The AFL Penetrometer Study: Work in Progress

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Five hundred and seventy one matches in the Australian Football League [AFL] had ground hardness measured using a Penetrometer, over the period 1997-2000. The method used was 3 drops at each of 20 locations over the playing field on the morning before games. Anterior Cruciate Ligament [ACL] injuries were recorded using an ongoing injury surveillance system. There was a non-significant trend towards a higher risk of ACL injury when the 3-drop average of the Penetrometer was less (harder) than 4.5cm, RR 2.36 (95% CI 0.90-6.24). When the first drop average of the Penetrometer was less (harder) than 2.5cm, the relative risk was 2.60 (95% CI 0.94-7.20). There was also a non-significant trend towards an increased risk of ACL injury in games where the predominant grass type was couch (Bermuda) grass, as opposed to rye grass, RR 2.37 (95% CI 0.89-6.36). This study confirms previous findings from the AFL that early season matches and matches played at northern (warmer) venues have a higher risk of ACL injury. It is likely that ground-related variables are partially responsible for these observations, but to date, the relative contributions of ground hardness, grass type, shoe-surface traction and other confounding factors are not certain. There was a significant fall in the number of ACL injuries in the AFL (to approximately half the previous level of incidence) during seasons 1999 and 2000. It is possible that reaction to this study and related publicity has led to the preparation of ground conditions in the AFL that are less likely to produce ACL injuries.

Introduction

Injuries in the Australian Football League (AFL) still result in 15% of listed players being unable to play at any given time, despite the best efforts in injury prevention (Orchard & Seward, 2001). The overall injury rates for teams based in the southern state of Victoria are consistently lower than for teams based in the more northern (warmer) states (Orchard, 2000). The injuries with greatest disparity of incidence due to location are Anterior Cruciate Ligament (ACL) injuries of the knee, and these injuries due to their severity are responsible for a substantial amount of missed playing time. ACL injuries in the AFL are more common on grounds where there has been higher water evaporation over the previous month and lower rainfall over the previous year (Orchard, Seward, McGivern & Hood, 1999). Weather conditions themselves are non-reversible, but it is likely that weather conditions are indirect risk factors that influence ground conditions, which may be reversible risk factors. The ground characteristics considered most likely to be associated with injury risk (particularly to the ACL) are hardness and shoe-surface traction (Ekstrand & Nigg, 1989). Other risk factors that have been identified for ACL injuries in the AFL are first grade matches, previous history of ACL injury and player height (Orchard, Seward, McGivern & Hood, 2001).

The aim of this study has been to use an objective measure of ground hardness to further analyse the relationship between ground conditions and ACL injury rates in the AFL.

Methods

Penetrometer readings

Methods were established for this study based on methods for the measurement of track hardness in the horse racing industry in Australia. The Penetrometer (Gill Engineering, Melbourne) is the most established and reliable technique for measuring track hardness in horse racing and has better correlation with race times than the Clegg hammer (Dr Baden Clegg Pty Ltd, Perth) (Neylan & Stubbs, 1998). Minor changes to methods were made each season as detailed below.

Season 1997

A pilot study was performed by the author at Sydney Swans games in 1997 to develop a method for measuring football ground hardness with the Penetrometer (Orchard, Seward & Garlick, 1997). An average of three shocks (drops), at 20 locations, was taken as the official reading at AFL venues to achieve consistency with the values in horse racing. The 20 locations corresponded to the 18 player positions on the ground, with 2 extra readings taken in the centre square area (see Figure 1). For each location, the Penetrometer was not moved between drops, so that the third drop always gave the highest reading, followed by the second drop then the first. The three-drop average (average of first, second and third drops) was usually slightly lower than the average for the second drop.

Season 1998

For the 1998 season, the AFL purchased Penetrometers for all major venues. Ground managers were asked to measure ground hardness according to protocol developed (see appendix). During the 1998 season, it was noted that there was a universal tendency for cricket pitch areas to be harder than the remainder of the playing surface, lowering the average Penetrometer readings on those grounds with cricket pitches. There was also noted to be a significant positive correlation between rainfall in the 2 weeks prior to the match and Penetrometer reading ($t=3.8$, $p<.001$) and a negative correlation between annual evaporation and Penetrometer reading ($t=-7.5$, $p<.001$) (Orchard, 1999).

Season 1999

The same protocol was followed with two exceptions in the instructions:

1. For grounds with a cricket pitch area, it was specified that no more than 4 readings (out of 20) were to be taken on the cricket surface. For grounds with a large cricket pitch area, if necessary, some of the centre square positions were to be changed slightly to avoid the cricket surface.
2. Ground staff were encouraged to be active in trying to prepare grounds with "a degree of give in the surface", if possible. The mechanism suggested was extra watering of grounds when evaporation was high and rainfall was low. A Penetrometer reading of 4.5cm or harder for the three-drop average was

Ground: ____________________ **Date:** __________

Time taken: ____________________ **Time of match:** __________

Weather conditions: ____________________

Location	1st drop	2nd drop	3rd drop
R back pocket (20m diagonally out from point post)			
Full back (just outside front of square)			
L back pocket (20m diagonally out from point post)			
L half back (15m diagonally away from corner of square)			
10m diagonally inside corner of centre square (L back)			
CHB (1/2way between 50m line & centre square)			
10m diagonally inside corner of centre square (R back)			
R half back (15m diagonally away from corner of square)			
R wing (30m from square on centre line)			
2m outside centre circle (R back side)			
Inside centre circle			
L wing (30m from square on centre line)			
L half forward (15m diagonally away from corner of square)			
10m diagonally inside corner of centre square (L forward)			
CHF (1/2way between 50m line & centre square)			
10m diagonally inside corner of centre square (R forward)			
R half forward (15m diagonally away from corner of square)			
R forward pocket (20m diagonally out from point post)			
Full forward (5m outside front of square)			
L forward pocket (20m diagonally out from point post)			
Average reading for each shock (sum of columns divided by 20)			
	=1st drop average	*=2nd drop average*	*=3rd drop average*

3 drop-average = (1st + 2nd + 3rd drop averages) divided by 3:

Interpretation of ratings (to be used as a guide only):

Rating/ Description	**Penetrometer reading (cm, average three shocks)**	**Penetrometer reading (cm, average first shock)**	**Clegg 2.25kg hammer (gravities, first drop from 46cm)**
Fast/hard	<=3.5	<=1.8	>=90
Good/firm	3.6-4.4	1.9-2.4	65-90
Dead/slow	4.5-5.9	2.5-3.4	30-65
Heavy/soft	>=6	>=3.5	<=30

Figure 1: Penetrometer recording sheet.

suggested as a level that could indicate the need for more watering. This was in reaction to the growing sentiment that ground hardness may be a risk factor for injury, although at that stage the link was still speculative.

Season 2000

In season 2000, most of the grounds using cricket pitches replaced these using portable grass at the start of the football season. This was partially based on the recommendation of this ongoing study, and also that the technology to do this was becoming more available and affordable.

An extra emphasis was placed on the technique of making the Penetrometer readings, after ground managers reported a lack of consistency in subtracting any initial reading (before the Penetrometer drop was made) from the final reading. This was emphasized more strongly in the instructions for the 2000 season.

In the year 2000, the AFL season was brought forward one month (to run the regular season from March-July rather than the usual April-August) to accommodate the Olympic Games which were to be staged in Sydney during September 2000. This change in fixturing left a shorter period of time between the cricket season and the football season in the early months of 2000. Traditionally, grounds that are used in summer for sports such as cricket are prepared in a harder condition than for the winter football season, due to the requirements of the sport and the prevailing climatic conditions. The Gabba ground in Brisbane underwent a resurfacing at the start of season 2000, and Waverley Park in Melbourne was replaced by Colonial Stadium as an AFL venue. Both the Gabba and Colonial Stadium had a very short time period between the turf being laid and the start of matches in season 2000.

A methodological flaw of this study, in a scientific sense, was that it was being conducted in a professional football competition where all stakeholders have a strong incentive to use 'the latest' injury prevention measures and where all issues relating to injury are discussed in depth in the media. From the 1998 season onwards, the issue of ground hardness potentially being a risk factor was one that was featured in the media and of which most ground managers would have been aware. This almost certainly has affected the way in which grounds were prepared to some degree.

Injury surveillance

The occurrence of ACL injuries has been determined by an ongoing injury surveillance system supplemented by an ACL injury register (Orchard & Seward, 2000). For the purposes of this survey, the definition of an ACL injury was that it required a knee reconstruction, and the population at risk was all AFL senior listed players. Very few ACL injuries in AFL players are managed non-surgically (only partial tears that lead to no functional instability) (Orchard et al., 2001).

The surveillance system for measuring injuries was independent of the measurements of ground hardness. As ground measurements were taken before the games, the managers were effectively 'blinded' to the occurrence of injury.

Statistical analysis was performed using univariate techniques only, as the new data correlating injury and ground conditions did not reveal statistically significant results. The major technique was to transform variables into binary values and compare the two groups using a relative risk, with 95% confidence limits estimated with a Taylor-series expansion (Hennekens & Buring, 1987).

Ground name	Cricket pitch?	Predominant grass & soil type	Number of matches 1992-2000	Matches with Penetrometer readings taken
Victorian grounds:			**1183**	**359**
Colonial Stadium	No	Rye on reinforced sand	49	45
Shell Stadium	1992-97	Rye on sandy loam	84	26
MCG	1992-99	Rye on reinforced sand	497	176
Optus Oval	1992-2000	Rye on sandy loam	161	42
Waverley Park	No	Rye on sandy loam	287	70
Other Southern		Various	105	0
Northern grounds:			**574**	**212**
SCG	1992-99	Couch on loam	110	46
Gabba	1992-99	Couch on sandy loam (1992-99), Rye on sand (2000)	98	38
Football Park	No	Rye on sandy loam	165	70
Subiaco Oval	No	Couch (1992-1998), Rye (1999-2000) on sand	124	51
WACA	1992-2000	Couch on sand	50	7
Other North		Various	27	0
Total matches			**1757**	**571**

Table 1: List of ground details and matches studied.

	1997	1998	1999	2000
Victorian matches				
Games measured	7	113	117	122
Three-drop average	4.73 ± 0.74	4.85 ± 0.41	5.04 ± 0.41	4.62 ± 0.47
First-drop average	3.01 ± 0.65	3.03 ± 0.35	3.15 ± 0.39	2.86 ± 0.39
Non-Victorian matches				
Games measured	16	65	64	67
Three-drop average	4.48 ± 0.81	4.58 ± 0.60	5.23 ± 0.80	4.72 ± 1.15
First-drop average	2.80 ± 0.63	2.54 ± 0.36	2.99 ± 0.56	2.81 ± 0.72

Table 2: Comparison of Penetrometer readings (cm) between seasons.

Season	ACL Injuries (reconstructions)				Number of matches		ACL injury rate (injuries per 1000 matches)		
	Total	VM	NM	Other	VM	NM	VM	NM	All
1992	16	4	6	6	138	48	29.0	125.0	53.8
1993	7	2	1	4	128	43	15.6	23.3	17.5
1994	13	4	3	6	139	49	28.8	61.2	37.2
1995	14	7	4	3	139	61	50.4	65.6	55.0
1996	19	5	6	8	134	66	37.3	90.9	55.0
1997	21	1	13	7	127	73	86.6	41.1	70.0
1998	15	2	8	5	126	74	15.9	108.1	50.0
1999	8	1	3	4	122	78	8.2	38.5	20.0
2000	8	2	2	4	130	82	15.4	24.4	18.9
	121	**38**	**36**	**47**	**1183**	**574**	**32.1**	**62.7**	**42.1**

VM=Victorian matches NM=Northern matches

Table 3: ACL injuries and injury rates per season.

Comparisons between Penetrometer readings were performed using single-factor ANOVA tests.

Only senior (first grade) matches were analysed for this study, as they were the only matches for which Penetrometer readings have been taken. Matches were subdivided into matches occurring in Victoria (VM) and matches occurring in the northern states, or outside of Victoria (NM).

Results

The grounds used as AFL venues are listed in Table 1. Almost all venues used both couch (bermuda) grass (*Cynodon dactylon*) and rye grass (*Lolium perenne*) as part of their profile. However, the proportions differed depending on climate and management. Couch is a warm-season turfgrass and therefore became dormant over winter at all Victorian venues due to low temperatures. Rye grass, a cool-season turfgrass, was the predominant species during the football season in Victoria. However, in Northern venues couch grass was often the preferred species over the entire winter season. Some Northern venues, particularly in recent seasons, made a conscious decision to sow rye grass for the winter months.

Victorian matches (VM) had softer grounds than Northern matches (NM) as measured by Penetrometer readings for both the three-drop average ($p<0.001$) and first-drop average ($p<0.001$) in 1998 (Table 2). In 1999, VM had softer readings than NM on the first-drop average ($p=0.03$) but harder readings on the three-drop average ($p=0.04$). There was no significant difference between VM and NM in season 2000 for either measure. Readings in season 1999 were softer than both seasons 1998 and 2000 for both three-drop and first-drop Penetrometer measures (all $p<0.0001$).

Condition	Games	ACL injuries	Injuries per 1000 games	Relative Risk	95% CI low	95% CI high
ALL GAMES this series	**571**	**17**	**29.8**			
Penetrometer reading (three-drop average):						
4.4 or less	156	8	51.3			
4.5-4.9	179	2	11.2			
5.0-5.4	153	3	19.6			
5.5 or greater	83	4	48.2			
Less than 4.5	*156*	*8*	*51.3*	*2.36*	*0.90*	*6.24*
4.5 or greater	*415*	*9*	*21.7*			
Penetrometer first-drop average:						
2.4 or less	99	6	60.6			
2.5-2.9	195	3	15.4			
3.0-3.4	197	7	35.5			
3.5 or greater	80	1	12.5			
Less than 2.5	*99*	*6*	*60.6*	*2.60*	*0.94*	*7.20*
2.5 or greater	*472*	*11*	*23.3*			
Predominant grass type:						
Couch (Bermuda)	*130*	*7*	*53.8*	*2.37*	*0.89*	*6.36*
Rye	*441*	*10*	*22.7*			

Table 4: Comparison of ACL injury rate for 571 matches where Penetrometer readings taken.

Matches in the months of March and April had harder readings than matches from May-August on the first-drop average ($P<0.01$) (Table 6). On the three-drop average, there was a trend towards harder grounds in these early months, but this was not statistically significant ($P=0.08$) (Table 6).

There was no statistically significant relationship between Penetrometer readings and risk of ACL injury (Table 4). However, there was a trend towards an increased risk of injury when the ground was harder. This trend was strongest for the first drop measurement of the Penetrometer. When the first drop average was 2.4 or less, the risk of ACL injury was 2.60 (95% CI 0.94-7.20).

There has been a fall in the incidence of ACL injuries during seasons 1999 and 2000 (Table 3). This decrease has reached a level of statistical significance (Table 5). Because of the lower number of injuries, the power of the study in showing associations between ground conditions and injury has been less than anticipated. Of the possible ground-related factors that may have been responsible for a decrease in injury incidence, none have, to date, been conclusively associated with injury:

1. Grounds were softer in season 1999, but to date there has not been a significant relationship between Penetrometer readings and injury risk.
2. There has been a movement towards grounds using rye grass as the predominant species in the Northern grounds. Couch grass shows a trend towards an increased number of injuries, but this is also statistically not significant (Table 4).
3. Many grounds have removed their cricket pitch in season 2000. However, the presence of a cricket pitch has also not been significantly associated with ACL injury (Table 4).

Condition		Games	ACL injuries	Injuries per 1000 games	Relative Risk	95% CI low	95% CI high
ALL MATCHES in this series		**1757**	**74**	**42.1**			
Month of year:	Dec-Feb	86	7	81.4			
	March	141	8	56.7			
	April	293	16	54.6			
	May	302	11	36.4			
	June	258	10	38.8			
	July	301	8	26.6			
	August	290	11	37.9			
	Sept-Oct	86	3	34.9			
Early (pre-May)		*520*	*31*	*59.6*	*1.71*	*1.07*	*2.75*
Late (May onwards)		*1237*	*43*	*34.8*			
Northern senior games (NM)		*574*	*36*	*62.7*	*1.95*	*1.22*	*3.11*
Victorian senior games (VM)		*1183*	*38*	*32.1*			
Matches 1992-98		*1345*	*66*	*49.1*	*2.53*	*1.20*	*5.31*
Matches 1999-00		*412*	*8*	*19.4*			
Grounds with cricket pitch		*890*	*40*	*44.9*	*1.14*	*0.72*	*1.82*
Grounds without cricket pitch		864	34	39.4			

Table 5: Comparison of ACL injury rate for all 1757 senior matches 1992-2000.

		March	April	May	June	July	August
Victorian games	First drop	3.0	2.9	3.0	3.2	3.0	3.1
	Three drop average	4.8	4.7	4.8	5.0	4.8	4.9
Non-Victorian games	First drop	2.6	2.7	2.8	2.9	2.9	2.7
	Three drop average	4.7	4.8	4.9	4.9	4.8	4.7

Table 6: Comparison of average Penetrometer readings by month.

Although injury location (section of the ground) has been recorded as part of the ACL injury register, it cannot be analysed whether the cricket pitch area is more likely to lead to injuries due to that section of the ground being harder. This is because it is not known what percentage of high-risk activities (cutting and landing) occur on the cricket pitch area. For example, it would be expected that proportionally more injuries would occur in the centre of the ground as many ruck contests occur there, but the exact expected increase in proportion is not known.

When injuries are analysed by state and month, the previously-reported relationships between early month of year, northern venues and ACL injury risk can be seen (Table 5).

Discussion

AFL injury surveillance data has found that ACL injuries are less likely at Victorian (more southern) venues and in games during the winter months (later in the season) (Orchard et al., 1999). Multiple studies have reported that the total injury incidence is higher earlier in the playing season in rugby union (Lee & Garraway, 1996; Alsop et al., 2000; Lee & Garraway, 2000), soccer (Hawkins et al., 2001), American football (Bramwell, Requa & Garrick, 1971; Andresen, Hoffman & Barton, 1989) and Australian football (Stevenson et al., 2000). As the higher early season injury incidence has also been reported in court sports where playing conditions do not change (Stevenson et al., 2000), it is likely that some intrinsic variables (e.g. player fitness) are partially responsible for an 'early-season' injury bias. The studies reporting an 'early-season' injury bias that have split the injury profile into various body parts have found that lower limb injuries are primarily responsible for this bias (Alsop et al., 2000; Lee et al., 2000). The AFL experience of a 'northern' bias (Orchard, 2000), in conjunction with the early-season bias for ACL injuries, suggests that the variation in ground conditions over the course of the season is partially responsible for the variation in injury incidence.

This study has not, to date, been able to specify the particular characteristic(s) of grounds that is/are responsible for the 'northern' bias and 'early-season' bias for ACL injuries. There was a non-significant trend towards more ACL injuries on harder grounds, as well as a similar trend towards more injuries on grounds where couch grass was the predominant species. It has been presumed, but not reported, that couch (Bermuda) grass leads to greater shoe-surface traction that rye grass. Studies that have compared traction of grass types have been conducted in a single climate (Dunn, Minner, Fresenburg & Bughura, 1994; McNitt, Middour & Waddington, 1997), which does not address the relative traction of couch grass growing in a warm climate compared to rye grass growing in a temperate climate. Couch grass grows by creeping (forming a matting below the leaves) whereas rye grass grows in bunches or tufts, without creeping stems to knit the bunches. Couch grass is generally considered to have greater wear tolerance than rye grass because of the matting.

In football games, traction is a function of both the shoe and the surface, whereas hardness is related to surface characteristics and mass of the body. Traction and hardness of football surfaces have been shown to correlate significantly ($r=0.26$, $p<0.001$) (Bell & Holmes, 1988). Traction is most highly correlated with amount of grass cover (Bell et al., 1988; Baker, 1991), whereas hardness is most highly correlated (inversely) with soil moisture content (Bell et al., 1988; Baker, 1991). Rootzone materials with a higher sand content (as opposed to soil) maintain greater grass cover, have higher traction and have less variation in hardness due to recent rainfall (Baker, 1991). Figure 2 shows some of the relationships between weather variables and ground characteristics. The positive correlation between shoe-surface traction and hardness is due to their common (inverse) relationship to soil moisture content. There are confounders that prevent a linear relationship between traction and hardness. Player choice of shoes (in reaction to moisture content) reduces the relationship between traction and moisture. In the longer term, traffic on grounds with greater moisture will have an adverse effect on the thatch layer of the grass. This may decrease traction but increase hardness. ACL injuries in the AFL are associated with reduced rainfall over the previous *year*, but not over shorter periods, suggesting that long-term effects of rain on the thatch layer (reducing grass root density) are more important than the soil moisture content.

It is unlikely that surface hardness (independent of shoe-surface traction) is the

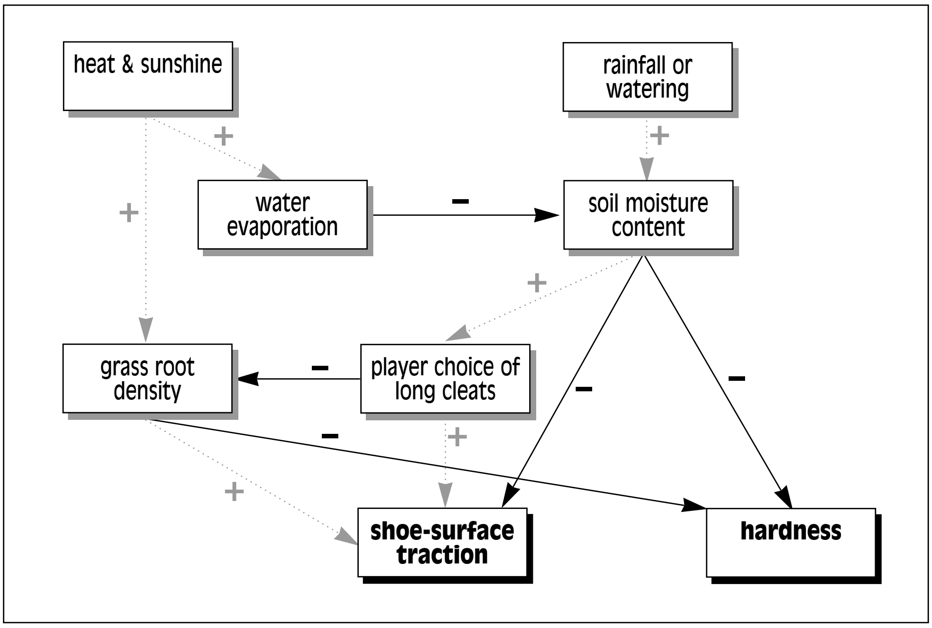

Figure 2: Relationship between hardness, shoe-surface traction and other ground characteristics.

most important extrinsic risk factor for ACL injury across a variety of sports. Court sports such as basketball are played on much harder surfaces than football fields yet the ACL injury rates are not higher than football injury rates (Arendt, Agel & Dick, 1999; de Loes, Dahlstedt & Thomee, 2000). Skiing is an activity that enjoys a very soft surface yet ACL injuries occur at a rate that is comparable to football games (Ettinger, Johnson & Shealy, 1995; de Loes et al., 2000). Volleyball injuries have been reported as being much more likely on hard surfaces than on sand, but it is not known whether this difference relates to hardness or shoe-surface (foot-surface) traction (Briner & Ely, 1999).

It is quite plausible that shoe-surface traction is a risk factor for ACL injury in football, and that on harder football fields, players are generally able to choose boots that create a greater amount of shoe-surface traction. The theory that increased shoe-surface traction is a cause of knee injuries is well established (Torg, Quendenfeld & Landau, 1974). In the study of Torg et al., the traction from various boots on various surface conditions was measured. Torg and others presumed that increased traction increased the risk of knee injury and concluded that "at least from the safety standpoint, (players generally choose) the wrong shoes...on the wrong turf". Players, of course, choose football boots for a very good reason - to improve their performance. It is very likely that players will choose boots on a given day that maximise shoe-surface traction and therefore minimise the risk of slipping performing a movement and reduce the amount of time taken to perform a cutting manoeuvre.

There is one study that suggests that boots that probably increase shoe-surface traction are associated with a higher risk of ACL injury (Lambson, Barnhill & Higgins, 1996). Despite this evidence, it is unlikely that players would ever voluntarily lower their injury risk by choosing a boot that lead to lower shoe-surface traction, as their performance may be jeopardised.

There has been debate over the relative merits of the Penetrometer and Clegg hammer as devices to measure surface hardness (Neylan et al., 1998; Ford, 1999). The Clegg hammer has the advantage of giving a digital reading which is less prone to user error. There also exists a proposed standard for surface hardness of soccer pitches in England, with a recommended range of 20-80 gravities, as measured by the 0.5kg Clegg hammer dropped from 300mm (Canaway, Bell, Holmes & Baker, 1990). A difficulty with Clegg hammers is that they are available in different weights (e.g. 500g, 2.25kg and 5kg) and may be dropped from different heights (varying numbers of times), with the 2.25kg hammer dropped from 457mm often preferred in Australia and the USA (Rogers & Waddington, 1990; Ford, 1999). Although the 0.5kg and 2.25kg Clegg hammers have a high correlation with each other (Rogers et al., 1990), ratings cannot be assumed to be equal between different hammers.

Although there is a correlation between Penetrometer and Clegg readings, they are not measuring exactly the same surface characteristics. The Clegg hammer measures maximum deceleration for a light object which does not penetrate the thatch layer. The Penetrometer uses a much greater effective weight and measures depth of soil penetration. Given that a horse has a far greater mass than a Clegg hammer, it is not surprising that race times correlate better with Penetrometer readings than with Clegg hammer readings (Neylan et al., 1998). The first drop average of the Penetrometer has also correlated well with horse race winning times in New Zealand (Murphy, Field & Thomas, 1996).

Both the Ford and Neylan papers recommend that the Penetrometer reading should be measured as the first drop average only. The AFL study results support this recommendation, as the first-drop average has a stronger relationship with injury, location and month of season than the three-drop average.

There is a need to utilise and further develop instruments to measure ground conditions. The greatest need is for a portable, readily available, inexpensive device that can measure a value for Maximum Available Traction (MAT) on a given field at a given time (Dunn et al., 1994; McNitt et al., 1997). MAT would be the amount of shoe-surface traction for the boot stud configuration that gave the highest reading on the day (and hence would be the preferred choice for most players). On a dry day, this would usually be a moulded-sole configuration and on a wet day, this would usually be a long stop (cleat) configuration.

AFL grounds will continue to take Penetrometer readings, preferring the single drop method. In time, further standard readings will be added to the AFL ground profile, such as Clegg hammer and traction readings. If future readings are found to correlate with injury, then a more definite understanding of risk factors will arise. It may already be the case that injuries are being prevented by measures to soften the ground and the increased preference of rye grass to couch grass at most venues. ACL injury rates have fallen over the past few years, but there is not enough comparative data to attribute this to either reductions in ground hardness, traction or the removal of cricket pitches at this stage. Perhaps some of these interventions have been successful in combination. There may be other confounding factors, such as individual club proprioceptive training programs, that could have contributed to the recent reduction in ACL injury incidence.

Based on the lack of conclusive scientific evidence, it would be premature to make any strong recommendations about preferred ground conditions to prevent knee injuries. A randomised controlled trial would be the best method to determine conclusively whether changing ground conditions can prevent injury. This is not practical within the framework of a professional competition such as the AFL, and would be very expensive to conduct in a amateur competition. The AFL will continue to monitor ground conditions and report injury rates. Hopefully there will be a sustained decrease in the incidence of ACL injuries, in association with a historical non-randomised change in the way that grounds were prepared. This link would give stakeholders good reason to invest in a randomised control trial to further assess the relationship between ground conditions and injury.

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Appendix

Technique for using the Penetrometer at an AFL ground

The Penetrometer is a metal instrument with the following important parts:

1. A **scale** at the top of the shaft, marked in centimetres.
2. A **weight**, (1kg) which is released around the shaft from a height of 1m.
3. A **trigger** to release the weight.
4. A **shaft**, (1cmx1cm) which is forced into the soil by the falling weight.
5. A **base**, which stays level with the surface.

Penetrometer readings are made in sets of three (called shocks or drops). The standard ground reading is taken as the average of 20 different sets of three shocks - therefore 60 readings taken at 20 separate places on the ground.

The technique to be used is as follows:

1. The weight is pulled up to the top of the machine and held in place by the trigger.
2. The shaft is pulled up so that its bottom is level with the base of the machine. If the grass is short and compact, the shaft will not move at this stage, and the scale reading should be zero (0.0). If the grass is longer, the shaft may drop down so that the scale reading starts at a higher point (for example, 0.4). The initial reading (if it is not zero) should be remembered, as it must be subtracted from any subsequent readings.
3. The trigger is released, which will cause the weight to fall, pushing the shaft into the soil. The first reading (or first shock) is now taken, which is the current reading on the scale, minus any initial reading above zero.
4. **Without** moving the shaft from its new position, the weight is pulled back up to its full height.
5. The trigger is again released. The second shock is now calculated, being the current reading on the scale, minus any initial reading. Do not subtract the first reading. Using this technique, the second reading must be higher than the first reading.
6. Repeat pulling the weight back up and then releasing the trigger. The third shock is now calculated (final position of the scale, minus any initial reading). The third reading will be the highest reading taken in each position.
7. Move to a new position and start again.

The twenty positions on the field represent one for each starting position of players on one team, plus an extra 2 positions in the centre square, as play is concentrated in this area. The locations to be used are shown on the blank form. For grounds with a cricket pitch area, it is recommended that no more than 4 readings are taken on the cricket surface. If necessary, some of the centre square positions can be changed slightly to avoid the cricket surface.

Readings are to be taken to the nearest 0.1.

A reading is marked in each blank space on the form. The average of all readings becomes the Penetrometer reading for the ground at that time. It should take 20-30 minutes to take readings and then calculate the overall ground reading. It is best done by two people, with one handling the machine and reading the values, with the other acting as a scribe.