THE INFLUENCE OF SUBJECTIVE TRAINING LOAD ON INJURY AND ILLNESS IN ELITE TRACK CYCLING

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Abstract

Introduction: Training time loss due to injury or illness is a major predictor of performance outcome in Olympic athletes. Athlete monitoring is increasingly being utilised in elite sport to examine internal, external and psychological variables that may be related to injury and illness risk. Subjective load monitoring has been shown to be an effective method to monitor training load across a multitude of sports. The Cycling New Zealand (CNZ) high performance track cycling program currently collects external load in the form of power data from selected road and track sessions and subjective load is collected from gym training sessions. There is no load variable utilised across all disciplines and training modalities. Implementing a method to monitor subjective load across all aspects of training may help to reduce injury and illness risk along with optimizing performance in the CNZ high performance track cycling program. These methods may also help to inform athlete monitoring across the wider High Performance Sport New Zealand system.

Aim: The primary aim of this research was to investigate the relationship between subjective load and injury or illness in elite CNZ track cycling athletes.

Methods: A prospective longitudinal study of two cohorts of elite CNZ track cycling athletes was undertaken in the lead up to the Rio de Janeiro Olympic Games (n=6) and over the 2016/2017 international track cycling season (n=10). This study was approached using stages one and two of the Translating Research into Injury Prevention Practice (TRIPP) model which involved surveillance along with establishing the aetiology and mechanisms of injury and illness. Injury and illness surveillance was performed in line with the International Olympic Committee approach. To investigate the aetiology of injury and illness subjective load monitoring was conducted using the session rating of perceived exertion method with acute load, chronic load and acute to chronic workload ratios calculated. Data was analysed descriptively along with repeated measures logistic regression with exchangeable correlation matrix to determine any relationship between subjective load and injury or illness. A total of 270 weeks was analysed over the two data collections.

Results: An increase in chronic load per 100 units increased the combined odds of injury or illness, and individual odds of injury by four percent (p=0.05). Increasing acute load per 100 units or acute to chronic workload ratio per one unit reduced the odds of illness by two percent and 63% respectively (p=0.05). Female athletes had a twenty times higher odds of illness than male athletes (p=0.05). Injury or illness did not always relate to time loss or modification of training and there was a high amount of individual athlete variation in response to load.

Conclusions: Subjective load monitoring is an effective method to monitor injury and illness risk in CNZ high performance track cycling athletes. The ability to withstand high chronic loads may be a key factor in developing resilient CNZ athletes and further research is needed to understand the high rates of illness in female athletes. The methodology utilised in this research should be continued in High Performance Sport to collect ongoing data that may help improve performance outcomes for all athletes.

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Attestation of Authorship

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution"

Signed:  Date: 14/05/2018

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The Auckland University of Technology Ethics Committee granted ethical approval for this research on the 16th of June 2016, ethics application number 16/204 (see appendix 1).

Chapter 1: Introduction

1.1 Statement of the Problem

1.1.1 The Role of Athlete Monitoring in Elite Sport

The margins for winning in elite sport are getting smaller with one of the key indicators of success minimising training time loss due to injury or illness (Raysmith & Drew, 2015). With this strong association sports are interested in ways to minimise training time loss to give the best possible chance of achieving success (Hulin, Gabbett, Lawson, Caputi, & Sampson, 2015). One potential way to do this is via athlete monitoring allowing feedback of variables to the athletes, coaches and support teams that may help to reduce this risk (Saw, Main, & Gastin, 2015c).

Athlete monitoring has become a key part of elite sport (Taylor, Chapman, Cronin, Newton, & Gill, 2012), it can be used to gauge effectiveness of training programs, determine individual and team response to training, guide training progression and plan future training sessions. It can also be used to assess readiness to train and compete (Gabbett, Hulin, Blanch, & Whiteley, 2016), and as a potential indicator of overtraining (Halson, 2014). There are a multitude of variables that can be monitored from the very complex and multifactorial such as heart rate variability and global positioning system analysis, through to the very basic, for example, asking the athlete “how are you feeling today?” (Black, Gabbett, Cole, & Naughton, 2016; Halson, 2014). Determining what variables to monitor and the methods used to perform this monitoring can have a large impact on the utility of athlete monitoring (Saw, Main, & Gastin, 2015a).

1.1.2 Load Monitoring in Elite Sport

There has been a growing interest in monitoring athlete load and how this relates to performance and injury or illness risk (Gabbett, 2016; Hulin, Gabbett, Caputi, Lawson, & Sampson, 2016). It was previously thought that the higher the load the higher the injury and illness risk (Gabbett, 2004). More recently it has been shown that it is not the absolute load that is the main concern but rather the relative load, with too much or not enough relative load leading to an increased injury and illness risk (Hulin et al., 2015). This has been developed into the acute to chronic workload ratio model (Blanch & Gabbett, 2015) which was previously described as training stress balance (Hulin et al., 2014). The acute to chronic workload model is a way to represent the athletes’ status with respect to fitness versus fatigue and to highlight large variations or spikes in load (Blanch & Gabbett, 2015). In the model acute load represents fatigue and is most often the sum of the weekly training loads, and chronic load represents fitness, commonly reported at the average of the last four weeks training loads (Blanch & Gabbett, 2015) . The acute to chronic workload ratio is simply the acute load divided by the chronic load to give a numeric value with values above one representing more fatigue than fitness and values below one more fitness than fatigue (Blanch & Gabbett, 2015) . In this model it has been shown that in certain sports too high or too low acute to chronic workload ratios leads to an increased injury and illness risk (Hulin et al., 2016). The ability to accurately provide a marker of this risk has been a significant development in the monitoring of athletes and has the potential to be the difference between success and failure (Gabbett et al., 2016).

Elite sport in its essence is all about performance with the aim of winning. Reducing injury and illness risk and reducing the potential time loss to training is one way to improve the winning odds. The other is to push the amount of training that an athlete can do within this risk window. Having a better understanding of an athlete's ability to withstand training load and how quickly these loads can be progressed or reduced can be of huge benefit to the support team (Gabbett, 2016). This can be referred to as the optimal training zone or the "sweet spot" (Gabbett, 2016) which is an ideal mix of fitness versus fatigue while still allowing for training adaptation. It is likely that this is not a linear curve but more likely a U shaped curve as proposed by Walsh et al., (2011) or a J shaped curve as presented by Blanch and Gabbett, (2015). Identifying the ideal point or zone in this curve for a team or individual athlete may be a key factor in reducing injury and improving performance.

1.1.3 Cycling New Zealand High Performance Track Cycling

Cycling is an increasingly popular sport with track cycling a smaller subset of this. Given the unique nature of the sport there is no known published literature from New Zealand or internationally on this specific discipline with reference to load monitoring. Within Olympic track cycling the sport can further be divided into sprint and endurance events. In the Cycling New Zealand (CNZ) high performance program, the athletes and type of training for these two subsets are quite distinct however there are some similarities that can be grouped together. Both groups perform training that can be broadly categorised into road cycling, track cycling, ergometer training and gym work. The relative contributions of each of these types of training modalities will vary according to the discipline and time of the season. Traditionally endurance riders perform more road and ergometer training with sprint athletes favouring track and gym. This is starting to change with the changing nature of the sport and improved performance support for athletes.

The CNZ program and athletes receive funding and support from High Performance Sport New Zealand (HPSNZ). The aim of HPSNZ is to work in partnership with sports to deliver world leading support that impacts performance with a specific focus on teams and athletes that have the potential to win on the world stage (High Performance Sport New Zealand, n.d.). Given these objectives both HPSNZ and CNZ will be interested in any systems that can potentially help to improve performance such as athlete monitoring to reduce injury and illness risk.

1.1.4 Load Monitoring in Cycling New Zealand High Performance Track Cycling

With the varied type of training, one challenge can be quantifying the loading that an athlete or group of athletes performs over a given timeframe. Within the CNZ high performance track cycling program this has traditionally been recorded utilising power meters and heart rate monitors with programs such as Training Peaks ™ (https://www.trainingpeaks.com/) used to monitor and plan training progress and progression. In endurance training, this gives a relatively good indication of the internal and external loading that is being applied to and experienced by the athlete allowing coaches to monitor and manipulate training. What it has not been good at recording is gym and track training sessions especially for sprint athletes. It does not allow for a common monitoring unit to be applied to all training sessions across all disciplines that can be utilised by all athletes, coaches and support staff.

With the potential for load monitoring to have a positive impact on NZ track cycling athletes it would seem valuable to identify a system that can be applied to all disciplines and all training modalities. This should be considered in terms of both internal and external load variables (Drew & Finch, 2016). Within the CNZ track program external load is well monitored with the collection of power data from athletes. Internal load is only currently monitored within gym sessions with the use of session rating of perceived exertion (RPE) multiplied by session duration (Foster et al., 1995).

Internal load monitoring via athlete self-report measures has been identified as a reliable and valid way to record internal load (Saw, Main, & Gastin, 2015b) and shows a strong association with injury and illness risk (Drew & Finch, 2016). Having a measure of internal load to complement the power data representing external load would be a good addition to the monitoring of athletes in track cycling. Athletes within the CNZ program are familiar with the Foster et al. (1995) method for load monitoring and it would therefore seem sensible to use this as a measure of internal load across all training modalities.

1.2 Purpose of the Study

The primary aim of this research is to investigate the relationship between subjective load and injury or illness in elite CNZ track cycling athletes. This will be undertaken by performing injury surveillance along with collecting subjective load monitoring data in a prospective longitudinal cohort study. The data will then be analysed to see if there is any association or relationship between the variables.

It is also hoped that by investigating these relationships a consistent methodology for collecting load monitoring data for CNZ track cycling athletes will be established. This methodology may also help to inform the wider athlete monitoring systems within HPSNZ and New Zealand Sport at all levels.

1.3 Significance of the Study

This study will build on the current literature looking at the relationship between subjective load and injury or illness risk but in the specific cohort of elite CNZ track cycling athletes. It will have significance for coaches, performance scientists, strength and conditioning coaches, health professionals and athletes that are interested in athlete monitoring with a particular focus on injury and illness reduction and improved performance outcomes. The methodology developed and any associations found will help to improve the current load monitoring methods being utilised in the CNZ track cycling program. This may identify key subjective load markers to better inform training plan development on a program and individual athlete basis leading to improved performance outcomes which is the overall goal of any high-performance program.

Chapter 2: Review of Literature

This chapter will introduce the most commonly used injury prevention model, an update of this model along with the aspects of the updated model this research is attempting to address. The remainder of the chapter will provide a review of the literature that has investigated the relationship between subjective load and injury or illness in sport.

2.1 Injury and Illness Prevention Models

The success of an athlete or team can in large part be attributed to the ability to avoid training time loss due to injury or illness (Hägglund et al., 2013; Raysmith & Drew, 2015). With this strong association, it is important for high performance sports programs to establish good injury and illness prevention models.

The most widely cited model of injury prevention is that of van Mechelen, Hlobil and Kemper (1992). In this model, the authors propose a four-step process to injury prevention (see figure 2.1). This model has been further developed by Finch (2006) into a new framework termed the Translating Research into Injury Prevention Practice (TRIPP). The new framework adds a further two stages to the van Mechelen et al. (1992) model, specifically examining the implementation of injury prevention in sporting contexts (see figure 2.1). There is literature investigating the association between load and injury or illness for all stages of the TRIPP model. The current study will be situated in stages one and two.

Model Stage	van Mechelen et al.	TRIPP
1	Establish extent of problem	Injury surveillance
2	Establish aetiology and mechanisms of injury	Establish aetiology and mechanisms of injury
3	Introduce preventative measures	Develop preventative measures
4	Assess their effectiveness by repeating stage 1	"Ideal conditions"/scientific evaluation
5		Describe intervention context to inform implementation strategies
6		Evaluate effectiveness of preventative measures in implementation context

Figure 2.1. Comparison of Injury prevention models as proposed by Finch (2006) and van Mechelen et al. (1992).

2.1.1 Injury and illness surveillance. According to van Mechelen et al. (1992) the first step in an injury prevention program is to establish the extent of the problem, which is further defined in the TRIPP model as injury surveillance (Finch, 2006). Injury surveillance is becoming common place in high performance sport, as support teams seek to understand the extent and nature of injuries (van Mechelen et al., 1992). With this information support teams can develop targeted programs to reduce injury rates which may ultimately lead to improved performance outcomes (Hägglund et al., 2013). Injury surveillance also allows sports organisations to compare injury and illness rates across their own program, with other programs of the same sport and with different sports (van Mechelen et al., 1992).

The difficulty when comparing injury and illness rates is that surveillance programs often employ different methodologies (Finch, 1997). Some of the common areas for inconsistency are injury and illness definitions, classification of injury and illness, refence exposure rates, and method of collection (Ekegren, Gabbe, & Finch, 2015; Finch, 1997). This has prompted calls within some sports for consensus on definitions and data collection procedures (Fuller et al., 2006; Junge et al., 2008; Timpka et al., 2014). Moving towards consensus is a positive step forward for consistency within a sport but not necessarily across sport.

Defining injury or illness would seem a simple task as it appears to be a dichotomous variable with an athlete either injured or not, and ill or not. In practice, it is less straight forward, the main difference being that some report all injuries and illness while others report only those that cause time loss (Finch, 1997). Within Olympic sport the most common definition for injury is: *''any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training''* (Junge et al., 2008, p. 414). This definition gives a good account of the actual injury rate; however, only an estimate of time loss is recorded. In contrast the consensus statement provided for Rugby Union by Fuller and colleagues (2006) propose three categories for injury: time loss, medical attention and recurrent. This has also been supported in the consensus statement for epidemiological studies in athletics (Timpka et al., 2014). Perhaps the most important point when undertaking epidemiological studies is that a clear definition of injury and illness should be provided along with a way of determining the effect on training and competition.

Classification of injury or illness also brings its challenges and may reflect the difficulty of obtaining an accurate diagnosis in the first instance. For example, the association between imaging and pain or function is often poorly related (Docking, Ooi, & Connell, 2015; Lewis, 2009). The most widely utilised classification system is the Orchard Code system which brings consistency to the way injury and illness is classified and how it is recorded (Rae & Orchard, 2007). This system is continually evolving meaning that studies that have utilised older versions of the code may not be as comparable to studies that have used more recent versions. If all surveillance studies utilised the Orchard Code system this would allow for improved comparison and consistency.

For injury surveillance to be meaningful and allow for comparisons across athletes, teams and sports, a consistent exposure reference is vital. This is most often expressed as an injury or illness rate per 1000 hours of training. There is some variation in the literature with studies reporting rates per training or competition exposure, odds ratios or relative risk ratios (van Mechelen et al., 1992). Providing an exposure reference per 1000 hours would seem like the best choice for consensus; however, as long as an exposure rate is provided the reader can make an inference about the extent of injury or illness in a specific athlete, sport or group.

The method of data collection will also impact on injury and illness surveillance. The main two methods are either self-report or observed. There are pros and cons to both approaches along with time and monetary implications (Saw, Kellmann, Main, & Gastin, 2017). Self-report is by far the most cost and time effective approach and has be reported to outperform objective measures (Saw et al., 2015b). Self-report does have a higher element of recall bias, however, this may be mitigated with good implementation (Saw et al., 2015a). Observed is likely to be more accurate but require a much larger investment of time and money which may be a major limitation in many sports in particular non-professional, or those with limited support personnel.

In summary, working towards a consensus of methodology in injury surveillance will allow for improved data collection and comparisons amongst studies. Where different methodologies have been used, accurate reporting of this including injury and illness definitions along with exposure rates are vital. For Olympic sports the IOC approach for injury surveillance as reported by Junge et al (2008) is recommended.

2.1.2 Establish aetiology and mechanisms of injury. Stage two of the van Mechelen et al. (1992) and TRIPP model (Finch, 2006) is to establish the aetiology and mechanism of injury and illness. There are multiple factors that can contribute to injury which can broadly be divided into internal factors that are related to the athlete and external factors which would be considered the environment (van Mechelen et al., 1992; Meeuwisse, 1994). Within each of these there are modifiable and non-modifiable risk factors, with the modifiable risk factors being of most interest in injury and illness prevention (Bahr & Holme, 2003).

Stage two of the injury prevention model is the specific focus of this research where the aim is to investigate the relationship between subjective load and injury or illness. Subjective load is the product of the RPE and the session duration expressed in arbitrary units (Foster et al., 1995). In the context of the van Mechelen et al. (1992) model, subjective load could be considered an internal factor as the athlete rates the difficulty of the session using the RPE scale (Foster et al., 1995). The session duration can also be considered an external factor as it is determined by the duration of the training or competition session. Subjective load therefore, represents both internal and external factors that could potentially modify injury and illness risk.

In attempting to determine the aetiology of injury and illness two main study designs are used: case-control and cohort studies, each with its own strengths and weaknesses (Bahr & Holme, 2003). Case-control studies are a good starting point to get an indication of possible risk factors and are often performed retrospectively (Bahr & Holme, 2003). The retrospective nature limits the reliability and requires very accurate matching of cases and controls (Finch, 2006). Cohort studies are conducted prospectively and are the preferred method for gaining accurate aetiological information (Bahr & Holme, 2003; Finch, 2006). The limitation of these studies is the duration of data collection and number of participants needed to gain meaningful data (Finch, 2006).

Therefore, in attempting to determine the aetiological factors associated with injury and illness risk in track cycling, investigating a variable that considers both internal and external factors such as subjective load would seem like a good choice. Along with subjective load using a prospective cohort study design would be the most effective approach to investigate any associations.

2.2 A Critical Review of Subjective Load Monitoring, Injury and Illness Literature

2.2.1 Introduction. There is currently no literature available on the topic of subjective load monitoring and injury or illness in the specific population of track cyclists when searching the data bases of medline, CINAHL and SPORTDiscuss. This review therefore looked at the available literature in all sports.

2.2.2 Literature search strategy. A review of the literature was conducted in keeping with the PRISMA statement (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009). Using the primary aim of the research question, key concepts were identified as follows: subjective load, injury and illness, training time loss and modification of training. Based on these key concepts it was determined that a keywords search would be the best way to approach the literature search and the following lists were identified:

1. Subjective, ‘self-report*’, internal, RPE, sRPE, perceive*, ‘self-rate*’
2. Load*, exert*, workload*, “training load*’
3. Injur*, ill*, ‘time loss*’, modif*, restrict*, reduce*

After an initial trial, search list three was further refined to:

3. injur*, ill*

For each of the keyword lists the individual keywords were combined with OR. Lists one and two were then combined with a proximity search of three degrees. This was then combined with the refined list three using AND. The databases searched using this strategy were medline, CINAHL, and SPORTDiscuss.

2.2.3 Selection criteria. The initial search was limited to English language and human only articles. The titles and abstracts were reviewed and any duplicates removed. The search was limited to articles published before April 2017. Articles were excluded if they did not report an association between subjective load and one of the key variables of injury or illness. Based on this exclusion criteria systematic reviews, descriptive studies and surveys were excluded.

Full texts were obtained and further screened for inclusion. A flow chart of the search strategy can be seen in figure 2.2 and an example of the search strategy can be found in appendix 2.

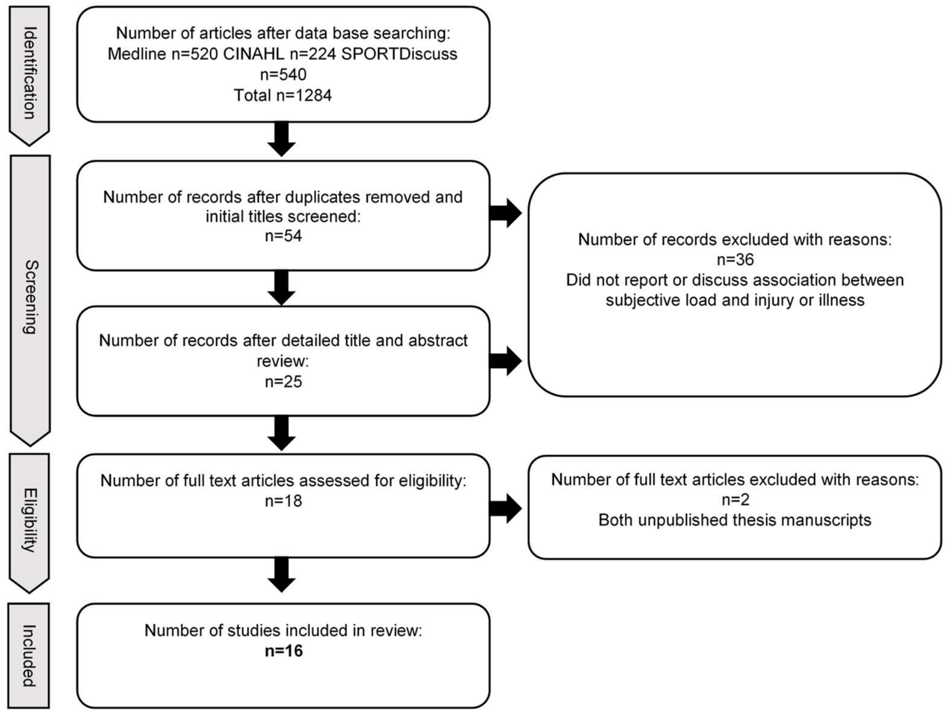

Figure 2.2. Flow chart of literature search.

2.2.4 Quality assessment. From the identified articles the methodological quality was assessed using the Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses (Wells et al., 2013). The NOS is one of two tools identified in the Cochrane handbook for assessing methodological quality or risk of bias in non-randomised studies (Higgins & Green, 2011). The NOS has been successfully used in the systematic review by Drew and Finch (2016) looking at the relationship between training load and injury, illness and soreness. It was therefore felt to be an effective tool to analyse the studies of interest in this review.

There are two scales, one for case control studies and the other for cohort studies with the latter chosen for this review. The NOS scores a study in three sections: selection, comparability and outcome with a maximum sore of 4, 2 and 3 stars respectively for each section. This gives a maximum possible score of 9 stars for a study.

2.2.5 Results. The results of the search strategy can be seen in figure 2.2. A total of 16 articles were identified for review and are summarised in table 2.1 along with quality assessment rating using the NOS. Seven articles investigated the relationship between subjective load and injury, four between subjective load and illness and five between subjective load and both injury and illness. As noted in the introduction there were no studies looking at track cycling. From the articles that were included in this review the following sports were represented: basketball (3), Australian football (3), football (2), rugby league (3), volleyball (1), cricket (1), running (1), swimming (1) and multiple sports (1).

The quality of the literature was good with an average NOS score of 6.6 (range 5 to 8) and no article scoring under 5 (median value of the NOS rating scales equals 4.5). None of the articles scored the maximum of nine stars, with all but two articles failing to report if injury or illness was present prior to the start of the study. A detailed breakdown of the quality assessment of each article can be seen in table 2.2.

Seven studies investigated the relationship between injury and training load (Freitas et al., 2015; Gabbett, 2004; Hulin et al., 2014; Kluitenber et al., 2016; Malisoux, Frisch, Urhausen, Seil & Theisen, 2013; Nagle et al., 2015; Rogalski, Dawson, Heasman, & Gabbett, 2013). Of these five showed a relationship between the two variables, one did not have enough data to reach statistical significance and therefore draw robust conclusions and one study showed no relationship between the internal load measure and injury.

In the four studies (Freitas et al., 2013; Moreira, Arsati, De Oliveira Lima-Arsati, Simões, & De Araújo, 2011; Thornton et al., 2016; Thornton, Duthie, Delaney, Sanctuary, & Dascombe, 2014) investigating the relationship between training load and illness all showed an association between the two variables. Two of the studies reported an increased illness rate with increased training load while the other two studies reported the opposite relationship.

For the five studies (Anderson, Triplett-McBride, Foster, Doberstein, & Brice, 2003; Brink et al., 2010; Piggott, Newton, & Mcguigan, 2009; Veugelers, Young, Fahrner, & Harvey, 2016; Watson, Brickson, Brooks, & Dunn, 2017) looking at the relationship between subjective training load and both injury and illness, four studies found a relationship between both variables and subjective training load. The one study that did not show a relationship with both variables, did show a relationship between training load and injury but not illness.

Table 2.1

Summary of articles included in review of subjective load, injury and illness.

Reference	Study Design and Duration	Participants	Sport and Country	Load/Stress Measures	Variable: Injury, Illness, Other	Findings	NOS Rating
Injury							
Hulin et al., 2014.	Prospective longitudinal cohort. 5 seasons.	28 (26±5y) (sex not stated).	Elite cricket fast bowlers. Australia.	External WL = total number of balls bowled in a week. Internal WL = RPE × duration.	Injury, assessed.	Relationship between acute external WL and injury risk in the current week with higher external WL associated with lower injury risk. No relationship between acute external WL and subsequent injury in the following week. Higher chronic external WL in current and subsequent week associated with lower injury likelihood. No relationship between acute or chronic internal WL and injury in the current or subsequent week. No relationship between internal or external training stress balance and injury in the current week. A negative external or internal training stress	8

						balance associated with injury in the subsequent week. Increased injury risk with training stress balance > 150% internal and > 200% external.	
Rogalski et al., 2013.	Prospective longitudinal cohort. 1 season.	46 (22.2±2.9y) (sex not stated).	Elite Australian Football League. Australia.	WL = RPE × session duration.	Injury, assessed.	Players with weekly load >1750 or two weekly load >4000 had a significantly higher injury risk. Higher injury occurrence in season for week to week load changes >1250. Players with 2-4 or 4-6 y experience in AFL significantly lower injury risk compared to +7y experience when previous to current week load change >1000. 1 y experience lower injury risk compared to 7+ y experience when one-week load >1650.	8
Gabbett, 2004.	Prospective longitudinal cohort. 9-month season.	79 (sex and age not stated).	Semi-professional Rugby League. Australia.	Internal TL = RPE × duration	Injury, assessed.	Training injuries highest start of season, match injuries highest end of season. Increased injury rate with higher standard of training and competition.	7

						Significant relationship between changes in incidence of training injuries and changes in training intensity, training duration, and TL. Changes in incidence of match-play injuries significantly correlated with changes in match intensity, match duration and match load.	
Kluitenberg et al., 2016.	Prospective longitudinal cohort. 6-week start to run program.	1696 (366 Male, 1332 Female, 43.3±10y).	Running. Netherlands.	Weekly running volume in minutes. Weekly average RPE. Number of training sessions per week.	Injury, self-report diary.	Higher intensity associated with higher injury occurrence in the subsequent week. Running > 60 mins in previous week protective for injury. Running frequency not associated with injury. Pain associated with running < 30 mins in previous week.	7
Malisoux et al., 2013.	Prospective longitudinal cohort. 41 weeks.	154 (100 Male, 54 Female, 12-19y ave 14.1y).	Elite athletes: handball, basketball, football, volleyball, badminton, tennis, table tennis, athletics, canoe-kayaking, cycling,	Daily and weekly TL using RPE × duration. Monotony = mean weekly TL ÷ SD weekly TL. Strain = weekly TL × monotony.	Injury, self-report online system, cross checked.	Intensity significantly higher in the week preceding injury compared to the 4 proceeding weeks. No significant effect of number of weekly training sessions and injury.	6

			gymnastics, swimming, judo, karate, triathlon. Country not stated, assumed Luxembourg.	Exposure volume using hours of training.		Team sports had the lowest WL but highest injury risk.	
Freitas et al., 2015	Prospective longitudinal cohort. 25-day pre-competition training block.	7 Male (15.8±0.5y).	Junior Volleyball. Brazil.	Internal TL = RPE x duration summed weekly. Monotony = mean weekly TL ÷ SD weekly TL. Strain = weekly TL × monotony.	Performance measure (Countermovement vertical jump test and intermittent vertical jump test). Injury and recovery: RESTQ-Sport.	Improved performance measures. No difference in internal TL despite increased external TL. Increased fatigue and injury score in RESTQ-Sport after week 4 compared to baseline.	5
Nagle et al., 2015.	Prospective longitudinal cohort. Collegiate competitive swimming season.	16 Female (Age not stated).	Elite Collegiate Swimming. USA.	External load = yardage swam. Internal TL = RPE. Total TL = yardage and RPE but not stated how calculated. Lack of information on how this was calculated.	Swim performance (force over a 30s-tethered swimming test). Perceived stress and recovery state: RESTQ-Sport.	Not enough data presented to make good conclusions. A lack of significance relating to load and the variables. There were significant changes in individual variables over the season. Potential inverse relationship between yardage and swim performance and perceived stress and recovery.	5

Illness							
Freitas et al., 2013	Prospective longitudinal cohort. 19-week first macrocycle of a competitive season.	20 Male (22±5 y).	Professional Basketball. Brazil.	Internal TL = RPE x duration summed weekly.	Stress: DALDA questionnaire. Upper respiratory tract infection: WRUSS-21.	Reduced internal TL associated with increased stress and upper respiratory tract infection.	8
Moreira et al., 2011.	Prospective longitudinal cohort. 4-week in season competition period.	15 Male (19±0.6y).	Elite basketball Brazil.	TL = RPE x duration summed weekly ÷ number of sessions. Stress via weekly DALDA questionnaire. Salivary sample pre and post study for cortisol concentration, salivary immunoglobin A (SIgA) concentration and SIgA secretion.	Upper respiratory illness: WURSS-21.	Highest TL at week 2. Significant reduction in TL between week 2 and 4. Significant increase in Cortisol concentration and reduction in SIgA secretion rate after the study period. Significant correlation between DALDA and WRUSS-21 at week 2, between DALDA part B at week 4 and salivary cortisol before and after and SIgA secretion rate after.	7
Thornton et al., 2016.	Prospective longitudinal cohort. 29-week season.	32 (26±4.8y) (sex not stated).	Professional Rugby League. Australia.	TL = RPE × duration. Monotony = weekly TL ÷ SD. Strain = weekly TL × monotony.	Two-part self-report wellness questionnaire weekly. Part A related to illness and Part B	Weekly TL > 2765, monotony >0.78 and strain > 2282 strong predictors of incidence of self-report illness. Perceptual ratings of overall well-being and	6

					wellness and muscle soreness.	muscle soreness related to incidence of self-reported illness.	
Thornton et al., 2014.	Prospective longitudinal cohort. 29-week season.	32 (18 NRL squad 27.2±4.1y and 14 cup squad 23.2±3.9y) (sex not stated).	Elite Rugby League. Australia.	TL = RPE × duration. Monotony = weekly TL ÷ SD. Strain = weekly TL × monotony.	Two-part self-report wellness questionnaire weekly. Part A related to illness and Part B wellness and muscle soreness.	Significantly higher incidence of illness in NRL group compared to cup group. Increased incidence of illness in competition phase of season. Highest TL during specific preparation phase and lowest during competition.	5
Injury and Illness							
Brink et al., 2010.	Prospective longitudinal cohort. 2 competitive football seasons.	53 Male (15-18y).	Elite Football. Netherlands.	TL = RPE x duration Monotony = daily mean TL ÷ SD weekly load. Strain = weekly TL × monotony.	Injury and illness. RESTQ-Sport.	Significant relationship between traumatic injuries and higher weekly duration, TL, monotony and strain in the preceding week. No significant association between overuse injuries and load variables. Duration in preceding week significantly higher for ill athletes.	8
Anderson et al., 2003.	Prospective longitudinal cohort. 21-week season.	12 Female (18-22y).	Collegiate Basketball. USA.	TL = RPE × duration (weekly average). Monotony =	Injury and illness, assessed.	Moderately positive correlation between weekly injuries and; weekly TL, strain and	7

				weekly TL average ÷SD for the week. Training strain = weekly average TL x monotony.		monotony. No correlation between TL and illness.	
Watson et al., 2017.	Prospective longitudinal cohort. 20-week season.	75 Female (15.5±1.6y).	Elite youth soccer. Country not stated but assumed USA.	Internal TL = RPE x duration. Daily total, 7 day and 28 day rolling average and acute:chronic ratio 7 day/28 day rolling average. Daily rating of fatigue, mood, soreness, stress, and sleep quality. Sleep volume in hours.	Injury and illness, self-report computer system.	Daily mood, daily TL, prior day TL, weekly TL and actue:chronic workload ratio are independent predictors of injury. Higher preceding weekly and monthly TL are significant predictors of in-season illness.	7
Veugelers et al., 2016.	Prospective longitudinal cohort. 15-week preseason.	45 (23.4±4.8y) (sex not stated).	Elite Australian Football. Australia.	RPE field sessions only and then all sessions. TL = RPE x duration for field only and all sessions. 1 and 2 weekly cumulative TL calculated for	Non-contact injury and illness, assessed.	Significant association between injury incidence and 1 week all training RPE and all training RPE x duration. Significant association between 1-week field only RPE and illness. High TL group had reduced odds ratio for injury and illness.	6

				each of the above.		1 week, all training RPE, and all training RPE x duration best for predicting injury risk and field only RPE for illness. Addition of duration did not change ability to predict injury or illness.	
Piggott et al., 2009.	Prospective longitudinal cohort. 15-week preseason training period.	16 (23.8±5.1y) (sex not stated).	Professional Australian Football League. Australia.	TL = RPE × duration. Monotony = weekly TL ÷ SD of TL. Strain = TL × monotony. GPS for total distance run and distance above 12k/h. HR time spent above 80%. HRmax and averaged for session.	Injury and illness, assessed.	42% of illness and 40% of injuries associated with spike (>10%) in TL in preceding 7 days. 33% of illness and 20% of injuries associated with a preceding spike in monotony. 25% of illness and 40% of injuries associated with a preceding spike in strain.	5

TL=Training Load, sRPE=Session Rating of Perceived Exertion, WL=Workload SD=Standard Deviation, RPE=Rating of Perceived Exertion.

Table 2.2

Rating of studies using the Newcastle-Ottawa Quality Assessment Scale (NOS).

Reference	Selection/4	Comparability/2	Outcome/3	Total Score/9
Brink et al., 2016.	3	2	3	**8**
Freitas et al., 2013	3	2	3	**8**
Hulin et al., 2014.	3	2	3	**8**
Rogalski et al., 2013.	3	2	3	**8**
Anderson et al., 2003.	3	1	3	**7**
Gabbett, 2004.	3	1	3	**7**
Kluitenberg et al., 2016.	4	2	1	**7**
Moreira et al., 2011.	4	1	2	**7**
Watson et al., 2017	2	2	3	**7**
Malisoux et al., 2013.	2	2	2	**6**
Thornton et al., 2016.	2	2	2	**6**
Veugelers et al., 2016.	3	1	2	**6**
Freitas et al., 2015.	3	1	1	**5**
Nagle et al., 2015.	3	0	2	**5**
Piggott et al., 2009.	3	0	2	**5**
Thornton et al., 2014.	2	1	2	**5**
Mean Score	2.9	1.4	4.4	**6.6**

2.2.6 Discussion

2.2.6.1 Subjective load measures. The primary method for determining subjective load is to multiply the session duration by the RPE to give a load value in arbitrary units. This method was originally described by Foster and colleagues (1995) and was the calculation used in all but two studies (Kluitenberg et al., 2016; Nagle et al., 2015). Of the two studies that did not use this method Kluitenberg et al. (2016) did look at the independent variables that make up subjective load breaking it down to RPE, session duration, and frequency of training but did not combine them to give a subjective load value. In the study performed by Nagle et al. (2015) total training load was calculated by multiplying RPE with total yardage swum rather than session duration.

Where many of the studies differ is in the analysis of subjective training load data relative to injury or illness. This is in part due to the multiple ways of interpreting the subjective training load. All studies apart from Gabbett, (2004) and Nagle et al. (2015) looked at the total subjective load values over a week, most often termed the acute workload, and then change from week to week and the relationship to injury or illness. There was variation in reporting of acute load with some studies reporting the average weekly load (Anderson et al., 2003; Piggott et al., 2009; Watson et al., 2017) while other studies reported the total weekly load (Brink et al., 2010; Freitas et al., 2013; Freitas et al., 2015; Hulin et al., 2014; Malisoux et al., 2013; Moreira et al., 2011; Rogalski et al., 2013; Thornton et al., 2016; Thornton et al., 2014; Veugelers et al., 2016).

The other common analysis method performed was to look at longer periods of workload most often termed the chronic workload. This was commonly represented as the average of the acute workloads over a four-week period; however, two studies did look at the total value rather than average (Rogalski et al., 2013; Veugelers, et al., 2016).

Analysis of monotony and strain was more prevalent in earlier research whereas acute to chronic workload ratios more common in later work. Monotony was calculated by dividing the mean weekly subjective training load by the standard deviation of the weekly training load. Strain was determined by multiplying weekly training load with monotony. Acute to chronic workload analysis is seen in the more recent publications and is a form of the training stress balance theory as first reported by Calvert, Banister, Savage, & Bach (1976). It is most often calculated by dividing the acute workload by the chronic workload to give a ratio or percentage (Hulin et al., 2014). This form of analysis is very good at identifying spikes in load (Hulin et al., 2014) but does require longer durations of data collection.

There has been some discussion in the literature about the best method of calculating the acute to chronic workload ratio (Menaspà, 2016; Williams, West, Cross, & Stokes, 2016). This is based around the time frames for calculating the workloads and the decay of chronic load over time. For the studies in this review that calculated acute to chronic workload ratios, all used the weekly total divided by a rolling average over four weeks as described by Hulin and colleagues (2014).

The time frame for looking at the loading data in relation to current injury or illness varied*,* seven studies looked at the weeks preceding (Brink et al., 2010; Gabbett, 2004; Hulin et al., 2014;

Kluitenberg et al., 2016; Malisoux et al., 2013; Piggott et al., 2009; Rogalski et al., 2013), in comparison the remaining nine studies only examined the current week data. This highlights the need for studies to be of adequate duration to detect potential delayed associations otherwise known as the lag effect. The studies by Freitas et al. (2015), Kluitenberg et al. (2016) and Moreira et al. (2011) were too short in duration to calculate acute to chronic workloads and the possible lag effect of load in relation to injury and illness.

The large variation in the way that subjective load has been analysed will mean that some studies will over or under report associations. This variation also makes it difficult to make direct comparisons across studies with different methods. A challenge for future research will be to bring consistency to the way that subjective load is defined and analysed.

2.2.6.2 Definition of injury and illness. One of the difficulties when comparing epidemiological studies is the inconsistency of injury and illness definitions which was also found to be a problem in this review. Ten studies utilised self-report questionnaires, with two utilising the Wisconsin Upper Respiratory Symptom Survey (WURSS - 21) for upper respiratory symptoms (Freitas et al., 2013; Moreira et al., 2011). Three used the Recovery Stress Questionnaire for Athletes (RESTQ-Sport) which has multiple sections including a section on injury (Brink et al., 2010; Freitas et al., 2015; Nagle et al., 2015). Two studies with the same data set used a bespoke self-report questionnaire looking at illness, general wellness and muscle soreness designed by the club (Thornton et al., 2016; Thornton et al., 2014). Two studies used different online software self-report programs (Malisoux et al., 2013; Watson et al., 2017), and one study used a self-report diary for recording injury (Kluitenberg et al., 2016).

For the remaining six studies injury or illness was given a specific diagnosis and classification by a member of the support team (Anderson et al., 2003; Gabbett, 2004; Hulin et al., 2014; Piggott et al., 2009; Rogalski et al., 2013; Veugelers et al., 2016). Within these studies the definitions of injury or illness varied with most utilising training or game time loss as part of the definition, some included modification of training while others included all injuries or illness regardless of time loss.

The recording and definition of illness appeared to be more consistent across studies due to the nature of illness, which is more likely to lead to time loss. Within the injury analysis Veugelers et al. (2016) only included non-contact injuries, in contrast, most included all injuries based on their injury definition. There was also an attempt by many of the studies to classify the severity of the injury or illness by the amount of time lost.

Due to the variety of definitions making direct comparisons across studies is challenging. Studies with stricter criteria will tend to under report incidents while self-report methods may over or under report rates. For future research, aiming to utilise similar methodology for injury and illness classification will aid in building the pooled literature base.

2.2.6.3 Relationship between subjective load and injury. Injury was the most investigated variable in the studies assessed in this review. Seven of the studies investigated only injury and of these, five showed an association between subjective load and injury in the subsequent week (Gabbett, 2004; Hulin et al., 2014; Kluitenberg et al., 2016; Malisoux et al., 2013; Rogalski et al., 2013). In the two studies that did not report statistically significant associations both had methodological limitations (Freitas et al., 2015; Nagle et al., 2015). In the remaining five studies that reported on both injury and illness all showed an association between subjective load and injury (Anderson et al., 2003; Brink et al., 2010; Piggott et al., 2009; Veugelers et al., 2016; Watson et al., 2017).

In the study by Freitas et al. (2015) investigating seven male junior volleyball athletes, there was no association between internal training load and injury despite an increase in applied external load and an increase in injuries over the four-week study. A significant limitation of this study was the short duration of data capture and the small number of participants making it difficult to draw firm conclusions.

Gabbett (2004) investigated the relationship between subjective load and injury in a cohort of 79 rugby league athletes over a nine-month season. The author reported a positive correlation between injury incidence and increasing load in both training and match play. It was also reported that the highest training injuries and load occurred at the start of the season and correlated with the biggest changes in load. The author suggests that this may reflect too much load in the early phase of the season and could also represent an inadequate preseason. Acute to chronic workload ratios were not analysed in this study and would have been helpful for looking at potential spikes in load at the start of the season.

Hulin et al. (2014) conducted a five-season long study looking at the relationship between both external and internal load and injury in 28 cricket fast bowlers. One of the main findings of the study was that training stress balance was a strong predictor of injury risk in the subsequent week. There was no relationship between acute or chronic internal workload and injury in the current week or subsequent week. Although the focus of this review is subjective load, it is worthwhile highlighting that another key finding of this study was that high external workloads were shown to reduce injury risk in the subsequent week. This study highlights the importance of analysing not just the acute and chronic loads but also the acute to chronic workload ratio and looking earlier than the week of injury reporting. This may explain why some of the earlier studies that did not use acute to chronic workload ratios failed to show associations between subjective training load and injury risk.

Kluitenberg et al. (2016) conducted a short duration but large participant numbers (n=1696) study looking at a six week start to run program. The authors found an association between running intensity determined by RPE and injury in the subsequent week. An interesting finding was running more than 60 minutes in the previous week was protective for injury and running less than 30 minutes increased the injury risk. This trend has been hypothesised in several studies suggesting an optimal training zone for reducing injury risk. It should be noted that the authors defined injury based on pain (limited to the lower limb and lumbar spine only) which has a poor association with diagnosis. They did further define this to pain that impacted on running for at least three days making the analysis more specific. The other limiting factor for further analysis is the short duration which does not allow for acute to chronic ratios to be calculated. The positive aspect of this study is following a very common cohort with large numbers, allowing findings to be applied more widely.

Increased injury risk with increased preceding week load is further supported by Malisoux and colleagues (2013) who reported significantly higher intensity in the week preceding injury in their study of 154 elite youth athletes across multiple sports. Of interest, this study showed that sports with the lowest weekly training load had the highest injury risk. This might add weight to the argument for injury protection once at high training loads as proposed by Gabbett (2016).

It was difficult to draw any specific conclusion from the study by Nagle et al. (2015) due to the limited methodological detail and results data provided. The study investigated 16 female collegiate level swimmers over a competitive season. The authors report no statistically significant findings and it appears that there was a lack of detailed recording and analysis in this study.

The study by Rogalski et al. (2013) is a clear example of how to design and analyse subjective loading data with reference to injury risk in a cohort of elite Australian Football League (AFL) athletes. They followed 46 athletes over a full season (including pre-season) and reported specific in-season load values that lead to increased injury risk in subsequent weeks. Their study adds weight to the preceding week load change and injury risk trend. Interestingly they found no association in the pre-season phase, with the authors suggesting this could be attributed to a well-planned and controlled pre-season.

In contrast to their findings of no association between subjective training load and illness, Anderson and colleagues (2003) do report an association between training load and injury in 12 collegiate female basketball athletes followed over a 21-week season. Unfortunately, they did not look at acute to chronic workload ratios which may have highlighted the association even more. This can be seen in their training load to injury graphs where injury corresponded with dramatic spikes in training load.

The study by Brink et al. (2010) investigated 53 elite male football players over two competitive seasons and supports the trend of preceding week load change leading to increased acute injury risk. They did not see the same association in chronic injuries, this would likely require looking at loading data over extended periods of time preceding the chronic injury and could be a line of investigation for future research.

The link between the preceding weeks load change and injury is further supported by Piggott et al. (2009) who reported that 40 percent of injuries were preceded by a spike in internal workload of more than 10 percent in 16 AFL players over a 15-week pre-season. This does contrast the results of Rogalski et al. (2013) who did not find an association in pre-season and may reflect how well designed and controlled the pre-season trainings are. Unfortunately, the nature of the pre-season training is not reported in these studies due to confidentiality in professional sport.

Veugelers et al. (2016) was one of the few studies in this review that showed a reduced injury incidence with higher subjective training load groups and supports the theory of a protective effect once at high loads. The authors studied 45 elite Australian Football players over a 15-week pre-season. The analysis could have been influenced by the relatively low injury rates recorded (13) and only the preseason being studied. This is a more recent study and it would be assumed that the preseason was well constructed and controlled as mentioned earlier potentially leading to lower injury rates.

The final and most recent study reviewed was conducted by Watson et al. (2017) investigating the relationship between load, injury and illness over a 20-week season in 75 female youth soccer athletes. The study only investigated in-season load and the authors reported that daily training load, prior day training load, weekly training load and acute to chronic workload ratio were all predictors of injury.

One of the key findings in this review was that subjective load data from the preceding weeks was of most value in determining injury risk. This is a key point for researchers or clinicians who should ensure that time frames are long enough to accurately capture injury risk when analysing loading data. The other important consideration is to include some analysis of the acute to chronic workload ratio. This is very important when looking for relative spikes in load and can be missed if only acute and chronic loads are analysed independently (Windt & Gabbett, 2016). Finally, it appears that there may be optimal training load progressions and zones that can have a protective effect from injury (Gabbett, 2016; Windt & Gabbett, 2016). Determining what this is on a cohort to cohort basis and even individual basis will assist in injury reduction and improved performance.

2.2.6.4 Relationship between subjective load and illness. All but one of the studies reported an association between one of the components of subjective load and illness. Amongst the studies reporting an association some reported a reduced risk, while others reported an increased risk relative to increasing load.

The study by Anderson and colleagues (2003) did not show any association between illness and subjective load in 12 female collegiate basketball athletes over a 21-week season. In the study, only weekly subjective load relative to illness was investigated. Had the authors investigated acute to chronic ratios, or week to week relative changes in load, they may have found more of an association. They did look at strain and monotony but did not correlate this with illness. The authors suggested that illness may be more matched to stress as has been shown in earlier research and felt that this may be a better avenue for future research.

Three of the studies reported a reduced illness risk with increased subjective load. Freitas et al. (2013) followed 20 male professional basketball athletes over a 19-week competitive macrocycle and found that as internal load reduced the reporting of upper respiratory tract infections via the WRUSS-21 questionnaire increased along with increased reporting of stress. This supports the assumptions made by Anderson et al. (2003) that stress may be an important factor in illness. The authors also highlight that the phase with the lowest internal training load corresponded with the pinnacle of the season with games leading to play offs and finals. It would be common to taper for the most important games of the season, so not surprising to see internal training load reduce and pressure and stress increase. It would be interesting to investigate if this increased illness and stress impacted on performance.

The role of stress in illness incidence is further supported by Thornton et al. (2014) who showed that in 32 rugby league athletes over a 29-week season the highest rate of illness occurred in the competitive phase of the season which also corresponded with the lowest internal training load. They also found that the higher level competitive group had statistically significant higher illness rates. The authors propose that stress from increased travel, demands of the higher level of play and psychological stress may be contributing factors. They commented that travel had a negative impact on sleep and nutrition and has been linked to increased illness risk in athletes in previous literature (Prather, Janicki-Deverts, Hall, & Cohen, 2015; Svendsen, Taylor, Tønnessen, Bahr, & Gleeson, 2016; Timpka et al., 2014).

The third study to show a reduced risk of illness with high subjective training load was by Veugelers et al. (2016). They followed a cohort of 45 AFL athletes during a 15-week pre-season and found that athletes with high weekly training loads had lower injury and illness risk. Interestingly they also showed that field RPE alone without the addition of duration was the best predictor of illness. The authors suggest that the high training load group may have been training in the optimal zone to gain the protective effects from exercise. The authors make reference to the U shape model proposed by Walsh et al. (2011) which is a similar concept to the sweet spot zone proposed by Gabbett (2016).

The remaining five studies that investigated the relationship between subjective load and illness showed an association between increased loads or components of this, and illness risk. Moreira and colleagues (2011) investigated the effect of subjective training load on illness assessed via the WRUSS-21 questionnaire in 15 elite basketball athletes. The main limitation of this study was the duration of only four weeks making it difficult to generalise the findings. Putting the study duration aside the highest rates of upper respiratory tract infections corresponded with the highest weeks training load in the study. This also correlated with stress scores recorded on the Daily Analysis of Life Demands for Athletes (DALDA) questionnaire, again supporting the hypothesis that stress plays an important role in illness risk.

Thornton et al. (2016) have re-analysed the data from their 2014 study specifically looking to see if there were any strong predictors of self-report illness. They identified strain over 2282 units, a weekly training load greater than 2765 arbitrary units, and a monotony value greater than 0.78 units as the strongest predictors of illness in the cohort of 32 professional rugby league athletes over a 29-week season. They also analysed responses to a bespoke wellness questionnaire and found that an overall rating of decreased wellness and increased muscle soreness were related to illness incidence. This would seem to further support the role of stress in illness risk. It is interesting that their more recent study had slightly conflicting findings from the 2014 study given that the same data was analysed. An explanation for this is the more in-depth analysis methods used and that they were looking at predictor variables rather than causative variables.

The study by Brink et al. (2010) investigating 53 elite male football players over two competitive seasons is interesting because the preceding week duration but not subjective load was related to increased illness risk. This is in contrast to Veugelers et al. (2016) finding that RPE alone was the best predictor of illness as mentioned above. The authors also report an association with the stress scores on the RESTQ-Sport and illness, supporting further that stress plays an important role in determining illness risk.

Piggott et al. (2009) continues the theme seen in the injury section showing that the preceding weeks loads are important predictors of injury and illness. They report that 42 percent of illness was predicted by a spike in load of greater than 10 percent in the preceding week of 16 AFL athletes followed for a 15-week pre-season. Preceding week load as a strong predictor of illness is also supported in the final article by Watson et al. (2017) in a cohort of 75 female youth soccer players followed for a 20-week season. The authors reported that higher preceding weekly and monthly loads were the strongest predictors of in-season illness in their study cohort.

It appears that the association between illness and subjective load is less clear when compared to injury. Similar themes do emerge of preceding loads being an important predictor variable and higher loads or optimal loading zones may have a protective effect. Perhaps the most consistent theme across the articles reviewed was that stress may be the most important variable for determining illness risk.

2.2.6.5 Quality of evidence. The quality of the literature reviewed utilising the NOS showed that all studies were above the median value of 4.5, with the average NOS score for the 16 articles 6.6 and a range of 5 to 8. One of the main areas of methodological weakness was not indicating if participants were injured or ill on entering the study, this occurred in 14 of the 16 studies. In the case of injury this could be a possible confounder given that it is widely cited that the biggest predicting factor for injury is previous injury (Bahr, 2016). For future research, providing an indication of prior injury and any current injury when entering a study would be advisable.

The studies by Nagle et al. (2015) and Piggott et al. (2009) did not control for one or more variables that could have affected the relationship being investigated. For example, time of the season, training age, external environmental factors, travel, and sleep could all have had impacts on both injury and illness. A further six studies (Anderson et al., 2003; Freitas et al., 2015; Gabbett, 2004; Moreira et al., 2011; Thornton et al., 2014; Veugelers et al., 2016) did control for at least one variable but failed to control for other factors that could have influenced injury or illness. This was especially true for time of the season with studies reporting different outcomes for pre-season when compared to in-season. For illness, it was apparent that stress was a large factor so having an ability to control for this would been helpful in the analysis.

Thirteen studies followed participants for enough time to draw accurate conclusions. The duration of these studies was for specified training blocks, one or multiple seasons. A major limitation of short duration studies is an inability to analyse acute to chronic workload ratios and accurately show relative spikes in week to week training. If following the acute to chronic workload method as described by Hulin et al., (2014) at least four weeks of data is required before acute to chronic workloads can be calculated. It would therefore be advisable for future research to take this into account when devising study duration.

Self-report methods were used in ten of the studies which provides a convenient way to collect data; however, this does increase recall bias and as participants are required to report injury or illness rather than by specific diagnosis. As discussed earlier the definitions of injury or illness play a factor in the self-reporting rates. Making definitions clear and consistent will not only help comparisons between research but also help to improve accuracy in self-report studies.

Finally, it may be beneficial for future research to evaluate their methods against the NOS tool to improve the quality of research. This would be particularly helpful in the design stage of research planning and would lead to improvements in the quality of research related to this topic.

2.2.6.6 Future research recommendations. The following are some suggested areas for future research based on the studies analysed in this review. Classification of injuries into acute, chronic, new or recurrent may add further insight into the impact that loading has on each type of injury. Along with these injury classifications, subgrouping injuries into their type, for example, muscular, bone, cartilage, and ligamentous will further develop our understanding of the relationship that load has on injury. It is widely reported that load plays a large part in injuries of different tissue types and that optimal loading has an essential role in the recovery (Khan & Scott, 2009). This is an exciting area that could be developed with respect to the current subjective load monitoring models being utilised in recent research.

In most of the studies it was the preceding week load that predicted injury or illness risk which suggests there is a lag effect of load and injury or illness risk. In this review the longest duration that was analysed with respect to injury was four weeks. For chronic conditions, meaningful analysis may require looking at loading beyond the commonly used chronic load definition of four weeks. This lag effect is highlighted in the review by Drew & Finch, (2016) who also suggest this should be an area looked at in future research.

Of particular interest is the protective effect that loading can have on both injury and illness risk. As mentioned earlier there appears to be an optimal loading zone with a U or J-shaped curve for load and injury or illness risk. Recent literature has reported optimal acute to chronic workload ratio zones for specific cohorts (Blanch & Gabbett, 2015; Gabbett, 2016; Hulin et al., 2014), taking this a step further it may be that there are optimal zones for individual athletes. There is a trend in elite sport to develop robust athletes that can train to the maximum without injury or illness. The key to this may be determining individual optimal training load zones and it is likely that these will change over the career of the athlete. Individual athlete rather than pooled cohort data may provide some insights into a potential performance enhancing area.

It was clear from this review that stress was one of the main predictors of illness. Further research on the relationship between stress and load would be recommended along with analysis of the specific stressors that are most closely associated with illness.

2.2.6.7 Conclusion. This review is one of the first to look exclusively at subjective training load and the relationship with injury or illness risk. There appears to be a good association between subjective training load and injury risk with preceding week load being the best predictor. The relationship to illness is less clear and from this review it appears that the components of stress are the best predictor of illness. For injury and illness, it seems that load can have both a positive and negative effect on risk. Determining the optimal loading zone and progression of load at a cohort and more specifically an individual athlete level may be the key to reducing injury and illness risk and improving sports performance, which ultimately is the goal of athletes and teams.

2.3 Summary

This chapter has looked at the most common injury prevention model that has been developed to form the TRIPP model. The aim of this study was to investigate the relationship between subjective load and injury or illness in elite CNZ track cycling athletes focusing on stages one and two of the TRIPP model, which involves surveillance along with establishing the aetiology and mechanisms of injury and illness. Within epidemiological literature there is growing consensus on the methodology used for research which will improve the accuracy of data collection and reporting. This study will utilise a prospective cohort design, in-line with methodological procedures outlined by the IOC for Olympic sport.

A review of the literature was conducted looking at the relationship between subjective load, injury and illness in multiple sports. There was still some variation in the methodological approaches used in the reviewed studies, making direct comparisons challenging. The key themes that emerged was firstly that there is an association between injury and subjective load with preceding weeks values often the best predictor of injury. Secondly there was both positive and negative relationships between subjective load and illness; however, from the review it appeared that stress may be a better predictor of illness. Finally, for both injury and illness, it appears that there may be optimal training zones which often follow a U or J-Shaped curve. Determining this zone will result in optimal training with reduced injury and illness risk, which ultimately should lead to improved performance.

Chapter 3: Methods

This chapter will outline the research methods used to collect and analyse subjective load, injury and illness epidemiological data. The cohort of participants was drawn from elite CNZ track cycling athletes. Data collection took place over two defined time frames, an 11-week build up to the Rio Olympic Games and a 25-week period leading up to the 2017 World Track Championships.

3.1 Study Design

A prospective longitudinal cohort study design was used to record subjective load and injury or illness data.

3.2 Ethics

Ethics approval was obtained from the Auckland University of Technology Ethics Committee (AUTEC) (see Appendix 1) to recruit elite level CNZ track cycling athletes.

3.3 Participants

All elite level CNZ track cycling athletes were eligible for inclusion in this study. For the purposes of this study elite level was defined as any track cycling athlete listed as carded by HPSNZ. Athletes are currently carded in three levels based on performance and potential to perform at pinnacle events now and in the future. Carded athletes are provided with a tiered level of support and funding based on their carding level.

The participants were provided with a written information sheet (see Appendix 3) along with a consent form (see Appendix 4) which was distributed and collected by an independent administrator (see Appendix 5). If participants required further information about the study they could contact the lead researcher or primary research supervisor. Participation was voluntary with no impact on training or selection. Consent forms were returned electronically to the independent administrator ensuring confidentiality.

The initial study group was made up entirely of sprint athletes selected to compete in the Rio de Janeiro (Rio) Olympic Games in 2016. Data collection took place over an 11-week training and competition phase. The group completed their build up training phase in Germany, Switzerland, France and finally Brazil. The primary researcher was the lead Physiotherapy provider for this team and was with this group the entire time. The primary researcher collected all data first hand which reduced any potential recall bias.

For the second data collection, another round of recruitment took place. Participants were still limited to carded CNZ athletes; however, all track disciplines were considered. A total of 10 participants consented to be involved in the second data collection. The participants were followed for a 25-week period aligning with a standard track cycling season culminating in the World Championships in Hong Kong in April 2017. Athletes can be on varying training programs and competition schedules during a season which is reflected in the variable load data for the individual athletes. During the second data collection, all information was provided by self-report from the athletes to the primary researcher on a weekly basis via e-mail. The primary researcher was no longer the clinical Physiotherapist for any of the athletes, limiting any potential reporting bias.

3.4 Data Collection

3.4.1 Subjective load monitoring. Subjective load was determined by recording RPE on a 0-10 scale (see table 3.1) multiplied by the training or competition session duration in minutes (Foster et al., 1995). The value is expressed as arbitrary units (AU).

Subjective Load = RPE x Session Duration

Participants were instructed to record or report RPE as soon as possible after completing any training or competition. This was then documented into an individual athlete recording sheet (see figure 3.1). The daily and weekly load values were then transcribed into a master spreadsheet for further analysis.

Table 3.1

RPE from (Foster et al., 2001)

Rating	Descriptor
0	Rest
1	Very, Very, Very Easy
2	Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	-
7	Very Hard
8	-
9	-
10	Maximal

Instructions: for each session please fill out what the activity was (e.g. gym, track, road) the RPE for the session 0-10 (see RPE scale), the duration in minutes, if you completed the session, modified the session were injured or ill.

Week	Session 1								Session 2								Session 3								Total Load
	Activity	RPE	Duration	Competed Y/N	Modified Y/N	Injured Y/N	Ill Y/N	Session Load	Activity	RPE	Duration	Competed Y/N	Modified Y/N	Injured Y/N	Ill Y/N	Session Load	Activity	RPE	Duration	Competed Y/N	Modified Y/N	Injured Y/N	Ill Y/N	Session Load	
Mon								0.0								0.0								0.0	0.0
Tue								0.0								0.0								0.0	0.0
Wed								0.0								0.0								0.0	0.0
Thur								0.0								0.0								0.0	0.0
Fri								0.0								0.0								0.0	0.0
Sat								0.0								0.0								0.0	0.0
Sun								0.0								0.0								0.0	0.0
																						Weekly Total Load			0.0

Week	Session 1								Session 2								Session 3								Total Load
5: 21/1	Activity	RPE	Duration	Competed Y/N	Modified Y/N	Injured Y/N	Ill Y/N	Session Load	Activity	RPE	Duration	Competed Y/N	Modified Y/N	Injured Y/N	Ill Y/N	Session Load	Activity	RPE	Duration	Competed Y/N	Modified Y/N	Injured Y/N	Ill Y/N	Session Load	
Mon	road	2.0	45.0	y	n	n	n	90.0	track flyin	7.0	170.0	y	n	n	n	1190.0								0.0	1280.0
Tue	gym	7.0	75.0	y	n	n	n	525.0	track star	6.0	140.0	y	n	n	n	840.0								0.0	1365.0
Wed	track prog	7.0	130.0	y	n	n	n	910.0								0.0								0.0	910.0
Thur	rest							0.0								0.0								0.0	0.0
Fri	gym	5.0	50.0	y	n	n	n	250.0	track star	5.0	120.0	y	n	n	n	600.0								0.0	850.0
Sat	road	4.0	60.0	y	n	n	n	240.0								0.0								0.0	240.0
Sun	track race	6.0	480.0	y	n	n	n	2880.0								0.0								0.0	2880.0
			840.0								430.0										1270.0	Weekly Total Load			7525.0

Figure 3.1: Example of weekly athlete loading sheets: top blank sheet, bottom completed week example.

3.4.2 Time loss. In this study time loss was defined as any missed training or competition for any reason (Junge et al., 2008). It should be noted that this definition varies slightly from other studies in the literature that define times loss as missed training or competition the day following the incident (Fuller et al., 2006; Timpka et al., 2014). The reason for the modified definition was to more accurately represent times loss in the high-performance sport setting. For athletes in cohort one, time loss was recorded directly to the master spreadsheet by the primary researcher. For athletes in cohort two, time loss was obtained from the individual loading sheets via athlete self-report.

3.4.3 Modification of training. This was defined as any training or competition that was completed but felt to have been modified in any way by the athlete. This is a novel inclusion in this study and not reported in previous literature to the authors knowledge. It is similar to the concept of "*medical attention*" injury described by Timpka and colleagues (2014, p. 485) but was felt to be more relevant to high performance sport where athletes often modify rather than miss a training session. In the authors experience modification of training may be more prevalent than time loss but can still mean that the intended training stimulus is not achieved potentially impacting on performance. Athletes could indicate this directly to the primary researcher in cohort one and on the daily loading sheet in cohort two (see Figure 3.1).

3.4.4 Injury and illness. Injuries and illnesses were defined in line with the International Olympic Committee approach, "any new or recurring complaint that occurred due to training or competition that required medical attention regardless of the consequences with respect to absence from training or competition" (Junge et al., 2008). Injury and illness was classified using the first character of the Orchard Sports Injury Classification System version 10 (OSICS-10) (Rae & Orchard, 2007) (see table 3.2). Injuries were also classified as acute, chronic, exacerbation, left, right or bilateral and a rating of severity based on the classification system developed by Fuller et al., (2006) (see table 3.3).

Table 3.2

Injury Classification System.

Generic Location	Body Part	OSICS10 prefix
Head & Neck	Head / Face	H
	Neck / Cervical Spine	N
Upper Limb	Shoulder / Clavicle	S
	Upper Arm	U
	Elbow	E
	Forearm	R
	Wrist	W
	Hand / Finger / Thumb	P
Trunk	Chest / Ribs / Upper Back	C, D
	Abdomen	O
	Lower Back / Pelvis / Sacrum / Coccyx	B, L
Lower Limb	Hip / Groin	G
	Thigh	T
	Knee	K
	Lower Leg (including Achilles Tendon)	Q, A
	Ankle	A
	Foot / Toe	F
Medical Illness		M

Table 3.3

Injury Severity Rating System

Severity	Days lost
Slight	0-1 day
Minimal	2-3 days
Mild	4-7 days
Moderate	8-28 days
Severe	>28 days
Career Ending	
Non-Fatal Catastrophic	

3.4.5 Acute load calculation. The acute load was calculated as the sum of all subjective load totals for every training session during the training week defined as Monday to Sunday (Hulin et al., 2014). The value is expressed as arbitrary units (AU).

Acute Load = ΣSubjective Load (Monday - Sunday)

3.4.6 Chronic load calculation. The chronic load was calculated by summing the current week and previous three weeks' acute loads and dividing by four to give an average load value. This was performed as a rolling average every week from week 4 (Hulin et al., 2014). The value is expressed as arbitrary units (AU).

Chronic Load = (ΣAcute Load current week and preceding three weeks) ÷ 4

3.4.7 Acute to chronic work load ratio calculation. The acute to chronic workload ratio was determined by dividing the acute load by the chronic load giving a fraction above or below one. Values below one suggests low relative load when compared to the rolling four-week average or put another way low fatigue and relative high fitness. Values above one suggest high relative acute load when compared to the rolling four-week average or a high fatigue with relative low fitness (Hulin et al., 2014).

Acute:Chronic Workload Ratio = Acute Load ÷ Chronic Load

3.4.8 Collection periods. The data collection for cohort one occurred in the three months build up and competition phase to the Rio de Jenerio 2016 summer Olympics. This involved travel, training and racing phases. The data collection for cohort two occurred in the 2016/2017 UCI track racing season starting in October 2016 and ending in April 2017 with the World Championships. The schedule for each athlete in cohort two was variable and consisted of training blocks, travel and racing. The total collection period for cohort one was 11 weeks and for cohort two was 25 weeks.

3.5 Statistical Analysis.

In two instances athletes did not return a week of data in their collection period. To ensure that acute to chronic workload ratios were not affected the acute load was calculated as the average of the week before and the week after the missing week.

The data was organised into weekly blocks in an excel spreadsheet under the following groups, acute load, chronic load, acute to chronic workload ratio, weekly duration, percentage change in acute load from the previous week, planned number of weekly sessions, completed number of weekly sessions, if any session was missed in the week, if any session was modified in the week, if the athlete was ill, if the athlete was injured along with OSICS10 code, region, side, mechanism of injury and severity. This was transcribed to SPSS version 24 for specific statistical analysis.

The data was initially analysed using descriptive statistics to look at the mean, range and standard deviation of the load data, and frequency analysis of the injury, illness, modification and time loss data. This was performed across the two cohorts and on an individual athlete basis.

Following the descriptive analysis and on consultation with a biostatistician a repeated measures logistic regression with exchangeable correlation matrix was performed using SAS 9.4 (www.sas.com). Analysis was performed with respect to the dependant variables of injured or not, ill or not and then injured or ill or not. Independent variables available for analysis were sex, cohort, acute load, chronic load, and acute to chronic ratio. They were analysed for bivariate and multiple variable associations with odds ratios, 95 percent confidence intervals and p-values reported with the level of significance set at 0.05. All independent variables were examined for the bivariate analysis, and a best subset selection process was utilised to select the best subset of statistically significant variables for the multiple variable logistic models using p-values and a relevant form of AIC model fit statistics.

Chapter 4: Results

The following chapter will present the main findings from this research study. Data collection was divided into two cohorts (cohort one and cohort two) with information provided separately for each cohort. The first section will provide details of the participants that took part in the study. The second section will present the descriptive statistics for cohort one and cohort two. The third section will provide details of the cohort group statistical analysis. The final section will look in detail at the individual load profiles from the two data collection cohorts.

4.1 Participants

4.1.1 Cohort one. For cohort one only sprint athletes were considered for inclusion and a total of six athletes consented to be involved in the research study. Data was collected for a total of 11 weeks with a complete set of data, 100% compliance and no drop outs.

The participants were made up of four males aged between 21 to 27 years (mean 24.5; SD: 2.52) and two females aged 19 and 27. The mean height and mass of the males was 181.83 cm (SD: 2.25) and 88.55 kg (SD: 5.81) respectively, and for the females was 169.95 cm (SD: 4.88) and 68.65 kg (SD: 0.35) respectively. For the cohort as a total the average age, height and mass can be seen in table 4.1.

4.1.2 Cohort two. In cohort two all track disciplines were considered for inclusion with a total of 10 athletes (2 men's sprint, 2 women's sprint, 5 women's endurance, 1 men's endurance) consenting to be involved in the study. Data was collected over 25 weeks with six athletes providing a full 25 weeks of data and four athletes providing incomplete data. Of the incomplete data one athlete provided only four weeks of data and then dropped out of the study, no reason was given for dropping out. A second athlete provided 15 weeks of data including one missed week being estimated from the average of the week prior and after, the reason for missing the remaining nine weeks was that the athlete had forgotten to fill in the data that week. The third athlete provided 23 weeks including one missed week being estimated from the average of the week prior and after, the remaining two weeks missed was at the end of the study and no reason was given for not providing the data. The final athlete not providing full data completed 14 weeks with no reason given for not providing the rest of the weeks. The average age, height and mass of participants in cohort two can be seen in table 4.1.

Table 4.1

Participant Numbers, Sex, Age, Height and Mass for Cohort 1 and 2.

Cohort	Number	Male	Female	Age (yrs)	Height (cm)	Mass (kg)
Cohort 1	6	4	2	24 (3.29)	177.87 (6.74)	81.92 (11.22)
Cohort 2	10	3	7	22.9 (3.81)	174.78 (5.29)	73.45 (6.79)

Note: For age, height and mass data are means with standard deviation in brackets.

4.2 Subjective Load

4.2.1 Cohort one. The average acute load in cohort one was 5197AU (SD: 2043) with a range of 600AU to 9925AU and average chronic load was 5282AU (SD: 7389) with a range of 3169AU to 6774AU. Acute to chronic workload ratios ranged from 0.19 to 1.62 with an average of 0.88 (SD: 0.31). The average week to week percentage change in acute load was 12.36% (SD: 81) with a large range from -84.29% to 287.7%. The average acute load, chronic load, acute to chronic workload ratios and percentage week change for cohort one can be seen in table 4.2 and in figure 4.1.

Table 4.2

Subjective Load Range and Averages for Cohort 1.

	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	600.0	9925.0	5197.16	2043.95
Chronic Load (AU)	3168.75	6773.75	5281.74	7389.00
Acute:Chronic Ratio	0.19	1.62	0.88	0.31
Week % change	-84.29%	287.70%	12.36%	80.57%

4.2.2 Cohort two. For cohort two the average acute load was 5133AU (SD: 2156) with a range of 0AU to 14770AU. The average chronic load was the same value of 5133AU (SD: 1275) but with a range of 2011AU to 8251AU. The acute to chronic workload ratio ranged from 0 to 2.15 with an average of 1.01 (SD: 0.36). The week to week percentage change again had a large variation from -100% to 1257% the average was 24% (SD: 119). The average acute load, chronic load and acute to chronic workload ratios for cohort two can be seen in table 4.3 and in figure 4.1.

Table 4.3

Subjective Load Range and Averages for Cohort 2.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	0.0	14770.0	5132.76	2156.05
Chronic Load (AU)	2011.13	8251.25	5132.75	1275.03
Acute:Chronic Ratio	0.00	2.15	1.01	0.36
Week % Change	-100.00%	1257.47%	24.68%	119.42%

4.3 Injury, Illness, Time Loss and Modification of Training.

4.3.1 Cohort one. In cohort one a total of 64 training weeks were analysed, athletes reported 14 (21.9%) weeks where an injury was present and 4 weeks (6.3%) with an illness present at some point in the week. From the 64 weeks, 2 weeks (3.1%) were identified where at least one training session was missed and 5 weeks (7.8%) where at least one session was modified in the week (see table 4.4).

4.3.2 Cohort two. For cohort two, 206 training weeks were analysed with a reported 15 weeks (7.3%) where an injury was present at least one day in the week and 19 weeks (9.2%) were identified as an athlete being ill at least one day in the training week. From the total 206 training weeks, 12 weeks (5.8%) were identified where at least one training session in the week was missed and 41 weeks (19.9%) identified as having at least one training session modified in the week (see table 4.4). It should be noted that the one male endurance athlete did not report any injury or illness. For this reason, bivariate and multivariate analysis by discipline was not undertaken.

Table 4.4

Training Weeks Injured, Ill, Missed or Modified for Cohorts 1 and 2.

Cohort	Total Wks	Injured	Ill	Missed	Modified
Cohort 1	64	14 (21.9%)	4 (6.3%)	2 (3.1%)	5 (7.8%)
Cohort 2	206	15 (7.3%)	19 (9.2%)	12 (5.8%)	41 (19.9%)

4.4 Repeated Measures Logistic Regression with Exchangeable Correlation Matrix Analysis.

4.4.1 Injury.

4.4.1.1 Bivariate associations. The repeated logistic regression analysis looking at the individual factors of sex, cohort, acute load, chronic load and acute to chronic workload ratio and relationship to injury shows that there was a statistically significant reduced injury rate for cohort two when compared to cohort one (p=0.04). There was also a statically significant effect of chronic load on injury (p=0.02). For every 100AU rise in the chronic load there was a four percent increased odds of injury (see table 4.5).

Table 4.5

Bivariate Associations for Injury.

Factors		% injury	OR	95% CI	p-value
Sex	**Female**	12%	-		
	Male	8%	0.60	(0.15, 2.37)	0.46
Cohort	**1**	22%	-	-	
	2	7%	0.33	(0.11, 0.94)	0.04
Acute (per 100AU)			1.01	(1.00, 1.02)	0.06
Chronic (per 100AU)			1.04	(1.01, 1.08)	0.02
Acute:Chronic Ratio (per 1 units)			1.23	(0.72, 2.09)	0.45

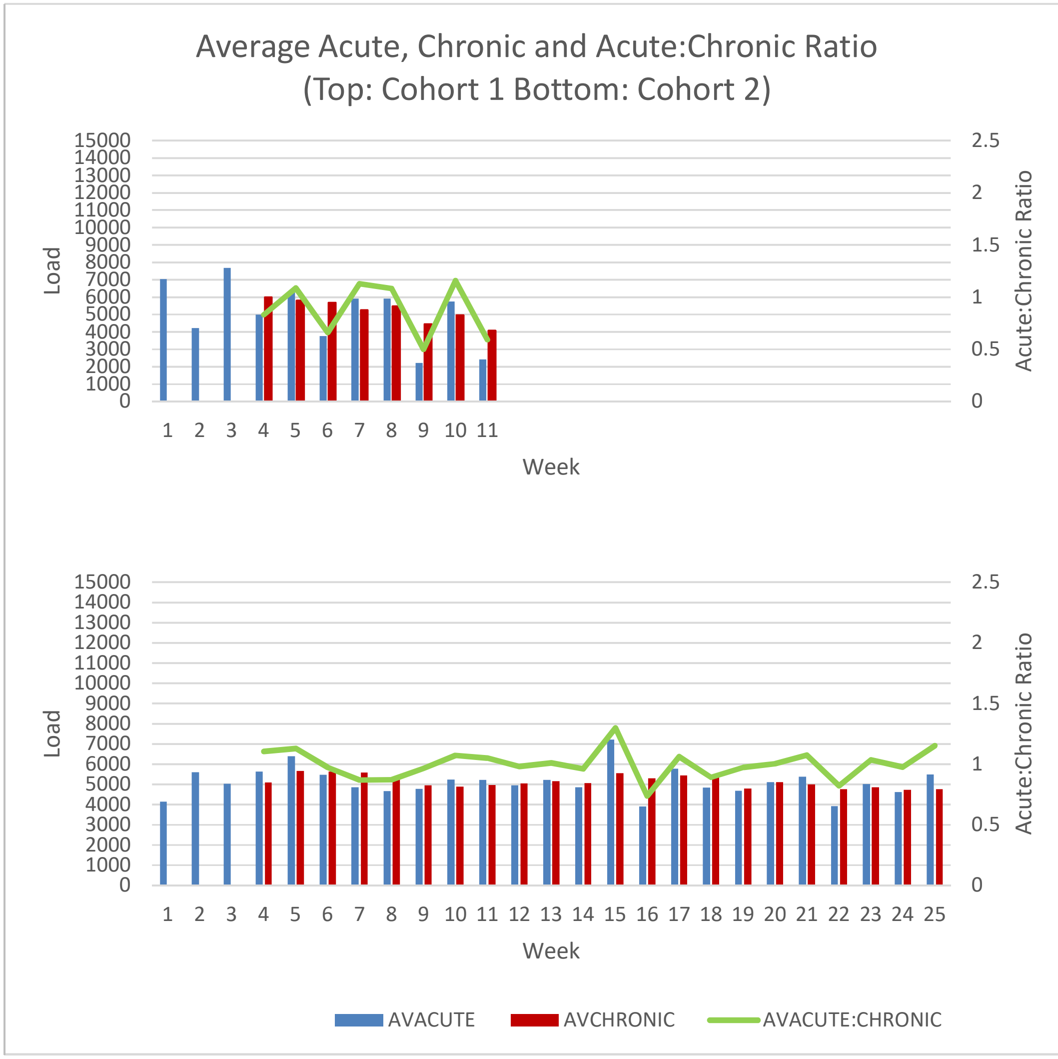

Figure 4.1. Average acute, chronic and acute to chronic workload ratio for cohort 1 and 2.

4.4.1.2 Multiple variable associations. When assessing for multiple variable factors that impact on injury the only factor to have an effect was chronic load as seen in the bivariate analysis (see table 4.6).

Table 4.6

Multiple Variable Associations for Injury.

Factors	**OR**	**95% CI**	**p-value**
Chronic (per 100AU)	1.04	(1.01, 1.08)	0.02

4.4.2 Illness

4.4.2.1 Bivariate associations. The repeated logistic regression analysis looking at the individual factors of sex, cohort, discipline, acute load, chronic load and acute to chronic workload ratio and relationship to illness shows a significant increased odds of illness in female athletes when compared to their male counterparts (p=0.004). An increase in acute load per 100AU reduced the odds of illness by two percent and an acute to chronic workload ratio rise of one unit substantially reduced the illness odds by 63% (see table 4.7).

Table 4.7

Bivariate Associations for Illness.

Factors		% illness	OR	95% CI	p-value
Sex	**Female**	14%	-		
	Male	1%	0.05	(0.01, 0.41)	0.004
Cohort	**1**	6%	-		
	2	9%	1.44	(0.44, 4.74)	0.55
Acute (per 100AU)			0.98	(0.97, 0.99)	<0.0001
Chronic (per 100AU)			1.01	(0.95, 1.06)	0.84
Acute:Chronic Ratio (per 1 units)			0.37	(0.19, 0.74)	0.005

4.4.2.2 Multiple variable associations. When assessing for multiple variable associations for illness the gender effect and acute load factors were statistically associated (see table 4.8).

Table 4.8

Multiple Variable Associations for Illness.

Factors		% illness	OR	95% CI	p-value
Sex	**Female**	14%	-		
	Male	1%	0.05	(0.01, 0.38)	0.003
Acute (per 100AU)			0.98	(0.97, 0.99)	0.001

4.4.3 Injury or Illness

4.4.3.1 Bivariate associations. The repeated logistic regression analysis looking at the individual factors of sex, cohort, acute load, chronic load and acute to chronic workload ratio and relationship to either injury or illness shows that cohort two had a statistically significant lower injury and illness rate compared to cohort one (p=0.04). Chronic load per 100AU rise was also significantly associated with an increased injury or illness odds (p=0.02) (see table 4.9).

Table 4.9

Bivariate Associations for Injury or Illness.

Factors		% injury or illness	OR	95% CI	p-value
Sex	**Female**	12%	-		
	Male	8%	0.60	(0.15, 2.37)	0.46
Cohort	**1**	22%	-	-	
	2	7%	0.33	(0.11, 0.94)	0.04
Acute (per 100AU)			1.01	(1.00, 1.02)	0.06
Chronic (per 100AU)			1.04	(1.01, 1.08)	0.02
Acute:Chronic Ratio (per 1 units)			1.23	(0.72, 2.09)	0.45

4.4.3.2 Multiple variable associations. When looking for multiple variable associations the only factor to show a significant effect was a chronic load per 100AU rise (p=0.02).

Table 4.10

Multiple Variable Associations for Injury or Illness.

Factors	OR	95% CI	p-value
Chronic (per 100AU)	1.04	(1.01, 1.08)	0.02

4.5 Individual Athlete Relationship between Load and Injury, Illness, Time Loss and Modification of Training.

The following section will present the individual loading, injury and illness data for each athlete. Due to the small cohort numbers and the high level of individual variation in this research study, individual profiles may provide more insight into the effect of subjective load than group means. In high performance sport it is also important to look at individual response as well as group values as this can provide specific data that may lead to individual athlete improved performance outcomes. For these reasons the individual profiles of each athlete have been provided.

4.5.1 Cohort one.

4.5.1.1 Athlete 111. The athlete reported a knee injury in week 4 and a thigh injury in week 5 both on the left side and of slight severity. They did not report any missed or modified training because of these injuries.

Table 4.11

Subjective Load Range and Averages for Athlete 111.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	2210.0	8005.0	5189.09	2023.11
Chronic Load (AU)	4278.75	5980.00	5204.22	613.32
Acute:Chronic Ratio	0.51	1.23	0.89	0.32
Week % Change	-63.47%	187.10%	15.32%	86.14%

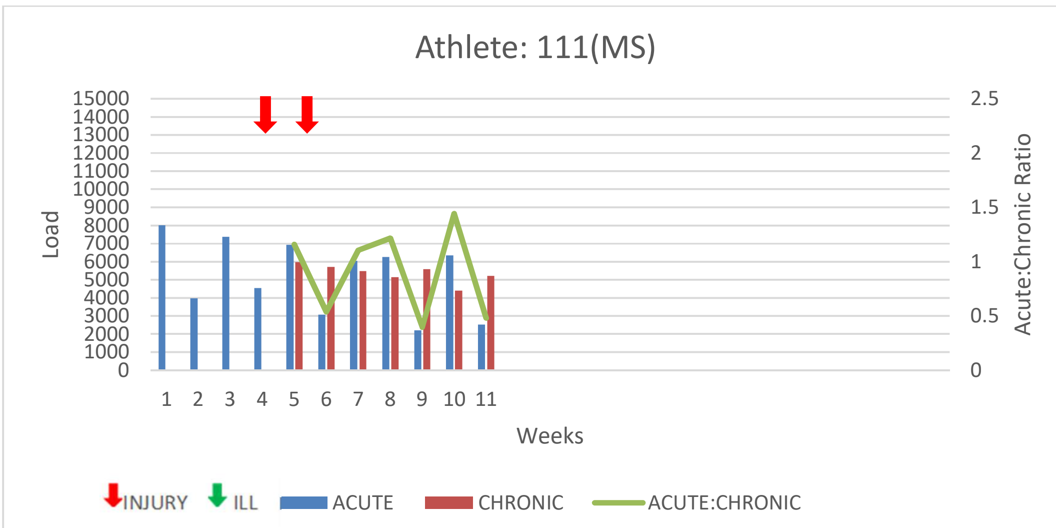

Figure 4.2 Load, injury and illness relationship for athlete 111.

4.5.1.2 Athlete 112. The athlete reported a bilateral knee injury in week 2 of slight severity that did not lead to any missed or modified training.

Table 4.12

Subjective Load Range and Averages for Athlete 112.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	2560.0	9925.0	6013.77	2413.73
Chronic Load (AU)	4607.50	6504.13	5768.64	551.11126
Acute:Chronic Ratio	0.56	1.62	0.96	0.36
Week % Change	-59.42%	287.70%	24.07%	109.40%

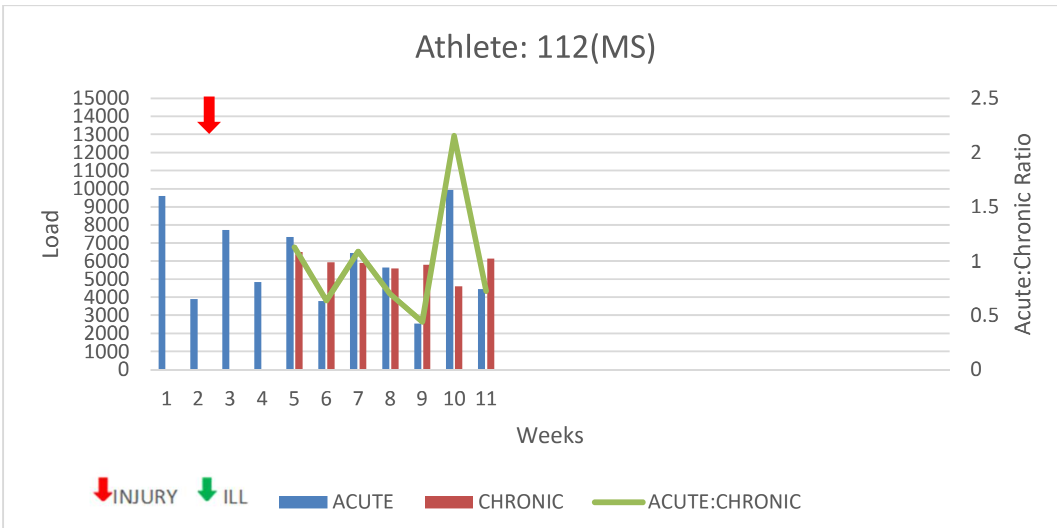

Figure 4.3 Load, injury and illness relationship for athlete 112.

4.5.1.3 Athlete 113. The athlete reported injuries in weeks 2, 6, 7, 8, and 9 along with illness in week 9. None of the injuries or illness lead to missed or modified training and were all slight in severity. The injury in week 2 was on the left side to the elbow, hip/groin, and knee regions. In week 6 the regions injured were the chest/ribs/upper back and lower back/pelvis/sacrum/coccyx. In week 7 the athlete reported an upper back region injury, and in week 8 reported injuries to chest/ribs/upper back and lower back/pelvis/sacrum/coccyx regions again. In week 9 the athlete reported illness along with injury to the knee and hand/finger/thumb region.

Table 4.13

Subjective Load Range and Averages for Athlete 113.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	600.0	6975.0	4439.09	1949.23
Chronic Load (AU)	3168.75	5375.00	4723.91	708.66
Acute:Chronic Ratio	0.19	1.22	0.81	0.36
Week % Change	-84.29%	92.15%	1.08%	63.74%

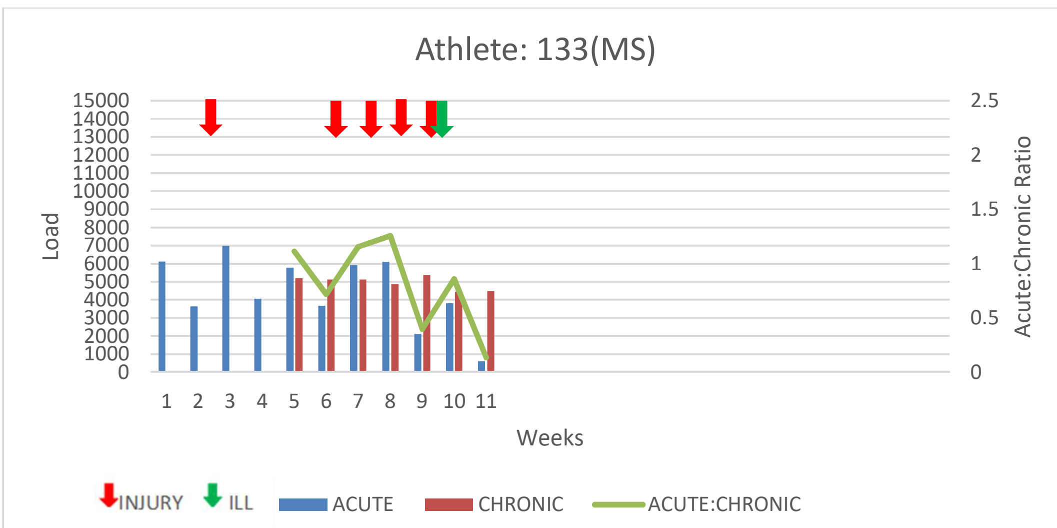

Figure 4.4 Load, injury and illness relationship for athlete 113.

4.5.1.4 Athlete 114. The athlete did not report any injury or illness with no modified or missed trainings. In week 6 the athlete had seven sessions planned but only ended up completing five which was not related to injury or illness.

Table 4.14

Subjective Load Range and Averages for Athlete 114.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	1505.0	8087.5	5194.15	1994.56
Chronic Load (AU)	4082.50	6335.38	5567.07	860.18
Acute:Chronic Ratio	0.37	1.12	0.82	0.29
Week % Change	-61.05%	68.88%	-6.64%	41.56%

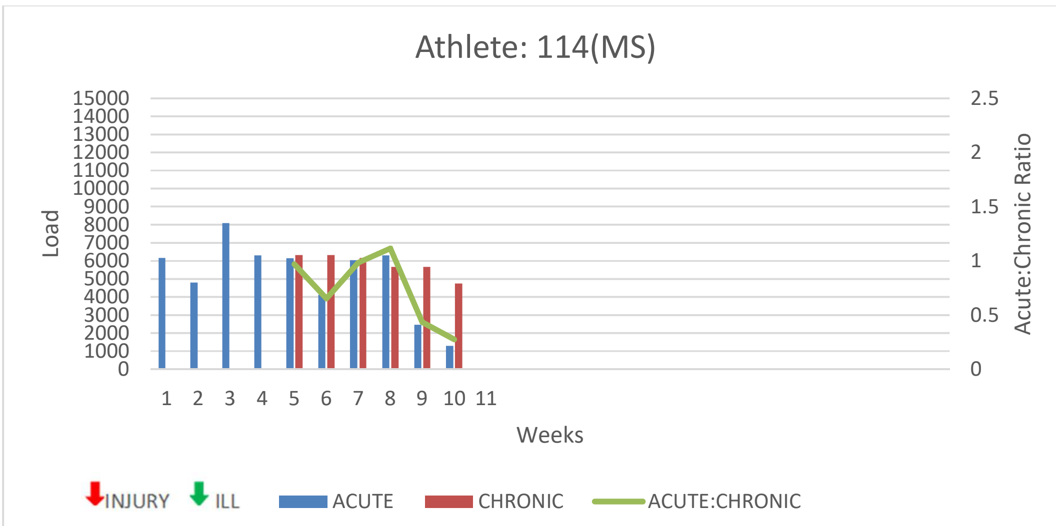

Figure 4.5 Load, injury and illness relationship for athlete 114.

4.5.1.5 Athlete 121. The athlete reported injuries in weeks 2, 3, 4 and 5 and illness in week 5. The injury region in week 2 was the lumbar spine bilaterally and was slight in severity leading to two missed training sessions and modification of training in the week. The injury in week 3 was to the upper back and in weeks 4 and 5 to the neck/cervical spine regions, there was no reported missed or modified training for these injuries. The athlete reported illness in week 5 with no effect of training. The athlete did report modified training in week 7 due to side effects from alcohol.

Table 4.15

Subjective Load Range and Averages for Athlete 121.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	2030.0	8390.0	4718.64	1968.74
Chronic Load (AU)	4228.75	5838.75	5011.25	582.71
Acute:Chronic Ratio	0.48	1.39	0.90	0.32
Week % Change	-69.21%	235.96%	23.30%	96.87%

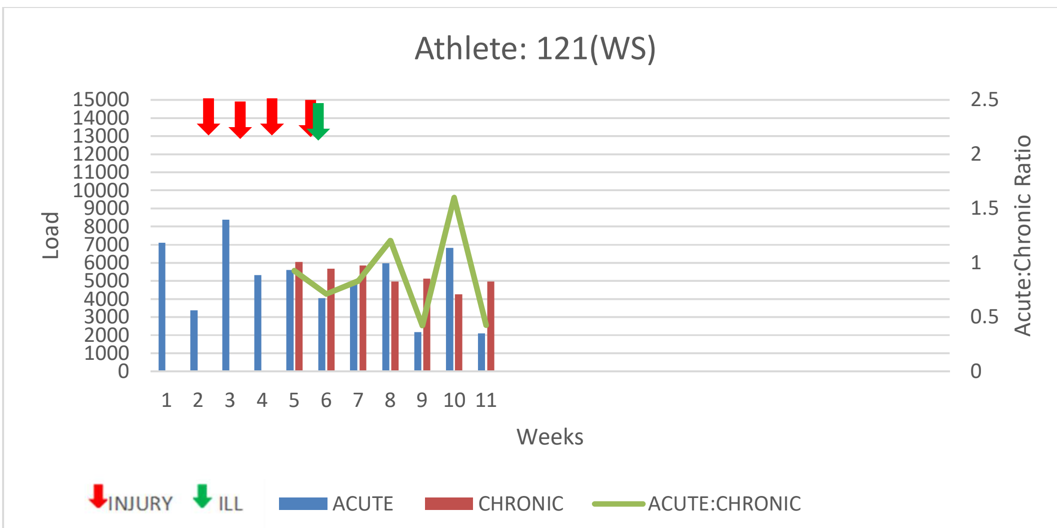

Figure 4.6 Load, injury and illness relationship for athlete 121.

4.5.1.6 Athlete 122. The athlete reported bilateral knee and lower leg injuries in week 1, they were slight in severity and did not cause any missed or modified training. Illness was reported in weeks 4 and 6 leading to one day missed training and two days modified training respectively. In week 10 the athlete suffered multiple injuries to the left side of her body in a crash. The athlete also modified training in week 7 reporting being affected by her teammate.

Table 4.16

Subjective Load Range and Averages for Athlete 122.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	1980.0	9025.0	5671.00	1915.63
Chronic Load (AU)	4365.00	6773.75	5475.18	778.15
Acute:Chronic Ratio	0.45	1.23	0.90	0.29
Week % Change	-63.57%	204.80%	15.42%	81.73%

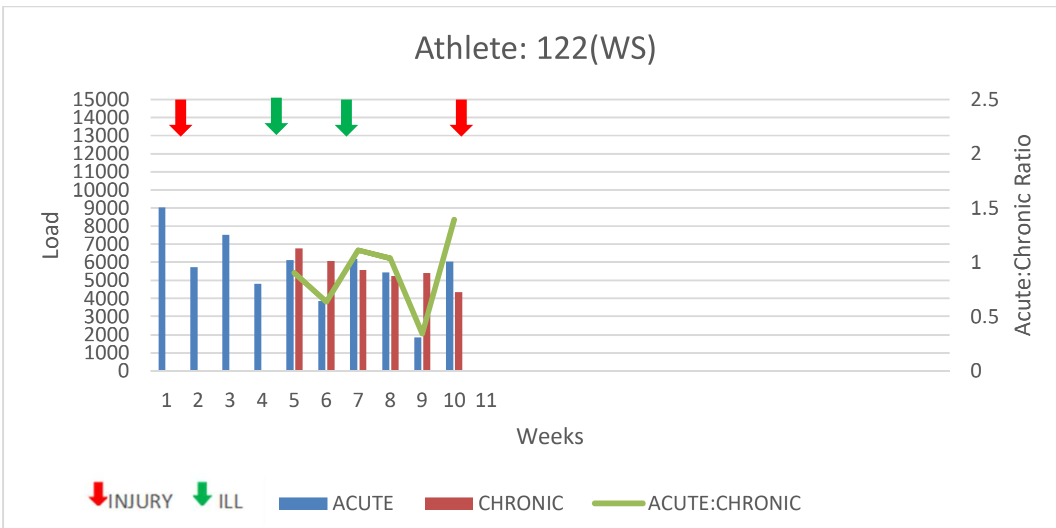

Figure 4.7 Load, injury and illness relationship for athlete 122.

4.5.2 Cohort Two.

4.5.2.1 Athlete 2112. The athlete did not report any injury or illness along with no report of missed or modified training.

Table 4.17

Subjective Load Range and Averages for Athlete 2112.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	1470.0	12840.0	6389.70	2780.14
Chronic Load (AU)	4121.25	8040.63	6115.88	1253.64
Acute:Chronic Ratio	0.22	1.68	1.08	0.40
Week % Change	-78.08%	159.86%	21.45%	60.11%

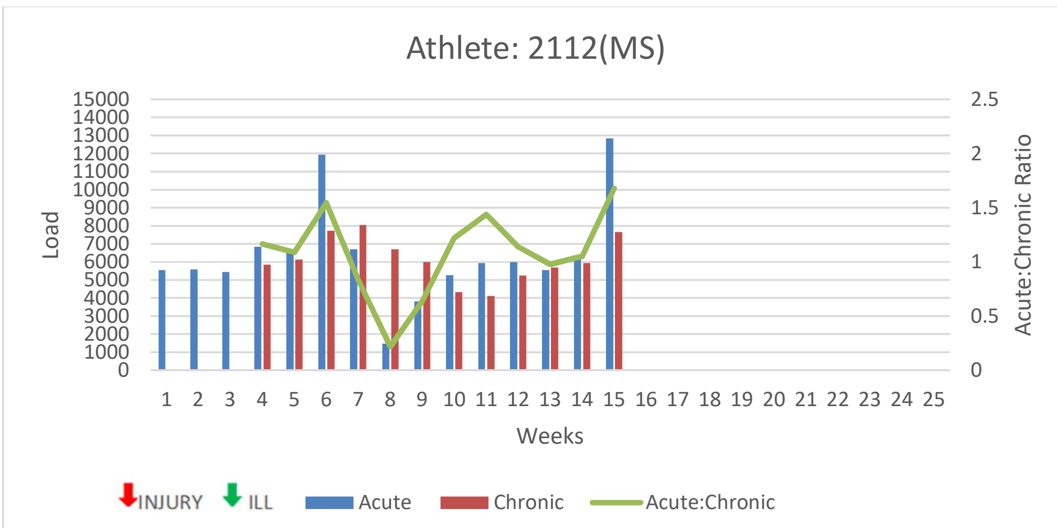

Figure 4.8 Load, injury and illness relationship for athlete 2112.

4.5.2.2 Athlete 2113. The athlete suffered one injury in week 4 to their left knee rated as slightly severe. This caused them to modify one out of the nine planned training sessions in the week.

Table 4.18

Subjective Load Range and Averages for Athlete 2113.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	1300.0	14770.0	5655.26	2753.88
Chronic Load (AU)	3677.38	8251.25	5635.80	1368.29
Acute:Chronic Ratio	0.27	1.83	1.00	0.39
Week % Change	-82.64%	356.54%	35.36%	102.49%

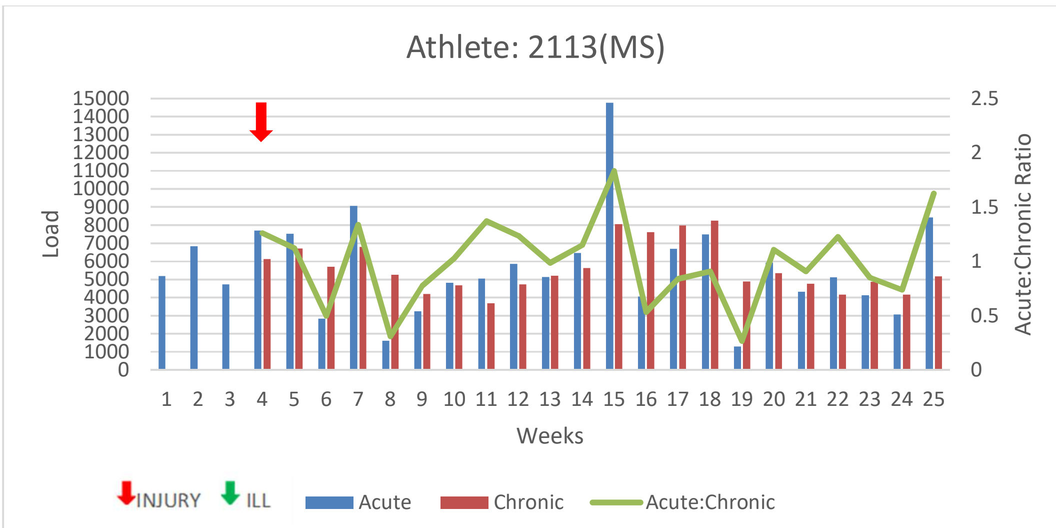

Figure 4.9 Load, injury and illness relationship for athlete 2113.

4.5.2.3 Athlete 2121. The athlete reported a lumbar injury in week 1 and week 14 which were both minimal in severity. The lumbar injury caused two missed training sessions and modification of training in the week, modification of training also occurred in week 14 with the lumbar injury. The athlete identified a further three weeks of modified training in weeks 2, 4, and 13 but with no report of injury or illness.

Table 4.19

Subjective Load Range and Averages for Athlete 2121.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	2915.0	5430.0	3902.68	729.55
Chronic Load (AU)	3294.38	4725.00	3957.90	497.93
Acute:Chronic Ratio	0.80	1.34	1.03	0.15
Week % Change	-26.99%	40.31%	3.60%	19.09%

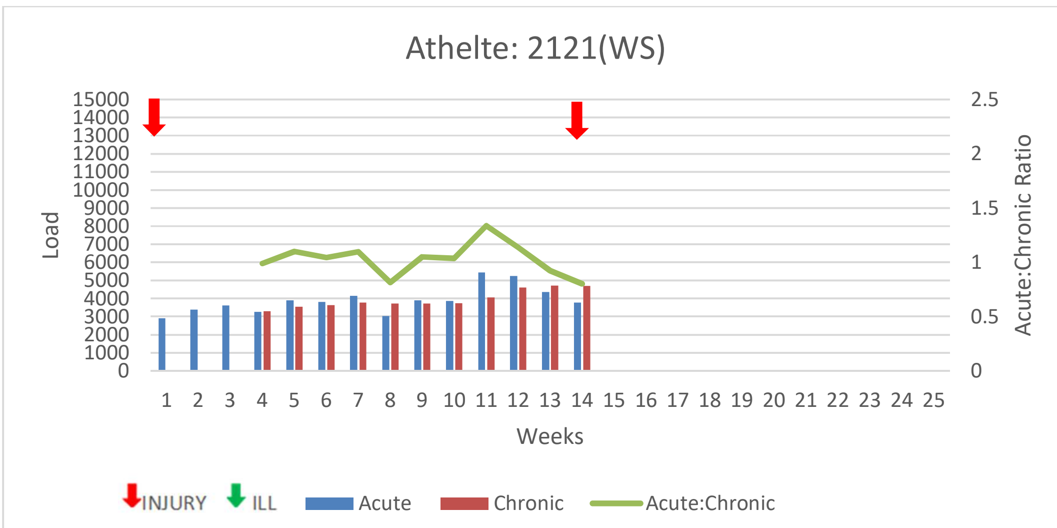

Figure 4.10 Load, injury and illness relationship for athlete 2121.

4.5.2.4 Athlete 2122. The athlete had illness in weeks 1, 2 and 15. The illness in week 1 resulted in modified training, in week 2 the athlete missed the entire week of training representing a moderate illness, and in week 15 they could train as normal. The injury in weeks 11, 12 and 13 was to the shoulder/clavicle region, was on the right side and of slight severity requiring some modified training but no missed training. The athlete indicated modified training in weeks 4 and 6 not related to injury or illness.

Table 4.20

Subjective Load Range and Averages for Athlete 2122.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	0.0	8520.0	5006.90	2156.37
Chronic Load (AU)	2530.00	6875.00	5198.24	1272.20
Acute:Chronic Ratio	0.00	2.15	1.07	0.39
Week % Change	-100.00%	137.27%	9.71%	60.62%

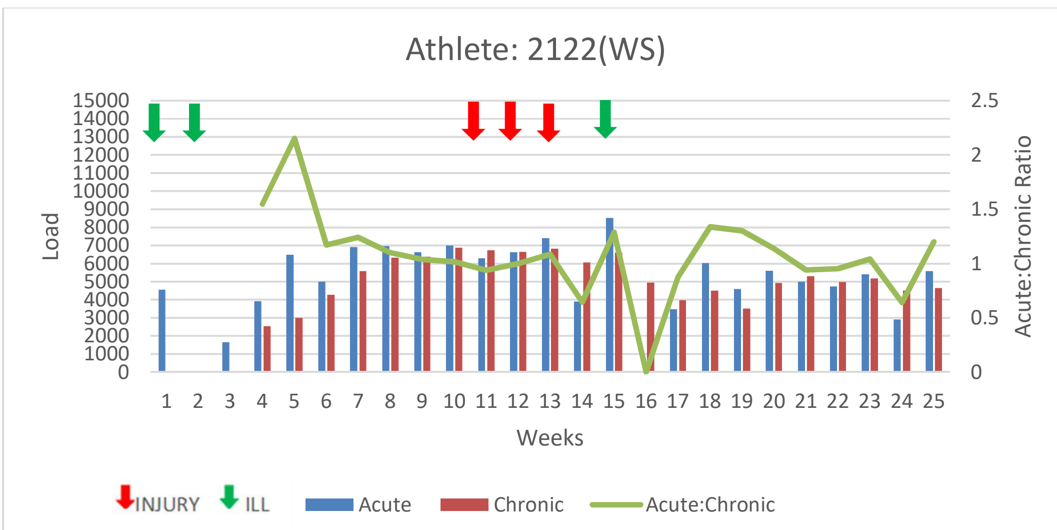

Figure 4.11 Load, injury and illness relationship for athlete 2122.

4.5.2.5 Athlete 221. The athlete suffered illness in week 7 and week 20 of slight severity. Despite this they completed all their training sessions but did indicate that they had modified training during the second illness in week 20. The athlete also indicated that they had modified training in weeks 1, 2, 5, 6, 19 despite no injury or illness.

Table 4.21

Subjective Load Range and Averages for Athlete 221.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	2205.0	9270.0	5543.60	1635.85
Chronic Load (AU)	4103.75	6911.25	5638.1818	767.91
Acute:Chronic Ratio	0.45	1.54	0.98	0.26
Week % Change	-72.26%	145.58%	8.96%	49.60%

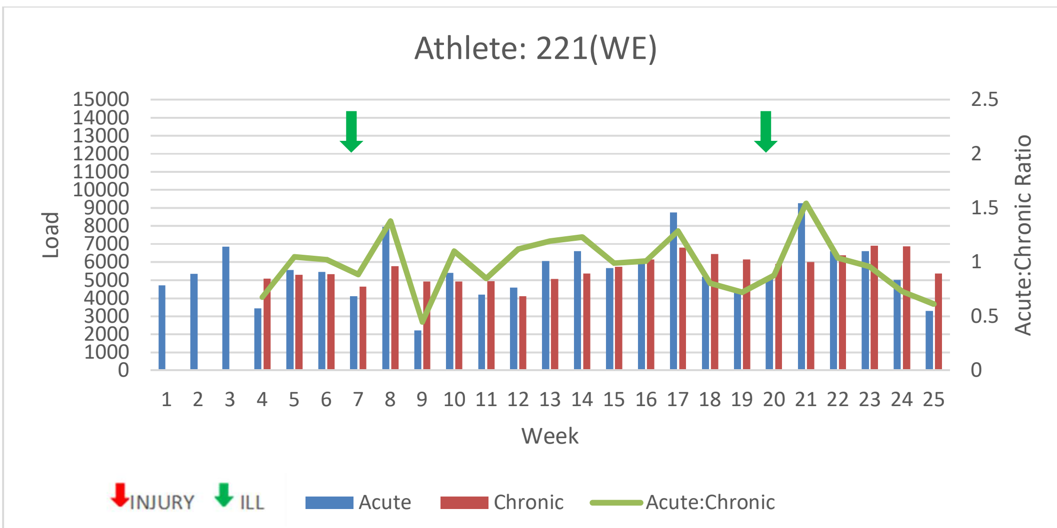

Figure 4.12 Load, injury and illness relationship for athlete 221.

4.5.2.6 Athlete 222. The athlete reported illness in weeks 1, 9, 19 and 20 and injury in weeks 5, 6 and 11. The illness resulted in two weeks where at least one session was missed and modification to training was also indicated (weeks 1 and 9), one week with at least one modified session (week 20) and one week where that athlete could train as normal (week19). The injuries were to the thigh region two on the right and one both sides. The first injury was minimal in severity lasting two weeks (weeks 5 and 6) and the second injury slight (week 11). The first injury resulted in five missed sessions in week 5 and no missed training in week 6. The second injury resulted in one missed session in week 11. The athlete also indicated that they had modified training in weeks 3, 4, 14, 24 and 25 despite no injury or illness.

Table 4.22

Subjective Load Range and Averages for Athlete 222.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	1770.0	7350.0	5085.80	1465.79
Chronic Load (AU)	3975.00	5667.50	4954.8864	444.47684
Acute:Chronic Ratio	0.39	1.55	1.00	0.28
Week % Change	-69.67%	128.81%	14.09%	52.04%

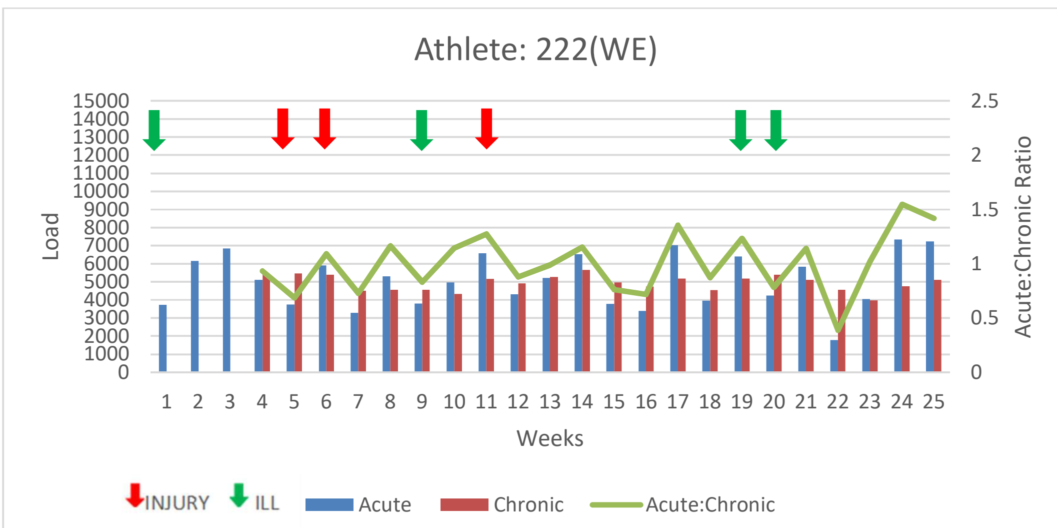

Figure 4.13 Load, injury and illness relationship for athlete 222.

4.5.2.7 Athlete 223. The athlete reported illness in weeks 1, 2, 11, 13, 14 and 18. They were all slight in severity leading to only two weeks requiring modification of training with no missed training. The athlete also reported modification of training in week 19 despite no report of injury or illness.

Table 4.23

Subjective Load Range and Averages for Athlete 223.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	174.0	6581.0	3774.48	1675.65
Chronic Load (AU)	2011.13	5636.75	3602.22	1009.56
Acute:Chronic Ratio	0.06	2.07	1.0104	0.46
Week % Change	-93.84%	1257.47%	66.00%	264.11%

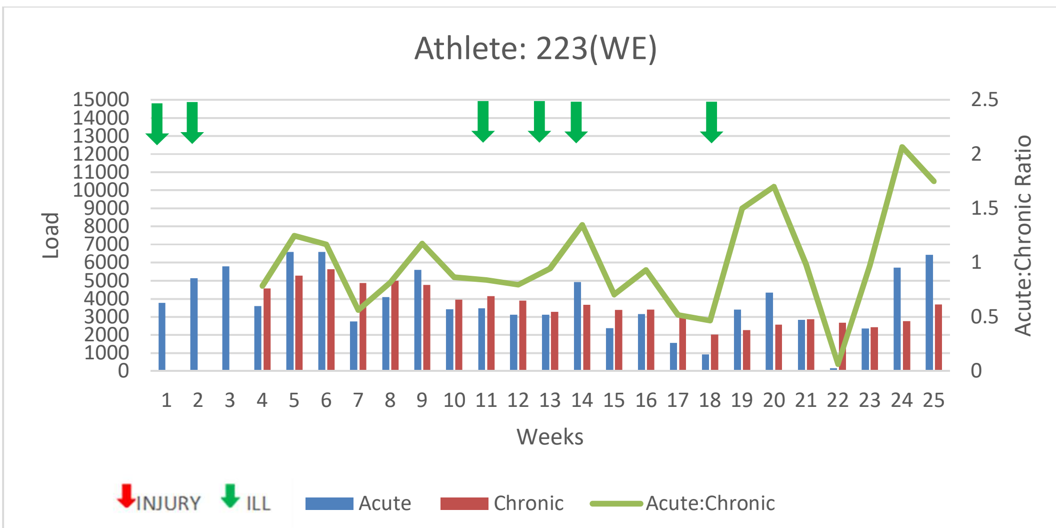

Figure 4.14 Load, injury and illness relationship for athlete 223.

4.5.2.8 Athlete 224. The athlete reported injury in weeks 2, 3 and 4 to head/face and neck/cervical spine regions bilaterally of mild severity. This did not cause any missed training but did cause two weeks where training was modified.

Table 4.24

Subjective Load Range and Averages for Athlete 224.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	848.0	6259.0	4585.00	2536.25
Chronic Load (AU)	4585.00	4585.00	4585.0000	0.0
Acute:Chronic Ratio	1.37	1.37	1.37	0.0
Week % Change	3.20%	509.43%	176.66%	288.27%

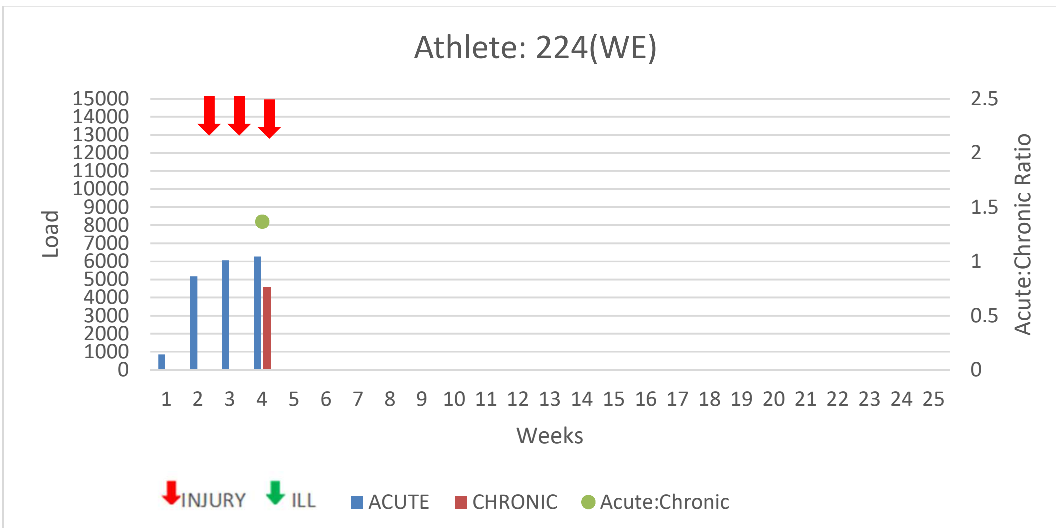

Figure 4.15 Load, injury and illness relationship for athlete 224.

4.5.2.9 Athlete 225. The athlete reported illness in weeks 6, 7, 8 and 12. They were all slight in severity leading to modification in three of the weeks (weeks 6, 8 and 12) and three training sessions missed in week 8. Injury to the right knee was reported in weeks 10, 11 and 12. Slight in severity in weeks 10 and 12 and minimal in week 11. This resulted in a total of four missed training sessions with modification of training in all the injury weeks. The athlete reported modified training in weeks 1 and 5 not related to injury or illness.

Table 4.25

Subjective Load Range and Averages for Athlete 225.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	2700.0	9420.0	5793.44	1527.81
Chronic Load (AU)	4503.75	7377.75	5831.11	767.68
Acute:Chronic Ratio	0.60	1.41	0.97	0.24
Week % Change	-55.41%	136.44%	7.77%	42.84%

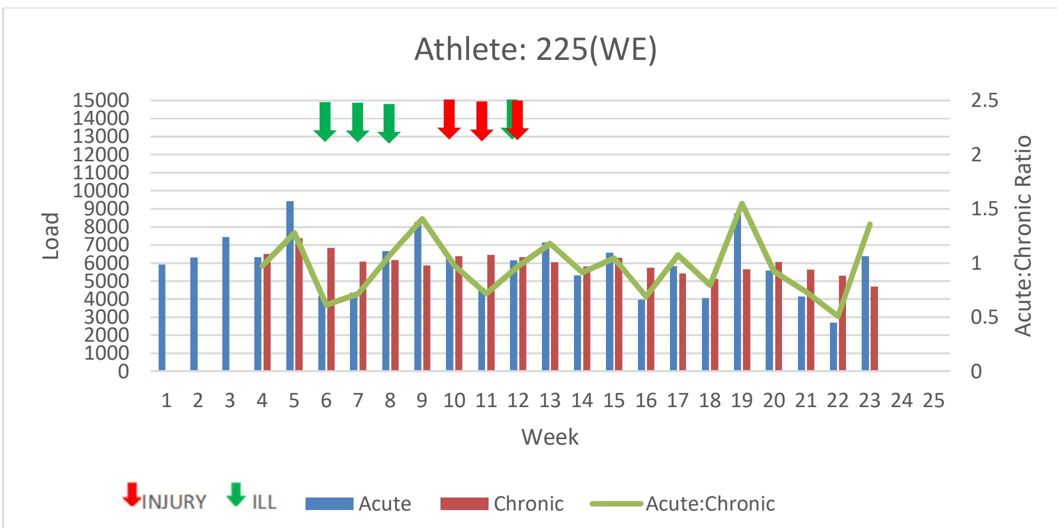

Figure 4.16 Load, injury and illness relationship for athlete 225.

4.5.2.10 Athlete 211. The athlete did not report any injury or illness during the 25-week training block. They did report one modified training in week 13 not related to injury or illness.

Table 4.26

Subjective Load Range and Averages for Athlete 211.

Load Measure	Minimum	Maximum	Mean	Std. Deviation
Acute Load (AU)	0.0	12060.0	5145.000	2712.98
Chronic Load (AU)	2021.25	7838.75	5208.41	1411.17
Acute:Chronic Ratio	0.00	2.07	0.99	0.49
Week % Change	-100.00%	446.56%	22.44%	117.05%

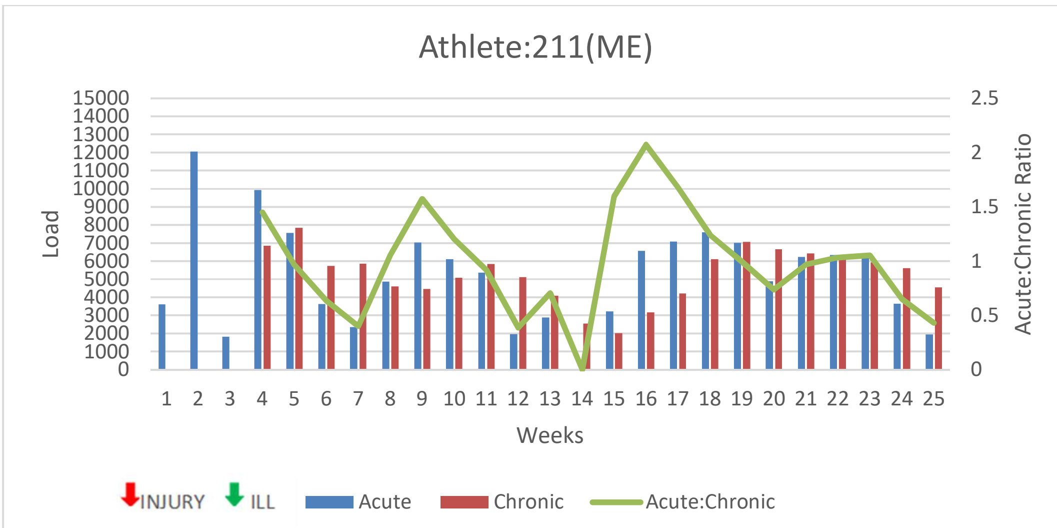

Figure 4.17 Load, injury and illness relationship for athlete 211.

Chapter 5: Discussion

This chapter presents a summary of the key findings of this research study. It then provides a more detailed interpretation of the results and suggests how this can inform future work in CNZ athletes. The study limitations and future research suggestions are discussed along with wider applications for the use of subjective load monitoring outside of track cycling. The chapter finishes by providing conclusions and future directions from this research.

5.1 Summary of Key Findings

Large individual variation of load was reported in the two cohorts; however, the mean load values were very similar across the two groups. The mean acute to chronic workload ratios reflected the stages of training and competition of the two cohorts, with cohort one in the build-up to the Rio Olympic Games and cohort two followed for a full season leading up to the World Championships following the Olympics representing more of rebuilding phase.

There was a statistically significant difference in the injury rates between the two cohorts ($p=0.04$). For cohort one, in 22% of weeks an injury was reported in contrast with seven percent in cohort two. Chronic Load was the only load variable to show an association with injury, for every 100AU rise in chronic load the injury odds increased by four percent ($p=0.02$).

The biggest predictor for illness was gender, with female athletes 20 times more likely to report an illness than their male counterparts ($p=0.004$). Both acute load ($p=0.001$) and acute to chronic workload ratio ($p=0.005$) showed a reduced illness odds with increasing values suggesting a protective level of load.

When injury or illness were considered together with respect to load there was a statistically significant difference between the two cohorts with cohort two reporting lower overall rates ($p=0.04$). Chronic load was once again associated with an increased injury or illness odds which increased by four percent ($p=0.02$) for every 100AU increase.

Injury or illness did not always relate to time loss or modification of training and the converse was also true where time loss or modification was not always related to injury or illness. This suggests that there are other factors that may determine time loss and that some athletes are able to continue training with injury or illness.

5.2 Participants and Data Collection Time Frames

There were differences between the two cohorts, the most obvious being that cohort one contained only sprint athletes that were selected for the Rio Olympic Games. This group was made up of more males than females. The fact that cohort one only contained athletes selected for the Rio Olympics may have led to bias in the data collected with potentially higher injury and illness rates. These athletes had a high amount of travel, were in the peak stages of training for a pinnacle event, and were competing at the highest level. Previous research has shown that travel, stress and level of competition is associated with higher injury and illness rates (Svendsen et al., 2016). In contrast, cohort two had a mix of athlete level and discipline but did have a higher representation of female endurance athletes followed by sprint and only one men's endurance athlete. Female athletes have been shown to have higher rate of illness and relative energy deficiency conditions (Drew et al., 2017; Engebretsen et al., 2013). Endurance athletes also report a higher rate of illness compared to other types of athletes (Timpka et al., 2016) and so the high weighting of both female and endurance athletes in cohort two may bias injury and illness rates in cohort two. Finally, there was a major under representation of men's endurance athletes in cohort two meaning that any findings may only be applicable to sprint and woman's endurance athletes.

The data collection periods for the two groups was also different. For cohort one this was the final lead up phase to the Rio Olympic Games with selection based on training and performance over the preceding four-year cycle. It could be hypothesised that these athletes may have self-selected as the most resilient and robust athletes of the group to get to this point. In other words, if they were prone to injury or illness then it would be unlikely they would have progressed to this point, much like survival of the fittest. In the lead up phase there is often a taper which can be up to six weeks or longer in some strength athletes, therefore peak loads in training may be underrepresented. It is also likely that competition loads and stress associated with a pinnacle event would be the highest in the four-year cycle. Cohort two was followed for a full track season in the lead up to a World Championships. This was the season following the Olympics which often represents a rebuilding or lower load phase. Athletes within this group were also at different phases in their career and on different training and competition schedules which may influence the load data recorded.

5.3 Subjective Load

Even though there were differences in the data collection time frames and makeup of the two cohorts the average acute and chronic loads were very similar. As expected the average acute to chronic workload ratio in cohort one was below one (0.88) with a range on the lower end (0.19-1.62). This represents lower relative fatigue to fitness (Hulin et al., 2014) which is expected in the taper phase leading up to a major event. In cohort two the average acute to chronic workload ratio was just above one (1.01) with a much larger range (0-2.15). This would be expected with the wider range of athletes in the cohort, the different training schedules and the data collection period representing the season post Olympics which is more of a building phase. When an athlete reported no load in a week this also impacted on the acute to chronic workload ratio producing a value of zero for that week which may not give a true reflection of the fitness versus fatigue state for that week.

The week to week percentage change which represents the change in acute load one week to the next had a mean value of 12.36% (SD: 80.6%) in cohort one and 24.68% (SD: 119.4%) in cohort two. The range in both groups was substantial from -84.29% to 287.70% in cohort one and even more pronounced in cohort two from -100% to 1257.47%. This is most likely a reflection of the variable training programs of each athlete and the effect of taking a week off training in some circumstances which then inflates the week to week change. Due to this high level of variation, week to week percentage change was not included in the group analysis. This may be an area to look at in the future as there is some suggestion that keeping increases in training load below 10% may reduce injury risk (Piggott et al., 2009; Soligard et al., 2016).

Looking at the subjective loads for each of the athletes it is clear to see that there is a high level of individual variation. This is less prominent in the athletes in cohort one as they were all working towards their final pinnacle event in the same discipline of sprint, so even though the individual values vary, the acute to chronic workload ratios are quite similar which is an expected finding given that the athletes were on very similar training programs. In cohort two subjective load is much more variable reflecting the different training and competition schedules of each athlete.

5.4 Relationship Between Load and Injury

In cohort one for the 64 weeks of data recorded, 21.9% of these weeks an athlete reported an injury. In cohort two 206 weeks of data was recorded and in 7.3% of these weeks an injury was reported. The difference between the two groups was statistically significant (p=0.04) and may represent the different makeup of the two groups along with the training phases as reported earlier.

In both bivariate and multivariate analysis, the only load value to have a statistically significant association with injury was chronic load. For every 100AU increase in chronic load the odds for injury went up by four percent (p=0.02). The two main explanations for this are the preceding week load association with injury and upper levels of load that an athlete can tolerate. In other studies investigating the associations between subjective load and injury, it was found that the preceding weeks loads were more predictive of injury than the current weeks load (Gabbett, 2004; Hulin et al., 2014; Kluitenberg et al., 2016; Malisoux et al., 2013; Rogalski et al., 2013). The explanation provided for this is the lag effect of load where an injury or illness may not show up for several days or weeks after a potential inappropriate change in the load. In this study chronic load acted as a proxy for preceding weeks load. The chronic load represents the average of the preceding three weeks and current weeks load (Hulin et al., 2014) and is one possible reason for why this was associated with injury. The other explanation is that chronic load represents the average workload for a four week period, and although it has been shown that high chronic loads can be protective from injury (Hulin et al., 2014), there has also been evidence to show that there are upper limits and pushing the load too high also leads to an increased injury risk (Rogalski et al., 2013).

The current study did not show any significant association between acute load or acute to chronic workload ratio and injury. The lack of association suggests that the acute training load and acute to chronic workload ratio was appropriately periodised and is a positive factor from a CNZ program perspective. As mentioned above the average acute load over the preceding three weeks and current week determines the chronic load and so in effect is related to injury odds. It should be acknowledged that specific analysis of preceding weeks acute load was not undertaken and would warrant further analysis.

5.5 Relationship Between Load and Illness

For cohort one in 6.3% of the study weeks an illness was reported and in cohort two 9.2%; however, there was no statistically significant difference between the two cohorts (p=0.55). The most significant factor related to illness was gender with female athletes 20 times more likely to have an illness than males (p=0.004). This is consistent with the findings of Drew et al. (2017) and Engebretsen et al. (2013) mentioned earlier in the discussion showing that female athletes are at an increased illness risk.

Acute load was significantly associated with reduced illness odds. In the bivariate and multivariate analysis, for every 100AU increase in acute load there was a reduced odds of illness (p=0.001). This is consistent with the findings of Anderson et al. (2003), Thornton et al. (2014) and Veugelers et al. (2016) which was discussed in the literature review as showing a reduced illness risk with higher loads. It is likely that there will be an optimal loading zone, and with further data collection it would be expected that a U-shaped curve as proposed by Walsh et al. (2011) would emerge. This optimal zone may be very athlete specific and understanding this on an individual athlete basis will be important for future analysis.

Along with the acute load, the acute to chronic workload ratio was also associated with illness odds reduction in the bivariate analysis. For every 1 unit rise in the acute to chronic workload ratio the illness odds reduced by 63%. This finding is harder to explain and is most likely a product of the small cohort numbers and large units of change. Acute to chronic workload ratio values above one represents more fatigue than fitness (Hulin et al., 2014) but can also mean that the athlete is in the optimal training zone to gain the protective effects of exercise (Gabbett, 2016; Windt & Gabbett, 2016) . As with the acute load, analysis of the acute to chronic workload ratio on an individual athlete basis and for a larger data set will likely give more valid insights into this relationship.

5.6 Relationship Between Load and Injury or Illness

Looking at the relationship between injury or illness and load there was a statistically significant (p=0.04) lower odds in cohort two (seven percent) when compared to cohort one (22%). This could potentially be explained by the phase of training and competition for cohort one leading up to the Olympic Games. As mentioned in the participants and data collection section above this cohort experienced large amounts of travel, high levels of stress and very high competition loads potentially increasing their overall injury and illness rate. For both bivariate and multivariate analysis, a chronic load rise of 100AU leads to an increased injury or illness odds of four percent (p=0.02). This is the same relationship that was shown in the earlier discussion looking at injury and load, and it is likely that the same reasons for the association will be at play here. It also suggests that chronic load is a very important load variable in a cohort of elite track cyclists and should be included in future research where injury and illness are of interest.

5.7 Individual Athlete Variation and Resilience

In this study, it was found that injury and illness did not necessarily mean time loss or training modification and suggests that some athletes were able to carry on training with a certain level of injury or illness. The converse is also true and in some cases training was modified not related to injury or illness, the specific reason for this modification was not investigated but it may be that athletes and coaches were able to recognise the early signs of training load imbalance and adjust accordingly. Athletes were provided with feedback from the primary researcher each week on their workload and advice was also given with regards to increased recovery or rate of building back into training. This could have affected the injury and illness rates as athletes were able to respond to weekly training load changes that may have otherwise led to injury or illness.

One of the most apparent findings from this study is the large inter athlete variability. Some athletes were injury and illness free and able to tolerate large variations in load while others appeared to be more susceptible. For example, athlete 211 could tolerate very large week to week changes in load, very large acute loads, along with a large variation in acute to chronic workload ratio without any injury or illness. In contrast many of the women’s endurance athletes had higher injury and illness rates with less variation in load. Athlete 225 is a good example of this, all her average load values were within the ranges that would be considered low risk, yet she had three injury weeks and four illness weeks. This variation is most likely the difference between a resilient and less resilient athlete. Resilience is a huge area of interest to high performance programs, finding out how to make an athlete more resilient will ultimately lead to reduced time loss to injury or illness and improved performance outcomes (Gabbett, 2016; Soligard et al., 2016). The specific factors that determine resilience are still under investigation however, the ability to tolerate load in all its forms (external, internal, psychological) are key areas of interest (Gabbett, 2012; Windt & Gabbett, 2016). This research would suggest that the ability to tolerate high chronic loads is one of the key attributes of a resilient athlete in the cohort of elite track cycling. It is most likely that it is a combination of factors that interact with each other and so must be approached in a holistic individualised way (Windt & Gabbett, 2016).

5.8 Study Limitations

The main challenge of this study was the low number of participants. This is always difficult in elite sport as by its very nature there are limited numbers of athletes when compared to community or lower level sport. It is however, very important to undertake research on the elite level population as they will often respond in a very cohort specific way. There were no previous studies on subjective load monitoring in track cycling so even with low participant numbers this research is the first in the area to the authors knowledge, and will be valuable in the future management of CNZ track cycling athletes.

Although the number of participants was low, there was a large amount of repeated measures data collected for each athlete, which brings challenges to statistical analysis. This was addressed in the use of the repeated measures logistic regression with exchangeable correlation matrix model used. This is a problem seen in many elite and professional sports settings with high levels of data where the challenge is to interpret this into clinically useful information for athletes and coaches in a timely manner. Recently becoming available are bespoke automated systems that can analyse large amounts of data and this is already being utilised in some professional sports settings. Examples of such systems include smartabase (https://www.fusionsport.com/), athletemonitoring (http://www.athletemonitoring.com/) and metrifit (http://metrifit.com/) with many more available. There has also been interest in machine learning based algorithms to better understand the data from the sporting environment which is less linear than more traditional data.

Accuracy of data collection can be a challenge and in this study both direct reporting and self-report methods were utilised. The direct reporting is more accurate; however, is much more time and resource consuming (Saw et al., 2017). Self-report does still require an investment of time but generally allows for easier access to data collection especially with athletes travelling to variable training and competition locations nationally and internationally (Saw et al., 2015c). With the greater interest in load monitoring there are now a wide variety of automated platforms as mentioned earlier to improve data collection and is something that could be investigated in any future research.

Lastly, there is a need to consider the learning effect of using subjective methods. Investing in some prior training for athletes so that they understand the different ratings in relation to effort can improve the utility of the data, specifically when making between athlete comparisons (Saw et al., 2017). Another way to counter this is to use deviation from baseline (Saw et al., 2017) which is a potential area to investigate for future research.

5.9 Future Directions and Research

The primary aim of future research in this cohort should be to collect more data from more participants. This will help to strengthen any group analysis and conclusions that can be drawn from the data. For the current athletes in this study their average values can be determined and it would be possible to look at variations from baseline utilising standard deviations which may be helpful for individual analysis. It would have been beneficial to overlay specific training blocks and competition events in the loading graphs as this may bring more meaning to the interpretation and is something that should be included in future research. To improve the quality and quantity of data consideration should be given to increasing athlete buy in along with coach and program support. The methods used for data collection should also be targeted towards reducing athlete time burden. Working through the implementation steps as proposed by Saw et al. (2015c) would be a good approach to this challenge.

From the literature review it was clear that stress played an important role in illness risk (Anderson et al., 2003; Brink et al., 2010; Freitas et al., 2013; Moreira et al., 2011; Thornton et al., 2016, Thornton et al., 2014), any future research should include some metric of stress in athlete monitoring. This will help to qualify any association between stress and injury or illness and load. It may be that increasing chronic load is in fact also a marker of stress in this study cohort. Along with a marker of stress, determining the best way to quantify the effect of travel load on athletes would be an important consideration. CNZ athletes are often required to undertake extensive long-haul travel across many times zones in a season, anecdotally leading to increased illness rates. Travel stress can be both a physical and psychological load and is a key risk factor for both injury and illness along with reduced performance as highlighted in the studies mentioned in the literature review (Prather et al., 2015; Svendsen et al., 2016; Thornton et al., 2014; Timpka et al., 2014).

In this research, subjective load has been utilised as a marker of internal load and currently in CNZ power data is used as a marker of external load. Future research could look at the relationship between external load captured by power meters and subjective load as recorded by athlete self-report. Combining internal load, external load and a specific marker of athlete stress would give a nice holistic approach to athlete monitoring and would give valuable feedback to both athlete and coach when making decisions on training planning and progression.

The primary aim of this research was to investigate the relationship between subjective load and injury or illness in CNZ track cycling athletes; however, it has also been undertaken to inform and develop systems and processes for athlete monitoring in HPSNZ. The methods for data collection used in this study should be continued by the CNZ track cycling program to build on the data already obtained if the program is to see value in athlete monitoring for reducing injury and illness. Consideration should also be given to implementing the suggestions made above to further improve this data. HPSNZ should also consider aspects of this research that may apply to sports that are currently not undertaking athlete monitoring and could utilise a similar methodology for implementation.

5.10 Wider Applications

Subjective load monitoring utilising the session rating of perceived exertion method does have its limitations; however, a major advantage of this approach is the relative simplicity, ease of application and understanding along with being very cost effective. This study has focused on a specific group of elite track cyclists, although the methods used can be easily transferred to the non-elite population and can also be applied to other sports. This method of load monitoring could also be applied to management of specific musculoskeletal conditions. A good example would be in the management of tendinopathy where load has been identified as a key variable in the management of the condition (Bohm, Mersmann, & Arampatzis, 2015; Cook & Purdam, 2013; Reinking, 2012). Utilising subjective load data would be an excellent way to gauge progression of rehabilitation and monitor the athlete once they have returned to play.

Outside of sport this method has potential application in management of a wide range of conditions with one good example being return to work programs. As with the tendinopathy example the success of rehabilitation is in the progressive exposure to workloads (Cancelliere et al., 2016). Utilising subjective load monitoring would be a simple and cost-effective way to monitor and feedback on progress of a patient returning to work with a graded increase in load. The same principles of avoiding spikes in load along with larger increases in load could also be applied in this setting.

5.11 Conclusion

This research investigated the relationship between subjective load and injury or illness in two cohorts of elite CNZ track cycling athletes. There were differences between the two cohorts most notably the timeframes and phase of training and competition for data collection along with the makeup of the two groups. Cohort one was made up of sprint athletes that were in the final build up to the Rio Olympic games, they had overall higher injury and illness rates which may be explained by the large amount of travel and stress of a major event.

When considering both cohorts together there was a statistically significant association between increasing chronic load and increased odds of injury or illness. Increasing acute load or acute to chronic workload ratio appeared to have a protective effect against illness. Gender was the biggest predictor of illness with female athletes 20 times more likely to report illness in this study.

Injury or illness did not necessarily mean time loss or modification of training and the opposite was also true where modification or time loss was not necessarily related to injury or illness. This suggests that some athletes can continue to train and compete with injury or illness and that there may be other factors outside of injury or illness that cause an athlete to miss or modify training.

Future research should look to build on the data collected in this study with increased study participants and weeks of data collection. Consideration should also be given to include markers of stress along with incorporating external load measures to provide a well-rounded athlete monitoring approach. Quality and quantity of data will be improved with increased athlete buy in, coach and program support along with using systems to increase the ease of data collection and reduce time burden.

Subjective load monitoring is a simple and cost-effective approach to athlete load monitoring and the methodology utilised in this research could be applied to other sports as well as non-sporting environments. It is also hoped that the methods developed in this research will help to inform and improve the HPSNZ athlete monitoring systems.

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Appendices

Appendix 1: Ethics Approval

16 June 2016

Duncan Reid
Faculty of Health and Environmental Sciences

Dear Duncan

Ethics Application: **16/204: Duncan The influence of subjective training load on training time loss in elite track cycling.**

Thank you for submitting your application for ethical review. I am pleased to confirm that the Auckland University of Technology Ethics Committee (AUTEC) has approved your ethics application for three years until 13 June 2019.

As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 13 June 2019;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 13 June 2019 or on completion of the project;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Mark Harris mark.harris@hpsnz.org.nz

Appendix 2: Example Literature Search Strategy

Title of Research: The influence of subjective training load on injury and illness in elite track cycling

Primary aim: to determine if there is a relationship between subjective training load and injury or illnesses in elite track cyclists.

Secondary aim: to determine if there is a relationship between subjective training load and time loss or modification of training in elite track cyclists.

Key Concepts:

Subjective load

Injury and illness

Training time loss

Modification of training

Possible key words:

Subjective, ‘self-report*’, internal, RPE, sRPE, perceive*, ‘self-rate*’

Load*, exert*, workload*, “training load*’,

Injur*, ill*, ‘time loss*’, modif*, restrict*, reduce*

Data Bases to Search:

Medline

Sports Discuss

CINAHL

Initial Search Strategy:

Search 1.0: 27/10/2016

Medline, CINAHL, Sport Discuss

#1

subjective or "self report*" or internal or RPE or sRPE or perceive* or "self rate*"

#2

load* or exert* or workload* or 'training load*"

#3

injur* or ill* or "time loss*" or modif* or restrict* or reduce*

#4

#1 AND #2

#5

(S1 N3 S2)

#6

S3 AND S4

#7

S3 AND S5

<u>Results/Thoughts/Notes</u>

A large amount of result with first combination 17308 the proximity search helped to narrow this down to 3574 but still a large volume of articles to go through. Perhaps restrict to just injury or illness and see if this give a more manageable number to review. Scanning first pages of results the articles are good and related to topic.

When limits of full text and English applied to #7 total number of articles came down to 925, further limited to peer reviewed, English, human, abstract and full text then 522. Looking at articles after limits removed some key articles so may have to keep without limits and review as above.

Search 1.1 27.10.2016

Medline, CINAHL, Sport Discuss

#1

subjective or "self report*" or internal or RPE or sRPE or perceive* or "self rate*"

#2

load* or exert* or workload* or “training load*"

#3

injur* or ill*

#4

(S1 N3 S2)

#5

S4 and S3

Results/Thoughts/Notes

A bit more refined now 1521 and the hit rate looks good on the first page. With limit of full text/abstract selected then 413 but seems to eliminate some key articles so may need to manually scan.

Appendix 3: Participant Information Sheet

Participant Information Sheet

Date Information Sheet Produced:

01 May 2016

Project Title: ***The influence of subjective training load on training time loss in elite track cycling.***

An Invitation:

My name is Mark Harris I am a Physiotherapist currently undertaking a master's degree with the School for Sports and Recreation at AUT.

I would like to invite you to be a participant in this research study looking into the relationship between subjective load and time loss from training.

I am looking to recruit elite Cycling New Zealand athletes that are carded with High Performance Sport New Zealand (HPSNZ).

To be eligible for this study you should be a current member New Zealand Track Cycling team – defined as all those athletes listed as "carded" track cycling athletes with HPSNZ.

If you agree to be a participant in this research:

1. All injury, illness, time loss and load data will be confidential unless you state otherwise.
2. You will in no way be personally identified in the study unless you choose to do so.
3. Participation in this research is voluntary and you will in no way be disadvantage or advantaged if you choose to participate or not.
4. You may withdraw yourself or any information at any time prior to the completion of the study without being disadvantaged in any way.
5. You may choose to share information from this research with named members of your support team you will need to provide consent for this and name these individual on your consent form.

What is the purpose of this research?

The purpose of this research is to better understand the relationship between how hard an athlete is working in training and the risk of training time lost due to injury or illness. This may help inform injury and illness prevention programs along optimisation of training to improve performance.

There have been similar studies conducted in other sports on the relationship between load and injury risk and this is an area that HPSNZ is looking to develop. To date there is very limited research available on all aspects of track cycling. Conducting formal research in this area will be of benefit to Cycling New Zealand, HPSNZ, you and future athletes.

This research will form a major part of my thesis and will contribute towards my master's qualification. As part of this research I may be required to provide a summary of the findings for publication in research journals or conference paper and presentation. You will in no way be identified in any publications or presentations.

How was I identified and why am I being invited to participate in this research?

You have been invited to take part in this study as you are currently a carded athlete within the Cycling New Zealand track program and are registered on the PILLS injury and illness surveillance system. There is currently no literature related to track cycling and subjective load monitoring which is the reason why you have been asked to participate in this study.

Your contact details have been provided by High Performance Sport New Zealand.

If you are no longer a carded athlete with the New Zealand Cycling track program then you will unfortunately not be eligible to be involved in this study.

What will happen in this research?

As you are currently registered with the PILLS injury and illness surveillance system you will continue to upload this weekly as normal. You will also be asked to provide a session rating of perceived exertion (sRPE) for each training session that you undertake along with the duration of the session. You will also be asked to indicate if you felt that you had to modify the training session. You will be instructed to upload this to training peaks, a specific spreadsheet or it will be collected in person.

What are the discomforts and risks?

There are no foreseeable risks to being involved in this study.

What are the benefits?

As a participant you will be provided with an individual load profile on request. This has the potential to be very beneficial for injury and illness risk reduction which in turn could lead to improved performance. It also has the potential to help fine tune your training plans again allowing for potential improved performance.

The Benefits to the lead researcher include the use of your data to develop a master's thesis and potentially publishable research papers.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

For research and publication purposes you will only be identified by your PILLS unique identifier number. This will ensure that any data that is presented in the public areas will remain anonymous outside of the lead researchers and research supervisor.

As this research has the potential to reduce your injury and illness risk and improve performance, you may wish to share your loading data with selected Cycling New Zealand support staff. If you would like to share this information then you will need to indicate this on the consent form.

If you indicate you would not like to disclose any of your information then it will be kept confidential at all times unless you provide express written consent to share this information.

What are the costs of participating in this research?

The main cost to you for being involved in this research is filling in the weekly PILLS survey (3-5minutes) along with recording your sRPE information after each training session (1 minute).

If you do not have access to training peaks then you may be required to e-mail your subjective load data to the primary researcher each week (5 minutes).

What opportunity do I have to consider this invitation?

You have until the end of June to sign up to this study for the first data collection. You will have the opportunity to join a further data collection from October.

Participation is voluntary and has no impact on selection, carding or any other factors related to your role in the Cycling New Zealand program.

If you require further information then you may contact my supervisor Dr Duncan Reid or me directly.

You are free to withdraw from the study at any time during the data collection and should do so by contacting myself or my supervisor to indicate you would like to withdraw. There will be no consequence should you choose to withdraw from this study at any time.

How do I agree to participate in this research?

If you agree to be a participant in this study then you will need to sign the attached consent form and return to Claire at reception in person or via e-mail.

Will I receive feedback on the results of this research?

Yes you will be provided with an individual subjective load data profile on request. You can also obtain a copy of the final report from this study if you so wish.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Duncan Reid, Duncan.reid@aut.ac.nz, +64(9) 921 9999 Ext 7806

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Mark Harris, mark.harris@hpsnz.org.nz, +64(0)21606876

Project Supervisor Contact Details:

Dr Duncan Reid, Duncan.reid@aut.ac.nz, +64(9) 921 9999 Ext 7806

Approved by the Auckland University of Technology Ethics Committee on 16th June 2016, AUTEC Reference number 16/204.

Appendix 4: Consent Form

AUT
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Consent Form

Project title: ***The influence of subjective training load on training time loss in elite track cycling.***

Project Supervisor: ***Dr Duncan Reid***

Researcher: ***Mark Harris***

☐ I have read and understood the information provided about this research project in the Information Sheet dated 01 May 2016.

☐ I have had an opportunity to ask questions and to have them answered.

☐ I understand that if I receive treatment from the Physiotherapist at HPSNZ details of my injury will be recorded utilising the OSICS-10 system (Orchard Codes).

☐ I understand that I will need to continue to complete the weekly PILLS survey along with providing a rating of perceived exertion scale (sRPE) for every training session.

☐ I understand that the results of this study may be published/reported at conferences however that I will not be identified individually

☐ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

☐ All my personal details, injury data and questionnaire answers are confidential and I will in no way be personally identified.

☐ All of my load monitoring data will be confidential unless I specifically request for this to be shared with named support staff below. I understand that I can withdraw this consent at any stage without reason and without being disadvantaged in any way.

☐ If I withdraw, I understand that all relevant information collected, or parts thereof, will be destroyed.

☐ I agree to take part in this research.

☐ I wish to receive a summary of the research findings (please tick one): Yes☐ No☐

☐ I would like to share my loading data with Cycling New Zealand staff (please tick one):

Yes☐ No☐

If you ticked Yes to sharing your loading data please name specific staff or for all Cycling New Zealand High Performance Staff please write "All Cycling New Zealand HP staff":

____

Participant's Signature : ______________________________

Participant's Name : ______________________________

Participant's Contact Detials : ______________________________

Address : ______________________________

Phone : ______________________________

e-mail : ______________________________

Date : ______________________________

Approved by the Auckland University of Technology Ethics Committee on 16th June 2016 AUTEC Reference number 16/204.

Note: The Participant should retain a copy of this form.

Appendix 5: Independent Administrator Agreement

10th May 2016

To whom it may concern,

I am happy to act as an impartial administrator for the research entitled "*The influence of subjective training load on training time loss in elite track cycling*".

I will send out the initial participant invitations, information sheets and consent forms. I will act as the contact for return of the electronic consent forms and will forward these onto the research supervisor Dr Duncan Reid.

I agree to maintain the confidentiality of all participants and will not disclose any information beyond the consent forms that I forward to the research supervisor. Once the consent forms have been forwarded I will securely delete any record of the participant from my computer.

Yours sincerely,

Clair.Brown@hpsnz.org.nz

Claire Brown
Medical and Rehabilitation Administrator