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Research article

Monitoring of lower limb comfort and injury in elite football

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Abstract
The aim of the study was to examine the relation between lower limb comfort scores and injury and to measure the responsiveness of a lower limb comfort index (LLCI) to changes over time, in a cohort of professional footballers. Lower limb comfort was recorded for each individual using a comfort index which assessed the comfort status of five anatomical segments and footwear. Specifically we tested the extent to which comfort zones as measured by the LLCI were related to injury measured as *time loss events*. The hypothesis for the study was that poor lower limb comfort is related to *time loss events* (training or match day). A total of 3524 player weeks of data was collected from 182 professional athletes encompassing three codes of football (Australian Rules, Rugby league, Rugby Union). The study was conducted during football competition periods for the respective football leagues and included a period of pre-season training. The results of regression indicated that poor lower limb comfort was highly correlated to injury (R^2 =0.77) and accounted for 43.5 time loss events/ 1000hrs football exposure. While poor comfort was predictive of injury 47% of all *time loss events* it was not statistically relevant (R^2 =0.18). The results indicate lower limb comfort can be used to assess the well-being of the lower limb; poor comfort is associated with injury, and the LLCI has good face validity and high criterion-related validity for the relationship between comfort and injury.

Key words: Lower limb comfort, musculoskeletal, football, injury.

Introduction

The football codes require superior levels of physical fitness and skill for competition. Participation at all levels of football (professional, amateur, pre-adult) is associated with a certain risk of injury. To benchmark the level of injury risk it has been estimated the risk of playing football (soccer) compared with the work environment is 1000 times greater than high risk industrial occupations (Drawer and Fuller, 2002). Statistics from elite football leagues indicate injury epidemiology rates as high as 60-90% for football (soccer), 60-75% for Australian rules, 75-90% for rugby league and 55-80% for rugby union (Engstrom et al., 1991; Gabbett, 2006; Hagglund et al., 2009; Luthje et al., 1996; Orchard and Seward, 2008). A study of injury in Australian football suggested the high rates of injury may affect the long-term viability of playing football as potential players seek other forms of activity (Norton et al, 2001).

Injury risk modeling can be divided into extrinsic (environmental, ground surfaces, and training methods) and intrinsic (foot kinematics and lower limb morphology) variables (Bahr and Holme, 2003; van Mechelan et al., 1992). The lower limb has been identified as the primary region of the body vulnerable to injury not only affecting the football codes, but also the majority of running based sports (Burns et al., 2003; Gosling et al, 2008; Walden et al., 2005; Wong and Hong, 2005). However, statistics on lower limb injury vary greatly depending upon definition and methods of recording data. Lower limb epidemiology research is complicated by inherent difficulties of research design. Difficulties arise from the vast array of confounders and interactions of internal and external factors that can influence epidemiology and biomechanical research (Bahr and Krosshaug, 2005). Divergent research conclusions for causes of injury are therefore likely, and difficult to measure. Links with injuries specific to the lower limb and the football codes, include climate conditions (Orchard, 2002), ground surfaces (Gabbett, 2006; Takemura et al, 2007), footwear (Wong and Hong, 2005), kicking action (Apriantono et al., 2006; Baczkowski et al., 2006), and lower limb morphology (Gabbe et al., 2004; McManus et al., 2004). While these and like individual risk factors have been identified and are often appropriately managed, the separate entities provide an incomplete description of the mechanisms ("chain of events"), which culminates in injury (Bahr and Holme, 2003; Murphy et al., 2003).

A novel concept measuring lower limb comfort over time, using a comfort index has been established (Kinchington, 2009). The instrument which is termed the Lower Limb Comfort Index, LLCI (Kinchington et al., 2010) provides quantitative data on the physical preparedness of an individual pertaining to the lower limb. The sum of six segmental measures (foot, ankle, calf-achilles, shin, knee and football boot) provide a mechanism for establishing base-line comfort for each individual. The LLCI provides a tool to (a) prospectively monitor lower limb comfort at multiple anatomical regions, (b) create a baseline for comfort norms for individual players for future assessment, and (c) to use prospectively in the event of injury to monitor rehabilitation progress (Kinchington et al., 2010). The theory behind the LLCI contends that pain (discomfort) is a neural stimulus due to the interaction of nociceptive stimulation and the cerebral cortex. A discomfort (pain) stimulus via the neural networks of the body provides information about the state of comfort. Over a lifetime of experience, a databank of perceptions of pain (discomfort) is gathered from interrelated human experiences. Thus, pain stimulus can be considered innately individual, meaning different things to different people.

The clinical application of comfort theory as acomponent of injury management is the use of a self-

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rating psycho – physical comfort index. The setting of individual lower limb comfort benchmarks in sport for players can be used to monitor lower limb musculoskeletal health, plan for training and formulate prehabilitation and rehabilitation programs. If discomfort can be identified early, it may be possible to intervene before injury occurs. The data provide an assessment tool to inform individual players about the status of their own individual comfort for any nominated anatomical segment of the lower limb. Data can also be useful to the medical teams who care for them. The outcome data if catalogued over a period of time would then establish baseline comfort markers, which would in turn act as a barometer for future assessment of comfort or discomfort. Similar systems are well documented including pain scales which are generally visual analogue scales or numerical rating scales (Williamson and Hoggart, 2005). Such scales are typically used reactively, following an injury event to gauge the severity of injury. For injury prevention, reactive measures are not beneficial. The frequent collection of comfort data in a state of relative comfort (prospective) enables cumulative episodes of comfort events to be established.

In the environs of elite sport, a player is rarely free from musculoskeletal discomfort and often will contend with multiple areas of discomfort at one time. The LLCI provides the player and medical-conditioning staff with quantifiable information about the state of multiple anatomical areas and the lower limb as a whole. The index is therefore capable of capturing information about an injured area, and also adjacent body linkages which are subjected to compensatory movement. Captured data for any given week are compared to baseline comfort and therefore an assessment can be made about the overall state of lower limb well–being.

The aim of this study was to examine the relation between lower limb comfort scores and injury and also to measure the responsiveness of the LLCI to changes of comfort over time. Specifically we tested the extent to which comfort zones as measured by the LLCI were related to injury measured as *time loss events*. The use of time loss is widely used in football (Hagglund et al., 2009; Orchard and Seward, 2008) as a measure of injury in football. The authors are not aware of research that has investigated the relationship between lower limb comfort and the use of a measuring instrument applicable to the lower limbs and time loss.

Methods

The population base for this study comprised athletes from three dominant football codes played in Australia (rugby league, rugby union, and Australian rules). In agreement with the guidelines of the Human Ethics Committee of Victoria University, players provided informed consent prior and letters of support for the study were obtained from the respective organizations.

Data collection

Of 200 recruited football players, the final sample comprised 182 players. During the study 18 players (9%) dropped out (five due to long term injury, two through transfer, and 11 were omitted because of incomplete data records. Data for 182 players were analysed. In total, 5033 player weeks of data were collected with a mean of 28 (SD 5) weeks per player. The study was conducted during football competition periods for the respective football leagues and included a period of pre-season training.

Lower limb comfort

Lower limb comfort was collected prospectively for the period of the study, using an instrument developed to measure lower limb comfort (Kinchington et al., 2010). The LLCI was developed to provide a tool for clinicians and athletes to monitor lower limb comfort at multiple anatomical regions. A sum score for lower limb comfort was calculated for each player. The score represented an aggregation of six anatomical areas (foot, ankle, calf-achilles, shin, knee, and football boot), totalling 36 points. Each anatomical area was scored between 0-6. A score of 0 indicated extreme discomfort, being unable to run or jump, and 6 was extremely comfortable (Table 1).

Comfort zones were individualized for each player and were determined post hoc using median scores from the collected data. "Post hoc" for this study was defined as end of season (20-30 collected events). This was a deliberate design of the study to allow for tracking of significant changes to comfort levels. It is possible zone comfort may need to be re-set for a variety of reasons including surgery, football conditioning, changing musculoskeletal maturity or other relevant football factors.

Three comfort zones were established. Each zone was apportioned an arbitrary colour to reflect level of comfort. Red zone represented poor comfort (median

Table 1. Lower Limb Comfort Index shows a numeric rating scale with fixed anchor points at key positions on the scale. Visual descriptive explanations provide further interpretation of the anchors relevant to physical requirements participating in football.

Name:	**Place a score 0 to 6 in each box**						**Sum Comfort /36 maximum score**
Lower Limb Comfort: Rank each body area from 0-6 using the ***comfort descriptors***	**Foot**	**Ankle**	**Calf- Achilles**	**Shin**	**Knee**	**Footwear**	
COMFORT DESCRIPTORS **0 = extremely uncomfortable** (unable to run or jump); **1** **2** **3= neither uncomfortable or comfortable** (more or less uncomfortable / comfortable) **4** **5** **6= zero discomfort** (extremely comfortable; best ever feel)							

comfort $^{-2 \text{ comfort points}}$). Black zone was associated with median or usual comfort (median $^{\pm 1 \text{ comfort points}}$) and blue zone was a measure of high comfort (median $^{+2 \text{ comfort points}}$), Table 2. The apportioning of the upper and lower zones was established by trials using other scores above and below the median. The use median $^{\pm 1 \text{ comfort points}}$ were too narrow to delineate poor and high comfort zones because this did not allow for some fluctuation in comfort. Scores of median $^{\pm 3 \text{ comfort points}}$ created a range too wide to establish meaningful outcomes. Perceptions of comfort and performance are empirical measures and by their nature, will vary. Therefore, a median range was deemed appropriate.

Table2. Lower Limb Comfort index (LLCI) zones.

Comfort Zone	Formula
Red (poor comfort)	Median comfort -2 comfort points
Black (usual comfort)	Median comfort ± 1comfort point
Blue (high comfort)	Median comfort +2 comfort points

Collection of comfort data

All data were collected in a standardised manner under the supervision of the researcher or a club official, who was familiar with data collection protocol. Weekday comfort data collection occurred at the premises of participating football clubs in an environment that was consistent and familiar to players. Comfort data were recorded on one occasion, at the same time each week, which represented 24-36 hours post match days.

Injury data collection and definitions: Information of injury was collected by obtaining statistics gathered by fitness and medical staff of respective organisations. Injury data were collected routinely for the teams and did not represent an increase in workload for the support staff. Injury was defined as a *time loss event*. It included any event which resulted in absence from training or match participation. Training was defined as completion of a full regular training session. Match day was defined as a competitive scheduled match organized by the respective football leagues. For the purposes of this study, a *time loss event* was tabled only once for any given week. Where two or more field based training sessions were missed, in any given football week, only one (1) *time loss event* was recorded for the week. The reason for this was the argument that performance (physical and skill) is affected by missing a full training session, an area which will be examined in a future study by the authors. In the study here-in, an activity such as a field-based rehabilitation or "off-legs" session would be considered a *time loss event.* This injury definition has previously been used in football studies (Dvorak and Junge, 2000). Only injuries applicable to the lower limb (knee, shin, calf-achilles, ankle, foot and any combination thereof) were recorded. Any injuries outside the areas described were not classified as *time loss events.*

Injury incidence was used to define the onset of a new injury (Orchard and Seward, 2008). This study was not concerned with injury reoccurrence, but rather the merits of the association between comfort and injury *(time loss event)*. Once a full training session was completed or match participation resumed, the player was considered free from injury. Therefore, injury reoccurrence definitions were not applied. Where injury reoccurred following a return to one regular training session or match, any subsequent *time loss event* were treated as a new injury.

Time loss events were classified three ways: 1. Injuries/1000 hrs football exposure; 2. Predicted *time loss events* (Predicted ^{TLE}); 3. Known *time loss events* (Known ^{TLE}).

Injuries to the lower limb / 1000hrs is commonly used to compare injuries relative to exposure and enable comparisons to be made to other football related studies and other sports (Hagglund et al, 2003, Dvorak and Junge, 2000). This study compared lower limb comfort zones (poor, usual and high) to injury / 1000hrs football exposure. This enabled quantitative comparisons between levels of comfort and injury.

Classifying *time loss events* into Predicted ^{TLE} and Known^{TLE} enabled a determination of whether poor comfort was predictive of injury. A Predicted ^{TLE} was an injury occurring during the football week (training sessions or match) following the recording of poor (red zone) comfort (Predicted ^{TLE} = LLCI $^{\text{data pre injury}}$). Such injuries are generally non-contact or overuse in nature. An example of a Predicted ^{TLE} is poor (red zone) calf muscle comfort or midfoot pain which is registered pre training or match and the player subsequently proceeds to a *time loss event* during the ensuing football week. A Known ^{TLE} was as an injury occurring before the recording of lower limb comfort (Known ^{TLE} = LLCI $^{\text{data post injury}}$).These injuries are generally contact nature or a planned decision to rest a player from training or a match due to musculoskeletal discomfort. When a Known^{TLE} is determined, the lower limb comfort score provides confirmation of discomfort and the limitations on physical activity (Table 1).

Statistical analyses

Data were analysed using SPSS v15.0 for Windows (2004). For all analyses, P values less than 0.05 were considered statistically significant. Continuously distributed variables were summarized as means, standard deviations (SD) and 95% confidence intervals (95% CI) where appropriate. To describe the sample, summary statistics of the mean and median comfort score were computed together with the mean and median percentages of how many days players fell in poor (red), usual (black), or high (blue) comfort zones. Additional mean and median scores of *time loss events* and events in each zone injured, no injury events, injury prevalence, predicted injuries and injury mechanism were also computed. To display results graphically, box plots were used to compare outcomes between groups. In the plots, the dark line represents the median value, the box represents the 25% to 75% percentiles, and the whiskers show the range. Data points more than 1.5 times above or below the interquartile range are marked as outliers. Scatter plots were used to display relationships between two continuous variables. The degree of the association between continuous variables was described using Pearson's correlation coefficient (r) or the R square value from a linear regression model. Categorical data such as rates of injury were summarized using percentages. To validate the use of comfort score, repeated measures analysis of variance was used to determine significant differences in injury rates

Table 3. Characteristics of participants. Data are means (±SD).

	Age (year)	Height (m)	Weight (kg)
Australian Rules Football	24.7 (4.2)	1. 87 (.07)	86.5 (8.1)
Rugby League	23.8 (3.1)	1.84 (.06)	97.9 (8.9)
Rugby Union	24.8 (3.3)	1.85 (.07)	102.4 (10.7)

between the zones, with post-hoc tests used to compute specific between zone differences. Analysis of variance is robust to some departures from normality but because the data were not entirely normally distributed, a Friedman's non-parametric repeated measures test was used to verify that the P values were not biased towards statistical significance.

Results

Anthropometric data for participants were: age: mean 24.3 years (SD 3.6), weight 94.7kgs (SD 11.0); height 1.85 m (SD 0.06). No significant differences in anthropometric measurements between the three different codes of football represented. The players from three codes of professional football were well matched for age and height. There was a large difference in weight between players from Australian Rules and the rugby codes but had no effect on the results (Table 3). The differences in body types between the football codes, is due to the nature of the football codes. Australian Rules football is a high volume running game (Norton et al, 2001) compared to the collision and heavy contact associated with the rugby codes (Gabbett, 2010).

General lower limb comfort of 182 professional footballers

Figure 1 shows the box plots for the lower limb comfort events for all players. Usual (black zone) comfort had a median value of 15 events (range 1 to 42) per player. Poor (red zone) comfort had a median of six events (range 1 to18) and high (blue zone) comfort had a median of four events (range 1 to 17) indicating variations around median comfort range (black zone comfort). Usual comfort, calculated by median $^{\pm1 \text{ comfort points}}$ for each player, accounted for 58.6% of all comfort events (N=5033). Within the professional football environment examined, 23% of comfort scores recorded was categorized as poor (red zone) comfort, which corresponds closely with the number of *time loss events* (25.6%), recorded over the study period. Only 18% of players recorded high (blue zone) comfort responses, indicative of the demands placed upon the lower limb musculoskeletal system associated with football participation.

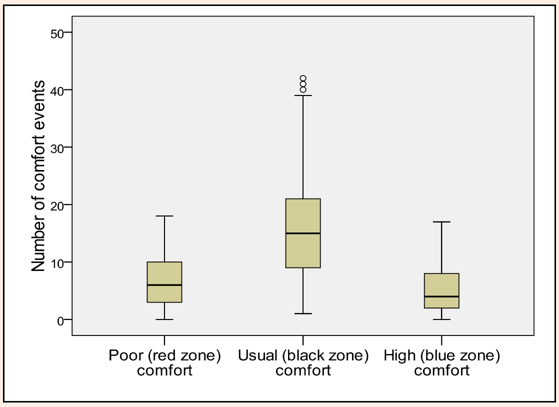

Figure 1. Lower limb comfort for 182 professional footballers classified into poor (red zone) comfort, usual (black zone) comfort, and high (blue zone) lower limb comfort categories.

Relation between comfort and injury for the football cohort

The relation between lower limb comfort and injury was examined by:

a. Calculating lower limb injury incidence/1000 hrs football exposure

b. Analysing lower limb comfort zones and *time loss events* (Predicted ^{TLE} and Known ^{TLE})

c. Determining the capacity of poor comfort to be predictive of injury

a. Lower limb injury incidence/1000 hrs football exposure: Overall injury for the study was calculated as 59.9 *time loss events* /1000 hours football exposure. Figure 2a shows the associate between comfort zones and *time loss events* using injuries/1000hrs of football exposure. Data for all players was analysed separately and

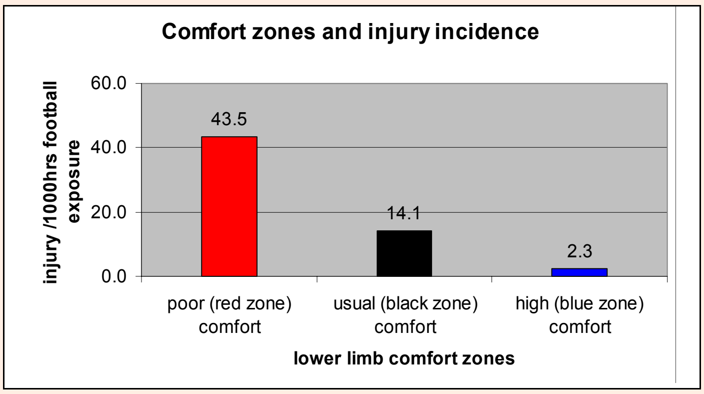

Figure 2a. Lower limb comfort and injury/1000hrs of football exposure. for 182 professional footballers.

collapsed into the three comfort zones. The incidence of injury was 43.5 *time loss events* / 1000hrs of football exposure when lower limb comfort was poor (red zone). The injury incidence rate was only 14.1/1000 hrs for usual (black zone) comfort and 2.3/1000 hrs when lower limb comfort was high (blue zone). The low injury incidence when comfort was within the usual (black zone) comfort range or high (blue zone) comfort range, shows the possible protective role comfort may have against injury.

There were no significant differences in injuries/1000hrs between the different codes of football studies; although Australian Rules had less injuries/1000hrs (50.9) compared to the Rugby codes (Rugby Union, 68.9; Rugby League, 67.4). The reason for high injury exposure in the rugby codes were due to the collision-contact nature of injury sustained compared to more non-contact injuries for Australian Rules.

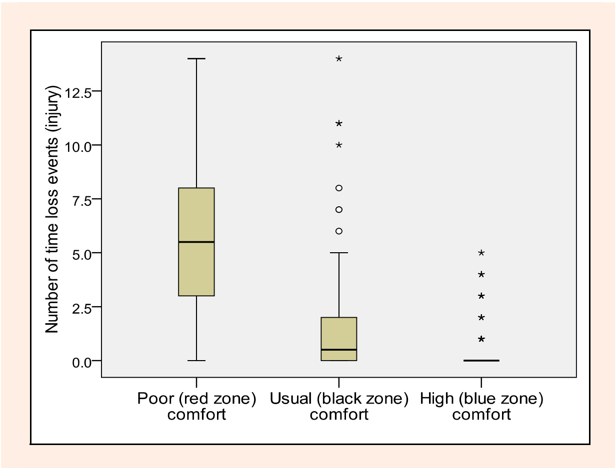

Figure 2b. Time loss events (injury) classified by lower limb comfort zones; poor (red zone), usual (black zone), and high (blue zone), for 182 professional footballers.

b. The influence of comfort zones on all injury (Predicted ^{TLE} and Known ^{TLE}): Figure 2b shows poor (red zone) comfort was associated with the largest number of *time loss events.* When the group (n = 182) recorded poor lower limb comfort, the median time loss (injury) was 5.75 events. For usual (black zone) comfort the median time loss was 1.0 event and for high (blue zone) comfort, the median time loss was zero events. The range of *time loss events* for poor comfort (red zone) was 0-14 events, with 50% of time loss between 3 and 8 *time loss events*. The majority of usual comfort (black zone) injury events were in the range 0-2, and zero when respondents registered high (blue zone) comfort. The data indicates when players recorded high comfort scores; there were no *time loss events* (injury) due to lower limb discomfort except for five outliers.

The injury data obtained from the classification of comfort into three zones is clinically relevant regardless of the injury type (Predicted ^{TLE} and Known ^{TLE})_because it quantifies discomfort, enabling clinicians to monitor the status of players, and implement programs to ensure an athletes lower limb comfort is well maintained.

Figures 3a, 3b, and 3c and Table 4 further explore the relationship between comfort zones and *time loss events*. The scatter plots illustrates that *time loss events* were strongly associated with poor (red zone) comfort (R^2 = 0.77) and not significant with usual (black zone), R^2 = 0.48 or high (blue zone) comfort (R^2 =0.15). Table 4 confirms *time loss events* were significantly correlated to poor (red), usual (black) and high (blue) comfort scores. The strongest correlation was for poor (red) comfort scores, followed by usual (black) comfort scores. Although the P-value for high (blue zone) comfort was statistically significant for injury, the correlation coefficient remained low (0.39) which indicated that only 15% of the variation in all *time loss events* was explained by high (blue) comfort events. The high P-value is due to small values quickly become statistically significant with a large sample. The R^2 value is more relevant. In general in clinical work, 0.39 is considered a weak correlation (Zou et al., 2003).

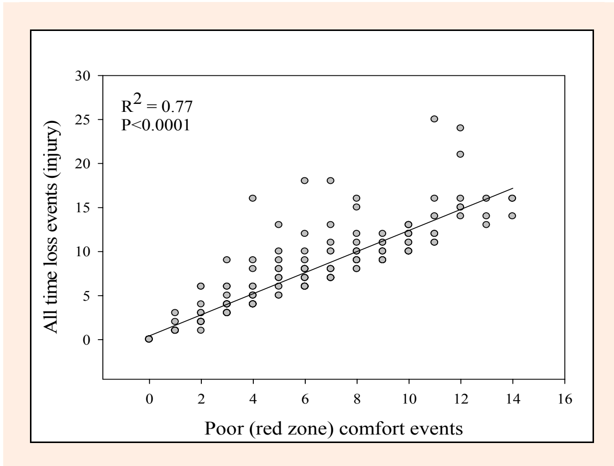

Figure 3a. Relationship between poor (red zone) comfort and time loss events (injury).

Figure 3a shows a small number of *time loss events* when poor (red zone) comfort events are low. For example, the number of *time loss events* was small when poor (red zone) comfort events (0 and 2) were low. As the number of poor comfort events increased, there was a corresponding increase in *time loss events* (injury) with a strong linear relationship (R^2 0.77) between poor comfort and all *time loss events* recorded by the group.

As comfort improved as described in Figure 3b (regular comfort v *time loss events*) and Figure 3c (high comfort v *time loss events*) the number of time loss events (injury) were fewer. As a consequence, there was a weaker relationship for *time loss events* between black zone comfort and all injury events recorded by the group (R^2 0.48). Figure 3b shows 108 *time loss events* could not be accounted for by usual (black zone) comfort (zero) events. In black zone comfort, the majority of *time loss events* were 0-4 comfort events, whereas for red zone comfort, the majority of *time loss events* occurred between 4-8 comfort zone events. Similarly, a weak relationship was observed for high (blue zone) comfort and *time loss events* (R^2 0.15), with 161 *time loss events* not associated with high comfort. The clinical significance of these results is that poor comfort (red zone) is a measure of injury and subsequent *time loss events,* while high comfort (blue zone) is protective against injury.

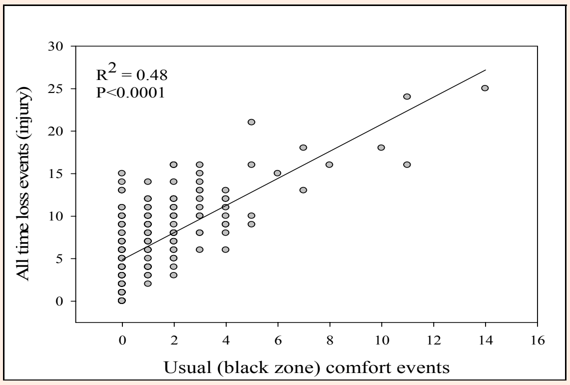

Figure 3b. Relationship between usual (black zone) comfort and time loss events (injury).

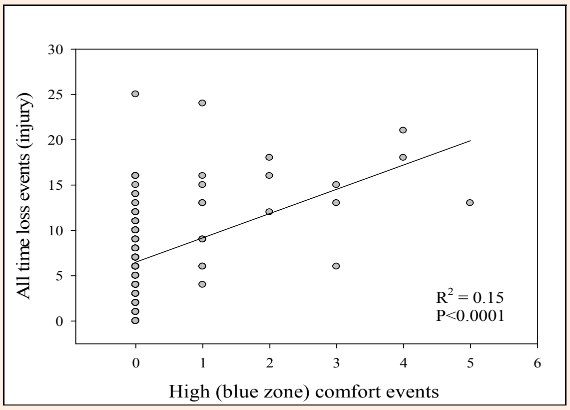

Figure 3c. Relationship between comfort (blue zone) and time loss events (injury).

Table 4. Correlation between all *time loss events* and poor (red zone), usual (black zone) and high (blue zone) comfort events in 182 players.

	Pearson correlation coefficient	Linear regression R^2 value	P value
Poor (red zone) comfort correlation to injury	.88	.77	<.0001
Usual (black zone) comfort correlation to injury	.69	.48	<.0001
High (blue zone) comfort correlation to injury	.39	.15	<.0001

c. Determining the capacity of poor comfort to be predictive of injury: Two aspects of assessing relation between poor comfort and *time loss events* were assessed:

i. Those occasions where poor (red zone) were not well correlated with injury was examined to test the inverse relationship of a poor comfort association with injury. In these situations, the individual footballers reported poor comfort scores, but were still capable of participating in full training sessions and matches. Figure 4 shows the sensitivity of comfort in the determination of injury; i.e. where poor (red zone) comfort zones had a weak correlation to *time loss events*.

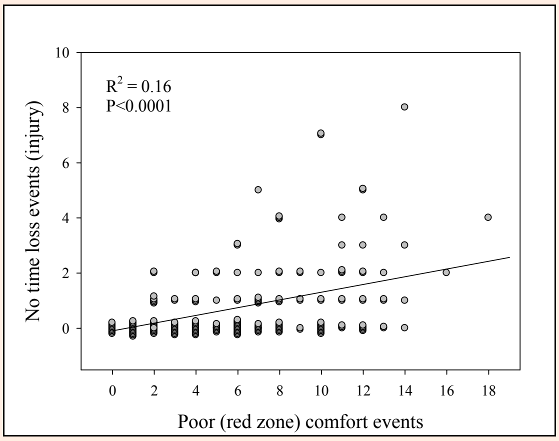

Figure 4. Poor (red zone) lower limb comfort not associated with injury.

For example, Figure 4 shows when two (2) poor (red zone) comfort events were registered, poor comfort was not predictive of time loss on 1-2 occasions. At the other end of the graph, on the 18 occasions, poor (red zone) comfort was recorded, poor comfort was not predictive of injury on only four (4) occasions. The maximum number of times poor comfort was associated with no *time loss events* was 8. The weak correlation ($R^2 = 0.16$) between poor (red zone) comfort and no *time loss events* provides confidence the method of measuring comfort by use of the LLCI is a valid test of determining *time loss events*. Where poor comfort did not result in missed training or match, this can be attributed to player discomfort not being clinically important enough to prevent full training or match participation.

ii. Poor lower limb comfort as a predictor of injury (Predicted ^{TLE}). To assess whether lower limb comfort was predictive of injury, player comfort data was extracted from all injury data to examine individuals who sustained an injury in the week following comfort data collection. Correlations were made between the incidence of new non-contact *time loss events* and comfort events recorded immediately before injury incidence (Figure 5). While, a weak correlation between non-contact *time loss events* and prediction of *time loss events* (Predicted ^{TLE} = LLCI $^{data\ pre\ injury}$) was calculated ($R^2 = 0.18$), poor (red zone) lower limb comfort was predictive of injury on 47% of occasions. Of the 423 non contact events recorded, 202 injuries were predicted by poor (red zone comfort). While the result does not have high statistical correlation, the result has high clinical relevance for those who deal with musculoskeletal injury. With caution, poor (red zone) comfort as a measured by using the LLCI can be used as a clinical tool to manage training and rehabilitation strategies to ensure poor comfort does not progress to *time loss events*.

Case studies of comfort and *time loss events*

To illustrate comfort variations over a given time period-within the study, data was extracted for three players who

Table 5. Lower limb comfort scores over a 25 week period for one representative player. Bold numbers indicate poor (red zone comfort scores).

Week	foot comfort score	ankle comfort score	calf-achilles comfort score	shin comfort score	knee comfort score	footwear comfort score	sum comfort
1	6	5	**3**	5	5	6	*30*
2	6	5	4	5	5	6	*31*
3	6	5	**3**	5	5	6	*30*
4	5	5	4	5	5	6	*30*
5	5	5	**3**	5	5	6	*29*
6	5	5	5	5	5	6	*31*
7	5	5	4	5	5	6	*30*
8	5	5	**3**	5	**2**	5	**25**
9	5	5	**3**	**3**	**3**	5	**24**
10	5	5	**3**	5	**2**	5	**25**
11	5	**3**	5	5	**3**	5	**26**
12	5	**3**	5	5	4	5	*27*
13	5	5	4	5	4	5	*28*
14	**3**	5	4	5	4	5	*26*
15	**3**	5	4	5	5	5	*27*
16	**3**	5	4	4	5	6	*27*
17	**2**	5	4	5	5	6	*27*
18	**2**	5	4	5	5	6	*27*
19	5	5	5	5	5	5	*30*
20	5	5	5	5	5	6	*31*
21	5	5	5	5	5	6	*31*
22	5	5	5	5	5	6	*31*
23	5	5	5	4	5	6	*30*
24	5	**2**	5	5	**3**	6	**26**
25	5	**2**	5	5	**3**	6	**26**
median	*5.0*	*5.0*	*4.0*	*5.0*	*5.0*	*6.0*	*28.0*
blue comfort zone							*>29*
black comfort zone							*27--29*
red comfort zone							*<27*

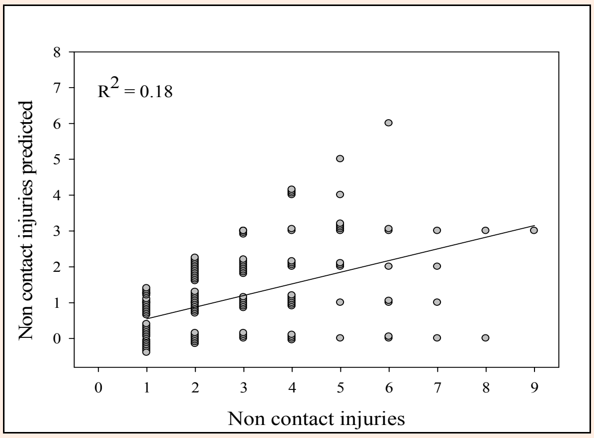

Figure 5. Incidence of non contact injury determined by poor (red zone) lower limb comfort.

were considered representative of the group. Player A, (Table 5); Player B, (Figure 6); and Player C, (Figure 7) show how overall lower limb comfort fluctuated throughout the study and the effect on *time loss events*. The measure of individual anatomical segmental comfort data (Table 5 and Figure 6) provided information on how segmental comfort contributed to overall lower limb comfort and highlights the importance of measuring multiple segments. The information provides data on how pain responses at one segment, due to injury, affects comfort at another segment. Figure 7 illustrates how training participation patterns and *time loss events* can be tracked over a timeline and provides a direct comparison between comfort and *time loss events*.

Case study Player A

Table 5 shows data for a Player A, who was selected at random from the cohort. Comfort scores for individual anatomical segments (foot, ankle, calf-achilles, shin, knee, footwear) provided a sum comfort score for a given week. The data collection was repeated weekly for the representative case over a 25 week period. Medians for each anatomical segment (foot, ankle, calf-achilles, shin, knee, footwear) and overall comfort of the lower limb were calculated. Using the formula (Table 1), comfort zones were then established; poor (red zone) comfort were scores <27 $^{\text{comfort points}}$. Usual (black zone) comfort range was inclusive of scores 28 $^{\pm 1 \text{ comfort point}}$. High (blue zone) comfort was assigned to scores >29 $^{\text{comfort points}}$. Individual anatomical segmental medians were also calculated. Comfort data for Player A indicated the calf-achilles complex was the least comfortable region of the lower limb, while all other sites had a median of 5 $^{\text{comfort points}}$. During the collection period, scores fluctuated around the median for all of the individual anatomical segments. These scores were representative of group data, comfort variations over the 25 week collection period. Lower limb comfort was recorded as poor (red zone) on six occasions due to knee, calf and ankle discomfort. The

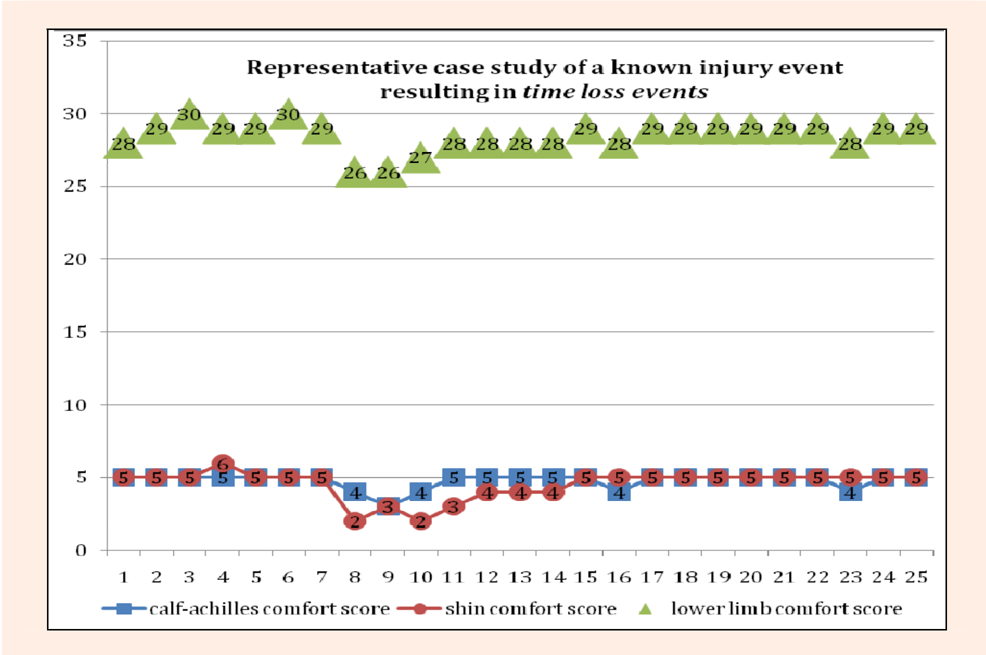

Figure 6. Representative case study of a known time loss event. The x-axis represents player comfort weeks, 1-25; the y-axis comfort scores 0-35.

highlighted cells within the table, for both individual anatomical segments and sum comfort, represent scores less than median for the anatomical segments which equate to poor comfort.

Case study Player B

Figure 6 is representative of how overall lower limb comfort at different anatomical regions of the body changed over a period of 25 weeks. Lower limb discomfort registered by Player B, shows the effect of shin discomfort (week 8) and overall lower limb comfort which reduced from 29 $^{\text{comfort points}}$ pre incident to 26 $^{\text{comfort points}}$. The incidence was a contact event sustained in a match and subsequently registered by the player as poor (red zone) comfort. The incident resulted in a time loss event during week 8. This example represents an occasion where the injury was classified as a Known $^{\text{TLE}}$ as the incident occurred prior to the recording of comfort (Known $^{\text{TLE}}$ = LLCI $^{\text{data post injury}}$).

Overall lower limb comfort reduced from a median score of 29 $^{\text{comfort points}}$, to a poor (red zone) comfort (26 $^{\text{comfort points}}$). Lower limb comfort did not return to usual (black zone) comfort range until week 11. The Known $^{\text{TLE}}$ between weeks 8-11 were associated with poor (red zone) comfort for the lower limb due to shin discomfort (less than median 5 $^{\text{comfort points}}$). When lower limb comfort returned to usual (black zone) range in week 11, a return to full training and match day participation occurred.

To illustrate the effect of musculoskeletal compensation due to comfort variations, *the time loss event* which was attributed to poor shin comfort also affected calf comfort (weeks 8-10). At the time of injury, shin comfort fell from 5 $^{\text{comfort points}}$ to 2 $^{\text{comfort points}}$. Calf-achilles comfort fell from 5 $^{\text{comfort points}}$ (week 7) to 3 $^{\text{comfort points}}$ (week 9) and did not return to usual comfort until week 11. The graph illustrates that as the player returned from injury, the overall lower limb comfort remained within the player's usual (black zone) comfort range for weeks 11-25, not missing any further training or matches due to lower limb injury. Shin comfort did not return to pre-injury comfort until week 15.

Case study Player C

Figure 7 shows the pattern of training participation, *time loss events*, Predicted $^{\text{TLE}}$ and Known $^{\text{TLE}}$ for data of a player who was represenattive of the group. The median lower limb comfort score for Player C, calculated over a period of 25 weeks was 30 $^{\text{comfort points}}$. A score of median $^{-2\text{ comfort points}}$, indicated poor comfort. A score of median $^{+2\text{ comfort points}}$ was labelled high comfort. Where comfort scores were within usual comfort range (29 - 31 $^{\text{comfort points}}$) or higher, full training participation occurred over the period. On only one ocassion a high score of 32 $^{\text{comfort points}}$ was recorded in week 3. This highlighted the demands of professional football on the lower limb and supports the group data (Figure 1) where high lower limb comfort is infrequent during in-season football. Poor comfort occurred in weeks 6,7,10,11,12, 13 and 24. In all weeks of poor comfort, *time loss events* were recorded except for week 24 during which poor (red zone) comfort was not associated with a *time loss event*. Two new *time loss events* occurred in weeks 6 and 10, during which poor (red zone) comfort, was predictive of injury (Predicted $^{\text{TLE}}$ = LLCI $^{\text{data pre injury}}$). In weeks 7, 11-13 *time loss events* were classfified as Known $^{\text{TLE}}$ as these weeks followed new injury events in weeks 6 and 10.

Discussion

The results from this study indicated a strong relationship between poor lower limb comfort and injury when defined as a *time loss event*. The use of a comfort index (LLCI) was a novel method of prospectively monitoring lower limb comfort in a cohort of elite footballers from

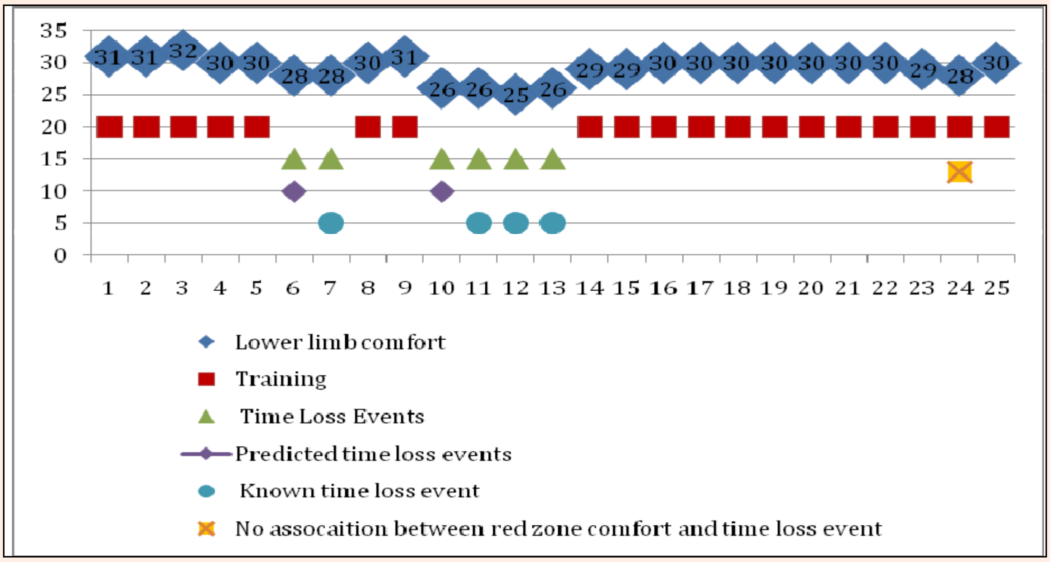

Figure 7. Shows lower limb comfort, participation in training sessions, *time loss events*, *predicted* and *known* injury events for one player whose data were representative of the sample. The x-axis represents player comfort weeks, 1-25; the y-axis comfort scores 0-35.

three different football codes. The comfort index was sensitive in assessing comfort by cataloguing fluctuating comfort scores for 182 professional footballers and the creation of high and low comfort tiers around a median comfort score to examine the relationship between comfort and injury. The concept of lower limb comfort has important relevance for future use in research and in clinical practice. High comfort scores can be interpreted as high comfort aligned to a protective mechanism for lower limb injury.

The authors are unaware of comfort as a concept previously being used prospectively in a comfort rating scale applied to the lower limb for elite or amateur sport. However, psychophysiological comfort ratings have been used in professions such as nursing (Chiu and Wang, 2007) and military (Mundermann et al., 2003) to assess footwear comfort. An advantage of the LLCI is the prospective recording of comfort. When an injury occurs, a discomfort event can be compared to a catalogue of comfort experiences (baseline comfort), providing a measure of the severity of the injury. Such information and recall is not possible with reactive pain scales if there is no injurious experience on which to draw upon. For example, where an injury occurs to a region of the body never before injured or damaged outside a discernable recall period, the player has no available measure to gauge the level of discomfort, if benchmark comfort has not been established. A perceived advantage of measuring multiple anatomical sites rather than an overall lower limb comfort value is the capacity to monitor multiple anatomical sites at the same time. This approach offers a monitoring tool for adjacent regions when injury occurs. The case studies show how compensatory musculoskeletal function will occur when discomfort and injury affects the body. In the present study, lower limb comfort variability was attributed to six segmental comfort regions providing an overall sum comfort score. The results provide the first insight into how the demands of elite football effects lower limb comfort. High comfort was registered by players only 18% of all comfort recordings, while poor comfort was recorded 23% of occasions. Poor comfort was strongly correlated to injury ($R^2 = 0.77$) and high (blue zone) comfort had a weak correlation ($R^2 = 0.15$). The use of a tiered comfort system, poor (red), usual (black), and high (blue) zones further quantifies comfort data. When a player falls into a comfort zone lower than the median range, the index acts as a warning system for both the player and the management team. The use of a median score for each player instead of an average score to determine zones provided a middle range score and was more accurate when data were non-normally distributed. A post-hoc analysis of all players indicated the median and range for zones was consistent with mean and standard deviation for majority of participants.

Usual (black zone) comfort as determined by median $^{\pm 1 \text{ comfort points}}$ enabled a 3 $^{\text{comfort point}}$ spread. This allowed for some variation within the zone of usual comfort as comfort variations occur due to pain stimuli via the neural networks of the body (Karoly and Jensen, 1987). A spread of four (4) $^{\text{comfort points}}$ between poor (red zone) comfort and high (blue zone) comfort enabled the capture of extreme comfort values for each player.

The interpretation of the study data, suggests comfort does play a part in the injury. Figure 1, highlights the spread of comfort and may represent the physiological adaptation of the lower limb to the demands of professional football. Usual (black zone) comfort which was calculated as a 3 $^{\text{comfort points}}$ spread around the median may be representative of a theoretical comfort threshold required for individuals to avoid injury associated with lower limb discomfort. This is an area of future research which is outside the scope of this study.

Of the 5033 collected events for 182 players usual (black zone) comfort accounted for 58.6% of all comfort events. Comfort scores greater than the median $^{\pm 1 \text{ comfort points}}$ resulted in no *time loss events* except for five outliers, however lower limb scores less than the median range resulted in a significant number of time loss events (R^2 =0.77). This may indicate high comfort scores act as a protective mechanism against lower limb injury, but poor (red zone) comfort does not. It is acknowledged this premise can only relate to non-contact injuries.

The incidence of injury, 59.9 injuries/1000 hrs reported in this study was greater than some reported injuries in the rugby league, 44.9/1000 hrs (Gibbs, 1993), and a ten year average in Australian Rules, 41.7/1000hrs (Orchard and Seward 2008), but less than others (160.6 /1000 hrs, rugby league) (Gabbett, 2000) and 83.9/1000hrs, rugby union (Fuller et al., 2008) However, different injury definitions and study designs will affect outcomes. The use of *time loss events* to describe non participation in full training (Drawer and Fuller, 2002; Hagglund et al., 2009) may have inflated injury rates. The use of time loss to define injury is increasingly used in football studies because it takes account of injuries most likely to affect a player's health and performance (Chomiak and Junge, 2000). For this study, *time loss event* was defined as not being able to take part in a regular training session or match because non-participation was considered to affect performance outcomes. The premise for the effect of non training participation and performance is to be investigated by the authors as an extension of this study.

The recording of *time loss events* to the knee and below were based on two criteria: the LLCI was not tested during development to include other anatomical locations such as the groin or hip and the inclusion of more areas would have created an index which was overly complicated, from a time to complete perspective. Moreover, the majority of injuries sustained in most running sports involve the anatomical segments used in this study (Chomiak et al., 2000). A perceived limitation of the LLCI was not including hamstring, groin, pelvic and back injury as a consequence of lower limb comfort. An assessment of 17 hamstring injuries sustained over a 30 week period indicated that the LLCI was predictive of time loss hamstring events on 8 (47%) occasions. This snapshot of injury outside the parameters of the LLCI may provide some insight to pain inhibition responses. It is possible that hamstring injury was due to compensatory function for lower limb discomfort. While supportive evidence exists for neurophysiologic compensatory theory, the effect of musculoskeletal discomfort at one anatomical segment being associated with injury at a different anatomical segment requires further investigation.

The capacity to use comfort in two ways, as a method to predict injury (Predicted ^{TLE}) or to categorize the extent of a known injury (Known ^{TLE}) by observing the comfort scores provides a mechanism to more capably manage an athlete in either a proactive sense (Predicted ^{TLE} = LLCI $^{\text{data pre injury}}$), or manage poor lower limb discomfort when it is known (Known ^{TLE} = LLCI $^{\text{data post injury}}$). A *time loss event* initially labeled a Predicted ^{TLE} will become a Known ^{TLE} in subsequent weeks where a player does not return to regular training (Figure 7). Therefore, as *time loss events* in the study were a combination of Known ^{TLE} and Predicted ^{TLE}, the capacity of poor (red zone) comfort to predict injury was not statistically significant (R^2 =0.18). However, conclusions about the LLCI lacking face validity for injury prediction should not only be interpreted by statistical validity but also by clinical application. Figure 7 indicated for two new injury events in weeks 6 and 10; poor (red zone) comfort was predictive of injury (Predicted ^{TLE} = LLCI $^{\text{data pre injury}}$). For the entire study, on 47% of occasions, *time loss events* were predicted. Because the football organisations involved in this study had good intervention programs, many of the *time loss events* were Known ^{TLE}. A study by the authors which is an extension of developmental and efficacy research on the use of a lower limb comfort which involved 59 rugby league players indicated where there was no organized or tailored lower limb intervention program; poor (red zone) comfort was a good predictor of injury where of 71 non contact injuries, 69% were predicted (95% CI = 58.2, 79.8%).

Many *time loss events* in this study were classified as Known ^{TLE}. The case study (Figure 6) was considered representative of Known ^{TLE} which occurred in the study. In the example provided poor (red zone) comfort was used to not only assess the site of injury (shin), but also comfort levels of adjacent anatomical sites (foot, ankle, calf-achilles, knee and footwear) due to the injury. Calf comfort reduced following shin injury most likely due to compensatory movement patterns and protective responses to unload the injured region. The use of a multi-segment lower limb comfort measure provided a barometer to assess comfort for return to full training participation which did not occur until week 11. Further, the site of injury did not return to pre-injury comfort level for some weeks following the incident, which highlights the benefit of how prospective measures of comfort provides medical and conditioning staff with quantitative data to implement more targeted intervention programs.

In the study all *time loss events* were highly correlated with poor (red zone) comfort (R^2 = 0.77; p <0.0001). However, there were occasions where poor comfort had a weak correlation *time loss events* (R^2 = 0.16; p <0.0001) where poor comfort was not associated with a *time loss event;* the player is capable of full physical activity. This creates a dilemma for medical staff about how to manage the athlete. While player base line comfort can be compared to comfort at the time of injury to enable quantification of the injured zone and adjacent anatomical segments not directly affected by injury, the study shows that where poor comfort is registered, there is a high correlation with injury (R^2 = 0.77), and 47% of Predicted TLE are associated with poor comfort. Thus, the challenge for the clinician is to process all available information, to enable an informed decision about the potential for injury with continued participation where poor lower limb comfort is registered. The use of lower limb comfort scores may offer one additional method of assisting with decision making.

Conclusion

The lower limb comfort index was developed to provide a tool for clinicians and athletes to monitor lower limb comfort at multiple anatomical regions. The registering of lower limb comfort scores using the LLCI provides a series of signposts for players and medical staff which contribute to the injury management paradigm by offering a method to monitor lower limb health prospectively as well as assisting with decision making when injury occurs. The LLCI has high face and criterion-related validity as a clinical tool with which to measure the lower limb well being of players. By quantifying lower limb comfort into high, usual and poor comfort zones, the study was capable of identifying the role of lower limb comfort on injury in three elite codes of football regularly played in Australia.

The monitoring of lower limb comfort data as one entity as well as individual anatomical segments offers a comprehensive overview of lower limb health status for football and may be used to assist with rehabilitation strategies and return to activity plans by quantifying comfort. The main advantages of the LLCI are its ease of implementation, the clarity of the information collected and most importantly, the direct clinical application of the information to the performance of individual players. The categorization of players into high and low injury risk groups for any given week day or match day training based upon lower limb comfort will facilitate critical clinical decisions about rehabilitation, medical interventions and training loads. Such decisions are likely to have a major influence on the reduction of injury events and on player performance.

References

Apriantono, T., Nunome, H., Ikegami, Y. and Sano, S. (2006) The effect of muscle fatigue on instep kicking kinetics and kinematics in association football. *Journal of Sports Sciences* **24(9)**, 951-960.

Baczkowski, K., Marks, P., Silberstein, M. and Schneider–Kolsky, M.E. (2006), A New Look into Kicking a Football: An Investigation of Muscle Activity Using MRI. *Australasian Radiology* **50(4)**, 324-329.

Bahr, R. and Krosshaug, T. (2005) Understanding injury mechanisms: a key component of preventing injuries in sport. *British Journal of Sports Medicine* **39**, 324-329.

Bahr, R. and Holme, I. (2003) Risk factors for sports injuries methodological approach. *British Journal of Sports Medicine* **37,** 384-392.

Burns, J., Keenan, A-M. and Redmond, A.,(2003) Factors associated with training related overuse injuries. *Journal of Orthopedic and Sports Physical Therapy* **33**, 177-184.

Chomiak, J., Junge, A., Peterson, L. and Dvorak, J. (2000) Severe injuries in football players. Influencing factors. *American Journal of Sports Medicine* **28,** S58-68.

Chiu, M. and Wang, M.J. (2007) Professional Footwear evaluation for clinical nurses. *Applied Ergonomics* **38,** 133-141.

Drawer, S. and Fuller, C.W. (2002) Evaluating the level of injury in English professional football using a risk based assessment process. *British Journal Sports Medicine* **36**, 446-451.

Dvorak, J. and Junge, A. (2000) Football injuries and physical symptoms: a review of the literature. *American Journal Sports Medicine* **28,** S3-S9.

Engstrom, B., Johansson, C. and Tornkvist, H. (1991) Soccer injuries among elite female players. *American Journal Sports Medicine*, **19,** 372-375.

Fuller, C.W., Laborde, F., Leather, R.J. and Molloy, M.G. (2008) International Rugby Board Rugby World Cup 2007 injury surveillance study. *British Journal Sports Medicine* **42**, 452-459.

Gabbe, B., Finch, C., Wajsweiner, H. and Bennell, K. (2004) Predictors of lower extremity injuries at the community level of Australian Football. *Clinical Journal of Sports Medicine* **14 (2)**, 56-63.

Gabbett, T.J. (2000) Incidence, site, and nature of injuries in amateur rugby league over three consecutive seasons. *British Journal Sports Medicine* **34**, 98-103.

Gabbett T.J. (2005) Science of rugby league football: A review. *Journal of Sports Sciences* **23 (9)**, 961-976.

Gabbett, T. (2006) Skill-based conditioning games as an alternative to training conditioning for rugby league players. *Journal of Strength Training & Conditioning Research* **20 (2),** 309-315.

Gabbett, T.J. (2010) Match and training injuries in rugby league: a review of published studies. *Sports Medicine* **1(40)**, 163-178.

Gibbs, N. (1993) Injuries in professional rugby league. A 3 year prospective study. *American Journal of Sports Medicine* **21**, 696-700.

Gosling, C., Gabbe, B. and Forbes, A. (2008) Training related musculoskeletal injuries: the status of injury prevention knowledge. *Journal of Science and Medicine in Sport* **11**, 396-406.

Hägglund, M., Waldén, M. and Ekstrand, J. (2003) Exposure and injury risk in Swedish elite football: a comparison between seasons 1982 and 2001. *Scandinavian Journal of Medicine and Science in Sports* **13(6),** 364-370.

Hägglund, M., Waldén, M. and Ekstrand, J. (2009) Injuries among male and female elite football players. *Scandinavian Journal of Medicine and Science in Sports,* **6 (19),** 819-827.

Hawkins, R.D. (1999) A prospective epidemiological study of injuries in four english professional football clubs. *British Journal of Sports Medicine* **33,** 196-203.

Kinchington, M. (2009) Lower limb injury implications for Taekwondo. In: *2nd International Symposium for Taekwondo studies. The Globalization of Taekwondo, October 12-13, Copenhagen, Denmark, October 12-13, Copenhagen, Denmark*. 22

Kinchington, M., Ball, K. and Naughton, G., (2010) Reliability of an instrument to determine lower limb comfort in professional football. *Open Access Journal of Sports Medicine* **1,** 77-85.

Lüthje, P., Nurmi, I., Kataja, M., Belt, E., Helenius, P., Kaukonen, J., Kiviluoto, H., Kokko, E., Lehtipuu, T., Lehtonen, A., Liukkonen, T., Myllyniemi, J., Rasilainen, P., Tolvanen, E., Virtanen, H. and Walldén, M. (1996) Epidemiology and traumatology of injuries in elite soccer: a prospective study in Finland. *Scandinavian Journal of Medicine & Science in Sports* **3(6),** 180-185.

McManus, A., Stevenson, M., Finch, C., Elliot, B. and Hamer, P. (2004) Incidence and risk factors for injury in non-elite Australian Football. *Journal of Science and Medicine in Sport* **7(3)**, 384-391.

Mundermann, A., Humble, R. and Nigg, B. (2003) Orthotic comfort is related to kinematics, kinetics and EMG in recreational runners. *Medical Science and Sports Exercise* **35**, 1710.

Murphy, D., Connolly, D. and Beynnon, B. (2003) Risk factors for lower extremity injury: a review of the literature. *British Journal of Sports Medicine* **37,** 13-29.

Norton, K., Schwerdt, S. and Lange, K., (2001) Evidence for the aetiology of injuries in Australian Football. *British Journal of Sports Medicine* **35**, 418-423.

Orchard, J. (2002) Is there a relationship between ground and climatic conditions and injuries in football? *Sports Medicine* **32(7),** 419-432.

Orchard, J. and Seward, H. (2008) Injury report 2008 Australian Football League. Available from URL: http://www.injuryupdate.com.au/images/research/AFL_Injury_Report_2008.pdf. Accessed 10 February 2010

Takemura, M., Schneiders, A., Bell, M. and Milburn, P., (2007) Association of ground hardness with injuries in Rugby Union, *British Journal of Sports Medicine* **41(9)**, 582-587.

van Mechelan, W., Hlobil, H. and Kemper, H.C. (1992) Incidence, severity, aetiology and prevention of sports injuries: a review of concepts. *Sports Medicine* **14,** 82-99.

Walden, M., Hagglund, M. and Ekstrand J. (2005) UEFA Champions League study: a prospective study of injuries in professional football during the 2001 – 2002 season. *British Journal of Sports Medicine* **39**, 542-546.

Williamson, A. and Hoggart, B. (2005) Pain: a review of three commonly used pain rating scales. *Journal of Clinical Nursing* **14(7),** 798-804.

Wong, P. and Hong, Y. (2005) Soccer injury in the lower extremities. *British Journal of Sports Medicine* **39**, 473-482.

Zou, K.H, Tuncali, K. and Silverman, S.G. (2003) Correlation and simple linear regression. *Radiology* **227,** 617-628.

Key points

- Comfort as a method to determine the well-being of athletes has a role in injury management.
- A lower limb comfort index is a mechanism by which lower limb comfort can be evaluated.
- Poor lower limb comfort is associated with injury in professional football.
- The use of a comfort as a marker of athlete health has practical and clinical relevance to sports medicine professionals managing musculoskeletal injury.

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