression coefficient; S.E. = standard error; 95% C.I. = 95% confidence interval.**

| | Quadriceps injury | |
|---|---|---|
| | t | P |
| Player age | 0.10 | 0.919 |
| Height | -2.39 | 0.017 |
| Weight | -0.88 | 0.378 |
| Body mass index | 1.01 | 0.311 |
| Month of year | 0.32 | 0.752 |
| Rainfall on day of game | -0.41 | 0.682 |
| Rainfall in previous 7 days | -2.72 | 0.007 |
| Evaporation in previous 7 days | -1.53 | 0.126 |
| Maximum temperature on day of game | -1.50 | 0.133 |

**Table 1.2 – Analysis of t-tests for selected variables [9]**

Quadriceps strains (like many other non-contact lower limb injuries) are relatively more likely on northern AFL grounds, where ground traction and hardness are greater [42]. By contrast, hamstring strains follow an opposite trend and are more common on southern grounds [42] (Table 1.3). It is possible that on grounds with less traction available, alterations are made to gait including over-striding to increase ground contact time, which makes hamstring strains more likely and quadriceps strains less likely. In grounds where traction is greater, the stride length may be relatively shorter, which makes an under-stride, and consequently a quadriceps strain, more likely.

| **Injury category** | Victorian incidence | Northern incidence | Relative risk (RR) | | 95% RR Confidence | |
|---|---|---|---|---|---|---|
| | | | N:V | | Low | High |
| **Groin and hip injuries** | 3.5 | 5.2 | 1.48 | * | 1.23 | 1.79 |
| **Hamstring strain injuries** | 8.0 | 7.2 | 0.90 | | 0.78 | 1.04 |
| **Quadriceps strain injuries** | 2.0 | 2.7 | 1.32 | * | 1.03 | 1.71 |
| **Anterior cruciate ligament injuries** | 0.7 | 1.1 | 1.71 | * | 1.13 | 2.58 |
| **Calf muscle strain injuries** | 1.8 | 2.4 | 1.35 | * | 1.02 | 1.77 |

**Table 1.3 - Injury risk for Victorian versus Northern teams [42]. An asterix ('*') indicates significantly higher risk of injury for Northern teams ($p<0.05$ or 95% confidence).**

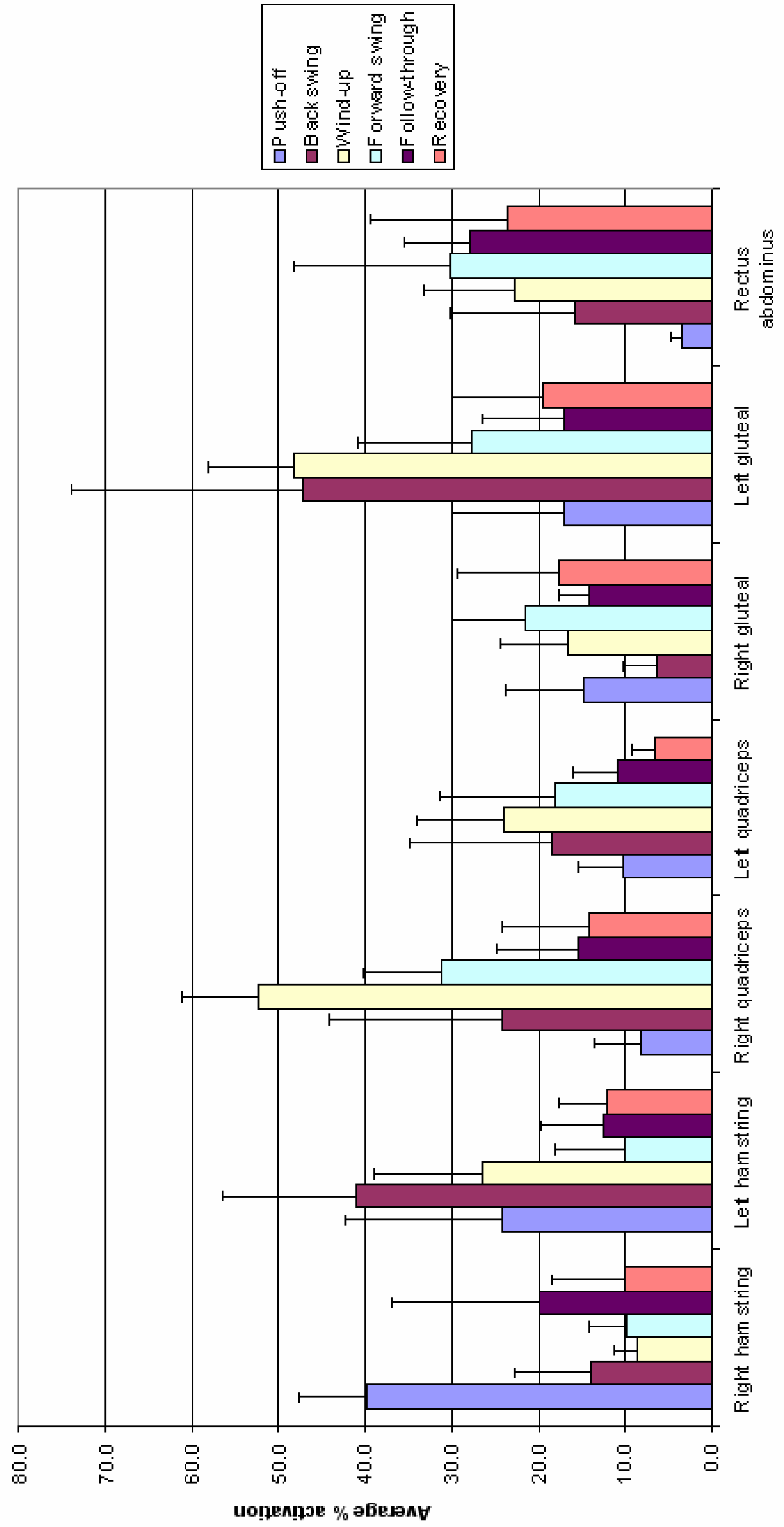
Recent hamstring strain has been found to be a risk for quadriceps strain [9]. It is possible that during recovery from a hamstring strain, alterations are made to gait

[43], which include reducing the stride length, protecting the weakened hamstring muscle from re-strain but increasing the chance of a secondary quadriceps strain.

## 1.6 Activation of rectus femoris during the drop punt

A study examining the muscle activation patterns during kicking has previously detailing the phases of drop punt kicking (push-off, backswing, wind-up, forward swing and follow-through). This involved four AFL players performing 40m drop punt kicks from a 6-8 step run (Orchard et al., 1998). This study found the kicking leg quadriceps was most active in the wind-up phase (acting eccentrically) rather than the forward swing phase, in which there is rapid knee extension prior to ball contact. It also found symmetry between left and right foot kicks in elite players. (Figure 2).

**Figure 2 EMG of R foot kick**



## 2 - Video analysis of quadriceps strains

For those quadriceps strains that occurred during matches from a kicking mechanism during the 2001 Australian Football League (AFL) season, video of all kicks performed by the players concerned in these matches was obtained from Champion Data, Melbourne (n=21, including a small number that occurred in season 2000 or 2002). These videos were analysed to try to isolate the occurrence of kicks which resulted in a quadriceps strain injury. This technique of analysis was available due to the software of Champion Data which enabled all kicks for nominated players in games to be automatically packaged into a digital file.

The limitations of this section of the study included:

1. Many quadriceps injuries had a gradual onset rather than specific onset in one kick.
2. There was *no* known occasion in 2001 where a player who suffered rectus femoris strains kicking in a match apparently felt a sharp tearing sensation and immediately was helped from the field, making the onset of injury obvious. There was one running kicking quadriceps strain in early 2002 where the onset was definite, but unfortunately the kicking motion was not fully captured by the cameras. There was also available one case of running quadriceps injury in a rugby league player and one of a cricketer fielding where that sequence of events followed (player felt sharp pain and was immediately assisted from the field).
3. As mentioned above, even in the few occasions where a specific kick could be isolated as almost certainly causing the injury, the usefulness of the video was dependent on the camera catching a full close-up in roughly sagittal view of the player during the kicking motion.

Video analysis of player kicks associated with twenty-one match-related quadriceps strains in the AFL was gathered and analysed. The 21 videos were also examined by the relevant team medical staff, to discuss with the players whether they could pinpoint the kick involved. There were 2 cases of almost certain acute injury in AFL players kicking captured on video adequately enough to be included as examples in this report (videos 1 and 2). Neither of these was chosen because the player could recall being injured by that particular kick. However, in case 1 (video 1) the injury was reported at the time of recording as a left foot quadriceps strain with a kicking mechanism, and video footage of the game from Champion Data (Melbourne) revealed that this player only took one left foot kick during the game. In case 2 (video 2) the injury was reported as a match-onset kicking-related left quadriceps strain and the player concerned took only 3 kicks during the game in question. The other two, whilst also on the left foot, were short kicks out of a pack with apparently small ground and ball reaction forces. The kick chosen as video 2 however was with a good run-up and is considered typical of the running kick where a quadriceps strain is most common.

Although only 2 AFL quadriceps kicking injury videos are presented as attachments, of all the other AFL kicks examined as possible or definite rectus femoris strains as part of this study, all were kicks ‘on the run’ and therefore none were kicks from a stoppage in play (mark, free kick, kick out etc.). Even though video quality or certainty of the onset of injury does not make these videos relevant as attachments or teaching tools, collectively they add evidence that running kicks regularly result in quadriceps strains whereas standing kicks rarely do.

Two cases of certain rectus femoris strain (one running, one kicking) that occurred in rugby league players were also captured adequately on video and have been included (videos 3 and 4). The kick which resulted in an injury in video 3 was notable as the player concerned was interviewed after suffering this injury and he confirmed the timing of the injury and that a grade 1 rectus femoris strain was shown on an MRI scan ordered by his club doctor [44]. He was the halfback and goal kicker of his team and he was able to continue in the match after suffering this injury, including his duties as a goal kicker. He sustained the injury in an NRL Preliminary Final and was able to play in the Grand Final the following week. He reported that the injury only imposed minor limits on his running play and field kicking and did not bother him at all during goal kicking [44]. In goal kicking, the kick, whilst often over a long distance, is from a standing start, similar to kicks from stoppages in the AFL that are known not to be likely to cause quadriceps strains in AFL players.

In the case of video 4, the player sustained a rectus femoris strain that was widely reported in the media, after he had a sudden onset of severe pain during the incident shown on video. He continued running with the ball for a few seconds after the incident, with a limp, and then was assisted from the field by trainers. The timing of the injury appears to be obviously when he leans back whilst running at top speed to catch an errant pass that had been projected behind him.

A recent quadriceps strain occurring in an international cricketer whilst fielding was captured and is worth mentioning as the mechanism was clearly decelerating from maximum speed in attempting to field the ball before colliding with the boundary rope. This video adds weight to the hypothesized deceleration mechanism of rectus femoris injury. Unfortunately the camera angle of this incident, which was obtained, did not offer a close-up sagittal view at the time of injury and hence this injury is not included as an attachment.

Video analysis of the known rectus femoris strain injuries presented shows similarity between the quadriceps strains occurring during running and those occurring during kicking. The common factor is deceleration of the kicking or standing leg with a relatively short stride. Normally during deceleration the leg providing the loss of momentum overstrides and lands well in front of the body, directing a strong ground reaction force backwards. However, this method cannot be used by the stance leg during a running kick, as the hips would also lower during this manoeuvre and the kicking leg could not swing through without hitting the ground. In fact, the opposite effect is needed, with a slightly short step in order to raise the hips to provide clearance for the kicking leg (see video 5). Analysis of this classic running kick video (where injury did not occur) shows that the dual aims of the penultimate stride with the kicking leg, in running drop punts, are to slow the body down and to raise the height of the hips. As mentioned, slowing the body down usually requires over-striding, to direct ground reaction forces behind the body. However, in order to raise the height of the hips, a shorter than normal step is required. This creates a greater than normal stretch on the rectus femoris as the upper body is inclined slightly backwards when the leg is behind the body.

Although video evidence suggests that the ‘under-stride’ during deceleration is the gross mechanism for rectus femoris strain, like the hamstring strain it is not clear whether the actual muscle failure occurs during the ground contact phase or swing phase. Like the hamstring, the swing phase is associated with the greatest muscle length (stretch), whereas the ground phase is associated with the greatest potential impact of external force (ground reaction force). In contrast to the hamstring strain injury, in rectus femoris strain injury the ground contact phase of risk precedes, rather than follows, the swing phase of greatest stretch.

For comparison a typical acute hamstring injury is shown (video 6). Although most of this video is taken from a camera view that is oblique, the stride where the injury appears to occur is captured in a sagittal view. The still frames of the video during this time clearly show an over-stride of the right hamstring with resulting extra tension on the hamstring muscle group. This is in contrast to the under-stride causing an increase in tension on the rectus femoris, seen in videos 1-4.

Refer to appendix 1 for still video frames and attached videos in .MPEG format for further illustration.

# 3 – Epidemiological analysis of ball pressure, ground hardness and risk of quadriceps strain

## 3.1 Ball pressure and quadriceps strains

The weight and pressure of the football are potentially relevant to the force on the quadriceps muscle during the ball contact phase of a kick. The rules of the game state that the dry weight of the ball when inflated should be between 450 and 500 grams [45]. The home club provides the balls during the regular season and the umpires check the specifications before the game. The pressure measurement guidelines they use are 9-12 psi (0.62-0.82 $km^{-2}$); with 11 psi the most common pressure measurement. The balls are re-checked at half time [46].

In 1975, the laws of soccer were modified to allow for a lowering of the ball pressure from 1.0 to 0.6-0.7 $km^{-2}$ [47]. This was reversed in 1983, so that the laws now allow pressures of 0.6-1.1 $km^{-2}$ [48]. A lowered ball pressure means that the ball deforms more, which increases the time of foot/ball contact (from 6 to 16ms when pressure is lowered from 1.0 to 0.6 $km^{-2}$) [47]. Estimated impact force at ball contact in soccer kicking is 1.0-1.1 kN.

Rebound resilience in soccer balls decreases as inflation pressure decreases [48]. Based on the studies of soccer ball mechanics, it is possible that a lowered inflation pressure of AFL footballs would decrease the peak force on the leg during the ball contact phase of kicking. Both soccer and the AFL allow for a surprisingly wide range of inflation pressures in their laws.

A further consideration is the type of football. The AFL uses leather (stitched) rather than synthetic (moulded) balls. Rugby league changed from leather to synthetic balls over 10 years ago, with an advantage being that synthetic balls do not retain water and become heavy in the wet [49]. As a wet ball would be heavier, there may be a greater susceptibility to any injuries which were related to ball contact, but the ball may be kicked in a different manner on a wet field to compensate for this. Ball contact time may vary between a dry and wet ball.

Stitched footballs have a slower ball contact phase than moulded balls, allowing more time to dissipate force. However, stitched balls become heavier than moulded balls in wet conditions, which increases impact forces [50].

Ball pressures were measured during 80 AFL games in Melbourne during the 2001 season, by the umpires' trainer, at the start of the game and before and after each quarter.

During these 80 matches, 8 players sustained quadriceps strains. The average ball pressures during the games are listed below:

| Quad strain during game? | Matches | Average ball pressure (Psi) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1st quarter | | 2nd quarter | | 3rd quarter | | 4th quarter | | Spare balls | |
| | | Start | End | Start | End | Start | End | Start | End | 1 | 2 |
| Yes | 8 | 10.88 | 10.50 | 10.88 | 10.79 | 10.94 | 10.79 | 10.94 | 10.79 | 12.56 | 12.50 |
| No | 72 | 10.99 | 10.61 | 11.00 | 10.74 | 10.99 | 10.79 | 11.00 | 10.95 | 12.29 | 12.43 |

**Table 3.1 - relationship between ball pressures and quadriceps strains**

There was very little variation in ball pressure during AFL matches. The vast majority of AFL matches and AFL quarters started with a ball pressure of 11 psi, as the umpires were instructed to inflate balls to this pressure. The balls lost very little pressure, on average, during quarters. At the end of each quarter the balls were either replaced (rotated) or re-inflated.

There was a much greater range in the pressures of balls before checking by the umpires, and generally the pressures were much higher. This suggests that clubs do not have the same scrutiny for checking ball pressures as umpires. This may be relevant for quadriceps strains which occur during training.

Because epidemiological study shows that quadriceps strains are more common in matches where there has been low rainfall over the previous week, a ground contact rather than a ball contact mechanism is the likely injury mechanism [9]. This is because that if quadriceps strains occurred during ball contact, it would be expected that these injuries would be more common on wet days, when the ball may be heavier.

If a rectus femoris strain injury occurred during the ball contact phase of kicking, it would be when the muscle was in a relatively shortened state, inactive and shortening further [29], apparently conditions where muscle is able to withstand greater force [8]. A comparative set of conditions in the upper limb, where the shortening triceps muscle is resisted by the ball when serving or spiking in volleyball, does not lead to muscle strain injury.

The data presented in this section, in combination with section 5, provides evidence that ball reaction forces are not the likely cause of quadriceps strain. This will be summarised further in section 6.

### 3.2 Penetrometer readings and quadriceps strains

Analysis of Penetrometer readings and the onset of match related quadriceps strains, over the period 1999-2001 inclusive, suggests minimal relationship, if any, between ground hardness and quadriceps strain injury. This suggests that the association between quadriceps strains and dry weather may be related to increased traction rather than increased hardness [51]. The findings with respect to quadriceps strains are very similar to those for knee ACL injuries, groin injuries and others, that are known to be related to warmer weather [42]. However, the relationship between these injuries and ground hardness, as measured by Penetrometer, is very weak, suggesting that another ground related variable is involved.

| Penetrometer reading | Harder (2.5 or less) | Medium (2.6 - 3.0) | Softer (3.1 or greater) |
|---|---|---|---|
| Matches with this reading | 184 | 243 | 226 |
| Quadriceps strains occurring | 9 | 18 | 9 |
| Quadriceps strains match incidence (injuries per 1000 player hours) | 0.8 | 1.3 | 0.7 |

**Table 3.2 – relationship between Penetrometer readings and quadriceps strains**

# 4 – Kinematic and kinetic comparison of sprinting, standing kicking and running kicking

## 4.1 Introduction

### 4.1.1 Aims

The aims of this project component were to:

- Identify kinetic and kinematic parameters of the AFL drop punt kick,
- Compare these parameters with those observed in sprinting,
- Estimate the strain in selected lower limb muscles including RF, and
- Correlate the kicking skill with potential for injury.

## 4.2 Methods

### 4.2.1 Development of Methods

A model was written using the Vicon BodyBuilder ™ code to determine in three dimensions:

- Segment kinematics - foot, shank, thigh and pelvis
- Joint kinematics - ankle, knee and hip
- Joint kinetics - moments and powers at the ankle, knee and hip

  The model uses as input:
- The coordinates of markers placed on the foot, shank, thigh and pelvis with respect to time during a kicking skill
- Anthropometric data for the foot, shank, thigh and pelvis. These allow for the estimation of segment masses and moments of inertia. These are necessary for inverse dynamics calculation of joint kinetics
- Ground reaction force data including centre of pressure.

Trials were undertaken at UNSW using a Vicon system 370 that operates at 50 Hz. Data collected during these trials were applied to the model in order to calibrate and test the model. It was realised that the video sample rate was too low to capture the movement data accurately. The preliminary trials were successful in preparing and testing the model.

A second model was written in Matlab™ to determine the length of selected muscles in the lower limb. A literature survey was undertaken to determine the most suitable algorithm to estimate muscle length and strain [17-19]. Calculation of muscle length and strain was performed using the following general algorithm:

$$L = C0 + C1\alpha + C2\beta + C3\beta^2 + C4\phi$$

Where L = muscle length, and $\alpha$, $\beta$ and $\phi$ are the hip, k nee and ankle angles; and the algorithm coefficients for biceps femoris (BF) rectus femoris (RF) vastus medialis (VM) and gastrocnemius (GAS) are:

| | $C_0$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ |
|---|---|---|---|---|---|
| BF | 1.048 | 2.09E-3 | 1.99E-3 | 0 | 0 |
| RF | 1.107 | -1.50E-3 | 1.99E-3 | 0 | 0 |
| VM | 0.489 | 0 | 3.07E-3 | -1.53E-3 | 0 |
| GAS | 0.9 | 0 | -6.20E-3 | 0 | 2.14E-3 |

### 4.2.2 Subjects

Six skilled AFL players (grade 1) formed the subject cohort for this study.

### 4.2.3 Procedures

Tests were conducted at the Biomechanics Laboratory of the Australian Institute of Sport, Canberra. Each subject was asked to perform the following skills:

a) Running kick (RK)
b) Set kick (SK)
c) Maximum Sprint (MS).

Seven repeat trials for each skill were recorded.

A Vicon™ system employing six high speed (200Hz) cameras was used to obtain the coordinates of optical markers and acquire analog data. Three Kistler™ force plates were used to measure ground reaction forces as part of a Vicon™ system. Ground reaction force data were obtained at 1,000 Hz.

#### 4.2.4 Analysis

Marker coordinate and ground reaction force data were input into the BodyBuilder model. The joint angle data calculated in this model were applied to a second model in Matlab to calculate muscle length. The data were normalised to three phases of the kicking cycle in order to average and compare between individuals.

### 4.3 Results

The subjects (age 23 ± 3 y.o., height 1.8 ± 0.04 m and mass 80 ± 2 Kg.), were right foot kickers except for one.

Task executions were divided into three phases. Phase 1 is the ground phase, which includes heel strike to toe-off of the dominant foot. Phase 2 starts at toe-off to maximum knee flexion. Phase 3 from maximum knee flexion to ball impact for kicking and knee extension for sprinting. Data were time normalised for each phase for each task per subject. Normalised data were averaged among subjects. Averaged time normalised data for hip and knee flexion, hip and knee moments and RF strain are presented in figures 4.1 – 4.5. A complete set of data is presented in appendix 2.

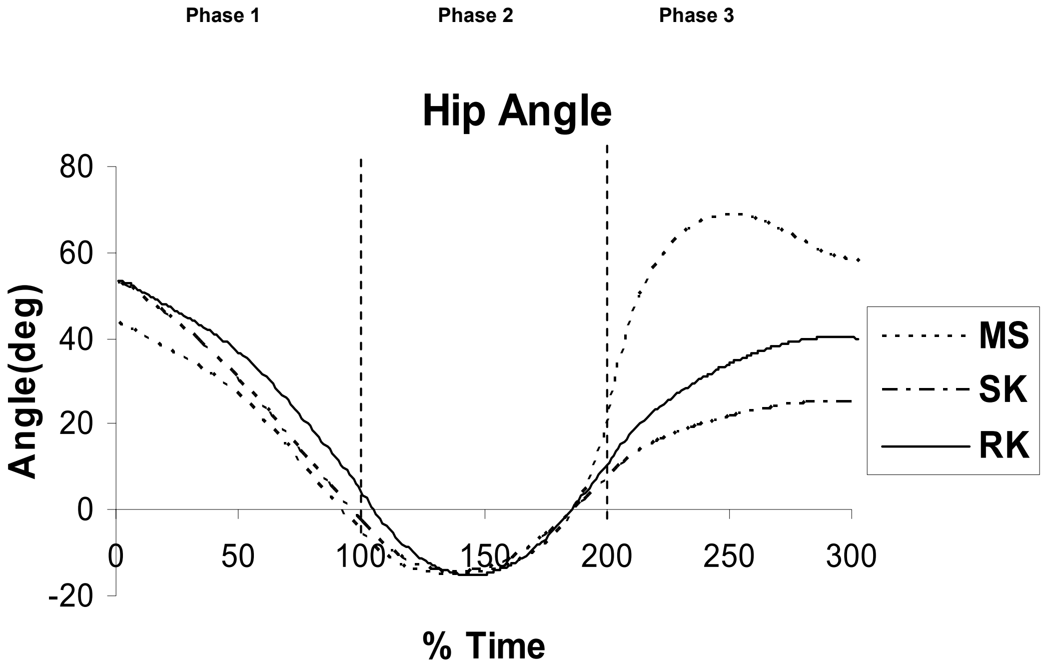


Figure 4.1

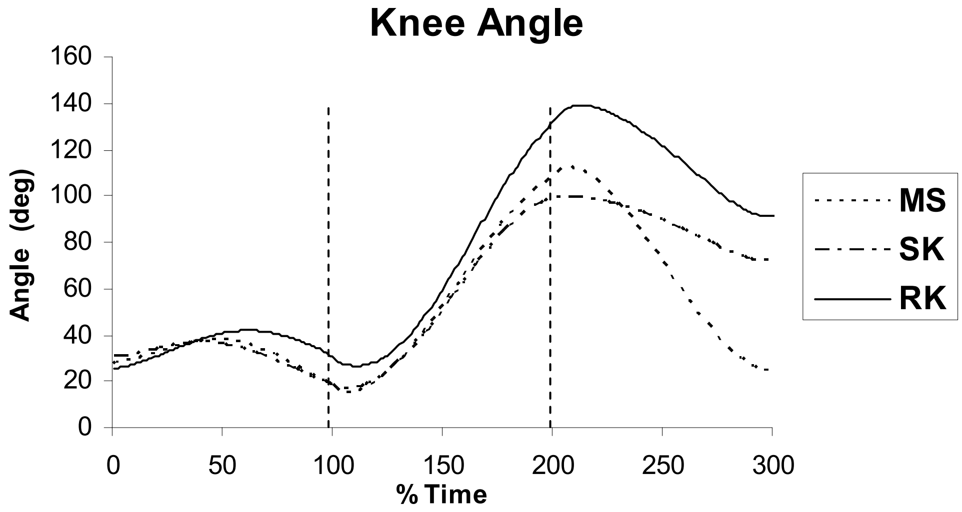


Figure 4.2

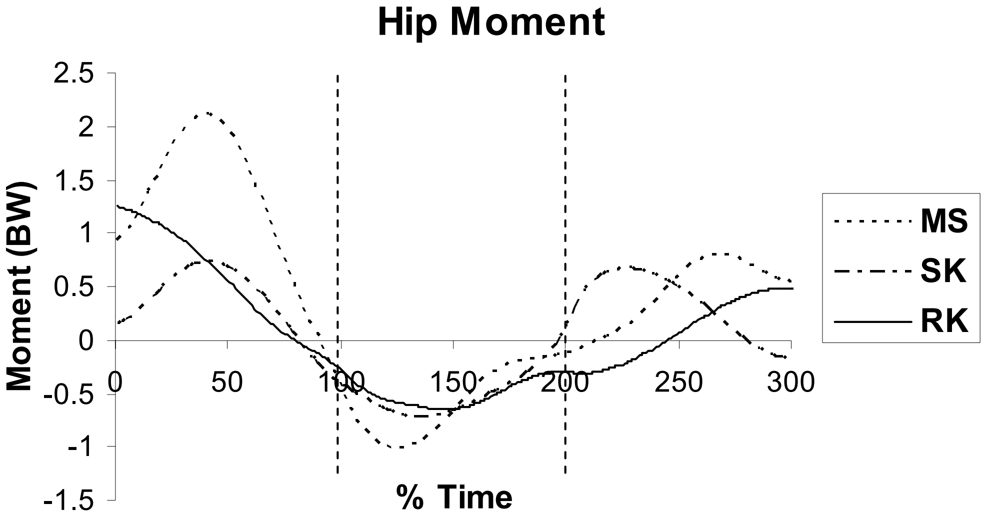


Figure 4.3

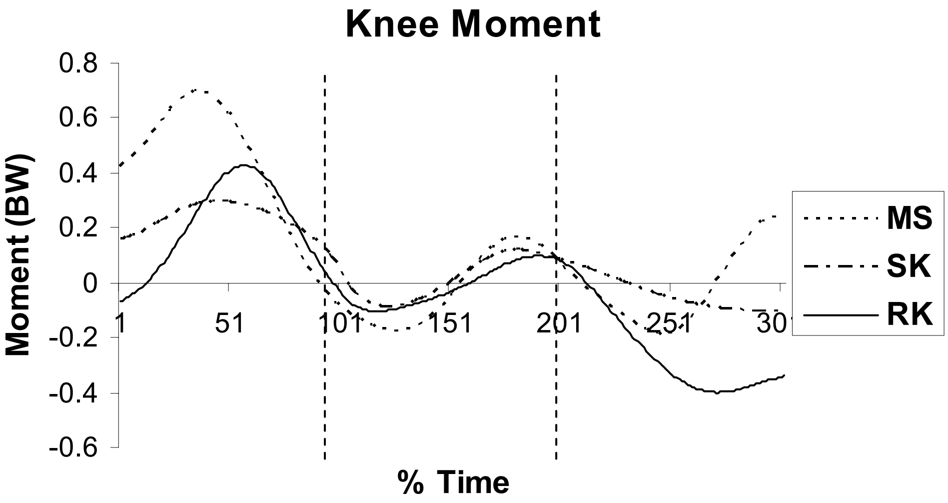


Figure 4.4

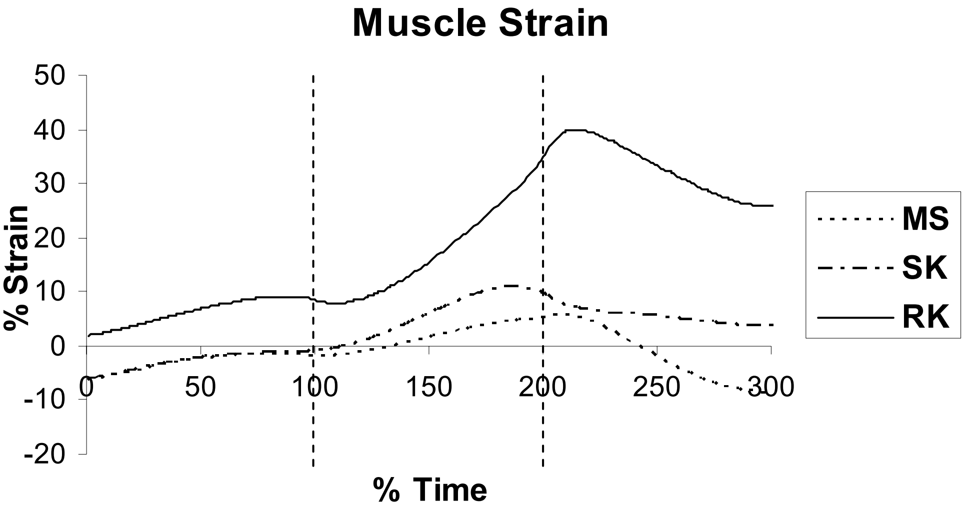


Figure 4.5

**Figures 4: Averaged and phase normalised (4.1) Hip and (4.2) Knee Angles; (4.3) Hip and (4.4) Knee Moments expressed in body weights (BW); and (4.5) Rectus Femoris (RF) strain expressed as a percentage of resting length. Negative strain represents shortening and positive strain lengthening. Negative joint moment refers to flexion. Positive moment to extension.**

## 4.4 Discussion

The differences in the joint angle progression for the three tasks are not significant ($p = 0.60$), except for phase 3. There is a greater degree of hip flexion and less of knee flexion during the maximum sprint task. This suggests that the strains to which muscles are subjected during this phase are less for a maximum sprint task than for both forms of kicking. RF strain is significantly larger for a running kick than for a set kick. This was expected as the knee flexion is greater in a running than in a set kick. Furthermore, the range of the leg swing phase, from maximum knee flexion to impact, is significantly less in a set kick relative to a running kick. Knee moments, flexion and extension, are as a consequence larger in running than in set kicks.

The combination of knee moment and muscle length in phase 3 of the running kick implies a greater risk of injury during the forward swing of the kicking leg during a running kick. This however needs to be further investigated along with other factors such as past injuries, fatigue, muscle fibre type and training status. The exact muscle injury mechanism and magnitude of force or strain required to damage the muscle are not well understood *in vivo*.

# 5 – Kinematic analysis of the relationship between ball-foot contact and ball conditions

## 5.1 Introduction

This study was conducted to examine the impact forces provided by the ball and the relationship to ball pressure and mass (which is primarily affected by wetness). Further, the more realistic environment allowed for targeted kicks to specific distances. In turn it was anticipated that this would provide for more accurate comparison between kicks and kickers. A two-dimensional high speed (1000 hertz) analysis of the ball-foot contact phase was taken as the previous section tests had shown that the movement was predominantly in the sagittal plane, but that the ball contact time was very brief.

### 5.1.1 Aims

The aims of this project component were to:

- Identify kinematic parameters of the AFL drop punt kick in more realistic, goal oriented kicks,
- Compare these parameters with those observed in sprinting,
- Compare kicking patterns and leg loading situations with balls of different inflation pressures and wet balls,
- Estimate the strain in selected lower limb muscles including RF, and
- Correlate the kicking skill with potential for injury.

## 5.2 Methods

### 5.2.1 Development of Methods

A model was written Excel and Matlab to determine in two dimensions:

- Segment kinematics - foot, shank and thigh
- Joint kinematics - ankle, knee and hip
- Ball displacement, velocity and acceleration during kick
- Ball-foot force estimates during kick

  The model uses as input:

- The coordinates of markers placed on the foot, shank, thigh and pelvis with respect to time during a kicking skill. Data were recorded at 50 frames per second using a Sony DV Cam camera.
- Anthropometric data for the foot, shank and thigh.
- Coordinates of the ball recorded using a high speed digital camera capturing at 1,000 frames per second.

Trials were undertaken at UNSW using a Sony DV Cam camera and Phantom high speed digital camera that operate at 50 Hz and 1,000 Hz respectively. Data collected during these trials were first applied to the models in order to calibrate and test the model.

### 5.2.2 Subjects

Three skilled AFL players (First Grade, Sydney AFL) formed the subject cohort for this study.

### 5.2.3 Procedures

Tests were conducted on the Village Green at UNSW (figures 1 to 4). These were carried out over a three day period during the middle of the Australian Rules football season. Two research assistants conducted and coordinated the experiments and additional staff assisted with the set up and testing of the equipment. Trials were videotaped and a KMS system was used to measure running speed. Ball pressure was controlled (9 or 12 pounds per square inch) and one ball, inflated to 12 psi, was soaked in a bucket of water to simulate a very wet ball. Witches hats were used to indicate 20 and 40 metre marks from the kick zone.

During testing, each subject was asked to perform the following skills:

(a) Running kick (RK),
(b) Set kick (SK) and
(c) Maximum Sprint (MS).

Table 5.1 is the test matrix for the experiments.

| Test Group | Running Speed | Kick distance (m) | Ball condition |
|---|---|---|---|
| 1 | Medium | N/A | N/A |
| 2 | Fast | N/A | N/A |
| 3 | Medium | 40 | 9psi |
| 4 | Medium | 40 | 12psi |
| 5 | Medium | 40 | Wet |
| 6 | Fast | 40 | 9psi |
| 7 | Fast | 40 | 12psi |
| 8 | Fast | 40 | Wet |
| 9 | Fast | 20 | 9psi |
| 10 | Fast | 20 | 12psi |
| 11 | Fast | 20 | Wet |

**Table 5.1: Test matrix for the Village Green experiments**

**Analysis**

A log of each experiment was maintained during the trials. Once the trials were finished the following procedures were undertaken:

i. Transfer of digital video onto a PC using fire wire technology
ii. Conversion of Phantom digital video into avi format.
iii. Scaling of digital video into real world coordinates
iv. Digitisation of coordinates of body and ball markers using WinAnalyze ™
v. Compilation of data sets
vi. Filtering of data (body coordinates at 10 Hz cut off frequency & ball coordinates at 100 Hz cut off frequency)
vii. Calculation of leg kinematics, muscle lengths, ball kinematics and ball-foot forces
viii. Cross checking of data was carried out, eg. comparing computed kicking distance using ball's velocity to actual kick distance and comparing measured joint or segment angle with video
ix. Graphing of data and preparation of tables of biomechanical parameters.

## 5.3 Results

### 5.3.1 Subject Details

| Subject ID | Height | Mass | Grade | Competition |
|---|---|---|---|---|
| BK | 180 | 71 | 1 | SFA |
| TA | 191.1 | 85.1 | 1 | SFA |
| SH | 180 | 80.7 | 1 | SAFL |

### 5.3.2 Gross Running Speed during Experiments

Just Before the Kick (speed m/s)

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BK | 7.06 | 8.00 | 6.97 | 6.61 | 6.43 | 7.37 | 7.46 | 7.37 | 7.31 | 7.19 | 7.12 |
| TA | 6.73 | 8.42 | 5.61 | 5.84 | 5.52 | 6.99 | 6.86 | 6.57 | 6.09 | 6.20 | 6.32 |
| SH | 5.49 | 7.27 | 5.20 | 5.29 | 5.04 | 6.56 | 6.69 | 6.26 | | | |
| Mean | 6.43 | 7.90 | 5.93 | 5.91 | 5.66 | 6.97 | 7.01 | 6.73 | 6.70 | 6.70 | 6.72 |
| SD | 0.83 | 0.58 | 0.93 | 0.67 | 0.71 | 0.40 | 0.40 | 0.57 | 0.86 | 0.70 | 0.56 |

Just After the Kick (speed m/s)

| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BK | 7.18 | 8.50 | 6.03 | 5.70 | 5.58 | 6.26 | 6.11 | 5.86 | 6.21 | 6.27 | 6.43 |
| TA | 6.80 | 8.39 | 5.36 | 5.82 | 5.29 | 5.96 | 5.68 | 6.83 | 6.06 | 6.22 | 6.40 |
| SH | 5.59 | 7.69 | 4.89 | 4.22 | 4.67 | 5.87 | 5.92 | 6.03 | | | |
| Mean | 6.52 | 8.19 | 5.43 | 5.25 | 5.18 | 6.03 | 5.90 | 6.24 | 6.14 | 6.25 | 6.41 |
| SD | 0.83 | 0.44 | 0.58 | 0.89 | 0.46 | 0.20 | 0.21 | 0.52 | 0.11 | 0.04 | 0.02 |

**Tables 5.2 & 5.3: Running speeds during trials.**

The data show running speed variation between individuals and reduction in running speed that occurs during the kick (conditions 3 to 11). The average reduction in speed was 0.5 m/s. For the running only trials, the player's speed was maintained or even slightly increased through the three sets of timing gates.

### 5.3.3 Kinematics of Kicks

In order to provide a descriptive reference for the segment and joint angle data, images from the 50 Hz digital video of body postures at typical phases during the kicking cycle are presented in Appendix 3.

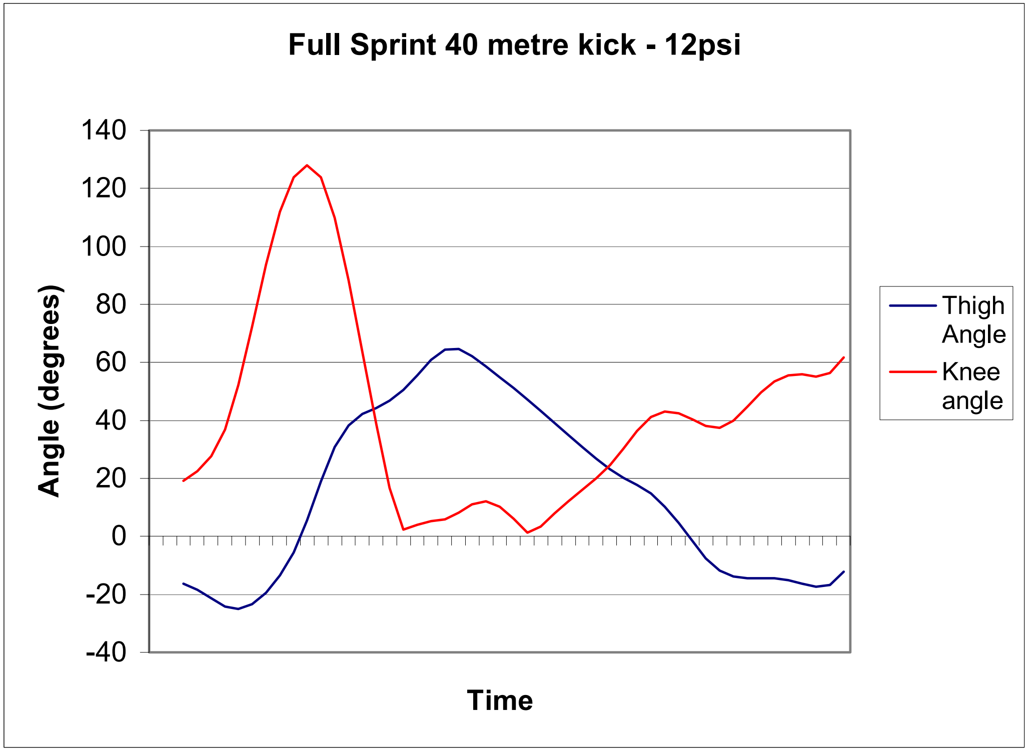


**Figure 5.1: Joint angles during sample running kick**

It can be seen that even after videoing the ball using a sample rate of 1,000 frames per second, that the duration of ball-foot contact is only 10-15 ms. With these small samples of data, eg. 30-40 data points, the filtering creates errors at the beginning and end of the time series. It would be expected that the ball's acceleration once ball-foot contact had finished would be approximately -10 $m/s^2$ in the vertical direction and 0 $m/s^2$ in the horizontal direction. This is clearly not the case. Partly in response to this and to provide a more direct comparison with other authors, the average ball acceleration was calculated using the velocity pre and post ball-foot contact. In this way, the affects of non rigid body motion of the ball, eg. ball deformation and elastic behaviour during the kick, on subsequent calculations are reduced. The means and standard deviations for each kicking condition for average ball-foot force are presented in table 5.4. The means and standard deviation for maximum ball force are presented in table 5.5.

| Running speed | Kicking distance | Ball condition | | | |
|---|---|---|---|---|---|
| | | 9psi | 12psi | Wet | |
| fast | 20m | 1160 | 1292 | 1689 | ξ |
| | | 130 | 255 | 168 | SD |
| fast | 40m | 1582 | 1703 | 2186 | ξ |
| | | 776 | 187 | 352 | SD |
| medium | 40m | 1592 | 1687 | 2146 | ξ |
| | | 215 | 153 | 244 | SD |

**Table 5.4: Estimates of max resultant force on ball (mean and SD) for each condition**

| | | | Force x | Force y | Resultant Force |
|---|---|---|---|---|---|
| 3 | 9 psi | Average | 705 | 670 | 977 |
| | | SD | 98 | 120 | 111 |
| 4 | 12 psi | Average | 774 | 721 | 1066 |
| | | SD | 132 | 95 | 66 |
| 5 | 12 psi Wet | Average | 828 | 1008 | 1304 |
| | | SD | 80 | 97 | 123 |
| 6 | 9 psi | Average | 757 | 790 | 1101 |
| | | SD | 222 | 216 | 269 |
| 7 | 12 psi | Average | 762 | 715 | 1051 |
| | | SD | 197 | 81 | 195 |
| 8 | 12 psi Wet | Average | 893 | 1053 | 1392 |
| | | SD | 98 | 413 | 368 |
| 9 | 9 psi | Average | 756 | 691 | 1031 |
| | | SD | 40 | 23 | 46 |
| 10 | 12 psi | Average | 692 | 510 | 869 |
| | | SD | 154 | 122 | 146 |
| 11 | 12 psi Wet | Average | 857 | 651 | 1082 |
| | | SD | 220 | 64 | 189 |

**Table 5.5: Estimate of average ball-foot force during kick.**

## 5.4 Discussion

This section reveals that the peak and average ball-foot impact forces are significant (approximately 2 times body weight) although they are still less than the average ground reaction forces in sprinting. Of most interest is that the major variations in ball-foot impact forces are due to (1) distance kicked and (2) weight of the ball based on state of wetness. That is, the impact forces in kicking a wet ball are significantly greater than kicking a dry ball and the impact forces kicking a long kick are significantly greater than kicking a short kick.

These findings, when compared to epidemiology and anecdotal data, are strong evidence that quadriceps strains are *not* caused by the ball-foot impact forces. Quadriceps strains are more common on days when there has been recent dry weather rather than wet weather [9] and they are more common in running short kicks than long kicks from a stoppage. If quadriceps strains were caused by ball-foot impact forces, the opposite findings would be expected.

The ball-foot impact forces may possibly be relevant for other injuries, most notably groin tendinopathies, although the relationship between the forces and these injuries is beyond the scope of this study.

With respect to the ball-foot impact, Alexander and Holt have concluded that more efficient transfer of momentum from the foot to the ball occurred when contact was made with the ankle region rather than the metatarsals [52]. Plangenhoef reported a case of a punter who lost distance when wearing a shoe which prevented full plantar flexion at the ankle, suggesting that this was also important with respect to efficient transfer of force [53]. Macmillan found that angular velocity of the leg determined foot velocity, which would correlate with distance kicked given efficient transfer of force [54]. Large angular velocities of the leg are achieved by rapid extension of the knee, assisted by a more gradual flexion of the hip. The prime movers of these movements are the quadriceps muscles with the chief antagonists being the hamstrings. Theoretically the momentum imparted to the ball could be increased by increasing the tangential velocity at the foot, e.g. increasing the shank length or increasing the shank's angular velocity.  The stabilisation of the ankle in plantar flexion effectively increases the shank length.

We found that a lower pressure of ball inflation decreased impact forces, similar to previous studies which showed that lower inflation pressure increases deformation and contact time [47] which would decrease peak retarding torque. However our study showed that ball weight (which increased when the ball was wet for a leather ball) was a greater determinant of impact forces than ball inflation pressure.

# 6 – CONCLUSIONS AND RECOMMENDATIONS

There is strong evidence that quadriceps strains do *not* occur during the ball contact phase, including the following:

1. Ground reaction forces in kicking are greater than ball reaction forces.
2. Speed of running during a kick (which relates to ground reaction forces) is a greater risk for quadriceps injury than distance kicked (which relates to ball reaction forces) in Australian football.
3. In other sports, the relative risks follow the same patterns (e.g. running passes in soccer = higher risk, punting from a standing start in the NFL = low risk, goal kicking in rugby = low risk).
4. Deceleration during running (without ball involvement) can cause a rectus femoris strain.
5. The action of the kicking leg in a running kick (during the final step and back-swing) is similar to a deceleration movement in running, and hence the timing of injury is probably the same in both.
6. Ball impact forces are greater on wet days when the risk of quadriceps strain is not higher.
7. Ball pressure does not correlate with risk of quadriceps strain.
8. Basic science studies suggest that stretch (muscle length) is an important determinant of muscle failure during a strain injury. The rectus femoris is not stretched during ball contact.
9. Upper limb muscles during swing phases that are retarded by a ball in a similar manner to rectus femoris (e.g. the triceps during volleyball serving) do not commonly strain.

The following table summarises the likely biomechanical environment for the three most common lower limb muscle strain injuries.

| | **Hamstring** | **Rectus femoris** | **Gastrocnemius** |
|---|---|---|---|
| Highest risk movement | Over striding during maximum velocity | Under striding during deceleration (esp. kicking on the run) | Single contact phase at mid second stride of push-off |
| Body position | Forward lean | Backward lean | Forward lean |
| Upper joint position | Flexed hip | Extended hip | Extended knee |
| Lower joint position | Extended knee | Flexed knee | Dorsi-flexed ankle |
| Maximal strain/stretch occurs | Late swing phase | Early backswing | Pre-take-off single leg support |
| Maximal tension/stress occurs | Early ground contact phase | Late ground contact phase | Pre-take-off single leg support |

**Table 6.1 – Parameters influencing two-joint muscles during movements at high risk for muscle strain injury**

## Conclusions

1. Quadriceps strains are most likely during decelerations movements during a drop punt kick. The kicks most at risk are those which involve rapid steps in the run-up.
2. Ball contact is not the likely mechanism of quadriceps strain (see start of this section for detail).
3. Players most at risk are those players with a recent or past history of quadriceps strain, and shorter players who are most likely to perform quick running kicks.
4. Quadriceps strains are almost as likely during training sessions as matches. They are the fourth most common injury overall and the second most common training injury (after hamstring strains).
5. Quadriceps strains are more common when there has been low recent rainfall, although this probably relates to increase shoe-surface traction rather than ground hardness.
6. Fatigue and repetition may be a risk factor for quadriceps strains, based on anecdotal evidence from players, and the theoretical concern that a fatigued quadriceps is more likely to lead to an under-stride.

## Recommendations

1. Drills at training in which rapid repetitive kicks on the run are required should be considered high-risk situations for quadriceps injuries, and should only be undertaken with special caution by players returning from a hamstring or quadriceps injury.
2. Kicking on the run, which must be examined in a biomechanical investigation into quadriceps injuries, can only be adequately analysed by high-speed equipment (at least 200 hertz for body movements and 1000 hertz for ball-foot impact analysis).
3. Prevention of quadriceps strains involves both ground maintenance to avoid surfaces offering excessive traction (similar prevention to knee ACL injuries) and avoidance of excessive use of high-risk training drills.
4. Despite ball contact not being likely to be the mechanism of quadriceps strains, it is recommended that clubs regularly monitor the pressure of all balls before training sessions to make sure that ball pressure is within the prescribed limits.

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## 6.2 - PUBLICATIONS

Raul Landeo has presented an abstract at the ABC4 conference in Melbourne in November 2002. John Orchard presented a keynote address at the New Zealand Sports Medicine conference in Christchurch in November 2002. Both these presentations acknowledged this study and the AFL R & D Board. John Orchard has submitted his presentation for publication in the New Zealand Journal of Sports Medicine. Raul Landeo will submit his presentation as a full paper to a peer-reviewed Biomechanics/Sports Science journal. Both of these publications will acknowledge the AFL R & D Board. Sections of this report will be submitted as abstracts to the Football Australasia Conference in Melbourne in September 2003.

# 7 - References

1. Ryan, A., *Quadriceps strain, rupture and charlie horse.* Med Sci Sports Exerc, 1969. **1**(2): p. 106-111.
2. Orchard, J., et al., *Comparison of injuries in elite senior and junior Australian football.* J Sci Med Sport, 1998. **1**(2): p. 83-8.
3. Gibbs, N., *Common rugby league injuries. Recommendations for treatment and preventative measures.* Sports Med, 1994. **18**(6): p. 438-50.
4. Fried, T. and G.J. Lloyd, *An overview of common soccer injuries. Management and prevention.* Sports Med, 1992. **14**(4): p. 269-75.
5. Orchard, J. and H. Seward, *Epidemiology of injuries in the Australian Football League, seasons 1997-2000.* British Journal of Sports Medicine, 2002. **36**: p. 39-45.
6. Hawkins, R.D. and C.W. Fuller, *A prospective epidemiological study of injuries in four English professional football clubs.* Br J Sports Med, 1999. **33**(3): p. 196-203.
7. Best, T.M., *Soft-tissue injuries and muscle tears.* Clin Sports Med, 1997. **16**(3): p. 419-34.
8. Garrett, W.E., Jr., *Muscle strain injuries.* Am J Sports Med, 1996. **24**(6): p. S2-8.
9. Orchard, J., *Intrinsic and extrinsic risk factors for muscle strains in Australian footballers.* Am J Sports Med, 2001: p. 300-303.
10. Lieber, R.L. and J. Friden, *Muscle damage is not a function of muscle force but active muscle strain.* Journal-of-applied-physiology-(Bethesda,-Md.); 74(2), Feb 1993, 520-526 Refs:26, 1993. **74**(2): p. 520-526.
11. Noonan, T., et al., *Identification of a Threshold for Skeletal Muscle Injury.* American Journal of Sports Medicine, 1994. **22**(2): p. 257-261.
12. Best, T., et al., *Axial Strain Measurements in Skeletal Muscle at Various Strain Rates.* Journal of Biomechanical Engineering, 1995. **117**: p. 262-265.
13. Brooks, S. and J. Faulkner, *Severity of contraction-induced injury is affected by velocity only during stretches of large strain.* J Appl Physiol, 2001. **91**: p. 661-666.
14. Mann, R. and P. Sprague, *A kinetic analysis of the ground leg during sprint running.* Research Quarterly, 1980. **51**: p. 334-348.
15. Mann, R. and J. Hagy, *Biomechanics of walking, running and sprinting.* American Journal of Sports Medicine, 1980. **8**(5): p. 345-350.
16. Novacheck, T.F., *Walking, running, and sprinting: a three-dimensional analysis of kinematics and kinetics.* Instr Course Lect, 1995. **44**: p. 497-506.
17. Gerritsen, K., et al., *Intrinsic muscle properties facilitate locomotor control - a computer simulation study.* Motor Control, 1998. **2**: p. 206-220.
18. Grieve, D., S. Pheasant, and P. Cavanagh, *Prediction of gastrocnemius length from knee and ankle joint posture*, in *Biomechanics VI-A*, Asmussen and Jorgensen, Editors. 1978, University Park Press: Baltimore. p. 405-412.
19. Hawkins, D. and M. Hull, *A method for determining lower extremity muscle-tendon lengths during flexion/extension movements.* Journal of Biomechanics, 1990. **23**: p. 487-494.
20. Wood, G., *Biomechanical limitations to sprint running.* Medicine and Sports Sciences, 1987. **25**: p. 58-71.

21. Orchard, J., et al., *Exact moment of a gastrocnemius muscle strain captured on video.* British Journal of Sports Medicine, 2002. **36**(3): p. 222-223.
22. Agre, J.C., *Hamstring injuries. Proposed aetiological factors, prevention, and treatment.* Sports Med, 1985. **2**(1): p. 21-33.
23. Brukner, P., K. Khan, and P. Coburn, *Predisposing factors in hamstring strain*, in *Clinical Sports Medicine*, P. Brukner and K. Khan, Editors. 2001, McGraw Hill: Sydney. p. 412-413.
24. Garrett, W.E., Jr., *Muscle strain injuries: clinical and basic aspects.* Med Sci Sports Exerc, 1990. **22**(4): p. 436-43.
25. Radin, E., S. Simon, and R. Rose, *Practical Biomechanics for the Orthopaedic Surgeon*. 1979, New York: John Wiley.
26. Zarins, B. and J.V. Ciullo, *Acute muscle and tendon injuries in athletes.* Clin Sports Med, 1983. **2**(1): p. 167-82.
27. Krejci, V. and P. Koch, *Muscle and Tendon injuries in Athletes*. 1979, Chicago: Yearbook Medical Publishers.
28. Mero, A., P. Komi, and R. Gregor, *Biomechanics of Sprint Running: A Review.* Sports Medicine, 1992. **13**(6): p. 376-392.
29. Orchard, J., et al. *Muscle activity during the drop punt kick*. in *Fourth World Congress of Science and Football*. 1999. Sydney.
30. Mann, R.V., *A kinetic analysis of sprinting.* Med Sci Sports Exerc, 1981. **13**(5): p. 325-8.
31. Belli, A., H. Kyrolainen, and P. Komi, *Moment and Power of Lower Limb Joints in Running.* Int J Sports Med, 2002. **23**: p. 136-141.
32. Garrett, W.E., et al., *Biomechanical comparison of stimulated and nonstimulated skeletal muscle pulled to failure.* American Journal of Sports Medicine, 1987. **15**: p. 448-454.
33. Magnusson, S., et al., *Passive tensile stress and energy of the human hamstring muscles in vivo.* Scandinavian Journal of Medicine & Science in Sports, 2000. **10**: p. 351-359.
34. Froimson, A.I., *Tennis leg.* JAMA, 1969. **209**(3): p. 415-6.
35. Kurokawa, S., T. Fukunaga, and S. Fukashiro, *Behaviour of fascicles and tendinous structures of human gastrocnemius during vertical jumping.* J Appl Physiol, 2001. **90**: p. 1349-1358.
36. Speer, K.P., J. Lohnes, and W.E. Garrett, Jr., *Radiographic imaging of muscle strain injury.* Am J Sports Med, 1993. **21**(1): p. 89-95; discussion 96.
37. Rask, M.R. and G.J. Lattig, *Traumatic fibrosis of the rectus femoris muscle. Report of five cases and treatment.* Jama, 1972. **221**(3): p. 268-9.
38. Hughes, C.t., et al., *Incomplete, intrasubstance strain injuries of the rectus femoris muscle.* Am J Sports Med, 1995. **23**(4): p. 500-6.
39. Hasselman, C.T., et al., *An explanation for various rectus femoris strain injuries using previously undescribed muscle architecture.* Am J Sports Med, 1995. **23**(4): p. 493-9.
40. Orchard, J., *Sydney Roosters Medical Report*. 2001: Sydney.
41. Bennett, D., *Personal Communication*. 2000: NFL player, San Diego.
42. Orchard, J., *The 'northern bias' for injuries in the Australian Football League.* Australian Turfgrass Management, 2000. **23**(June): p. 36-42.
43. Orchard, J. and T. Best, *The management of muscle strain injuries: An early return versus the risk of recurrence.* Clinical Journal of Sport Medicine, 2002. **12**: p. 3-5.
44. Johns, A., *Personal Communication*. 2001: Rugby League player, Newcastle.

45. NAFC, *Laws of Australian Football*. 1993, Melbourne: National Australian Football Council.
46. Geischen, J., *Personal Communication*. 2001: AFL Umpriring Director, Melbourne.
47. Barfield, W., *The Biomechanics of Kicking in Soccer.* Clinics in Sports Medicine, 1998. **17**(4): p. 711-728.
48. Holmes, G. and M. Bell, *The Effect of Football Type and Inflation Pressure on Rebound Resilience.* Journal of the Sports Turf Research Institute, 1985. **61**: p. 132-135.
49. Gould, P., *Personal Communication*. 1999: Rugby League coach, Sydney.
50. Levendusky, R., et al., *Impact characteristics of two types of soccer balls*, in *Science and Football*, T. Reilly, A. Lees, and K. Davids, Editors. 1988, E & FN Spon: London.
51. Orchard, J., *Is there a relationship between ground and climatic conditions and injuries in football?* Sports Med, 2002. **32**(7): p. 419-432.
52. Alexander, A. and L.E. Holt, *Punting, a cinema-computer analysis.* Scholastic Coach, 1974. **43**: p. 14-16.
53. Plangenhoef, S., *Patterns of Human Motion: A Cinematographic Analysis.* 1971, Englewood Cliffs, New Jersey: Prentice-Hall. 98-105.
54. Macmillan, M.B., *Kinesiological determinants of the path of the foot during the football kick.* Research Quarterly, 1976. **47**: p. 33-40.