Load Monitoring in Elite Paralympic Athletes: Implications for Training and Recovery

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A thesis submitted to the University of Limerick in fulfilment of the requirement for the degree of Doctor of Philosophy

University of Limerick

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Submitted to the University of Limerick, November 2018
Abstract

Title: Load Monitoring in Elite Paralympic Athletes: Implications for Training and Recovery

Accurate monitoring of training load (TL) and external loads from athletic and lifestyle demands has been promoted as essential in defining the relationship between load, illness and injury risk in athletes (Soligard et al., 2016; Schwellnus et al., 2016). Furthermore, according to Fry et al., (1991), a multi-faceted monitoring system should be applied to effectively evaluate training responses and include physiological, psychological, biochemical and immunological markers. Therefore, the aim of this research was to develop, implement and evaluate a multi-faceted athlete monitoring system for Paralympic athletes and determine if this can effectively identify the responses to training and competition.

Study 1 examined the athletic response to training using sRPE and subjective wellness measures and the relationship with incidence of injury and illness across three training seasons in Paralympic footballers. Multi-level analysis identified increases in measures of weekly TL (11%), training monotony (36%), cumulative 2wk TL (12%), cumulative 3wk TL (8%) and ACWR (29%) to be significantly associated with illness occurrence in the following week. Specific TL variables have now been identified which may reduce the number of training days lost to illness when included in a multi-faceted monitoring system. Despite a 3% increase in TL measures, none were found to be significantly associated with injury occurrence. Having examined a field-based team sport, study 2 determined the validity of the sRPE method for quantifying internal TL in Paralympic swimmers. Significant high to very high positive correlations were observed between sRPE and Banister’s TRIMP (r = 0.68, p < 0.01), Edward’s TRIMP (r = 0.66, p < 0.01) and Lucia’s TRIMP (r = 0.74, p < 0.01) in all four swimmers. Study 3 expanded on study 1 to increase the number of markers used to include sleep quality, sleep quantity, mood, energy and muscle soreness and examined the athletic response of Paralympic swimmers across a 48-week training season. Multi-level analysis identified illness occurrence was associated with increases in weekly TL (22%), cumulative 2wk TL (16%) and ACWR (24%) in the preceding week. A 28% increase in training monotony in the preceding week was observed to be significantly associated with injury. Finally, Study 4 examined the relationship between TL and salivary biomarkers IgA, alpha-amylase (AA) and cortisol during training and high-level competition in Paralympic swimmers. Results identified a dose-response relationship between TL and salivary biomarkers, thus supporting their use as an objective measure of internal TL in Paralympic swimmers.

TL variables for Paralympic swimmers and footballers have been identified when monitored may reduce the number of training days lost to illness. Regarding injury, this research observed an increase in training monotony of 28% to be significantly associated with injury amongst Paralympic swimmers, thus should be included in an athlete monitoring system to reduce the risk of injury. Subjective wellness markers including sleep quality, mood and energy are sensitive to changes in TL and should be included in a multi-faceted athlete monitoring system for Paralympic footballers with further research warranted in Paralympic swimmers. In conclusion, this research adds to the existing scientific literature by examining longitudinal TL monitoring in Paralympic athletes and their relationship with incidence of injury and illness and determining markers which should be included in a multi-faceted athlete monitoring system.
Author Declaration

I hereby declare that the work contained in this thesis is my own, and was completed with counsel of my supervisors, Dr. Giles Warrington and Dr. Tom Comyns of the Department of Physical Education and Sports Sciences, University of Limerick. This work has not been submitted to any other University or Higher Education Institute, or for any other academic award with this University.

__________________________  ___________________________  ___________________________
Ciara Sinnott-O’Connor        Dr. Giles Warrington           Dr. Tom Comyns
Acknowledgements

I would like to thank the following people who contributed to the completion of this thesis:

My supervisors Dr. Giles Warrington and Dr. Tom Comyns for the support, direction and encouragement throughout this research and write up. Thank you for reading my numerous chapter drafts and giving guidance and feedback.

To Paralympics Ireland and Sport Ireland Institute who jointly funded this research.

To Professor Alan Nevill for the assistance and feedback on the statistical approaches used for this research.

To the athletes and coaches who participated in the research studies, without you this PhD would not be possible. Thank you for filling in training diaries daily, wearing HR monitors when needed and providing saliva samples even during the Paralympic Games. Working with you all during the last few years has been memorable. A particular thanks to Jim, Dave and Hayley for their coaching input, acting as my sound board and for the thought-provoking questions and chats!

To my colleagues within SII including our PhD group who listened to rants on bad days, chats on good days and gave advice on stats, submission frustrations and numerous deleted paragraphs. We are all on different points in the PhD journey and I will give back the same support to you however I can. A particular thank you also to Toni Rossiter, for the input with the initial design of the research, for all the encouragement particularly on the days when I had just had enough, giving me the time to write and covering physiology while I did and for being a great mentor.

To Louise, Claire, Hayley, Nic and Gemma who have all helped in your own little ways while I worked to complete this thesis. Whether it was giving words of encouragement, distracting me with tea and chats when needed, bringing me treats to keep me going or planning my wedding while I buried my head in writing, I am truly luckily to count you as my friends.

To Stephen – we’ve come a long way since 2009 and our biggest adventures are still to come. I could not have done this without your constant support. Thank you.
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<tbody>
<tr>
<td>AA</td>
<td>Alpha-amylase</td>
</tr>
<tr>
<td>AB</td>
<td>Able-bodied</td>
</tr>
<tr>
<td>ACWR</td>
<td>Acute Chronic Workload Ratio</td>
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<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
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<tr>
<td>AU</td>
<td>Arbitrary Unit</td>
</tr>
<tr>
<td>Cort</td>
<td>Cortisol</td>
</tr>
<tr>
<td>CP</td>
<td>Cerebral Palsy</td>
</tr>
<tr>
<td>CPISRA</td>
<td>Cerebral Palsy International Sports and Recreation Association</td>
</tr>
<tr>
<td>CR-10</td>
<td>Category 10 Ratio Borg scale</td>
</tr>
<tr>
<td>CV</td>
<td>Coefficient of Variation</td>
</tr>
<tr>
<td>DALDA</td>
<td>Daily Analysis of Life Demands for Athletes</td>
</tr>
<tr>
<td>ELISA</td>
<td>Enzyme-linked Immunosorbent Assay</td>
</tr>
<tr>
<td>FINA</td>
<td>International Swimming Federation</td>
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<tr>
<td>FOR</td>
<td>Functional Over-reaching</td>
</tr>
<tr>
<td>GAS</td>
<td>General Adaptation Syndrome</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HPA axis</td>
<td>Hypothalamic-Pituitary-Adrenal axis</td>
</tr>
<tr>
<td>HR</td>
<td>Heart Rate</td>
</tr>
<tr>
<td>HR_max</td>
<td>Maximum Heart Rate</td>
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<tr>
<td>HR_rest</td>
<td>Resting Heart Rate</td>
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<tr>
<td>Abbreviation</td>
<td>Definition</td>
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<tr>
<td>HRV</td>
<td>Heart Rate Variability</td>
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<tr>
<td>IAT</td>
<td>Illinois Agility Test</td>
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<tr>
<td>IFCPF</td>
<td>International Federation of Cerebral Palsy Football</td>
</tr>
<tr>
<td>IgA</td>
<td>Immunoglobulin A</td>
</tr>
<tr>
<td>IOC</td>
<td>International Olympic Committee</td>
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<tr>
<td>IPC</td>
<td>International Paralympic Committee</td>
</tr>
<tr>
<td>LFD</td>
<td>Lateral Flow Device</td>
</tr>
<tr>
<td>MAT</td>
<td>Modified Agility Test</td>
</tr>
<tr>
<td>NFOR</td>
<td>Non-Functional Over-reaching</td>
</tr>
<tr>
<td>OFC</td>
<td>Oral Fluid Collector</td>
</tr>
<tr>
<td>OR</td>
<td>Odds Ratio</td>
</tr>
<tr>
<td>OTS</td>
<td>Over-training Syndrome</td>
</tr>
<tr>
<td>POMS</td>
<td>Profile of Mood State</td>
</tr>
<tr>
<td>PSG</td>
<td>Polysomnography</td>
</tr>
<tr>
<td>PSQI</td>
<td>Pittsburgh Sleep Quality Index</td>
</tr>
<tr>
<td>RE</td>
<td>Running Economy</td>
</tr>
<tr>
<td>RESTQ-Sport</td>
<td>Recovery-Stress Questionnaire for Athletes</td>
</tr>
<tr>
<td>RHR</td>
<td>Resting Heart Rate</td>
</tr>
<tr>
<td>RPE</td>
<td>Rate of Perceived Exertion</td>
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<tr>
<td>sAA</td>
<td>Salivary Alpha-amylase</td>
</tr>
<tr>
<td>SCI</td>
<td>Spinal Cord Injury</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>sIgA</td>
<td>Salivary Immunoglobulin A</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>SE</td>
<td>Standard Error</td>
</tr>
<tr>
<td>sRPE</td>
<td>Session Rate of Perceived Exertion</td>
</tr>
<tr>
<td>SSG</td>
<td>Small Sided Games</td>
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<tr>
<td>TL</td>
<td>Training Load</td>
</tr>
<tr>
<td>TRIMP</td>
<td>Training Impulse</td>
</tr>
<tr>
<td>TRIMP&lt;sub.MOD&lt;/sub&gt;</td>
<td>Modified Training Impulse</td>
</tr>
<tr>
<td>URTI</td>
<td>Upper Respiratory Tract Infection</td>
</tr>
<tr>
<td>VI</td>
<td>Visual Impairment</td>
</tr>
<tr>
<td>VO&lt;sub&gt;2 max&lt;/sub&gt;</td>
<td>Maximum Oxygen Uptake</td>
</tr>
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The abbreviations above are written in full when first mentioned and then abbreviated for the rest of the thesis.
# Units of Measurement

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Term</th>
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<tbody>
<tr>
<td>%</td>
<td>Percent</td>
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<tr>
<td>C</td>
<td>Celsius</td>
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<tr>
<td>cm</td>
<td>Centimetre</td>
</tr>
<tr>
<td>kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
</tr>
<tr>
<td>m/s</td>
<td>Meter per second</td>
</tr>
<tr>
<td>ng</td>
<td>Nanogram</td>
</tr>
<tr>
<td>µg.ml(^{-1})</td>
<td>Microgram per millilitre</td>
</tr>
<tr>
<td>s</td>
<td>Second</td>
</tr>
<tr>
<td>min</td>
<td>Minutes</td>
</tr>
<tr>
<td>yr</td>
<td>Year</td>
</tr>
</tbody>
</table>
Glossary of Terms

**Acute:chronic workload ratio (ACWR):** A sRPE training load (TL) variable calculated by dividing the average weekly TL (acute) by the rolling average of weekly TL in the previous four weeks (chronic) (Gabbett, 2016).

**External Training Load:** Measures of the work completed by an athlete during training that are objective and independent of athlete perception, including distance, power and velocity.

**Functional Over-reaching:** FOR is a deliberate short-term period of increased TL aimed to stimulate physiological adaptation which induces a temporary fatigued state in athletes.

**Internal Training Load:** Measures of the athlete response both physiological and psychological to the external load applied, using variables such as blood lactate, heart rate and rate of perceived exertion.

**Non-functional over-reaching:** Where recovery becomes consistently inadequate or TL continues at too high an intensity, an athlete is at risk of NFOR occurring, leading to stagnation or decrease in performance which will not resume for several weeks or months. However, with sufficient recovery the athlete will be able to fully recover.

**Overtraining Syndrome:** OTS symptoms may coincide with those of NFOR and may also include depression, disturbed eating and disturbed hormonal responses, in which recovery of performance capacity may take months, years or in extreme cases never return.

**Salivary Alpha-Amylase (sAA):** Release of sAA is facilitated by the autonomic nervous system and has been shown to be a reliable indicator of the adrenergic response to exercise. Produced in the salivary glands it has been reported to be more sensitive to exercise-induced stress than cortisol as it does not require transport from the blood to saliva.

**Salivary Cortisol:** Cortisol is the major glucocorticoid secreted by the adrenal cortex in response to physical or psychological stress, and salivary cortisol can
provide a reference for cortisol levels in the blood with research showing more pronounced changes in saliva in response to exercise.

**Salivary Immunoglobulin A (sIgA):** Measured in saliva, sIgA has a primary role in defence against infection of the upper respiratory tract and has been established as a reliable biomarker for identifying risk of infection in athletes. Changes in sIgA levels may reflect physiological and psychological stress when monitored over time.

**sRPE TL:** A measure of internal training load as an arbitrary unit using an athletes’ RPE score (1-10) multiplied by the training session duration in minutes (Foster et al., 1995).

**Subjective Wellness Markers:** Measures of internal TL which are subjective to the athlete’s perception including sleep, fatigue, energy and mood.

**Training Load:** The psychological and physiological demand put on an athlete through training.

**Training Load Monitoring:** Measurement of individual training stress for each athlete using physiological and psychological variables.

**Training Monotony:** A sRPE TL variable calculated as mean weekly TL divided by SD weekly TL, reflects the variability in training intensity throughout a week.

**Training Strain:** A sRPE TL variable representing the total stress perceived by the athlete during a training week, calculated as weekly TL multiplied by training monotony.
Chapter 1. Introduction
1.1 Background and Rationale

Attaining the balance between appropriate training stresses and adequate recovery is essential to achieve a successful training stimulus and adaptation (Comyns and Flanagan, 2013). Athletic training is based upon the principle of progressive overload where increased training stressors combined with appropriate recovery are employed to produce a positive training adaptation (Meeusen et al., 2013). In determining the appropriate overload, an athlete may sustain before maladaptation occurs, a multi-faceted monitoring system is critical to quantify both the load applied and the athlete responses to the training stress (Kanttä and Hassmén, 2002). The 2016 IOC consensus statement (Schwellnus et al., 2016, page 1044) defines load as:

“the sport and non-sport burden (single or multiple physiological, psychological or mechanical stressors) as a stimulus that is applied to a human biological system (including subcellular elements, a single cell, tissues, one or multiple organ systems, or the individual).”

Additionally, the consensus statements advocate regular athlete monitoring of training load (TL), wellness, external load, illness and injury to ensure care of athletes and reduce illness and injury risk (Schwellnus et al., 2016; Soligard et al., 2016). Quantifying TL requires valid and reliable objective and subjective measurement methods. According to Foster et al., (2001) monitoring TL is critical to the process of quantifying training periodisation plans. TL monitoring can be used to measure the individual training stress response for each athlete using a variety of physiological and psychological variables, ensuring individualisation of training prescription and minimising risk of non-functional over-reaching (NFOR) or overtraining (OTS) (Smith and Norris, 2002). Furthermore, Fulton et al., (2010) suggested that training prescription for elite swimmers with a disability should account for the impairment and their competitive class as well as the individual needs of the athlete. To successfully quantify and monitor TL, reliable monitoring tools are essential and research is required for their use and suitability in each sporting population they are applied to (Paulson et al., 2015).

The Paralympic Games represents the pinnacle sporting competition for athletes in six core disability categories – cerebral palsy (CP), visual impairment (VI), spinal cord injury (SCI), amputation, intellectual disability and Les Autres. The rise in
The popularity of the Paralympic Games has seen a shift in focus from rehabilitative participation in the first Stoke Mandeville games in 1948 (Tweedy and Howe, 2011) to elite high-performance sport. It has become one of the world’s biggest elite sporting competitions, with the 2016 Rio de Janeiro Paralympic Games hosting over 4300 athletes competing and representing 160 countries (IPC, 2016). However, despite its growing popularity and increased performance levels, scientific literature examining the training responses of Paralympic athletes continues to lag behind the research conducted in able-bodied (AB) athletes. Fagher and Lexell (2014) reported injury rates in Paralympic athletes to be higher when compared with AB athletes in the same sports. Furthermore, Fagher et al., (2016) suggested illness risk in Paralympic athletes may be increased due to existing medical conditions or disorders associated with disabilities. Confounding this, Schwellnus et al., (2016) suggest poor athlete load management can further increase risk of illness, NFOR and OTS. In order to understand the training and recovery needs of Paralympic athletes, a comprehensive understanding of TL and training response are required, along with a scientific rationale for the monitoring tools utilised. Limited research has examined monitoring tools in Paralympic athletes including heart rate (HR) (Edmonds et al., 2015), session rate of perceived exertion (sRPE) (Paulson et al., 2015), salivary markers (Leicht et al., 2012; Edmonds et al., 2015) and subjective wellness markers including sleep, mood, energy and wellness (Rodrigues et al., 2015). However, this limited research has been conducted during a short specific period of training or competition (Edmonds et al., 2015; Paulson et al., 2015), in contrast to more recent research suggesting that longitudinal athlete monitoring may be more beneficial to ensure adequate evaluation of the individual athlete response (Bourdon et al., 2017). Furthermore, a single, consistent marker has yet to be identified to accurately monitor both training and recovery responses in athletes (Kenttä et al., 2006); therefore, a variety of measures and markers should be utilised dependent upon the needs of the Paralympic sports and their athletes.

During a periodised training plan, an athlete will incur varying degrees of training stress and adaptation. The General Adaptation Syndrome (GAS) model, proposed by Selye (1936) describes the process of the physiological adaptation of the body in response to a stressor in three stages – alarm phase, resistance phase and supercompensation phase. Initial application of a stressor results in fatigue during the
alarm phase, but with adequate recovery the body enters the resistance phase where physiological adaptations occur. Finally, a supercompensation phase is entered where the body has positively adapted to the applied stressor. According to Buccheit (2014), the training stress and subsequent recovery timing must be carefully quantified as too high a TL or insufficient recovery may lead to NFOR or OTS.

A joint consensus statement of the European College of Sports Sciences and American College of Sports Medicine, identified three stages of overtraining in athletes – functional over-reaching (FOR), NFOR and OTS (Meeusen et al., 2013). FOR is a planned, short-term deliberate increase in TL in order to enhance performance which can temporarily result in fatigue (Lambert and Borresen, 2006). Where recovery becomes consistently inadequate or TL continues at too high an intensity, the athlete is at risk of NFOR occurring (Lambert and Borresen, 2006). During this time, an athlete is also at risk of increased injury or illness occurrence, whilst the training adaptation or competitive performance may plateau or even decrease (Meeusen et al., 2013). However, with sufficient rest an athlete will be able to fully recover (Meeusen et al., 2013). Where inadequate recovery or excessive TL continue for too long, an athlete may enter an OTS state, resulting in negative physiological and psychological symptoms together with performance decrements (Meeusen et al., 2013). Individuals recover from the same training stimulus differently with the response influenced by a range of factors including fitness level, previous training, nutritional intake, sleep, fatigue states, recovery modes and external environmental stressors (Halson, 2014a). Furthermore, among a Paralympic athlete population, it is necessary to consider the individual disability needs which may also impact on recovery and training adaptation (Fulton et al., 2010). Thus, it highlights the importance of monitoring individual athletic response throughout a training year.

Methods of TL monitoring can be external – objective and independent of athlete perception including distance and power or internal – subjective and measures how the athlete perceived the session including rate of perceived exertion (RPE) (Halson, 2014a). According to Mujika (2017), recording external TL alone does not consider the physiological stress of a training session on an athlete, thus internal and external measures should be included in any multi-faceted athlete monitoring system. In selecting monitoring tools to quantify TL for Paralympic athletes, it is necessary to
identify parameters which can be applied to all athletes regardless of their disability. HR is an objective and convenient monitoring tool for quantifying internal TL (Burgess, 2017) and has been previously utilised in monitoring TL in sports including soccer (Impellizzeri et al., 2004; Impellizzeri et al., 2005) and swimming (Wallace et al., 2009). Despite its ease of use and non-invasive method of data collection, there are limitations to the use of HR in Paralympic athletes. According to Paulson et al., (2013) readings can be unreliable in athletes with high SCI, whilst Thiesen (2012) suggests impairment of autonomic nervous system will also impact on HR. Buccheit (2014) has previously suggested HR monitoring cannot inform on all aspects of wellness, fatigue and performance and is better utilised in combination with daily training logs, psychometric questionnaires and performance testing.

Originally proposed by Foster et al., (1995), the sRPE method quantifies internal TL as an arbitrary unit using an athletes’ RPE score multiplied by the training session duration in minutes. Borresen and Lambert (2006) suggest the sRPE method is sufficiently accurate to measure training session intensity if HR data is not available or a more practical method is required for quantifying TL. Previous studies have shown sRPE to be valid across a wide range of sports and training types when compared with other methods, including HR and global positioning systems (GPS), of quantifying internal TL particularly in endurance sport (Foster et al., 2001; Coutts et al., 2007a; Wallace et al., 2009; Haddad et al., 2011; Lupo et al., 2014), intermittent team sports (Coutts et al., 2003; Impellizzeri et al., 2004; Moreira et al., 2012; Elloumi et al., 2012; Scott et al., 2013) and resistance training (Day et al., 2004; Sweet et al., 2004; Kraft et al., 2014). In intermittent Paralympic sport, sRPE has been validated against HR-based methods including Banisters TRIMP, Edwards TRIMP and Lucia’s TRIMP for use in wheelchair rugby (r = 0.62 - 0.81) (Paulson et al., 2015) and wheelchair basketball (Iturricastillo et al., 2016a). However, research is yet to be conducted in other Paralympic sports including swimming and football. The ability of sRPE to quantify TL in Paralympic athletes regardless of disability would determine its viability and possible use in a multi-faceted monitoring system but requires further research for its use.

Subjective wellness markers have been supported as a simple yet informative measure of monitoring TL and can assist in early detection of athletes negatively responding to training (Meeusen et al., 2013). A review by Saw et al., (2015)
proposed inclusion of subjective wellness measures in athlete monitoring systems which are responsive to acute and chronic training to evaluate stress, fatigue, recovery and general well-being. In addition, Halson (2014a) has advocated the regular monitoring of sleep quality and sleep duration to assist in early detection of performance or health impairments, whilst Kenttä et al., (2006) suggest monitoring mood state in athletes can provide a reliable indicator of individual response to TL. In this regard, the Recovery-Stress Questionnaire for athletes (RESTQ-Sport) was specifically designed to measure recovery and stress states in athletes using 76 components measuring the frequency of stress and subsequent recovery (Kellmann and Kallus, 2001). The Daily Analyses of Life Demands of Athletes (DALDA) proposed by Rushall (1990), measures training and non-training stressors along with symptoms of stress using a 34-component questionnaire. A limitation of the use of these questionnaires is the lengthy time requirement for completion each day which, as suggested by Thorpe et al., (2017), may not be suitable for longitudinal daily monitoring in athletes. A study involving high performance sport in Australia and New Zealand, reported the most popular self-report athlete monitoring questionnaires used are custom designed using Likert point scales ranging from 1-5 or 1-10 (Taylor et al., 2012). In support of this, Shearer et al., (2015) suggested wellness scales should take less than 1 min to complete to ensure long-term adherence in athletes. Despite this, subjective wellness markers and their response to TL have yet to be examined in a Paralympic athlete population. Therefore, further research is required to assess the efficacy of the use of various subjective wellness monitoring tools to evaluate the response to TL in Paralympic athletes.

In recent years, the use of salivary biomarkers as a monitoring tool has grown in popularity due to their non-invasive nature coupled with their ease of collection and measurement which can be quantified quickly and repeatedly (Papacosta and Nassis, 2011). Saliva contains both immunity and stress biomarkers including immunoglobulin A (IgA), alpha-amylase (AA) and cortisol, all of which have been shown to respond to training and competition stress in athletes (Libicz et al., 2006; Kivlghan and Granger, 2006; Neville et al., 2008; Bishop and Gleeson, 2009; Cunniffe et al., 2010; Edmonds et al., 2015; Chennaoui et al., 2016). An imbalance between TL and recovery has been shown to impair immune function thus increasing illness risk in athletes (Libicz et al., 2006; Bishop and Gleeson, 2009) whilst
research suggests athletes undertaking intensive and prolonged training may be at a higher risk of illness (Nieman, 2000). Therefore, monitoring salivary IgA (sIgA) may be a useful marker in determining when Paralympic athletes are at increased risk of illness and ensure modifications can be made to training to reduce this risk. Salivary AA (sAA) and salivary cortisol are stress markers which have been shown to respond to increased physiological and psychological stressors associated with competition (Kivlighan and Granger, 2006; Cunniffe et al., 2010; Edmonds et al., 2015; Chennaoui et al., 2016). However, according to Kellmann (2010), heightened stress levels in athletes can limit the ability to recover, therefore monitoring during periods of competition such as Paralympic Games would depict further the individual stress response of an athlete and determine the appropriate level of recovery needed. Furthermore, changes in selected salivary biomarkers levels have been shown in response to changes in TL (Filaire et al., 2003; Gomes et al., 2013; Diaz et al., 2013; Edmonds et al., 2015; Edmonds et al., 2016) but in spite of this, the current scientific literature has yet to research the response of sIgA, sAA and salivary cortisol measured together in Paralympic athletes. Paralympic athletes are at a higher pre-disposition to illness compared to their AB counterparts as a result of their disability (Webborn and Van de Vliet, 2012). Fatigue associated with intense training has been reported to have the potential to increase seizure risk in athletes with CP, thus requiring Paralympic footballers to be more closely monitored than their AB counterparts (Webborn, 1996). Monitoring of these variables may assist coaches in identifying periods of excessive TL or insufficient recovery amongst their Paralympic athletes thus reducing the risk of immunosuppression and possible occurrence of illness.

The timeframe for recovery and adaptation to return the body to homeostasis varies between athletes and must be individually prescribed as a result (Soligard et al., 2016). The 2016 IOC consensus statements suggest defining the relationship between load, illness and injury in athletes is reliant on accurate monitoring of TL and external lifestyle demands (Soligard et al., 2016; Schwellnus et al., 2016). It is therefore necessary to determine if a multi-faceted system using sRPE, subjective wellness markers and salivary biomarkers can effectively identify individual responses to TL and competition. Furthermore, examining the relationship between TL measures and occurrence of illness and injuries amongst Paralympic swimmers
and footballers will ensure coaches can maximise the stress recovery balance to achieve a positive training adaptation.

### 1.2 Research Background

The research undertaken for this thesis is the first research programme funded jointly by the Sport Ireland Institute and Paralympics Ireland. The Sport Ireland Institute (SII) works directly with high performance athletes, coaches and sporting governing bodies in developing and providing sport science and medical support to positively impact on performance. Performance services centre around three core elements of science, medicine and life-skills, with a focus to support athletes and coaches to perform to their best potential. Paralympics Ireland is the national governing body for elite athletes with a disability in Ireland. In addition to managing Irish team participation in European/World and Paralympic Games, Paralympics Ireland provides sports science and medicine support to funded athletes in collaboration with the Sport Ireland Institute. This body of research was specifically conducted on Paralympics Ireland athletes preparing to compete at major competition, including the 2016 Rio Paralympics, in order to provide valuable information in developing and optimising a multi-faceted athlete monitoring system. Following the decision by IPC in 2015 to cease inclusion of Paralympic football in the competition programme after Rio 2016 Paralympic Games, the focus of this research moved from a single sport to two. A benefit of this decision was expanding the applicability of the research outcomes to both a team field-based Paralympic sport and a water-based individual Paralympic sport. However, this meant sRPE needed to be validated in Paralympic swimming as the research of sRPE in water-based sport was low in comparison to available literature on field-based sport and soccer in particular. It also had implications in terms of the study time as there was only one season available to extend the research before Paralympic Games in Paralympic swimming compared to the three-year study in Paralympic football. A large proportion of the results were provided to the multi-disciplinary team of coaches and support staff on a weekly basis to report on the individual athlete TL and ensure training modifications could be made by the coach if deemed necessary. Results were also used to assist with monitoring fatigue from travel during the 2016 Paralympic Games using
baseline subject data and comparing with data upon arrival to determine when athletes had recovered from travel fatigue and should resume normal training.

1.3 Research Aim

Mujika (2017) promotes quantification of TL to determine the athlete response and ensure a sufficient stress/recovery balance for a positive training adaptation. A clear measure of the TL on the athlete provides a coach with a better understanding of what is required for sufficient recovery. Thus, the importance of athlete monitoring and its implications for training, recovery, well-being and performance has increased in recent years. A review by Ross et al., (2013), reported a daily monitoring system incorporating a validated questionnaire or RPE and physiological parameters provided the most reliable TL information. However, investigation of suitable monitoring tools for each particular sport and the athletes involved are required based on varied results amongst AB sports and limited research amongst Paralympic athletes, to ensure adequate and reliable quantification of the training response. Therefore, the aim of this research is to evaluate a multi-faceted athlete monitoring system for Paralympic athletes to determine if this can effectively identify the individual responses to training, competition and recovery. A further aim is to examine the relationship between TL measures and the occurrence of illness and injury in Paralympic swimming and football, in order to identify measures for inclusion in a multi-faceted monitoring system which may reduce the risk of such illnesses and injuries occurring and limit days of training lost.

1.4 Research Objectives

- Investigate sRPE to quantify TL over three seasons in Paralympic footballers preparing for Rio 2016 Paralympic Games (Study 1).
- Examine the relationship between sRPE quantified TL, subjective wellness markers and incidence of injury and illness in Paralympic footballers across three training seasons in preparation for Rio 2016 Paralympic Games (Study 1).
• Investigate the validity of sRPE in quantifying TL in Paralympic swimmers (Study 2).
• Examine the relationship between subjective wellness markers, sRPE quantified TL and incidence of injury and illness in Paralympic swimmers across a training season in preparation for Rio 2016 Paralympic Games (Study 3).
• Investigate the use of salivary biomarkers sIgA, sAA and salivary cortisol as an objective monitoring tool for use in Paralympic swimmers and their response to changes in sRPE TL across training and competition performance (Study 4).

1.5 Thesis Outline

Four sequential and related studies are presented for this thesis which is composed of seven chapters.

• **Chapter 1**: introduces the research topic and an outline of the aim and objectives of this research.

• **Chapter 2**: presents an introduction to Paralympic sport and focuses on scientific research published to date within Paralympic swimming and football. In addition, a comprehensive review of the current scientific literature is provided which critically examines TL monitoring methods and the importance of athlete monitoring.

• **Chapter 3**: presents a longitudinal investigation of the athletic responses of Paralympic footballers to training over the course of three seasons. The responses of subjective measures sleep quality, energy and mood to changes in TL using sRPE are examined.

• **Chapter 4**: investigates the validity of sRPE to quantify TL in Paralympic swimmers. It was necessary to examine its validity in Paralympic swimming due to the limited research using sRPE in swimming.
• **Chapter 5**: presents a longitudinal investigation of the athletic responses of Paralympic swimmers to training. Expanding on the variables used in Paralympic footballers in Chapter 3 (study 1) and after determining sRPE to be a valid measure in swimmers in Chapter 4 (study 2), this study increased the number of subjective variables collected.

• **Chapter 6**: investigates the efficacy and use of salivary biomarkers as a monitoring tool within a Paralympic athlete monitoring system. The responses of the salivary biomarkers were examined in response to changes in TL across three training phases and a competition phase during Rio 2016 Paralympic Games. Finally, the effect of participating in major competition and the associated psychophysiological stress response is researched to determine the impact on athletes and their competition recovery strategies.

• **Chapter 7**: provides a summary of research findings in addition to overall discussion, practical applications, research limitations and recommendations for future research.

1.6 Delimitations
Participants were restricted to members of the Irish Paralympic Football and Swimming teams preparing for the 2016 Rio Paralympic Games.
Chapter 2. Literature Review
2.1 Introduction

The purpose of this chapter is to review the current scientific literature related to the concepts of this research. This review of literature begins with an introduction to Paralympic sport, its growth from rehabilitative preparation to high performance sport, classification of athletes to establish an understanding of the athlete needs for a multi-faceted monitoring system and a focus on the two sports researched. Different methods used to quantify TL are then reviewed, evaluating both internal and external parameters. Particular attention is given to the importance of load monitoring to enhance performance, reduce injury and illness risk and prevent NFOR and OTS. Current practices of monitoring for assessment of individual athlete responses to training are critically evaluated with particular consideration to the practical application of objective and subjective measures for use amongst high performance Paralympic athletes.

2.2 Paralympic Sport

The Paralympic Games originated as a sporting event for injured military personnel. Dr. Ludwig Guttman believed that sport was a key part of the rehabilitation process and as director of the Stoke Mandeville Hospital, he established the Stoke Mandeville Games, first held in 1948 to coincide with the 1948 London Olympic Games (Tweedy and Howe 2011). The term “para” stands for parallel to represent the games running parallel to the Olympics. Since 1988, both the Paralympic and Olympic Games have been held in the same cities and competition venues. The Summer Paralympic Games currently comprises of 22 sports while the Winter Games has 5 sports, with both events governed by the International Paralympic Committee (IPC). The 2016 Paralympic Games were held in Rio de Janeiro, with over 4300 athletes competing and representing 160 countries (IPC, 2016).

There are five disability categories of athletes – SCI, CP, amputation, VI and Les Autres (other physical disabilities and intellectual impairment). Athletes are classified to identify those eligible to compete and determine how they are grouped for competition. Each sport is subject to its own classification process with numerous classes within each, dependent on the physical demand and skills required to perform the sport. Individual world and area-specific competitions are held in years outside
of a Paralympic Games year. Despite the shift in focus from rehabilitative participation to elite level sport, research into Paralympic sport and the monitoring of Paralympic athletes has lagged behind the large body of scientific literature in AB athletes.

2.2.1 Paralympic Football

Cerebral palsy (CP) or 7-a-side Paralympic football has been part of the Paralympic Games since 1984. The game is similar to that of AB soccer with some modifications and is played by ambulant individuals with CP or a neurological disorder for example, stroke or acquired brain injury. The game was previously governed under the Cerebral Palsy International Sports and Recreation Association (CPISRA). However, since 2015, it has been under the governance of the International Federation of Cerebral Palsy Football (IFCPF). Currently, the IFCPF looks after 40 representative country teams across five continents (IFCPF, 2017). CP football was removed from the Paralympic competition programme after the 2016 Rio Paralympic Games and must become more popular worldwide before it can be deemed to return to the Paralympic programme (IPC, 2015).

Figure 1. CPISRA Football 7-a-side pitch dimensions (CPISRA, 2014)
Pitch measurements are smaller than that of an AB soccer pitch measuring 70-75 m long and 50-55 m wide and smaller width goals measuring 5 m wide and 2 m high (Fig. 1). A competitive match is played for 60 min duration with a 15 min interval between each 30 min half. Specific rules relating to Paralympic football include no off-side rule, players may roll a ball into play instead of a conventional throw-in and a total of three substitutions may be made during a game (IFCPF, 2017). There are four functional ability classifications (FT5-FT8) in CP football (Table 2.1).

During competition, athletes compete against each other in the same class or rules apply for the sequence of classes that must be present on a pitch at all times. Classification is conducted through physical and technical assessments as well as evaluation during competitive play. In accordance with IFCPF rules, international classification is conducted by an accredited multi-disciplinary team consisting of a physician, physiotherapist and a sports technician (IFCPF, 2017). To ensure fairness during competitive play, specific rules apply to how a team may be composed at any one time. Of the seven players on a field, one FT5 or FT6 must be present at all times with no more than two FT8 players.

<table>
<thead>
<tr>
<th>Class</th>
<th>Impairment</th>
</tr>
</thead>
</table>
| FT 5  | Impairment in both lower limbs usually spasticity or hypertonia which may also be present in upper limbs  
Difficulty with running, turning and stopping - poor lower limb control |
| FT 6  | Co-ordination and balance impairments in all four limbs and trunk  
Difficulty dribbling, running, accelerating and stopping |
| FT 7  | Class designated to those with hemiplegic CP  
Players often present with a limp  
Often weak leg will kick ball in order to maintain balance using dominant side |
| FT 8  | Minimum impairment category  
Impairments may not be visible initially  
Involuntary muscle contraction constitutes activity limitations |

A 2006 medical consensus statement defined CP as “a group of permanent disorders of the development of movement and posture, causing activity limitations that are
attributed to non-progressive disturbances that occurred in the developing foetal or infant brain” (Rosenbaum et al., 2007, page 9). Prenatal injury to the brain has shown to be the most common cause, occurring in up to 80% of cases with other potential causes including genetics and congenital inflammatory, infection or metabolic issue (MacLennan, 1999). The location of the brain lesion will determine the implications on movement, spasticity, cognition, communication or behaviour for each individual (Carlon et al., 2010). In addition, intellectual disabilities, audio and visual impairments and epilepsy or seizure conditions can also be present (Sherrill, 2004). CP can be categorised by the pattern of limbs affected – monoplegia, hemiplegia, diplegia, triplegia or quadriplegia and by the predominant motor impairment – spastic, dyskinetic or ataxic (Sankar and Mundkur, 2005). According to Sherrill (2004), spastic CP is the most common type of motor disorder, affecting up to 65% of individuals diagnosed. Damage to the motor cortex of the brain impairs the antagonist pairing of muscles where both agonist and antagonist muscles activate together, leaving muscles under a constant state of tension. The hypertonic state can limit range of movement and co-ordination, disrupt protein synthesis in the affected limb or limbs and contributes to excessive fatigue (Sherrill, 2004). Furthermore, muscle weakness and imbalance associated with CP can increase the risk of injury in athletes (Andrade et al., 2005). This is an important consideration in the recovery of Paralympic athletes and highlights the requirement for an athlete monitoring system to ensure the athlete response to a training stimulus can be correctly quantified and prescribed recovery is sufficient.

According to Stølen et al., (2005) soccer is intermittent in nature, characterised by short periods of high intensity and maximum speed interspersed with brief periods of recovery. Thus, successful performance requires players to have sufficient aerobic and anaerobic capacities to meet the demands of play (Stølen et al., 2005). Kloyiam et al., (2011) examined the soccer-specific endurance, running economy and running gait of 14 national Paralympic footballers and compared them to previously published research of their AB counterparts. Soccer-specific endurance measured via distance covered in the Yo-Yo Level 1 test in Paralympic footballers was reported to be significantly lower than results in Danish national AB soccer players (993 ± 397 m vs. 2040 ± 60 m) respectively (Kloyiam et al., 2011; Mohr et al., 2003). No significant effect of classification on Yo-Yo results was observed, with a high degree
of variability reported between players and classes attributed to fitness level and playing position (Kloyiam et al., 2011). Furthermore, no significant differences were observed between running economy (RE) scores of both groups with the authors concluding they were unsure of the reason for this as it was initially hypothesised RE would be lower in those with CP due to the energy cost of the disability (Kloyiam et al., 2011). Investigating the anaerobic ability of Paralympic footballers, Yanci et al., (2016) reported Wingate test results for peak power (490.6 ± 125.7 W) to be lower compared to published data amongst AB footballers including collegiate level soccer players (722.1 ± 116.7 W) and national level players (873.6 ± 141.8 W) (Miller et al., 2011; Al’Hazzaa et al., 2001). Furthermore, mean power output was also reported to be lower in Paralympic footballers compared to national level players (399.4 ± 97.6 W vs. 587.7 ± 55.4 W) respectively (Yanci et al., 2016; Al’Hazzaa et al., 2001). Analysing goal-scoring patterns during a CP football tournament, Yanci et al., (2015) observed 59% of goals scored were recorded in the first half of a competitive game. Furthermore, the highest proportions of goals were scored in the first 15 min of play while the lowest number in the final 15 min. With lower aerobic and anaerobic capacities observed in Paralympic footballers, it is reasonable to suggest that fatigue may be contributing to the decline in number of goals scored as match play continues.

Using GPS, data amongst forty Paralympic footballers in eight matches during the 2012 Paralympic Football World Cup were recorded and analysed for total distance travelled (m), frequency of high intensity (s) and very high intensity activity (s), distance travelled at high intensity (4.9 – 6.4 m/s) and very high intensity (> 6.4 m/s) in the four playing classes (FT5-FT8) (Boyd et al., 2016). Results showed FT8 players covered the greatest distances during match play, 811 m more than FT7 players (p = 0.01) and 701 m more than FT5 and FT6 players combined (p = 0.03). In AB soccer, research has identified playing position as a factor in the varied TL recorded in players (Bangsbo, 1994; Di Salvo et al., 2007; Vigne et al., 2010). Midfielders were identified to cover a significantly greater (p < 0.05) total distance compared to all defenders and forwards during match play using multi-camera match analysis (DiSalvo et al., 2007), thus highlighting the positional nature of TL and athlete response. Also using multi-camera match analysis, Vigne et al., (2010) reported midfielders covered a significantly greater total distance than defenders and
forwards (p < 0.01) across 30 matches amongst professional level players. Whilst differences between playing classes have been reported in Paralympic footballers, differences in playing positions have yet to be investigated and is necessary to determine the demands on each player during training and competition. Having determined the hypertonic state of CP to contribute to fatigue levels, the response of Paralympic footballers to a training stimulus must be correctly quantified to ensure prescribed recovery is sufficient and reduce the risk of maladaptation. CP footballers have also been reported to have poorer change of direction ability compared with a control group of AB footballers in performance of modified agility t-test (MAT) and Illinois agility test (IAT) (Reina et al., 2016). Further investigation showed no significant difference between scores for players in FT5, FT6 and FT7 classes in performance of either test whilst those classified as FT8 were observed to have significantly quicker scores in performance of the IAT compared to players in the other three classes (Reina et al., 2016).

Early research of the 2000 Paralympic Games observed that ambulatory athletes such as CP footballers had reported a higher number of lower extremities, non-acute injuries including sprain, strain and contusion during competition whilst upper extremity injuries are more frequent in wheelchair athletes (Ferrara and Peterson, 2000). More recently, Fagher and Lexell (2014), reported injury rates in Paralympic athletes were higher compared to AB athletes. Furthermore, fatigue resulting from muscular hypertonic state may also contribute to injury rates amongst CP footballers. According to a 2016 IOC consensus statement on TL and injury risk, athletes undertaking high TL along with high levels of psychological stress, heavy competition calendars, travel demands and poor management of TL are at an increased risk of injury (Soligard et al., 2016), thus the importance of regular and consistent TL monitoring has been advocated. Halson (2014a) supports the use of regular TL monitoring as an important aspect for athletes to lower the risk of injury and illness occurrence. Recent research exploring the relationship between TL and injury in AB soccer players has identified that rapid increases in TL increase injury risk (OR = 2.33) compared to those maintaining a similar TL each week (Malone et al., 2017), thus supporting the use of athlete TL monitoring in footballers and warrants investigation for use amongst Paralympic footballers.
2.2.2 Paralympic Swimming

There are five individual racing strokes in Paralympic swimming (freestyle, backcrawl, breaststroke, butterfly and individual medley) and numerous team relay races (calculated by points). The sport complies with the International Swimming Federation (FINA) rules with adaptations for disability impairments. Swimmers compete in an Olympic-size 50 m swimming pool at all Paralympic and World level competitions. Competitors may start a race standing or sitting on a diving block before entering the water or may start the race in the water. VI athletes may be tapped on the head or back at each end of the pool using a pole to indicate when the swimmer is approaching the wall and should turn or touch the wall. There are ten physical impairment classes (S1-S10), three VI classes (S11-S13) and one intellectual disability class (S14). The prefix before the sport class number defines the stroke with “S” representing freestyle, butterfly and backstroke events, “SB” representing breaststroke and “SM” for individual medley events. Swimmers are classified according to the table below (Table 2.2) and may compete in a combination of classes, for example S6/SB5 or S6/SB6 depending on their impairment.

A significant proportion of the scientific research into Paralympic swimming has examined the biomechanical demands of strokes and movements including starts and turns with comparison between competitive classes and with AB athletes (Pelayo et al., 1999; Daly et al., 2001; Fulton et al., 2009; Fulton et al., 2010; Burkett et al., 2010; Dingley et al., 2014). A recent review by Dyer and Deans (2017), reported that swimmers with missing limbs show significant biomechanical and physiological differences when compared to AB swimmers. Thus, the importance of investigating the specific responses of Paralympic swimmers becomes even more apparent to ensure positive adaptation to training and ultimately optimised performance.
<table>
<thead>
<tr>
<th>Class</th>
<th>Impairment</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 / SB1</td>
<td>Significant loss of muscle power in legs, arms, hands with limited trunk control. Athletes rely on wheelchair use for daily life.</td>
</tr>
<tr>
<td>S2 / SB1</td>
<td>Limited hand, trunk and leg function. Tetraplegia or co-ordination issues.</td>
</tr>
<tr>
<td>S3 / SB2</td>
<td>Amputations of both arms and legs. No use of legs/trunk or severe co-ordination problems</td>
</tr>
<tr>
<td>S4 / SB3</td>
<td>Use of arms and function in hands with no use of legs or trunk. Amputations/missing of 3 limbs.</td>
</tr>
<tr>
<td>S5 / SB4</td>
<td>Short stature and additional impairments including missing/amputated limbs. Hemiplegic or paraplegic athletes</td>
</tr>
<tr>
<td>S6 / SB5</td>
<td>Short stature. Amputations/missing of both arms. Moderate co-ordination problems on one side of body</td>
</tr>
<tr>
<td>S7 / SB6</td>
<td>Arm and leg amputation or missing on opposite sides. Paralysis on one side of the body affecting arm and leg. Full arm and trunk control but limited leg function</td>
</tr>
<tr>
<td>S8 / SB7</td>
<td>Amputation or missing of one arm. Significant restrictions across hip, knee and ankle joints</td>
</tr>
<tr>
<td>S9 / SB8</td>
<td>Joint restrictions in one leg or amputation small section of arm. Double below-knee amputations or missing lower legs</td>
</tr>
<tr>
<td>S10 / SB9</td>
<td>Minimal physical impairments. Loss of one hand or lower leg</td>
</tr>
<tr>
<td>S11 / SB11</td>
<td>Low visual acuity and/or no light perception. Must wear blackened goggles during competition to ensure fairness. Must use a tapper at each wall for safety</td>
</tr>
<tr>
<td>S12 / SB12</td>
<td>Higher visual acuity than those in the S11/SB11 class. Visual field of less than 5 degrees radius</td>
</tr>
<tr>
<td>S13 / SB13</td>
<td>Least severe visual impairment athletes with highest visual acuity. Visual field of less than 20 degrees radius</td>
</tr>
<tr>
<td>S14 / SB14</td>
<td>Intellectual impairment impacting on pacing ability and reaction times. Higher number of strokes relative to speed vs AB</td>
</tr>
</tbody>
</table>

Investigating the training characteristics of Paralympic swimmers, Fulton et al., (2010) compared the periodised training programs of AB and Paralympic swimmers over a 16-week training block in preparation for competitive performance and
reported similar periodised training patterns in changing training volume and intensity in both groups. Average weekly training distance recorded was 24.6 km with training volume and intensity being disability class dependent, with the researchers concluding that coaches must account for both the disability and class of the Paralympic swimmers as well as the individual response when prescribing training sessions (Fulton et al., 2010). Monitoring eight Paralympic swimmers during a 14-week competition preparation period, Edmonds et al., (2015) reported average weekly training distances of 28-48 km but did not distinguish the distance of the primary competitive events. However, race distances are limited from 50 – 400 m for individual IPC swimming events, therefore athletes are competing in sprint and middle-distance events (IPC, 2016). In comparison, Stewart and Hopkins (2000) reported average weekly training distance of AB swimmers to be 59-62 km per week for those primarily competing in sprint and middle-distance events.

### 2.2.3 Summary

The Paralympic Games represents the highest level of competition for athletes with physical disabilities. Within the Paralympic athletic population, there are unique differences depending on disability which can impact on an athlete’s training and competitive performance. According to Halson (2014a) athletes may require different training stimuli to induce an appropriate response. In order to understand the training and recovery needs of Paralympic athletes, a comprehensive understanding of TL is initially required.

### 2.3 Athlete Monitoring

Athletic training is based on the principle of progressive overload where increased training stressors combined with appropriate recovery are employed to produce a positive training adaptation (Meeusen et al., 2013). A recent IOC consensus statement describes the stress response of athletes from sport along a continuum beginning with homeostasis (Fig. 2) where there is a sufficient balance between TL and recovery, and progressing through states of fatigue, FOR, NFOR, OTS and time-loss illness or injury (Schwellnus et al., 2016).
Proposed by Selye (1936), the GAS model describes three phases as the body adapts to a stress (Fig. 3). The initial response upon application of a stressor is an “alarm phase” resulting in fatigue. With adequate recovery, the body enters the “resistance phase”, during which the system returns to homeostasis and physiological adaptations are made. The third state “supercompensation” refers to the new level the body returns to, having positively adapted to the stressor and results in improved performance ability. However, with very high stressors or with insufficient recovery the body is unable to positively adapt and may enter a phase of overtraining.

Figure 2. Stress response of athletes on a well-being continuum (Schwellnus et al., 2016, page 1045)

Figure 3. Selye's General Adaptation Syndrome (G.A.S). (Hoffman, 2012, page 215)

Where recovery is consistently inadequate, resulting in under-recovery, the risk of injury and illness increases while the training adaptation or competitive performance may plateau or even decrease (Meeusen et al., 2013). A 2006 European consensus
statement defined three stages of overtraining as FOR, NFOR and OTS (Meeusen et al., 2006). FOR is a deliberate short-term period of increased TL aimed to stimulate physiological adaptation which induces a temporary fatigued state in athletes (Meeusen et al., 2006; Lambert and Borresen, 2006). Continued high TL and/or insufficient recovery and where training adaptation or competitive performance may plateau or even decrease following a recovery period is defined as NFOR (Meeusen et al., 2006). During this time, the athlete is also at a higher risk of illness or injury occurrence (Meeusen et al., 2013). According to Meeusen et al., (2013) a single gold-standard diagnosis of NFOR is currently lacking, however symptoms can include performance decrement, physical and psychological fatigue, increased muscle soreness, increased perception of effort and impaired sleep which may continue for a significant period of time. OTS symptoms coincide with those of NFOR and may also include depression, disturbed eating and disturbed hormonal responses in which recovery of performance capacity may take months, years or in extreme cases never return (Meeusen et al., 2006; Meeusen et al., 2013).

As an imbalance between TL and recovery is a major factor in NFOR and OTS, Meeusen et al., (2013), strongly promote self-monitoring through the use of a training diary for each athlete as well as recording daily TL. TL monitoring can be used to measure the individual training stress for each athlete using physiological and psychological variables, ensuring individualisation of training prescription and minimising risk of OTS (Smith and Norris, 2002). The time-frame for recovery and adaptation to return the body to homeostasis varies between athletes and must be individually prescribed as a result (Soligard et al., 2016). A common misconception in sport is the belief that to improve athletic performance one must continually increase TL (Bishop et al., 2008). During a training season an athlete will incur varying degrees of training stress and adaptation. To optimise the balance that exists between training prescription (stress) and subsequent recovery for positive adaptation, athlete training and responses should be adequately monitored (Borresen and Lambert, 2009).
2.3.1 Athlete Monitoring Systems

Kenttä and Hassmén (2002) determined three phases to consider for an athlete monitoring system – the stimulus, the perception of the stimulus and the response to the stimulus. The first phase describes the design of the training stimulus and suggests a correct stimulus can only be attained with consideration for the next two phases. Phase two is an understanding of the magnitude of the training stimulus using objective and subjective measures to fully understand the load on the athlete. Finally, the third phase focuses on how the athlete responds and adapts to the training stimulus (Kenttä and Hassmén, 2002). According to Halson (2014, page 146) the key features of a sustainable athlete monitoring system include:

“ease of use, flexible and adaptable use for different athletes and sports, efficient result reporting, can be accessed remotely, can identify meaningful change simply and efficiently, includes an assessment of cognitive function and can provide both individual and group responses”.

Kellmann (2002) suggests longitudinal athlete monitoring is essential to ensure adequate evaluation of the individual athlete response. A comprehensive understanding of the individual tolerance to training has been suggested to be the most valuable output of accurate TL monitoring (Coutts et al., 2004). In addition, the recent IOC consensus statements suggest that the risk of maladaptation to training can be significantly reduced with consistent athlete monitoring (Soligard et al., 2016; Schwellnus et al., 2016). Furthermore, Kenttä and Hassmén (2002) propose that minimal changes from individual baseline responses can be corrected with minor alterations whilst more long-term changes may indicate poor adaptation and require significant modifications to training. In accordance with the monitoring system described by Kenttä and Hassmén (2002), it is necessary to initially quantify the training stimulus.

2.4 Training Load Monitoring

The 2016 IOC consensus statement (Schwellnus et al., 2016, page 1044) defines load as:
“the sport and non-sport burden (single or multiple physiological, psychological or mechanical stressors) as a stimulus that is applied to a human biological system (including subcellular elements, a single cell, tissues, one or multiple organ systems, or the individual).”

Load has been further categorised as internal or external. Examples of internal and external loads and the measurement tools to monitor are detailed below (table 2.3). According to Mujika (2017) external TL measures alone do not consider the physiological stress of a training stimulus on an athlete, thus a combination of internal and external TL measures should be utilised to fully quantify the training stress (Bourdon et al., 2017).

2.4.1 Heart Rate Monitoring

HR measures are an objective and convenient depiction of internal TL (Burgess, 2017). Changes in HR during exercise correlate with changes in exercise intensity to meet oxygen demands of the working muscles and can be measured quickly and easily using a HR monitor (Karvonen and Vuorimaa, 1988). Measures of HR used in TL monitoring and exercise testing include resting HR, HR in specific training zones and maximal HR (HR_max). Keytel et al., (2005) support the use of HR monitoring as an efficient and economical method to monitor physiological load in multiple athletes during a training session. HR data can be recorded, analysed and a TL calculated using equations such as Banisters training impulse (TRIMP) (Banister, 1991), Edward’s TRIMP (Edwards, 1993) and Lucia’s TRIMP (Lucia et al., 2003). Within team sports HR has been utilised and supported as a tool to monitor TL in AB rugby and soccer (Comyns and Flanagan, 2013; Coutts et al., 2007a; Impellizzeri et al., 2005; Impellizzeri et al., 2004) and in wheelchair basketball (Iturricastillo et al., 2016a) and wheelchair rugby (Paulson et al., 2015).
Table 2.3 Examples of external and internal load and measurement variables (Soligard et al., 2016-page 1032).

<table>
<thead>
<tr>
<th>Load type</th>
<th>Examples of measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>External load</td>
<td>Training or competition time (seconds, minutes, hours, or days)[36]</td>
</tr>
<tr>
<td></td>
<td>Training or competition frequency (e.g., sessions or competitions per day, week, month)[37]</td>
</tr>
<tr>
<td></td>
<td>Type of training or competition[38]</td>
</tr>
<tr>
<td></td>
<td>Time-motion analysis (e.g., global positioning system (GPS) analysis)[39]</td>
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<tr>
<td></td>
<td>Power output, speed, acceleration [40]</td>
</tr>
<tr>
<td></td>
<td>Neuromuscular function (e.g., jump test, isokinetic dynamometry, plyometric push up)[41]</td>
</tr>
<tr>
<td></td>
<td>Movement repetition counts (e.g., pitches, throws, bowls, serves, jumps)[42, 43]</td>
</tr>
<tr>
<td></td>
<td>Distance (e.g., kilometres run, cycled or swam)[44]</td>
</tr>
<tr>
<td></td>
<td>Acute:chronic load ratio[45]</td>
</tr>
<tr>
<td>Internal load</td>
<td>Perception of effort (e.g., rating of perceived exertion, RPE)[46]</td>
</tr>
<tr>
<td></td>
<td>Session rating of perceived effort (e.g., session duration (min) x RPE)[28]</td>
</tr>
<tr>
<td></td>
<td>Psychological inventories (e.g., profile of mood states (POMS)),[47] recovery-stress questionnaire for athletes (REST-Q-Sport),[48] daily analysis of life demands for athletes (DALDA),[49] total recovery scale (TQR),[17] life events survey for collegiate athletes (LESCA),[50] multi-component training distress scale (MTDS),[51] the hassle and uplift scale,[52] brief COPE (Carver, 1997),[53] the Swedish universities scales of personality (SSP),[54] state trait anxiety inventory (STAI),[55] sport anxiety scale (SAS),[56], athletic coping skills inventory-28 (ACSI-28),[57], body consciousness scale,[58] perceived motivational climate in sport questionnaire (PMCSQ),[59] and commitment to exercise scale (CIES)[60]</td>
</tr>
<tr>
<td></td>
<td>Sleep (e.g., sleep quality, sleep duration)[61]</td>
</tr>
<tr>
<td></td>
<td>Biochemical hormonal/immunological assessments[18, 26]</td>
</tr>
<tr>
<td></td>
<td>Psychomotor speed[62]</td>
</tr>
<tr>
<td></td>
<td>Heart rate (HR)[63]</td>
</tr>
<tr>
<td></td>
<td>HR to RPE Ratio[64]</td>
</tr>
<tr>
<td></td>
<td>HR recovery (HRR)[65]</td>
</tr>
<tr>
<td></td>
<td>HR variability (HRV)[66]</td>
</tr>
<tr>
<td></td>
<td>Training impulse (TRIMP)[67]</td>
</tr>
<tr>
<td></td>
<td>Blood lactate concentrations[68]</td>
</tr>
<tr>
<td></td>
<td>Blood lactate to RPE Ratio[69]</td>
</tr>
</tbody>
</table>


The TRIMP method was initially introduced by Banister (1991) to calculate a unit of physical stress for a training session. TRIMP is calculated using training session duration together with resting, average and maximal HR.

\[
TRIMP = \text{time (min)} \times \Delta HR \text{ ratio} \times Y
\]

\[
\Delta HR \text{ ratio} = (HR_{\text{exercise}} - HR_{\text{rest}}) / (HR_{\text{max}} - HR_{\text{rest}})
\]

\[y = 0.64e^{1.92x}\] for males and \[0.86e^{1.67x}\] for females; \[e = 2.712; x = \Delta HR \text{ ratio}\]

Banister’s TRIMP calculates TL based on the mean HR for an interval or total training session but does not have the ability to reflect load during short duration, high-intensity or intermittent exercise (Stagno et al., 2007). Gender based equations assume this is the only differing factor between athletes and is based on a standard lactate curve which does not consider individual differences. The method has since been adapted by other researchers as a means to quantify TL using HR (Edwards, 1993; Lucia et al., 2003; Manzi et al., 2009).

Edwards’ TRIMP (Edwards, 1993) calculates TL using time spent in five pre-defined HR zones multiplied by a coefficient relative to each zone. Although commonly used in software of HR telemetry systems, the zones and coefficients are pre-defined with no consideration of individual physiological thresholds.

\[
Edwards' \ TRIMP = (\text{time in zone 1} \times 1) + (\text{time in zone 2} \times 2) + (\text{time in zone 3} \times 3) + (\text{time in zone 4} \times 4) + (\text{time in zone 5} \times 5)
\]

Zone 1 = 50-60% HR\(_{\text{max}}\); zone 2 = 60-70% HR\(_{\text{max}}\); zone 3 = 70-80% HR\(_{\text{max}}\); zone 4 = 80-90% HR\(_{\text{max}}\); zone 5 = 90-100% HR\(_{\text{max}}\)

Lucia et al., (2003) developed calculation of TL around ventilatory thresholds in cyclists using three zones. Time spent in each zone is multiplied by the relative coefficient.

\[
TRIMP = (\text{time at } <VT_1 \times 1) + (\text{time at } VT_2-VT_1 \times 2) + (\text{time at } >VT_2 \times 3)
\]

\(<VT_1 = \text{low intensity}; \ VT_2-VT_1 = \text{moderate intensity}; \ >VT_2 = \text{high intensity}\)

Impellizzeri et al., (2004) modified Lucia’s TRIMP calculation based on lactate threshold (LT) zones when investigating sRPE in soccer players. Time spent in each
zone (below LT, between LT and anaerobic threshold (AT) and above AT) is multiplied by the relative coefficient and summated.

\[
TRIMP = (time \text{ at } <LT \times 1) + (time \text{ between } LT \text{ and } AT \times 2) + (time \text{ at } >AT \times 3)
\]

Despite being a non-invasive and easily used monitoring tool there are limitations in the ability of HR and HR based equations to accurately quantify internal TL. Using TRIMP methods to quantify TL requires continuous HR readings to calculate average HR during a session or determine the time spent in each HR zone (Borresen and Lambert, 2006). HR based methods have been shown to poorly reflect session intensity during high-intensity training including weight training or plyometric and speed work (Foster et al., 2001; McGuigan and Foster, 2004). Little and Williams (2007) investigated the HR responses in professional soccer players during five commonly used training drills and reported HR to underestimate the workload during the most intensive 2v2 drill with average HR recorded at 89% HR\text{max} compared to 91% HR\text{max} recorded during 3v3 drill. Furthermore, Impellizzeri et al., (2004) reported HR to be limited in its ability to quantify internal TL in soccer particularly during periods of high-intensity movement in competitive games. Data collection may not always be possible in water-based sports and can be easily interrupted with movement of the monitor or recorder (Wallace et al., 2009). Downloading data also requires time and expertise to calculate TL using pre-determined equations.

Heart rate variability (HRV) has also been investigated as a HR based monitoring tool for internal TL amongst athlete populations. As the autonomic nervous system (ANS) interacts with many physiological systems to maintain homeostasis including HR, monitoring its response amongst athletes has been suggested to indicate adaptation to TL (Borresen and Lambert, 2008). HRV is an objective measure and refers to the time between consecutive heart beats (Buchheit, 2014). According to Buchheit (2014), availability of non-invasive, low-cost beat-to-beat telemetry devices and smartphone applications have increased the application of HRV monitoring amongst athletes. Longitudinal monitoring is recommended in order to define and understand the HRV profile unique to each athlete (Plews et al., 2013). Due to high daily variation in HRV data derived from endurance sport athletes, Plews et al., (2013) observed weekly averages or 7-day rolling averages to be more
significantly related to athletic performance. Furthermore, Oliveira et al., (2013) suggest monitoring changes in HRV across a training season can identify individual training adaptations to training as well as early signs of maladaptation. Measurement of HRV requires a highly standardized protocol to ensure consistency in measures including control of posture, sleep and hydration via bladder distention (Thorpe et al., 2015), thus it may not always be feasible as a daily measure for use in athletes. Furthermore, it has been suggested that HR data including HRV can only provide a limited insight into athletic response to training or competition and should therefore be combined with additional parameters (Schneider et al., 2018).

Within a Paralympic athlete population, reliable HR measures may not be possible due to diminished physiological response particularly in athletes with SCI or impairments of the autonomic nervous system (Paulson et al., 2013; Thiesen, 2012). Thus, it is necessary to investigate methods to quantify TL other than using HR which can be applicable to all Paralympic athletes irrespective of sport or disability.

2.4.2 Session Rate of Perceived Exertion (sRPE)

As an alternative approach to the use of HR, Foster et al., (1995) proposed quantifying TL using an athlete’s rating of perceived exertion (RPE) together with the duration of a training session to calculate an arbitrary unit (AU). According to Burgess (2017) sRPE is the most commonly used measure of internal TL in team sport research as it can be used for all forms of training and competition including high-intensity and intermittent training.

\[ \text{Training Load (TL)} = \text{Athlete RPE} \times \text{Session Duration (min)} \]

Using Borg’s category ratio 10 (CR-10) scale (Borg et al., 1985), athletes are asked to rate the intensity of a training session (table 2.4). The total load unit calculated represents the internal load of the athlete. A time delay between the termination of the training session and the sRPE rating is proposed to ensure athletes give a global rating for the training session intensity. Early research recommended 30 min (Foster et al., 2001) with subsequent research proposing readings may be recorded 10-15 min following termination of the training session (Green et al., 2009; Uchida et al.,
Most recently, Christen (2016) indicated post-exercise time does not impact on sRPE.

sRPE has been shown to be a valid method to quantify TL across a wide range of sports when compared to other quantification methods including HR and GPS (Foster et al., 2001; Impellizzeri et al., 2004; Coutts et al., 2007a; Wallace et al., 2009; Minganti et al., 2011; Lupo et al., 2014). According to Borresen and Lambert (2006), sRPE is sufficiently accurate in its ability to measure the difficulty of a training session if HR data is not available or a more practical method is required for quantifying TL. It has also been previously validated for use during high-intensity and intermittent training sessions (Foster et al., 2001) and in resistance training sessions (McGuigan and Foster, 2004), ensuring the same method to quantify TL can be used for all session types.

Table 2.4 The 10-point Rating of Perceived Exertion Scale (Borg et al., 1985)

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Rest</td>
</tr>
<tr>
<td>1</td>
<td>Very, Very Easy</td>
</tr>
<tr>
<td>2</td>
<td>Easy</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>Somewhat Hard</td>
</tr>
<tr>
<td>5</td>
<td>Hard</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Very Hard</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Maximal</td>
</tr>
</tbody>
</table>
2.4.2.1 sRPE variables

Further derivatives can be calculated from daily sRPE scores to provide additional quantification of the TL on the athlete. Training monotony (mean weekly TL / SD weekly TL) reflects the variability in training session intensity throughout a week (Foster et al., 1998). Consecutively, high TL or repetition of the same duration and intensity of training sessions in a training week will result in a high monotony score, whilst variation of high and low session intensities will result in a moderate to low monotony score (Comyns and Flanagan, 2013). According to Foster (1998), low intensity training days should be planned into each training week in order to vary intensities and keep training monotony scores lower. In support of this, Cross et al., (2016) suggested that athletes are more capable to coping with high daily TL once there is a variance in TL intensity each day. High monotony scores (≥ 2.0) have been reported to increase risk of maladaptation and increase injury and illness risk in athletes (Foster et al., 1995). However, to date TL and sRPE variables have yet to be reported longitudinally in Paralympic sports to depict patterns with training and incidence of injury or illness and it is currently unknown what level of training monotony may increase this risk in Paralympic athletes. Training strain (weekly TL x training monotony) represents the total stress perceived by the athlete during a training week. High training strain together with high training monotony can indicate an excessive stimulus while a low strain with high monotony may indicate inadequate training stimulus (Foster, 1998).

The acute:chronic workload ratio (ACWR) proposed by Gabbett (2016) expresses acute TL (average weekly TL) relative to chronic TL (rolling average of weekly TL over the previous four weeks). Recent research supports the use of the ratio as a significant predictor of injury occurrence with a range of 0.8-1.3 considered to minimise injury risk in cricket and soccer (Hulin et al., 2014; Gabbett, 2016; Malone et al., 2017). Carey et al., (2017) have proposed using 3-day acute and 21-day chronic ratio in Australian Rules football, however, the majority of research has conducted in AB team field sport athletes has used an ACWR of 1 week to 4 weeks. Additionally, calculations of two, three and four-week cumulative TL and week-to-week changes have been reported to be associated with increased injury risk (Rogalski et al., 2013) and warrants investigation in Paralympic athletes. Research has shown differences in ACWR ranges from sport to sport, for example Malone et
al., (2017) indicated a range 1.00-1.25 for lowest injury risk in soccer players whilst Hulin et al., (2015) suggested a range 0.85-1.35 in elite rugby league players. Having established differences in training and capacity between AB and Paralympic athletes and differences between ACWR ranges from sport to sport, it would not be appropriate to apply the current research findings to a Paralympic athlete population. Further research is needed to understand the application of ACWR in Paralympic swimming and football and determine if there are sport specific ranges which reduce the risk of injury in these sports.

2.4.2.2 sRPE in football

Impellizzeri et al., (2004) reported moderate to strong correlations (r = 0.5 - 0.85, p < 0.01) between sRPE and HR-based calculations of Banister, Edwards and Lucia TRIMP in quantifying TL in national level soccer players. In elite female soccer players, Alexiou and Coutts (2008) supported the use of sRPE to quantify TL reporting strong correlations (r = 0.83 - 0.85, p < 0.01) between sRPE and three TRIMP calculations. sRPE has been reported to significantly correlate with external measures of TL during training in semi-professional soccer players including total distance covered and player load measured via GPS units (r = 0.74, p < 0.01 and r = 0.76, p < 0.01 respectively) (Casamichana et al., 2012). Amongst professional soccer players, Little and Williams (2007) reported sRPE to be a valid measure of training intensity during soccer training drills compared to HR which was reported to underestimate the workload during periods of very high intensity. A benefit of the sRPE method is its ability to reliably quantify TL during training and competitive play, thus, enabling coaches to monitor multiply training modalities using the same measure (Coutts, 2001). Despite an abundance of literature published amongst AB footballers, the use of sRPE in quantifying TL has yet to be examined in Paralympic footballers.

2.4.2.3 sRPE in water-based sports

sRPE has also been shown to be a reliable method of quantifying TL in water-based sports where HR is not easily collected. Wallace et al., (2009) examined the validity of sRPE in quantifying internal TL in competitive swimmers and reported significant
moderate to strong correlations with Banister TRIMP \( (r = 0.55 - 0.92, p < 0.05) \) and Edwards’ TRIMP \( (r = 0.57 - 0.91, p < 0.05) \) Amongst elite divers, Minganti et al., (2011) reported significant moderate to strong correlations between Edwards’ TRIMP and sRPE \( (r = 0.71 - 0.96, p < 0.01) \) supporting its use for quantifying internal TL in water-based sport. Finally, Lupo et al., (2014) reported a strong correlation between sRPE and Edwards’ TRIMP \( (r = 0.88, p < 0.05) \) in water polo players. Results from this study along with those observed by Wallace et al., (2009) are indicators that sRPE may be a reliable measure to quantify TL in Paralympic swimming but similar to ACWR, requires its own investigation before use. Both studies incorporated both steady state and high-intensity training and reported strong correlations between sRPE and HR measures using TRIMP equations. Distance is commonly used as a criterion measure of external load in swimming. However, research by Wallace et al., (2009) reported wide ranging correlations from poor to very high between sRPE TL and distance \( (r = 0.35 - 0.85) \) across eight swimmers. Distance measures do not account for session intensity and as a result, sRPE has been proposed as a more sensitive measure particularly during high-intensity or intermittent training (Foster et al., 2001). Research has previously reported the average weekly training of Paralympic swimmers to be volume and intensity disability class dependent (Fulton et al., 2010). Given that varying disabilities can compete in the same class, it would seem more suitable for training to be prescribed based on disability. Despite limited research in water sports, the use of sRPE or distance as measures of TL have yet to be examined in Paralympic swimmers.

2.4.2.4 sRPE in Paralympic sports

sRPE has been investigated in two intermittent Paralympic sports of wheelchair rugby and wheelchair basketball. Paulson et al., (2015) reported a large moderate to strong correlation between sRPE and Banisters TRIMP \( (r = 0.62) \), Edwards TRIMP \( (r = 0.64) \) and Lucia’s TRIMP \( (r = 0.81) \) and concluded sRPE is a valid alternative to HR-based methods for low to moderate intensity activity in athletes with impaired HR response. During higher intensity activities in wheelchair rugby players, sRPE was reported to underestimate the external TL in some athletes (Paulson et al., 2015). Amongst national level wheelchair basketballers, Iturricastillo et al., (2016a) reported moderate correlations between sRPE and Edwards TRIMP \( (r = 0.629, p < \)
0.001) and TRIMP_{MOD} (Stagno et al., 2007) \( r = 0.627, p < 0.01 \). sRPE was reported to be a valid, cost effective and practical tool for use amongst trained wheelchair rugby players who were familiar with the CR-10 RPE scale, however large discrepancies were observed between those with and without SCI, with further research necessary (Iturricastillo et al., 2016a). Lewis et al., (2007) reported RPE to be an invalid measure of exercise intensity in those with paraplegia due to the autonomic dysfunction associated with SCI, which has previously been suggested to hinder the accuracy of RPE. Additionally, Iturricastillo et al., (2016b) reported wheelchair basketballers without SCI have similar increases in HR and RPE during small sided games (SSG) and suggested the physiological impairment associated with SCI may prevent the effective use of RPE in those with SCI. Research to date examining the validity of sRPE in Paralympic athletes has reported moderate to strong correlations with HR-based TL calculations in those without SCI (Paulson et al., 2015; Iturricastillo et al., 2016a) and supports further research of sRPE in Paralympic athletic populations.

### 2.4.3 Load Monitoring and Injury/Illness Risk

Athlete TL monitoring has been supported as a significant tool for prevention of NFOR and OTS (Meeusen et al., 2013). Furthermore, regular TL monitoring is an important aspect for athletes to lower risk of NFOR, OTS, injury and illness (Halson, 2014a). According to Engebretsen et al., (2013) both injury and illness can impact on an athlete’s ability to train and compete; therefore, athlete monitoring should focus on the impact of TL on both variables. Furthermore, accurate monitoring of TL and external loads from athletic and life demands has been promoted as essential in defining the relationship between load and illness and injury risk in athletes (Soligard et al., 2016; Schwellnus et al., 2016).

An imbalance between TL and recovery has been suggested to impair immune function in athletes (Bishop and Gleeson, 2009) with athletes undertaking prolonged and intensive exercise resulting in a higher risk of illness and infection (Nieman, 2000). An early study by Foster (1998) in experienced competitive speed-skaters reported a spike in training monotony greater than 2.0 AU was associated with 77% of illness occurrence in experienced athletes while 84% of illnesses could be
explained by a preceding spike in weekly TL. Watson et al., (2016) reported monthly TL to be significantly higher in female youth soccer players preceding illness occurrence and identified weekly TL and monthly TL as significant predictors of illness (OR = 1.5, p = 0.005 and OR = 1.54, p = 0.007 respectively). Piggott et al., (2009) reported 42% of illnesses in Australian AFL footballers were preceded by a spike in TL. Gabbett (2016) suggests limiting increases in weekly TL to 10% or lower depending on the sport and the injury patterns. Despite being examined in field-based team sports, no research has investigated the relationship between illness occurrence and TL in Paralympic footballers. During a four-year study in professional swimmers, Hellard et al., (2015) reported the risk of illness increased 1.10 (95% CI, 1.01-1.19) times for every 10% increase in TL and a 50-70% increase in illness risk during intensive training periods. Literature has shown a difference between the weekly training mileage recorded by Paralympic and AB swimmers but the thresholds for increased illness risk in Paralympic swimmers remain unknown. Soligard et al., (2016) suggests that the limited research in certain sporting populations prevents sport-specific guidelines for load management. Thus, research is needed to fully understand the athletic response of Paralympic athletes to changes in TL and to reduce the risk of illness in order to optimise training response and maximise performance.

Injury risk in athletes has been reported to increase with excessive TL or poor TL management (Soligard et al., 2016), while spikes in TL in athletes undertaking too little training also increases risk (Gabbett, 2016). Based upon this, Gabbett (2016) describes a “training-injury prevention paradox model” which proposes load related injuries can occur with both excessive and inadequate TL (Fig. 4), further supporting the use of a multi-faceted athlete monitoring system for Paralympic athletes.
According to Gabbett’s model, TL prescription may be more indicative of injury than the TL itself with rapid increases in TL increasing injury risk whilst chronic exposure to higher loads can improve injury resilience in athletes and also enhance performance (Gabbett, 2016). Furthermore, exposure to a spike in increased TL without accumulating sufficient chronic TL increases injury risk particularly in field-based sports like Australian Rules football (Stares et al., 2018). Amongst Australian Rules footballers, Vuegelers et al., (2016) reported players with weekly TL (≥ 3519 AU) were at a lower risk for injury (OR = 0.19) compared to those who recorded lower TL (≤ 3518 AU). Malone et al., (2017) observed elite Gaelic footballers who recorded a chronic TL (≥ 4750 AU) were at a lower risk of injury during maximal velocity sprints (OR = 0.22) compared to those with a lower chronic TL (≤ 4570 AU, OR = 1.44). It is reasonable to consider that the thresholds suggested by Vuegelers et al., (2016) and Malone et al., (2017) associated with lower injury risk may be representative of game intensity and load, thus players not achieving recommended weekly TL levels may be training at too low an intensity prior to match play. While research has previously demonstrated rapid increases in TL to increase injury risk in athletes (Malone et al., 2016; Fünten et al., 2014), the protective effect of higher
chronic workloads must be considered by coaches. Despite the numerous studies examining the impact of acute and chronic TL on injury risk in athletes, research has yet to report the relationship between TL and injury amongst Paralympic athletes.

The 2016 IOC consensus statement on TL and injury risk reported athletes undertaking high TL combined with high psychological stress, demanding competition calendars, travel demands and poor TL management are at a higher risk of injury (Soligard et al., 2016). Malone et al., (2017) reported elite AB soccer players who recorded weekly TL exceeding 3200 AU were at a higher risk of injury (OR = 2.33) than those maintaining weekly TL of 2120-3200 AU. It must be considered the difference in weekly TL amongst players may be related to training intensity as TL was quantified using sRPE, thus those training at a higher intensity were more prepared for the intensity of match play. Along with rapid increases in TL, spikes in ACWR have also been associated with increased injury risk particularly in team sports (Soligard et al., 2016; Malone et al., 2017; Carey et al., 2017). Additionally, increased injury risk has been reported amongst athletes undertaking insufficient TL (Gabbett, 2016), further demonstrating a need to quantify TL in Paralympic athletes. This literature review has established differences between Paralympic and AB athletes relative to aerobic capacity, anaerobic capacity and power as well as specific sport demands preventing any application of TL guidelines to Paralympic sports in a bid to reduce injury risk. Within Paralympic sport itself, the IPC London 2012 injury surveillance study identified large differences in injury occurrence across sports during competition and highlighted the necessity for future studies in Paralympic athletes to be both longitudinal and sport specific (Webborn and Emery, 2014).

2.4.4 Summary

Quantifying TL may involve the use of multiple measures of external and internal TL. Objective data whilst devoid of athlete subjective perception of training stress may not be suitable to certain sports due to a range of factors. In swimming, distance measures were reported to be a poor method of evaluating TL during high-intensity training whilst HR data can be easily interrupted with movement of the monitor (Wallace et al., 2009). Furthermore, within a Paralympic athlete population, reliable
HR measures can be hindered with diminished physiological response in athletes with SCI or impairments of the autonomic nervous system (Paulson et al., 2013; Thiesen, 2012). In contrast, sRPE has been proposed as a valid and simple method of monitoring internal TL (Lovell et al., 2013) and can be applied to all Paralympic athletes without the need for additional collection of HR data. Furthermore, it has shown to be valid for use in water-based sports (Wallace et al., 2009; Minganti et al., 2011; Lupo et al., 2013). To fully quantify TL, it is necessary to understand the individual athlete response (Halson, 2014a). Given that a single, consistent marker to accurately monitoring both training and recovery responses has yet to be identified (Kenttä et al., 2006), a combination of measures should be examined and utilised for a multi-faceted athlete monitoring system for Paralympic athletes.

2.5 Subjective Wellness Markers

Subjective wellness markers of internal training response including wellness, sleep, fatigue and mood in conjunction with objective measures of TL can provide a comprehensive understanding of the individual athletic response and recovery to a training stimulus (Halson, 2014a). Measures including non-training stress, fatigue, general well-being and physical recovery have been reported to respond acutely to athlete well-being and may help identify athletes at risk of negative training responses including NFOR and OTS more effectively than physiological measures (Saw et al., 2015). Sleep, muscle soreness and stress recorded daily in an athlete log have also been shown to correlate with scores of fatigue and staleness particularly evident later into a competitive season (Hooper et al., 1995). Subjective wellness markers have been supported as a simple, low cost, non-invasive yet informative measure of monitoring TL and may assist in early detection of athletes negatively responding to training (Meeusen et al., 2013). Furthermore, Coutts et al., (2007b) suggested subjective wellness markers may show negative athletic response to TL before any objective measures with markers including stress, wellness, mood and fatigue consistently showing a dose-response with TL (Meeusen et al., 2013). Disturbed mood states have been shown to increase athlete RPE at specific training intensities as well as impact on training and competitive performance (Morgan et al., 1987). A recent meta-analysis reported psychological stress response to be strongly associated with injury rates in athletes (Ivarsson et al., 2017), highlighting the
importance of subjective wellness markers in monitoring the athlete response to training. Furthermore, the IOC consensus statement on illness and TL in athletes’ advocates monitoring and managing subjective and objective measures of load to maintain healthy immunity status as no single method alone can eliminate illness risk (Schwellnus et al., 2016).

Questionnaires measuring changes in mood state and psychological stress have been previously established for use amongst athletic populations including POMS (McNair, Lorr and Droppleman (1971), DALDA (Rushall, 1990) and RESTQ-Sport (Kellmann and Kallus, 2001). A limitation of the use of the above questionnaires is the appreciable amount of time needed to complete each day, thus they may not be suitable for use in longitudinal athlete monitoring (Thorpe et al., 2017). A study by Taylor et al., (2012) reported the most popular self-report athlete monitoring questionnaires used in New Zealand and Australian high-performance sport were custom designed. Subjective wellness markers are measured on Likert point scales ranging from 1-5 or 1-10 with 4-12 variables per questionnaire (Taylor et al., 2012). Saw et al., (2015) recommends subjective wellness monitoring tools should be designed to provide “quality, meaningful data”, whilst Burgess (2017) suggests the use of custom-designed questionnaires are specific and relevant to each sporting population and be supported by other objective measures of internal TL such as salivary and blood markers.

2.5.1 Sleep

Sleep is considered a critical element for overall well-being and in aiding both physical and psychological recovery from training (Kellmann et al., 2018). Halson (2014a) recommends the regular monitoring of both sleep duration and sleep quality to aid early detection of performance or health impairment. Poor sleep quality has previously been identified by Meeusen et al., (2013) as a marker of poor recovery and an early sign of NFOR. Sleep quality, duration and phase of sleep have been identified as key aspects which impact on the restorative ability of sleep (Samuels, 2008); therefore, inclusion of both sleep quality and duration in athlete monitoring provides further insight into athlete sleep than sleep duration alone. Sargent et al., (2014) observed a significant effect (p = 0.02) of sleep duration on pre-training
fatigue when examining the sleep patterns of 70 elite athletes across a range of sports during a 2-week period of normal training, thus emphasising the need for daily sleep monitoring during all periods of the training season. Using a five-point Likert scale for wellness measures including sleep quality, Buccheit et al., (2013) reported daily variations in TL in elite AB footballers had a significant impact on wellness measures (CV = 6-18%, p < 0.01). In elite synchronized swimming, Schaal et al., (2015) reported significant reductions in both sleep quantity and quality, increased fatigue and impaired performance during a period of FOR. This research reported changes in sleep quality and quantity during periods of heavy training in elite athletes; however, they have been conducted over brief durations with no study reporting the response of sleep longitudinally across multiple seasons. Research has also observed changes in sleep quality in athletes during training camps compared to data recorded at home (Pitchford et al., 2017). Given that athletes are required to travel for both training camp and competition, it emphasises the importance of monitoring sleep daily for inclusion in an athlete monitoring system.

A number of methods have been utilised to measure sleep both objectively and subjectively. The gold standard for sleep measurement is polysomnography (PSG), a lab-based technique which collects all aspects of sleep measurement including brain waves, blood oxygenation, HR, breathing as well as eye and leg movements (Halson, 2014b). However, this is a laboratory-based test, conducted in a sleep laboratory, thereby removing the athlete from their natural sleeping environment and cannot be used as a daily monitoring tool. In studies involving measurement of sleep in athletes, the use of wrist actigraphy has been more commonly adopted in studies due to its non-invasive data collection in comparison to the gold standard (Halson, 2014b). Utilising actigraphy, objective sleep measures including sleep onset latency, total sleep time and sleep efficiency can be recorded. Weiss et al., (2010) reported strong to very strong correlations between three wrist actigraph devices and PSG (r = 0.72 - 0.82, p < 0.01) supporting their validity in measuring sleep variables. Marino et al., (2013) also reported very strong correlations between two wrist actigraph devices and PSG (0.86 - 0.92, p <0.01) further supporting their use. However, both studies were conducted over brief periods of time and with each device requiring time to download and analyse data, the use of actigraphs may not be suitable on a daily basis in athlete monitoring. Sargent et al., (2015) suggests using wrist
actigraphs for measuring sleep as a practical and non-invasive method in athlete populations, whilst, sleep diaries and questionnaires can also be used to record all sleeping periods throughout the day (Halson, 2014b). Whilst actigraphy has been shown to be a valid objective measure of sleep data, it requires downloading and analysis of sleep data which could prevent its inclusion in a daily athlete monitoring system. Sleep diaries and questionnaires can be utilised in athlete monitoring as a subjective measure. Commonly used sleep questionnaires include The Pittsburgh Sleep Quality Index (PSQI), a 19-item questionnaire which analyses sleep quality, duration, efficiency, disturbance, sleep medications and daytime dysfunction (Buysse et al., 1989) and the Epworth Sleepiness Scale measures an excess of sleepiness with individuals rating how likely they are to fall asleep in eight scenarios (Johns, 1991). More recently, Samuels et al., (2016) have proposed the Athlete Sleep Screening Questionnaire, a 15-item questionnaire selected from existing sleep tools designed specifically for athletes. However, similar to the mood questionnaires, the length of time required to complete daily would eliminate their inclusion in an athlete monitoring system.

Due to their ease of use and low-cost implementation, sleep diaries have been extensively used in research (Kawada and Suzuki, 2002). According to Halson (2014a), recording sleep duration and perceived sleep quality can be a simple but effective subjective tool in monitoring the athletic response to training which can be completed daily and included in an athlete monitoring system. Furthermore, training has been suggested to influence the sleep and waking patterns of elite athletes (Sargent et al., 2014) and therefore may be specific to each sporting population. More recently, Caia et al., (2017) examined the relationship between sleep via activity monitor and self-recorded sleep using a 1-10 Likert scale and reported a high positive correlation ($r = 0.85$, $p < 0.05$). While this study was conducted amongst a team of professional rugby league players, it does support the use of subjective measures to monitor sleep in individual athletes and warrants further research in Paralympic athletes. Sleep disturbances due to late training or competition were reported by Juliff, Halson and Peiffer (2015) from a cohort of 283 elite individual and team sport athletes using the PSQI and the Competitive Sport and Sleep Questionnaire (Erlacher et al., 2011) before and after the 2012 Olympic Games. Rodrigues et al., (2015) measured sleep, mood and depression in Paralympic track
and field athletes on three occasions over a training season using the PSQI and reported an increase in sleep duration prior to competition compared to data recorded at the beginning of the season. Whilst providing an insight into the sleep patterns of Paralympic athletes, this study only examined sleep data on three occasions across a training season. Longitudinal monitoring in a Paralympic athlete population will determine individual sleep patterns in each sport and ensure disruptions, which may indicate sub-optimal recovery can be identified and flagged as potentially adverse responses to a training stimulus.

2.5.2 Mood and Stress

According to Kenttä et al., (2006) monitoring mood state in athletes can assist in depicting the individual athlete response to TL. Increased TL and fatigue have been associated with mood disturbances, with monitoring recommended to identify optimum pre-training and pre-performance mood states (Beedie et al., 2000). Furthermore, changes in ratings of mood disturbance together with disrupted sleep and increased fatigue have been identified as early signs of poor recovery in athletes (Meeusen et al., 2006; Meeusen et al., 2013). An early study by Morgan et al., (1987) reported a dose-response relationship between TL and mood state, in competitive AB swimmers with increases in TL resulting in disturbances in athlete mood state which then returned to baseline levels as TL decreased. Using the POMS questionnaire, Tobar (2012) reported a dose-response relationship between training volume and mood states in collegiate swimmers with high scores reported for depression, anger, fatigue and mood and lower scores for vigour during peak training with improvement in scores with reduced training volume during taper.

A critique of the POMS questionnaire has been its limited focus on mood and therefore an inability to provide detail on recovery which Kellmann and Kallus (2001) argue may prevent it from correctly identifying a NFOR or OTS state. In response, Kellmann and Kallus (2001) proposed the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport), designed specifically to measure recovery-stress states in athletes. The 76 components of the RESTQ-Sport measure the frequency of stress using ten subscales and the subsequent recovery activities using nine subscales to produce three main scores – REST-Q total, global recovery and global stress.
González-Boto et al., (2008) reported significantly (p < 0.05) decreased REST-Q total and global recovery scores with increased global stress score in response to increased TL during a 6-week training block in swimmers. The research was conducted over a 6-week block but only four measures of RESTQ-Sport were taken during this time. Therefore, it is unknown how sensitive the questionnaire may be day-to-day in assessing stress scores. REST-Q Sport has been utilised in a range of sports including football (Meister et al., 2013), cycling (Halson et al., 2014c), triathlon (Hough et al., 2015) and swimming (González-Boto et al., 2008), however studies have been of short duration thus allowing for an in-depth questionnaire to be recorded which would not be possible during longitudinal studies. Despite its development for use in an athletic population, the length of RESTQ-Sport and time required to complete would discourage inclusion from a longitudinal athlete monitoring system.

The Daily Analyses of Life Demands of Athletes (DALDA) proposed by Rushall (1990), measures both training and non-training stressors along with other symptoms of stress using a 34-component questionnaire to calculate a total stress score. Using DALDA to monitor changes in fatigue and recovery in triathletes, Coutts et al., (2007b) reported athletes completing four weeks of intensive training reported a significantly greater (p = 0.031) number of “worse than normal” DALDA responses during week 4 in comparison to athletes completing a normal training programme. A subsequent reduction in TL during a two-week taper saw a significant (p = 0.028) reduction in the number of “worse than normal” responses in the same intensive training group demonstrating the capability of DALDA to respond to changes in TL. Similarly, to the work investigating RESTQ-Sport, it is worth noting that this research was conducted over an acute period of time and although data was collected daily during this time, a 34-component questionnaire may be deemed too cumbersome for daily completion and compliance over seasons of training. Several studies have shown the POMS, RESTQ-Sport and DALDA questionnaires to be responsive to changes in TL in athletes (Tobar, 2012; Morgan et al., 1987; Coutts et al., 2007b; González-Boto et al., 2008). However, a significant amount of research has focused on the impact of such questionnaires during short periods of intensified training followed by a reduction in TL, with few studies examining their longitudinal impact in response to normal training demands of athletes. According to Kellmann
Longitudinal athlete monitoring is essential to ensure adequate evaluation of the individual athlete response. Furthermore, previous research has failed to investigate their use within a Paralympic sport domain, which with a range of disabilities requires a more in-depth understanding of the stress response to training and competition.

### 2.5.3 Self-reported Perceived Wellness

In order to ensure compliance for daily longitudinal monitoring it is critical for data measures to be quick and easy to complete. Shearer et al., (2015) observed that subjective wellness scales should take less than 1 min to complete in order to ensure long-term adherence. Furthermore, Sawczuk et al., (2018) suggest self-report measure questionnaires are widespread in professional sport due to their inexpensiveness, time efficiency and ease of analysis. Following the findings of Taylor et al., (2012) and the use of custom designed subjective wellness questionnaires in high performance sport, Gastin et al., (2013) assessed the validity of a physical and psychological wellness monitoring system in elite Australian footballers using an analogue scale. Players were asked to rate scores for fatigue, muscle soreness, leg pain, sleep quality, stress and overall well-being on a 1-5 scale with wellness scores significantly improved (p < 0.05) during a lower TL week across the season while sleep quality was significantly lower (p < 0.05) following high TL periods including competitive matches (Gastin et al., 2013). Amongst professional level soccer players, scores for perceived fatigue, sleep quality and muscle soreness assessed using 1-7 scale were reported to be 40% lower following match play (p < 0.01) when sRPE TL was 600 AU greater than total TL on training days (Thorpe et al., 2016). Subjective wellness scores have also been shown to respond to changes in objective TL variables measured via GPS in professional level soccer players (Thorpe et al., 2015) where a significant negative correlation was observed between total high-intensity running distance (>14.4 km/h) and scores for perceived fatigue (r = -0.51, p < 0.01) measured using a 1-7 Likert scale. However, this research was only conducted over a period of 17 days and while it demonstrates a response of subjective scores to changes in TL, further research is needed exploring longitudinal responses across a training season.
2.5.4 Summary

The research above has demonstrated and evaluated the role and efficacy of subjective wellness markers in athlete monitoring. Decreases in mood measured via POMS in response to increases in TL have been observed (Morgan et al., 1987; Tobar, 2012) whilst changes in stress scores measured using RESTQ-Sport in response to increased TL were also reported (González-Boto et al., 2008). However, a significant amount of research has focused on the impact of such questionnaires during short periods of intensified training followed by a reduction in TL, with few studies examining their longitudinal impact in response to normal training demands of athletes. Given the duration of time required to complete questionnaires including POMS, RESTQ-Sport, and DALDA, more recent research has supported the use of concise analogue scales in depicting the individual response to training and recovery (Thorpe et al., 2016; Gastin et al., 2013). Self-reported perceived wellness measures including fatigue, sleep and muscle soreness have been shown to be sensitive to changes in TL (Thorpe et al., 2016; Thorpe et al., 2015; Gastin et al., 2013). The suitability of these concise scales ensures application and compliance on a daily basis and may assist in identifying patterns of response which may be sport specific (Halson, 2014a). According to Kellmann (2002), longitudinal athlete monitoring is essential to ensure adequate evaluation of the individual athlete response. Furthermore, previous research has failed to investigate their use within a Paralympic sport domain, which with a range of disabilities requires a more in-depth understanding of the stress response to training and competition.

2.6 Salivary Biomarkers of Fatigue and Recovery

Research continues to investigate the imbalance between training and recovery and the subsequent impact on the immune function of athletes (Bishop and Gleeson, 2009). The IOC consensus statement on TL and illness in athletes emphasises that research has failed to examine longitudinal routine measurement of immune system markers including salivary biomarkers. Furthermore, it recommends further research is necessary to determine their use for reducing this risk of illness in athletes (Schwellnus et al., 2016). Salivary biomarkers are easily accessible and can be
measured quickly and repeatedly in both lab and field settings (Papacosta and Nassis, 2011). Thus, they have emerged as a popular monitoring tool in athletic populations due to the ease of use and non-invasive method of sample collection.

Saliva contains both immunity and stress biomarkers including salivary immunoglobulin A (sIgA), salivary alpha-amylase (sAA) and salivary cortisol, all of which have been shown to respond to training and competition stress in athletes. Regular monitoring of controlled resting levels of salivary biomarkers has been recommended to determine individual reference data as variations within and between subject groups imply that the stress response to TL, competition and additional external stressors is highly individual (Neville et al., 2008). Furthermore, the emergence of a validated point of care test for sIgA, sAA and salivary cortisol has allowed for quick analysis of salivary biomarkers (Edmonds et al., 2015). The IPRO (Soma Bioscience, Wallingford, UK) oral fluid collector (OFC) has been validated against the gold standard Enzyme-linked Immunosorbent Assay (ELISA) method for analysing measures of sIgA, sAA and salivary cortisol (Coad et al., 2015; Dunbar et al., 2015; Dunbar et al., 2013). Coad et al., (2015) reported a very strong correlation \( (r = 0.93, p < 0.01) \) between IPRO and ELISA analysis amongst professional level soccer players supporting the validity of the device in measuring sIgA. Further analysis reported a strong reliability \( (r = 0.89, p < 0.01) \) through comparison of two saliva samples collected concurrently (Coad et al., 2015). Strong correlations were also reported between IPRO and ELISA analysis for measuring sAA \( (r = 0.87, p < 0.05) \) (Dunbar et al., 2015) and salivary cortisol \( (r = 0.79, p < 0.01) \) (Dunbar et al., 2013) in elite level footballers.

Nieman (1994), first described the relationship model between exercise and susceptibility to an upper respiratory tract infection (URTI) as a J-shaped curve (Fig. 5) where regular moderate intensity exercise can decrease relative illness risk but prolonged high-intensity or strenuous exercise is associated with an above-average relative risk. A suppressed immune function is more prominent following prolonged continuous exercise at a moderate to high intensity, a level at which most elite athletes would usually train (Nieman, 1994). According to Nieman (2000), this depression in immune function can last up to 72 hours post exercise and has been described as an “open window” where athletes who are training and competing continually are at an increased risk of infection.
Figure 5. The J-shaped model relationship between risk of upper respiratory tract infection (URTI) and exercise volume. Extracted from Nieman (1994)

The mucosal immune system is the biggest immune component in the body, promoting the release of immunoglobulins to defend the body from viruses and bacteria (Neville et al., 2008). sIgA has a primary role in defence against infection of the upper respiratory tract and has been established as a reliable biomarker for identifying risk of infection in elite athletes (Neville et al., 2008). Furthermore, changes in sIgA levels may reflect physiological and psychological stress in athletes when monitored over time. Previous research has reported an inverse relationship between sIgA and incidence of illness in athletes (Gleeson et al., 1999), while changes in sIgA levels may also indicate periods of excessive training or inadequate recovery (Libicz et al., 2006). Longitudinal studies amongst elite endurance athletes have shown sIgA levels to decrease in response to increases in volume and duration of training with a decline appearing to contribute to the increase risk of illness in athletes (Neville et al., 2008).

Salivary alpha-amylase (sAA) produced in the salivary glands has been shown to be a reliable indicator of the response of the sympathetic nervous system to exercise (Chennaoui et al., 2016). This response appears to peak rapidly at the onset of a stressor before returning to baseline levels 30-60 minutes later (Kivlighan and Granger, 2006) and this acute response has been associated with both physical and psychological stressors (Chatterton et al., 1996). Changes in sAA levels in response
to increases in TL have been reported in national level swimmers (Diaz et al., 2013) and Paralympic swimmers (Edmonds et al., 2015). The hypothalamic-pituitary-adrenal (HPA) axis is a self-regulated system designed to maintain homeostasis in the body and can be impacted by multiple factors including circadian rhythms and psychological stress (Tomas et al., 2013). A stress response can also be elicited from the strenuous exercise completed daily as part of an athletic training programme, activating the HPA axis and resulting in increases in cortisol (Paccotti et al., 2005). Thus, research has examined the response of cortisol to training and competition in athletes. Cortisol is the major glucocorticoid secreted by the adrenal cortex in response to physical or psychological stress, and salivary cortisol can provide a reference for cortisol levels in the blood with research showing more pronounced changes in saliva in response to exercise (Papacosta and Nassis, 2011). Cortisol levels have been shown to increase with TL in swimmers (O’Connor et al., 1989), while in rugby union players increases were observed following an international level game and remained elevated above pre-game levels fourteen hours later (Cunniffe et al., 2010). Regular monitoring of controlled resting levels of salivary biomarkers has been recommended to determine individual reference data as variations within and between subject groups implies that the stress response to TL, competition and additional external stressors is highly individual (Neville et al., 2008).

2.6.1 Salivary Immunoglobulin A (sIgA)

sIgA is the predominant immunoglobulin secreted at mucosal surfaces, found in body fluids including tears, sweat and breast milk. It exists as two subclasses – sIgA 1 and sIgA 2. It provides an immunological barrier by neutralizing and preventing viral pathogens from penetrating the body through the mucosal surfaces hence representing the body’s first line of defence against upper respiratory tract infections (URTI) (Schroeder and Cavacine, 2010), commonly reported in athletes. According to Tiollier et al., (2005) monitoring immune function through sIgA provides a marker of the athletic response to training and recovery. Research suggests that athletes undertaking intensive and prolonged training are at a higher risk for URTI (Nieman, 2000). In a study assessing sIgA and illness in elite swimmers during a seven-month training period, Gleeson et al., (1999) reported the median
concentration of monthly measures of slgA to be significantly lower in athletes who reported with higher incidence of URTI ($r_s = -0.51, p = 0.01$). During a 20-day competition in national level youth soccer players, Mortatti et al., (2012) reported a significant moderate correlation ($r = -0.65, p < 0.05$) between slgA levels and reported incidence of URTI. However, this was a short duration study across a competition period with further longitudinal investigation warranted. In contrast, Neville et al., (2008) reported no relationship between weekly slgA levels and URTI incidence in sailors across a 50-week observational period; although drops below 40% of mean healthy slgA levels were associated with an increased risk of contracting an URTI within three weeks (Neville et al., 2008). Similarly, Moreira et al., (2008) reported no association between levels of slgA and incidence of illness in national level basketball players across a 17-day training camp. However, saliva samples were only taken 1 day before and 1 day after the training camp which may have skewed results related to changes in TL.

Changes in slgA may also be used to indicate periods of excessive training or inadequate recovery. Libicz et al., (2006) reported a decrease of 51.9% in morning slgA levels ($p < 0.05$) in elite triathletes during repeated races whilst completing the 2001 French Iron Tour. It was concluded that repeated performance of intense exercise required during triathlon racing had a cumulative negative effect on resting levels of slgA. A significant negative correlation ($r = -0.59, p < 0.05$) between higher training intensities and slgA levels was reported in elite soccer players by Owen et al., (2016). Results also showed slgA levels were lowest during high training intensity compared to low training intensity (-46.6%, $p < 0.05$) during the fourth period of training, suggesting repeated exposure to higher intensity TL can attribute to increased fatigue and immune suppression. Based on the above data it was recommended that routine monitoring of internal and external TL and slgA levels would provide coaches with a better understanding of the athlete response during periods of high intensity training when the risk of illness is greater (Owen et al., 2016). Moreira et al., (2014) examined slgA levels and URTI during a 21-week competitive season in young soccer players with four specific sampling points identified - pre-season training, competitive play and twice during a 2-week detraining phase. Results showed a significant increase in slgA ($p < 0.05$) post detraining phase coinciding with a decrease in any URTI symptom scores reported.
However, TL values across the period were not reported, therefore changes in TL are assumed given the period during the competitive season but is not supported with quantified measures.

Based on the findings from the above research, it can be concluded that a short reduction in training, thus an increase in recovery periods can have beneficial effect on mucosal immunity and reduce relative risk of URTI in athletes. Furthermore, in a study investigating high school basketball players, Tharp (1991) reported a 25.1 µg.ml⁻¹ increase in mean sIgA levels across a season and suggested chronic training with adequate recovery may result in increases in resting sIgA levels and further reduce illness risk. Gleeson and Walsh (2012) report moderate exercise can in fact increase sIgA concentrations thus reducing the risk of URTI. Research supporting the use of sIgA as a marker in athlete monitoring recommends data to be collected across a training season to establish normative values and trends (Mortatti et al., 2012). Whilst sIgA can be used to identify periods of immune deficiency, this is just one component and it is therefore imperative to monitor other stress biomarkers to fully understand the athletic response to training and competition demands.

2.6.2 Salivary Alpha-amylase

Salivary alpha-amylase (sAA) release is facilitated by the autonomic nervous system and has been shown to be a reliable indicator of the adrenergic response to exercise (Chennaoui et al., 2016). Produced in the salivary glands, it has been reported to be more sensitive to exercise-induced stress than cortisol as it does not require transport from the blood to saliva (Rohleder and Nater, 2009). Increases in sAA peak quickly following the onset of a stressor, returning to baseline levels within 60 minutes after the stressor has been terminated mirroring the response of the sympathetic nervous system (Ali and Pruessner, 2012). Chatterton et al., (1996) reported sAA levels to rise in response to both physical and psychological stressors, with changes only significant when the stressors are high enough to induce a stress response from the body. According to Koibuchi and Suzuki (2014), increases in sAA secretion are more pronounced at exercise intensities greater than 70% \( \dot{V}O_{2\text{max}} \).

A study by Chatterton et al., (1996) examined the immediate response of sAA to physical and psychological stress using a final college examination group and a 20
min run group to induce stress responses alongside a control group. sAA levels were significantly higher in the exercise and exam protocol groups compared to the control group whilst in the exercise group baseline and post exercise levels of sAA were significantly higher. Amongst elite swimmers, Diaz et al., (2013) examined the response of sAA to changes in TL with monthly saliva measures during a 21-week training period and reported a significantly negative correlation ($r = -0.65$, $p < 0.05$). Furthermore, a strong negative correlation ($r = -0.78$, $p < 0.05$) was also reported between sAA and TL intensity measured via blood lactate concentrations (Diaz et al., 2013), further demonstrating the response of sAA to oscillations in TL and intensity. During a 14-week study amongst elite Paralympic swimmers, Edmonds et al., (2015) monitored weekly salivary measures and resting HR, reporting a moderate positive correlation between sAA and HR ($r_s = 0.309$, $p < 0.05$) following a national level competition, indicating an induced stress response due to repeated high-intensity efforts required during a 3-day competition. TL during this study was recorded by the coach solely as distance with no quantified TL reported despite being a longitudinal study across 17-weeks. In a follow-up study in the same athlete group, an increased stress response indicated by elevated sAA levels following competition remained even after a light training session with authors highlighting a requirement for increased recovery with competition performance before sAA returned to baseline levels (Edmonds et al., 2016).

Studies have shown an immediate response of sAA to physiological and psychological stressors (Chatterton et al., 1996). Research has focused on short-term exercise responses with little examination of the longitudinal response to training and competition. Research in swimming has observed elevated sAA levels in response to increases in TL and training intensity as well as competition (Diaz et al., 2013; Edmonds et al., 2015; Edmonds et al., 2016). As a biomarker of the sympathetic nervous system, sAA reacts rapidly to the onset of a stressor and in conjunction with subjective mood and stress scores could provide a reliable indicator of exercise-induced psychological stress response (Papacosta and Nassis, 2011). Given that sAA can be monitored easily and non-invasively in saliva and it is an indicator of stress response, it warrants inclusion as one of three salivary biomarkers to understand the response of Paralympic athletes to training.
2.6.3 Salivary Cortisol

Salivary cortisol has been extensively researched as an indicator of training stress (O’Connor et al., 1989; Alix-Sy et al., 2008; Cunniffe et al., 2010; Moreira et al., 2013). Secreted by the adrenal cortex in response to physical or psychological stress, its primary function is to increase glucose concentration to ensure adequate energy availability for the body. Salivary cortisol can provide a reference for cortisol levels in the blood with studies showing changes in levels are more pronounced in salivary measures in response to exercise (Papacosta and Nassis, 2011). It is therefore suitable for athlete monitoring as it can be measured non-invasively. As a stress response marker, cortisol will sharply increase at the onset of high intensity training and continue slowly to rise, however in athletic populations this response may be reduced as an adaptation to chronic training (Fry and Hoffman, 2008).

A study of by O’Connor et al., (1989) examined salivary cortisol levels with POMS questionnaire in collegiate swimmers during a 2-month period and reported a significant moderate correlation (r = 0.50, p < 0.05) between salivary cortisol and depressed mood state during a period of overtraining. Furthermore, salivary cortisol levels were significantly greater (p < 0.01) during the overtraining period compared to a taper period (O’Connor et al., 1989), demonstrating the response of salivary cortisol to changes in TL. In response to competition, Alix-Sy et al., (2008) reported increases ranging 166-200% in salivary cortisol levels compared to baseline (p < 0.01) in elite soccer players before commencement of three different competitive games. During a 4-week period in a competitive season amongst elite Futsal players, Moreira et al., (2013) monitored the weekly responses of salivary cortisol and sIgA to changes in sRPE TL and reported no significant changes in salivary cortisol levels. No baseline period was established for salivary cortisol levels prior to the commencement of the short-term study period which may have limited the response to changes in TL during this time. Thorpe and Sunderland (2012), observed that monitoring biomarker responses over a season must take account of factors outside of TL including nutrition, recovery strategies and seasonal variations which may impact on salivary cortisol levels, thus providing explanation for varying results reported in studies amongst athletic populations.
2.6.4 Summary

Research has shown immune and stress biomarkers to respond to increases in training and competition stress (Alix-Sy et al., 2008; Mortatti et al., 2012; Diaz et al., 2013; Edmonds et al., 2016; Owen et al., 2016). Contrasting results have also been reported with sIgA and salivary cortisol showing no change with increasing TL (Moreira et al., 2008; Neville et al., 2008; Moreira et al., 2013), however studies have reported varied methods of salivary sampling procedures, quantification of TL and periods of training which may contribute to the contrasting results observed. Given the sensitivity of immune function to physiological and psychological stressors, immune biomarkers such as sIgA may assist in the monitoring of athletic response to demands of training and competition (Gleeson and Robson-Ansley, 2005). Additionally, monitoring of salivary biomarkers has been suggested as one recommended measure in the IOC consensus papers on TL and injury and illness (Schwellnus et al., 2016; Soligard et al., 2016). Unfortunately, no gold standard or single salivary biomarker has as yet been identified for monitoring athlete responses and adaptations to training therefore the measurement of several biomarkers is recommended (Palacios et al., 2015). Athletic stress responses can also be attributed to competition where increased physiological and psychological stress can negatively impact on mucosal immunity (Mortatti et al., 2012). sAA has been shown to be a reliable indicator of the adrenergic response to exercise (Chennaoui et al., 2016), thus can be measured alongside cortisol to depict the stress response to training and competition in a bid to optimise recovery.

2.7 Chapter Summary

The goal of a multi-faceted athlete monitoring system is to closely follow indicators of maladaptation to training which may impact on performance and intervene to prevent such maladaptation from continuing (Soligard et al., 2016; Schwellnus et al., 2016). Furthermore, a multi-faceted monitoring system should include physiological, psychological, biochemical and immunological markers to effectively evaluate the training and recovery response (Fry et al., 1991).

The disability of a Paralympic athlete is a factor which cannot be modified and therefore requires research to focus on quantifying TL and other factors which can
be altered to reduce injury and illness risk (Silva et al., 2013). Whilst HR can be a convenient and non-invasive measure, there are limitations in its ability to accurately quantify internal TL in all Paralympic athletes particularly in those with SCI or during periods of high-intensity training including weight training or plyometric and speed work (Foster et al., 2001; McGuigan and Foster, 2004; Paulson et al., 2013). As an internal measure of TL, sRPE is most applicable in a Paralympic athlete population given that it can be applied to all sports and athletes irrespective of disability. Subjective wellness markers have been proposed as a simple yet informative measure of monitoring TL. A review by Saw et al., (2015) of 56 original studies reporting subjective and objective measures of athlete well-being observed subjective wellness markers including stress, mood and fatigue may report greater sensitivity to acute and chronic TL and fatigue compared to objective measures and should therefore be included in athlete monitoring systems. In contrast to previously designed wellness and recovery questionnaires, more recent research suggests it to be common practice for practitioners to design their own questionnaires utilising subjective wellness markers relevant to each sporting population (Burgess, 2017).

Technological developments have seen the emergence of salivary biomarkers as a popular monitoring tool in athlete populations due to the ease of use and non-invasive sample collection. Saliva contains both immunity and stress biomarkers which have been shown to respond to physiological and psychological stressors. Longitudinal monitoring of these biomarkers may assist in further understanding of the athletic responses to training and competition demands.

Kenttä and Hassmén (2002) recommend an athlete monitoring system to incorporate all aspects of training and recovery, focusing on the individual needs and responses of the athlete to maximise positive adaptations. A clear measure of the TL on the athlete provides a coach with a better understanding of what is required for subsequent recovery. Based upon a comprehensive review of the findings of the current scientific literature, having determined the parameters suitable for inclusion in the athlete monitoring of Paralympic athletes, research must now investigate their efficacy and effectiveness in identifying individual responses to TL and other athletic demands including competition.
Chapter 3. Longitudinal Monitoring of Athletic Response to Training and Incidence of Illness and Injury in Paralympic Football
3.1 Abstract

The purpose of this study was to examine the athletic response to training using sRPE and subjective wellness measures and the relationship with incidence of injury and illness across three training seasons in Paralympic footballers. Ten Paralympic footballers recorded three subjective wellness markers (sleep quality, energy and mood) on a daily basis across the 2013/2014, 2014/2015 and 2015/2016 seasons. TL was recorded for all training sessions using sRPE. Multi-level analysis identified increases in measures of weekly TL (11%), training monotony (36%), cumulative 2wk TL (12%), cumulative 3wk TL (8%) and ACWR (29%) to be significantly associated with illness occurrence in the following week. Specific TL variables have now been identified which may reduce the number of training days lost to illness when included in a multi-faceted monitoring system. Results have also indicated variables which are not associated with illness or injury and may be excluded from monitoring systems of Paralympic footballers including training strain, chronic TL and cumulative 4wk TL. Despite a 3% increase in TL measures prior to injury, none were found to be significantly associated with injury occurrence. A limitation of the current study is not collecting data regarding the injury occurrence, location of injury and nature of injury. Further research is warranted to examine the relationship between TL measures and injury to fully understand the injury patterns in Paralympic footballers. Spearman correlation analysis identified a moderate association between weekly TL and subjective wellness markers of sleep quality ($r_s = -0.51, p < 0.001$), energy ($r_s = -0.63, p < 0.01$) and mood ($r_s = -0.65, p < 0.01$) across the three-year study and between training monotony and sleep quality ($r_s = -0.51, p < 0.01$), energy ($r_s = -0.68, p < 0.01$) and mood ($r_s = -0.74, p < 0.01$), therefore changes may indicate maladaptive TL responses quickly. Additionally, future studies in Paralympic athletes should examine additional subjective wellness markers including muscle soreness and sleep quantity which may provide further feedback on the athlete response to training and competition demands.
3.2 Introduction

Monitoring TL provides a quantifiable understanding of the training performed and the subsequent athletic response. Recording external TL alone does not consider the physiological stress of a training session on an athlete (Mujika, 2017), therefore internal TL must also be quantified. Within a team sport environment, each player will respond differently to the same external TL placed upon them, with responses influenced by fitness level, previous training, external environmental stressors, sleep or fatigue state (Impellizzeri et al., 2005; Halson, 2014). Furthermore, the timeframe for recovery and adaptation to return the body to homeostasis varies between athletes and must be individually prescribed as a result (Soligard et al., 2016). Individual response can often become lost within group data analysis (Sands et al., 2017), thus it has been suggested that greater attention should be placed on the individual TL monitoring of athletes within a team sport environment (Bouchard and Rankinen, 2001).

Paralympic 7-a-side football or CP football has been included as a competitive Paralympic event since 1984, played by ambulant individuals with CP or a neurological disorder including stroke or acquired brain injury. The hypertonic state can limit range of movement and co-ordination, disrupt protein synthesis in the affected limb or limbs and contributes to excessive fatigue (Sherrill, 2004), highlighting the importance of monitoring TL in this unique athlete population. Moreau et al., (2008) reported fatigue to be closely related to muscle weakness in those with CP, thus it is important to understand the impact of the training stimulus to each differing athlete. Accurate monitoring of TL and external loads from athletic and life demands has been promoted as being essential in defining the relationship between load and illness and injury risk in athletes (Soligard et al., 2016; Schwellnus et al., 2016). Furthermore, reducing illness and injury risk in athletes ensures maximum player availability for team selection which Owen et al., (2016) suggest can significantly contribute to the team success.

sRPE is a popular method used for quantifying internal TL in sports research and practice (Burgess, 2017). Impellizzeri et al., (2004) reported moderate to strong correlations (r = 0.5 - 0.85, p < 0.01) between HR-based methods and sRPE method in quantifying TL in national level soccer players. Furthermore, Casamichana et al.,
(2012) reported sRPE to significantly correlate with external measures of TL during training in semi-professional soccer players including total distance covered and player load measured via accelerometer GPS units (r = 0.74, p < 0.01 and r = 0.76, p < 0.01 respectively). In intermittent Paralympic sports, research has shown sRPE to be a valid measure to quantify TL in wheelchair basketball compared to HR-based TRIMP measures (r = 0.62-0.81, p < 0.01) (Paulson et al., 2015) and in wheelchair rugby (r = 0.627-0.629, p < 0.01) (Iturricastillo et al., 2016a). sRPE also enables a coach to monitor multiple training modalities using the same measure (Coutts, 2001), having been reported to be valid method of quantifying TL in resistance training (McGuigan and Foster, 2004; Singh et al., 2007) and during soccer drills (Little and Williams, 2007). Whilst HR may be useful in quantifying load during training, monitors and GPS units are not permitted for use in Paralympic football outside of training and non-competitive matches (IFCPF, 2017). Therefore, it is necessary to implement other methods of quantifying TL, such as sRPE, which can be used throughout the football season including at major international competition such as World Championships or Paralympic Games.

A dose-response relationship between TL and self-reported subjective wellness markers have been previously demonstrated in research, highlighting the effectiveness of subjective wellness data in athlete monitoring (Haddad et al., 2013). A review by Saw et al., (2015) proposed inclusion of subjective wellness measures in athlete monitoring systems which are responsive to acute and chronic training to evaluate stress, fatigue, recovery and general well-being. However, no consistent association can be drawn between subjective and objective measures, thus it has been recommended to record and report both categories of variables on a regular basis (Saw, 2016).

Research suggests that athletes with CP may be more susceptible to fatigue accumulation thus highlighting the effective role TL monitoring may have in depicting the individual response to training and competitive demands. According to Bompa and Haff (2009), a balance is required between the training stimulus required to elicit adaptation and the recovery to reduce the impact of fatigue. Bourdon et al., (2017) promotes a combination of internal and external load measures and if used longitudinally, can provide information on TL adaptations for both individual and team athletes. Furthermore, athlete monitoring must be longitudinal to ensure
evaluation of individual athlete response (Kellman, 2002). With the abundance of TL research in AB soccer (Malone et al., 2017; Impellizzeri et al., 2004; Little and Williams, 2007) to determine the impact of excessive TL on individual athlete response, similar research is warranted in Paralympic footballers. Therefore, the aim of this study was to apply sRPE TL and its associated metrics, and three subjective wellness markers of sleep quality, mood and energy longitudinally across three training seasons in Paralympic footballers to determine the relationships between TL, subjective wellness measures and incidence of injury and illness.

3.3 Methods

3.3.1 Participants

Fourteen international Paralympic footballers participated in this study but changes in player selection across this three-year period resulted in ten players included in the final analysis (age 24 ± 4 yrs, body mass 72.1 ± 9.5 kg, height 1.77 ± 0.07 m). The ten footballers were members of the Irish Paralympic football team preparing for and competing at the Rio 2016 Paralympic Games. Athlete characteristics are presented below (Table 3.1). All players had been competing regularly in international competitions for at least one year prior to commencement of data collection. All testing protocols formed part of the on-going physiological support programme, delivered through the Sport Ireland Institute and Paralympics Ireland, which players were fully familiar with prior to participating in the study. All participants were fully informed of the requirements and potential risks and benefits of participation and provided written informed consent before commencement of data collection. All experimental procedures were approved by University of Limerick, Faculty of Education and Health Sciences Ethics Committee.
### Table 3.1 Athlete characteristics including playing class and playing position

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Gender</th>
<th>Playing Class</th>
<th>Playing Position</th>
<th>Competition Experience (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>FT5</td>
<td>Goal-keeper</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>FT7</td>
<td>Back</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>FT7</td>
<td>Forward</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>FT7</td>
<td>Mid-field</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>FT8</td>
<td>Forward</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>FT7</td>
<td>Mid-Field</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>FT7</td>
<td>Back</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>FT8</td>
<td>Forward</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>FT7</td>
<td>Back</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>FT7</td>
<td>Forward</td>
<td>4</td>
</tr>
</tbody>
</table>

*IPC Classification code; b Years competing as part of the national Paralympic football team*

### 3.3.2 Research Design

Data were recorded across three seasons – 2013/2014 (35 weeks), 2014/2015 (38 weeks), 2015/2016 (42 weeks). During the seasons, data was analysed daily and weekly by the researcher in their role as team physiologist to assist with individual player TL monitoring and training prescription. TL was calculated for all training done including football training, match play, strength and conditioning sessions, rehabilitation training, mobility and stretching work and general conditioning sessions of running, cycling, swimming or other. Players were familiar with the TL monitoring recording having completed the process over a familiarisation period of six weeks prior to commencement of the 2013/2014 season. Players were provided with an excel template to record TL (Fig. 6) and wellness scores (Fig. 7) to complete daily for the duration of the study. Samples of completed templates can be found in Appendix A and B.
3.3.3 Training Load

sRPE was used to quantify TL using the method proposed by Foster et al., (1995). Following the protocol of Green et al., (2009), approximately 15 min after each training session each player was required to rate the intensity of the session according to the CR-10 RPE scale (Borg et al., 1985). A six-week habituation period prior to commencement of the season ensured players were fully familiar with the protocol. To anchor the use of RPE, the CR-10 RPE scale was explained to players.
and sessions of specific intensity related to the scale. Coaches also conducted sessions at specific intensities to demonstrate the workload relative to each RPE value. Each session duration was recorded in minutes and multiplied by the RPE score given by each player (TL = session duration x intensity). TL was expressed in arbitrary units (AU).

### 3.3.4 Training Load Measures

TL was used to calculate training monotony (weekly TL mean/SD) and training strain (training monotony x weekly TL) (Foster, 1998). The mean weekly TL represented acute workload and a 4-week rolling average represented the chronic workload - ACWR was calculated by dividing acute workload by the chronic workload (Blanch and Gabbett, 2016). Chronic TL was calculated as a 4-week rolling average. Two, three and four-week cumulative TL and week-to-week changes were also calculated as they have been associated with increased injury risk previously (Rogalski et al., 2013).

### 3.3.5 Subjective Markers of Wellness

Players recorded three subjective wellness markers of sleep quality, energy and mood daily. The recorded markers were selected in collaboration with medical and coaching staff and were deemed to keep a lower number to ensure compliance across the data collection period. Data was entered each morning with players subjectively rating each variable using an analogue scale (table 3.2) ranging from 1 (poor state of well-being) to 5 (good state of well-being).
Table 3.2 Analogue scale for subjective wellness markers of mood, energy and sleep quality

<table>
<thead>
<tr>
<th>SLEEP, ENERGY, MOOD RATING SCALES</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLEEP:</td>
</tr>
<tr>
<td>1: VERY POOR</td>
</tr>
<tr>
<td>2: POOR</td>
</tr>
<tr>
<td>3: AVERAGE</td>
</tr>
<tr>
<td>4: GOOD</td>
</tr>
<tr>
<td>5: VERY GOOD</td>
</tr>
<tr>
<td>ENERGY:</td>
</tr>
<tr>
<td>1: EXTREMELY TIRED</td>
</tr>
<tr>
<td>2: MORE TIRED THAN USUAL</td>
</tr>
<tr>
<td>3: NORMAL</td>
</tr>
<tr>
<td>4: FRESH</td>
</tr>
<tr>
<td>5: VERY FRESH</td>
</tr>
<tr>
<td>MOOD :</td>
</tr>
<tr>
<td>1: VERY STRESSED/UNHAPPY</td>
</tr>
<tr>
<td>2: SLIGHT STRESS/UNHAPPY</td>
</tr>
<tr>
<td>3: AVERAGE</td>
</tr>
<tr>
<td>4: RELAXED/GOOD MOOD</td>
</tr>
<tr>
<td>5: GREAT MOOD</td>
</tr>
</tbody>
</table>

3.3.6 Injury and Illness

Any incidence of injury or illness across the three seasons was recorded in the individual monitoring file and self-reported to the team doctor or physiotherapist. Injury was defined as any pain, tightness or impairment that restricted full participation in training or match-play (Fuller et al., 2006). During any period of injury or modified training, players were required to record all cross-training or rehabilitation training sessions. Illness was defined as any medical issue which required the player to miss training, or training to be modified (Mountjoy et al., 2015). Individual player files were accessible by medical and physiotherapy staff who could also record injury or illness.

3.3.7 Statistical Analyses

Multilevel modelling approach using Multilevel Models Project MLn (Rasbash et al., 2009) was used to investigate longitudinal training and subjective wellness data with injury and illness occurrence. Multilevel analysis is an extension of multiple regression and can include dependent data. This type of analysis is more suitable for longitudinal research design as it does not require the same number of measures for
all participants. Significant changes are determined by dividing the mean by the SE, with values ≥ 2 deemed significant. Data did not meet the assumptions for parametric statistics as determined by significant (p ≤ 0.05) Shapiro-Wilk and Levene tests, therefore non-parametric statistics were used in analysis. Spearman correlations (r_s) were calculated to determine the relationship between TL measures and subjective wellness markers using SPSS statistical software package v24 (SPSS Inc., Chicago, IL). Cohen’s standard was used to evaluate the correlation coefficient to determine the strength of the relationship: <0.19 very weak, 0.20-0.39 weak, 0.40-0.59 moderate, 0.60-0.79 strong and >0.8 very strong (Cohen, 1988). Statistical significance was set at p ≤ 0.05 for all analyses.

3.4 Results

In total, 1084 observations for weekly TL, ACWR, training strain, training monotony, chronic TL, cumulative 2wk, 3wk and 4k TL were recorded across the three-year study period. Incomplete weeks of data or missed data entries resulted in that week of data being excluded from analysis, with a total of 66 data sets removed. A total of 79 injuries and 86 incidences of illness were also observed during this time.

Mean weekly TL data are presented below for all three seasons (Fig. 8-12). Pre-season periods were 7 weeks (2013/2014 season), 10 weeks (2014/2015 season) and 13 weeks (2015/2016 season).
Figure 8. Mean weekly TL for Paralympic football team across three seasons
Data presented as mean ± SE. Weekly TL calculated as sum across seven days of sRPE TL. Pre-season training indicated as red, in-season indicated as blue.
Figure 9. Cumulative TL of 2, 3 and 4 weeks for Paralympic footballers across three training seasons
Data presented as means. Cumulative TL calculated from sRPE weekly TL.
Figure 10. Weekly ACWR across three training seasons in Paralympic footballers
Data presented as means. ACWR calculated as acute (7-day average TL) divided by chronic (28-day rolling average TL)
Figure 11. Weekly training strain and training monotony across three training seasons in Paralympic footballers
Data presented as means. Training strain and training monotony calculated from sRPE quantified TL.
Figure 12. Pre-season and in-season mean TL across three training seasons in Paralympic footballers
Data presented as means ± SE.

Mean ± SD weekly TL during pre-season was 2185 ± 264 AU, 2171 ± 240 AU and 2034 ± 168 AU during 2013/2014, 2014/2015 and 2015/2016 seasons respectively. In-season mean ± SD weekly TL was 2248 ± 226, 2162 ± 206 and 2209 ± 274 in the three respective seasons (Fig. 12). Due to the Paralympic Games held in September 2016, the 2015/2016 was a longer season at 42 weeks and allowed for a longer pre-season period compared to the previous two seasons. Pre-season and in-season TL were similar across the three seasons, with season three having a greater in-season load recorded compared to pre-season (Fig. 12).

3.4.1 Training Load Measures

Multi-level analysis identified increases in TL measures of weekly TL (249 (89)), monotony (0.45 (0.05)) and 2 and 3wk cumulative TL ((511 (139)) and (526 (181)) were significantly associated with incidence of illness in Paralympic footballers (Table 3.3 and 3.4) in the following week. Training monotony was 36% higher prior to periods of illness compared to periods of good health (1.69 vs 1.24 AU
respectively). Weekly TL was 11% higher prior to illness at 2424 AU compared to mean weekly TL of 2175 AU during periods of good health.

Table 3.3 Multilevel regression analysis of TL measures (weekly TL, monotony, strain and chronic TL) of ten Paralympic footballers and periods of illness across three training seasons

<table>
<thead>
<tr>
<th>Weekly TL</th>
<th>Monotony</th>
<th>Strain</th>
<th>Chronic TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed explanatory variables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Estimate</td>
<td>S. Error</td>
<td>Estimate</td>
</tr>
<tr>
<td>Constant(a)</td>
<td>2175</td>
<td>69</td>
<td>1.24</td>
</tr>
<tr>
<td>Illness (△a)</td>
<td>249*</td>
<td>89</td>
<td>0.45*</td>
</tr>
<tr>
<td>% Change</td>
<td>11%</td>
<td>36%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Values are means ± SE. TL measures during periods of no illness were used as constant, indicated by (a) and compared to values in the seven days prior to onset of illness indicated by (△a). Weekly TL and monotony were significantly higher in the week preceding illness compared to periods of good health. * denotes significant changes from periods of no illness.

In the week prior to reported incidence of illness, cumulative 2wk and 3wk TL were significantly higher (12% and 8% respectively) compared to mean values of 4341 AU and 6529 AU respectively during periods of good health and normal training (Table 3.4). Furthermore, values for ACWR were also significantly increased (29% (0.3 (0.03))) prior to preceding reported illness (Table 3.4). Despite a 15% increase in training strain observed prior to incidence of illness, this was not found to be significant (436.6 (227.6)).
Table 3.4 Multilevel regression analysis of TL measures (cumulative 2, 3 and 4wk TL and ACWR) of ten Paralympic footballers and periods of illness across three training seasons

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cumulative 2wk TL</th>
<th>Cumulative 3wk TL</th>
<th>Cumulative 4wk TL</th>
<th>ACWR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>S. Error</td>
<td>Estimate</td>
<td>S. Error</td>
</tr>
<tr>
<td>Constant(a)</td>
<td>4341</td>
<td>137</td>
<td>6529</td>
<td>206</td>
</tr>
<tr>
<td>Illness ((\Delta a))</td>
<td>511*</td>
<td>139</td>
<td>526*</td>
<td>181</td>
</tr>
<tr>
<td>% Change</td>
<td>12%</td>
<td>8%</td>
<td>5%</td>
<td>29%</td>
</tr>
</tbody>
</table>

Values are means ± SE. TL measures during periods of no illness were used as constant, indicated by (a) and compared to values in the seven days prior to onset of illness indicated by (\(\Delta a\)). Cumulative 2 and 3wk TL as well as ACWR were significantly higher in the week preceding illness compared to periods of good health. * denotes significant changes from periods of no illness.

In the week preceding a reported injury, increases were observed for TL measures however none were found to be significant (table 3.5 and 3.6).

Table 3.5 Multilevel regression analysis of TL measures (Weekly TL, monotony, strain and chronic TL) of ten Paralympic footballers and periods of injury across three training seasons

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Weekly TL</th>
<th>Monotony</th>
<th>Strain</th>
<th>Chronic TL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>S. Error</td>
<td>Estimate</td>
<td>S. Error</td>
</tr>
<tr>
<td>Constant(a)</td>
<td>2178</td>
<td>89</td>
<td>1.25</td>
<td>0.08</td>
</tr>
<tr>
<td>Injury ((\Delta a))</td>
<td>165</td>
<td>88</td>
<td>0.17</td>
<td>0.09</td>
</tr>
<tr>
<td>% Change</td>
<td>8%</td>
<td>13%</td>
<td>8%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Values are means ± SE. TL measures during periods of no injury were used as constant, indicated by (a) and compared to values in the seven days prior to report of injury indicated by (\(\Delta a\)). No values were found to be significantly different in the week preceding an injury.
Despite a 13% increase in training monotony observed prior to periods of injury, this was not found to be significant (0.17 (0.09)) (Table 3.5). In contrast to results regarding illness, ACWR showed no association with periods of injury (Table 3.6).

### Table 3.6 Multilevel regression analysis of TL measures (cumulative 2, 3 and 4wk TL and ACWR) of ten Paralympic footballers and periods of injury across three training seasons

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cumulative 2wk TL</th>
<th>Cumulative 3wk TL</th>
<th>Cumulative 4wk TL</th>
<th>ACWR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>S. Error</td>
<td>Estimate</td>
<td>S. Error</td>
</tr>
<tr>
<td>Constant(a)</td>
<td>4361</td>
<td>137</td>
<td>6553</td>
<td>206</td>
</tr>
<tr>
<td>Injury (Δa)</td>
<td>239</td>
<td>140</td>
<td>208</td>
<td>182</td>
</tr>
<tr>
<td>% Change</td>
<td>5%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Values are means ± SE. TL measures during periods of no injury were used as constant, indicated by (a) and compared to values in the seven days prior to report of injury indicated by (Δa). No values were found to be significantly different in the week preceding an injury.

### 3.4.2 Subjective Wellness Markers

A dose-response relationship was observed between TL and subjective wellness markers (Table 3.7) across the three training seasons. Significant moderate to strong negative correlations were observed between TL and sleep quality ($r_s = -0.510$, $p < 0.01$), energy ($r_s = -0.633$, $p < 0.01$) and mood ($r_s = -0.648$, $p < 0.01$). Significant strong negative correlations were shown between training monotony and sleep quality ($r_s = -0.512$, $p < 0.01$), energy ($r_s = -0.684$, $p < 0.01$) and mood ($r_s = -0.743$, $p < 0.01$).
Table 3.7 Spearman correlation ($r_s$) between sRPE TL measures and subjective wellness markers

<table>
<thead>
<tr>
<th></th>
<th>Sleep Quality</th>
<th>Mood</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL</td>
<td>-.510*</td>
<td>-.648**</td>
<td>-.633**</td>
</tr>
<tr>
<td>Training monotony</td>
<td>-.512**</td>
<td>-.743**</td>
<td>-.684*</td>
</tr>
<tr>
<td>Cumulative 2wk TL</td>
<td>.148</td>
<td>.135</td>
<td>.119</td>
</tr>
<tr>
<td>Cumulative 3wk TL</td>
<td>.150</td>
<td>.116</td>
<td>.095</td>
</tr>
<tr>
<td>Cumulative 4wk TL</td>
<td>.145</td>
<td>.108</td>
<td>.088</td>
</tr>
<tr>
<td>ACWR</td>
<td>.054</td>
<td>.050</td>
<td>.055</td>
</tr>
<tr>
<td>Chronic TL</td>
<td>.161</td>
<td>.139</td>
<td>.112</td>
</tr>
</tbody>
</table>

*denotes data significant at $p \leq 0.05$ ** denotes data significant at $p \leq 0.001$.

Sleep quality scores were strongly correlated with scores for energy ($r_s = 0.72, p < 0.01$) and mood ($r_s = 0.77, p < 0.01$) demonstrating the importance of sleep for athlete perception of mood and energy.

No association was observed between subjective wellness markers and cumulative TL measures, indicating changes in scores for sleep quality, mood and energy are more sensitive to changes in acute TL measures of training monotony and weekly TL.

Multilevel analysis identified a significant decrease in subjective wellness scores for sleep quality (16%), mood (19%) and energy (19%) during periods of illness compared to periods of good health respectively (Table 3.8). During periods of injury, multilevel analysis identified minimal decreases in scores for sleep quality (3%), mood (6%) and energy (3%) with none found to be significant (Table 3.9).
Table 3.8 Multilevel regression analysis of subjective wellness markers for ten Paralympic footballers and periods of illness during three training seasons

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sleep Quality</th>
<th>Mood</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed explanatory variables</td>
<td>Estimate</td>
<td>S. Error</td>
<td>Estimate</td>
</tr>
<tr>
<td>Constant(a)</td>
<td>3.2</td>
<td>0.1</td>
<td>3.2</td>
</tr>
<tr>
<td>Illness (△a)</td>
<td>-0.5*</td>
<td>0.1</td>
<td>-0.6*</td>
</tr>
<tr>
<td>% Change</td>
<td>16%</td>
<td></td>
<td>19%</td>
</tr>
</tbody>
</table>

Values are means ± SE. Subjective wellness marker scores during periods of no illness were used as constant, indicated by (a) and compared to scores during periods of illness indicated by (△a). Daily scores for sleep quality, mood and energy were significantly lower during periods of illness. * denotes significant changes from periods of no illness.

Table 3.9 Multilevel regression analysis of subjective wellness markers for ten Paralympic footballers and periods of injury across three training seasons

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sleep Quality</th>
<th>Mood</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed explanatory variables</td>
<td>Estimate</td>
<td>S. Error</td>
<td>Estimate</td>
</tr>
<tr>
<td>Constant(a)</td>
<td>3.3</td>
<td>0.1</td>
<td>3.2</td>
</tr>
<tr>
<td>Injury (△a)</td>
<td>-0.1</td>
<td>0.1</td>
<td>-0.2</td>
</tr>
<tr>
<td>% Change</td>
<td>3%</td>
<td></td>
<td>6%</td>
</tr>
</tbody>
</table>

Values are means ± SE. Subjective wellness marker scores during periods of no injury were used as constant, indicated by (a) and compared to scores during periods of injury indicated by (△a).

3.4.3 Summary of Results

Amongst Paralympic footballers, increases in TL measures of weekly TL (11%), training monotony (36%) and 2wk and 3wk cumulative TL (12% and 8% respectively) were found to be significantly associated with incidence of illness in the following week. Mean weekly TL of 2424 AU was significantly associated with illness in the following week compared to 2175 AU during periods of good health. A
36% increase in training monotony was significantly associated with illness the next week. Furthermore, mean cumulative 2wk and 3wk TL values of 4852 AU and 7055 AU respectively were associated with illness in the following week compared to values of 4341 AU and 6529 AU respectively during periods of good health. In contrast, no TL measures were identified to be significantly different in the week preceding an injury. Chronic TL showed no association with injury or illness, and no relationship was identified with subjective wellness markers suggesting its use should be limited to calculation of ACWR and not as a stand-alone TL measure.

Scores for subjective wellness markers of sleep quality, mood and energy were significantly lower (16-19%) during periods of illness compared to periods of good health. During periods of injury, daily scores were observed to have minimal changes (3-6%) compared to periods of no injury with no significant differences identified.

A dose-response relationship was evident between TL and subjective wellness markers with decreases in scores for sleep quality, energy and mood with increases in TL across the three training seasons. Furthermore, increases in training monotony were also shown to negatively impact on scores for all three subjective wellness markers.

Additionally, this research has quantified mean weekly TL of Paralympic footballers across three training seasons in preparation for competition at Rio 2016 Paralympic Games. Pre-season and in-season TL have been described as well as TL measures of training strain, training monotony, cumulative 2wk, 3wk and 4wk TL and ACWR. Pre-season TL values were similar to in-season levels across the three seasons, with season three having a greater in-season load (2209 ± 274) recorded compared to pre-season (2034 ± 168).

3.5 Discussion

Accurate monitoring of TL and external loads from athletic and life demands has been promoted as essential in defining the relationships between load and illness/injury risk in athletes (Soligard et al., 2016; Schwellnus et al., 2016). The IPC London 2012 injury surveillance study identified large differences in injury
occurrence across sports during competition and highlighted the necessity for future studies to be both longitudinal and sport specific (Webborn and Emery, 2014). Furthermore, Jones et al., (2017) reported the use of longitudinal monitoring allows for quantification of TL and fatigue variables to identify trends in occurrence of injury or illness and provide objective data for practitioners to implement across the training seasons. The current study is the first investigation into the athlete response of Paralympic footballers to training and the relationship with incidence of injury and illness across three training seasons. Results demonstrated a moderate to strong relationship between TL and subjective wellness scores of sleep quality, energy and mood. TL measures of weekly TL, training monotony and cumulative 2, and 3wk TL were shown to be significantly greater in the week preceding an illness compared to periods of good health. Whilst small increases (~3%) were also observed in TL measures prior to reports of injury, these were not found to be significant. Findings from the current study highlight the importance of regular TL monitoring in Paralympic footballers and identify specific TL monitoring variables associated with incidence of illness.

According to Reilly (2007), the purpose of pre-season training is to rebuild the fitness levels of players following an off-season whilst the focus during in-season is to maintain fitness developed during the pre-season period. Nevertheless, weekly training programmes of AB soccer players have been suggested to vary due to scheduled games, phases of annual plan, competition period and coaching experience (Impellizzeri et al., 2005; Bangsbo, Mohr and Krstrup, 2006). A primary finding of the current research is the quantification of TL of Paralympic footballers across three training seasons during pre-season and in-season training. Mean pre-season TL values were lower compared to in-season TL during 2013/2014 and 2015/2016 seasons, whilst during the 2014/2015 season there was a minimal difference in TL between pre-season and in-season periods. Jeong et al., (2011) reported pre-season sRPE quantified TL values to be significantly greater than in-season values in professional soccer players, but reported on a single week in each training period. Therefore, it is unknown what values would have been reported across the full training season. Wrigley et al., (2012) reported weekly TL in elite junior soccer players during in-season period increases with age from under-14 (2524 ± 128 AU), under-16 (2919 ± 136 AU) and under-18 (3948 ± 222 AU, p < 0.05). Results from
the current study agree with those reported in junior under-14 players. Previous research has shown Paralympic footballers to have a significantly lower soccer-specific endurance, mean and peak power output than their national AB counterparts (Al’Hazzaa et al., 2001; Kloyiam et al., 2011; Yanci et al., 2016) which may partially explain the lower TL values quantified in the current study and the similarity with values to junior soccer players.

Rapid increases in TL have previously been demonstrated to increase injury risk in soccer players (Malone et al., 2017; Ekstrand, Waldén and Hägglund, 2004; Fünten et al., 2014). Ekstrand, Waldén and Hägglund (2004) reported elite soccer players competing with congested match calendars during periods of competition such as World Cup are at a higher risk of injury due to fatigue. In agreement, Soligard et al., (2016) highlighted heavy competition calendars, high psychological stress and poor management of TL put athletes at a higher risk of injury. CP soccer players have been reported to be at a higher risk of injury as a result of muscle strength asymmetry and lower limb muscle weakness and in particular knee injuries (Andrade et al., 2005). Results from the current study identified minimal increases in TL measures (3%) in the week preceding reports of injury but none were found to be significant. The low number of injuries recorded during the study (79 across three seasons) may have contributed to the lack of relationship observed with TL measures. Malone et al., (2017) reported elite soccer players who recorded weekly TL of ≥ 2120 - ≤ 3200 AU during the season were at a lower injury risk than those who recorded ≥ 3200 AU (OR = 2.33). In agreement, mean weekly TL recorded during in-season periods in the current study were 2248 ± 226, 2162 ± 206 and 2209 ± 274 AU respectively, inside the thresholds determined by Malone et al., (2017) and may provide an explanation for the low number of recorded injuries across the study period.

In contrast to periods of injury, weekly TL was found to be significantly higher preceding reports of illness in the current study. An imbalance between TL and recovery has previously been suggested to impair immune function in athletes (Bishop and Gleeson, 2009) with athletes undertaking prolonged and intensive exercise at a higher risk of illness (Nieman, 2000). Amongst female youth soccer players, weekly (p = 0.005, OR = 1.5) and monthly (p = 0.007, OR = 1.54) TL were reported to be significantly higher preceding illness and both identified as predictors
of illness (Watson et al., 2016). In agreement, results from the current study identified significantly higher measures of cumulative 2wk and 3wk TL as well as ACWR preceding illness. Reviewing the relationship between TL and illness, Jones et al., (2017) reported athletes who were subjected to spikes in TL without sufficient recovery experience an extended period of immune function suppression placing the athlete at higher risk of illness. Amongst collegiate soccer players, Putluur et al., (2004) reported 55% of illnesses recorded over a nine-week period were associated with a preceding spike in TL. However, as this study was conducted in collegiate athletes it is unknown what degree of external demands may also have contributed to the increase in illness occurrences during the investigation period. Finally, chronic TL showed no association with injury or illness in the current study suggesting its use should be limited to calculation of ACWR and not as a stand-alone TL measure in an athlete monitoring system for Paralympic football.

Few studies have reported associations between injuries or illness and training monotony with mixed results observed (Jones et al., 2017). An early study by Foster (1998) reported a spike in training monotony above 2.0 AU was associated with 77% of illness incidence. This finding agrees with results from the current study which identified a 36% increase in training monotony to 1.69 AU be significantly associated with reports of illness occurrence in the following week. It is possible the variance in training monotony values during periods of illness is due to the different sports investigated in both research studies. Also, in a population of field-sport athletes, Thornton et al., (2015) reported weekly TL, monotony and strain to be strong predictors of incidence of illness in professional rugby players. Prior to periods of injury, increases in training monotony to 1.25 AU were not found to be significant in the current study. These results disagree with the findings of Brink et al., (2010) who reported monotony scores of 1.07 ± 0.25 AU were significantly associated with injuries in elite AB soccer players. Training monotony scores reflect the variability in training session intensity throughout a week (Foster et al., 2010) with repetition of the same duration or intensity of training resulting in a higher monotony score. Therefore, while monotony scores from the current study are higher than those observed by Brink et al., (2010), the training intensity may have been lower thus contributing to the low injury rates recorded and lack of relationship detected between injury and monotony scores. A more recent study by Lu et al.,
(2017) reported no significant changes in training monotony in the three weeks preceding a reported injury in professional soccer players. Based on the conflicting reports in literature regarding training monotony and its relationship with illness and injury, Jones et al., (2017) have suggested that future research should incorporate other metrics including ACWR.

ACWR has been proposed as a more sensitive predictor of injury in athletes as it accounts for both accumulation and variability in TL over time (Jones et al., 2017). Research suggests a range of 0.8-1.3 minimises injury risk and is considered the training “sweet spot” however, this range has been suggested to be sport specific (Gabbett, 2016). In professional soccer players, Jaspers et al., (2017) identified an ACWR range between 0.85-1.12 to have a protective effect against injury. Similarly, Malone et al., (2017) reported elite soccer players with an ACWR ≥ 1.5 were 3.03 times more likely to become injured with the authors recommending a range between 1.00-1.25 minimised injury risk. In contrast with these findings, the current study observed no relationship between ACWR and incidence of injury in Paralympic footballers. The low number of injuries recorded during this study may explain why no associations were found to be significant with 79 injuries recorded across the 115 weeks of data, in contrast to studies of Malone et al., (2017) who reported 75 incidences of injury in just one season. Despite no relationship observed between ACWR and injury in Paralympic footballers, previously published ranges of ACWR were increases in ACWR to 1.32 ± 0.03 were significantly associated with illness whilst average ACWR during healthy periods were 1.02 ± 0.01.

Research suggests that athletes with CP are susceptible to seizures resulting from fatigue with intense training and excessive stress (Webborn and Van de Vliet, 2012), thus emphasising the importance of establishing a TL monitoring system amongst Paralympic footballers. By accurately quantifying TL and the individual response of athletes through subjective wellness markers, prescription of recovery following training can be based on objective data. According to Meeusen et al., (2013) subjective wellness markers are a cost effective, simple and informative measure monitoring TL and may assist in early detection of athletes negatively responding to training. In fact, Coutts et al., (2007) suggested subjective markers may show negative athlete response to TL before objective measures with markers including stress, mood, wellness and fatigue consistently showing a dose-response with TL
(Meeusen et al., 2013). Results from the current study identified significant moderate associations between TL measures of weekly TL and training monotony with subjective wellness scores for sleep quality, energy and mood in Paralympic footballers across three training seasons. The current findings agree with those of Buccheit et al., (2013) who reported increases in TL resulted in decreases in scores for sleep quality, mood, stress and muscle soreness amongst professional Australian Rules football players during a 2-wk pre-season training camp. Self-report monitoring of subjective scores using an analogue scale has previously been validated by Gastin et al., (2013) who reported that self-reported measures of fatigue, muscle soreness, sleep quality, stress and well-being were sensitive to changes in TL and a suitable method to monitor responses of athletes to training and competition demands. In the current study, no association was observed between cumulative TL measures (2wk, 3wk, 4wk), chronic TL and subjective wellness markers and indicates that practitioners should focus on acute measures such as weekly TL, training monotony and ACWR when monitoring subjective wellness marker response to TL in Paralympic footballers.

3.6 Conclusion

The current study is the first of its kind to longitudinally examine the athletic response of Paralympic footballers and incidences of injury and illness across three seasons. Increases in TL measures of weekly TL, training monotony and cumulative 2wk and 3wk TL and ACWR were significantly associated with illness in the following week amongst the ten Paralympic footballers. Specific TL variables have now been identified which may reduce the number of training days lost to illness when included in a multi-faceted monitoring system. Results have also indicated variables which are not associated with illness or injury and may be excluded from monitoring systems of Paralympic footballers including training strain, chronic TL and cumulative 4wk TL.

Further research is warranted to examine the relationship between TL measures and injury to fully understand the injury patterns in Paralympic footballers. Despite a 3% increase in TL measures prior to injury occurrence, none were found to be significantly associated with injury. A limitation of the current study is not
collecting data regarding the injury occurrence, location of injury and nature of injury. Given that the TL monitoring was implemented by support staff and coaches across the three-year investigation period, the low numbers of injuries and illnesses recorded in this study supports the use of TL monitoring in Paralympic footballers.

Results have also highlighted the importance of sleep monitoring in Paralympic footballers and the impact of increased TL measures on sleep quality scores. Acute TL measures of weekly TL and training monotony were shown to be significantly associated with subjective wellness marker scores of sleep quality, energy and mood, therefore changes may indicate maladaptive TL responses quickly. Additionally, future studies in Paralympic athletes should examine additional subjective wellness markers including muscle soreness and sleep quantity which may provide further feedback on the athlete response to training and competition demands.
Chapter 4. Validity of Session-RPE to Quantify Training Load in Paralympic Swimmers
4.1 Abstract

Multiple measures may be used by coaches to quantify TL. The most popular measure of internal TL is HR but its application in swimming has some limitations. Furthermore, in Paralympic athletic populations, HR may not always be a suitable measure. Therefore, the aim of this study was to determine the validity of the sRPE method for quantifying internal TL in Paralympic swimmers through comparison to previously validated HR based TRIMP calculations and training distance as criterion measures. A further aim was to examine the relationship between athlete and coach perceptions of sRPE TL across sessions deemed easy, moderate and hard intensities to ensure consistency in prescription and quantification of TL. Four international Paralympic swimmers (1 male, 3 female, 19 ± 4 yrs, body mass 48.5 ± 7.6 kg) selected to compete at Rio 2016 Paralympic Games and representing all the members of the Irish Paralympic swimming team participated in this study. The four swimmers used in this study did not have any impairment which would impact on HR measurement during training. Swimmers completed 30 randomly selected training sessions of varied intensities across a six-week period. HR was recorded continuously during each session. RPE was recorded by each individual athlete after every training session by the researcher and sRPE TL calculated. Significant high to very high positive correlations were observed between sRPE and Banister’s TRIMP (r = 0.68, p < 0.01), Edward’s TRIMP (r = 0.66, p < 0.01) and Lucia’s TRIMP (r = 0.74, p < 0.01) in all four swimmers. Moderate correlations were observed between sRPE and distance measures (r = 0.53, p < 0.05) but were lower than those observed with HR based measures. A two-way ANOVA identified significant differences in the sRPE ratings between coach and athletes’ (F (2,108) = 170.4, p < 0.01, η² = 0.75). Sessions deemed to be low intensity had the lowest correlation (r = 0.43, p < 0.05) whilst moderate-to-strong correlations were observed during moderate (r = 0.58, p < 0.01) and harder intensity (r = 0.64, p < 0.05) training sessions. The results of this study suggest that sRPE method may be an appropriate monitoring tool for quantifying TL during water-based training using a single measure in Paralympic swimmers.
4.2 Introduction

The ability to quantify TL provides a comprehensive understanding of the individual tolerance to training and competition stress. González-Boto et al., (2008) previously suggested that competitive swimmers are subjected to high TL resulting from high training frequencies and intensities, typically employed, which can often induce decreased power and impaired performance when too greatly exceeded. Thus, in order to determine the correct training intensity for each individual athlete it is important that TL is monitored during each training session (Foster et al., 2001). Monitoring TL assists in understanding the individual tolerance to training, therefore developing and implementing a TL monitoring system in Paralympic swimming may assist in regulating TL level to reduce the risk of a maladaptive response.

HR measures are an objective and convenient depiction of internal TL (Burgess, 2017). However, despite being a non-invasive, easy to use monitoring tool, there are limitations to the use of HR in Paralympic swimming. Using TRIMP methods to quantify TL requires continuous HR readings to calculate average HR during a session or determine the time spent in each HR zone (Borresen and Lambert, 2006). Data collection can be interrupted during swimming training due to the movement of the monitor or loss of signal (Wallace et al., 2009). Furthermore, HR measures can be unreliable in athletes with high SCI (Paulson et al., 2013) or impairments of the autonomic nervous system (Thiesen, 2012). Thus, it is necessary to identify a method to quantify TL other than HR for use in Paralympic swimmers. As an alternative to HR, Foster et al., (1995) proposed measuring internal TL using a sRPE method. According to Burgess (2017), sRPE is the most commonly used measure of internal TL in team sport research particularly as it can be used for all forms of training and competition including high-intensity and intermittent training. sRPE has previously been examined and supported as a reliable method of quantifying TL in water-based sports including swimming (Wallace et al., 2009), diving (Minganti et al., 2011) and water polo (Lupo et al., 2014) but has yet to be examined amongst Paralympic swimmers.

Within Paralympic sport there are five disability categories of athlete – SCI, CP, amputation, VI and Les Autres (other physical disabilities and intellectual impairment) (IPC, 2015), therefore HR measures may be unreliable in a high number
of athletes depending on their classification. Fulton et al., (2010) recommends training prescription for elite swimmers with a disability should account for the impairment and their competitive class as well as the individual needs of the athlete. In designing a TL monitoring system for Paralympic athletes, it is necessary to identify methods of quantifying TL which can be utilised by all athletes regardless of their disability. Wallace et al., (2009) reported distance to be a poor method of evaluating TL in swimming due to the common high-intensity nature of training. Having previously been validated in sports including water-based sport (Wallace et al., 2009; Minganti et al., 2011; Lupo et al., 2014), the use of sRPE or distance as measures of TL have yet to be examined in Paralympic swimmers. Prescription of TL must be carefully quantified as the balance between appropriate training stresses and adequate recovery is essential in achieving a successful training adaptation (Comyns and Flanagan, 2013). In order to determine appropriate recovery, coaches must be sure the TL prescribed is perceived as intended. Therefore, it is essential to have alignment in the sRPE of both the athlete and the coach. The aim of this study was to determine the validity of sRPE to quantify TL in Paralympic swimmers through comparison to previously validated HR based measures of TL and distance. A secondary aim was to examine the difference between athlete and coach perception of internal TL using sRPE.

4.3 Methods

4.3.1 Participants

Four international Paralympic swimmers (1 male, 3 female, 19 ± 4yrs, body mass 48.5 ± 7.6kg) selected for competing at Rio 2016 Paralympic Games and representing all members of the Irish Paralympic swimming team participated in this study. Athlete characteristics are presented below (Table 4.1). The four swimmers used in this study did not have any impairment which would impact on HR measurement during training. The athletes had been competing regularly in international competitions for at least 2 years. All testing protocols formed part of the on-going physiological support programme, delivered through Paralympics Ireland and the Sport Ireland Institute, which all swimmers were fully familiar with prior to participating in the study. All participants were fully informed of the
requirements and potential risks and benefits of participation and provided written informed consent before commencement of data collection. Ethical approval was granted from the University of Limerick Ethics Committee.

Table 4.1 Paralympic swimmer characteristics including swimming class and disability

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Gender</th>
<th>Disability Type</th>
<th>Swimming Classa</th>
<th>Competition Experience (yrs)b</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>Les Autres</td>
<td>S5</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>Amputee</td>
<td>S9</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>Arthrogryposis</td>
<td>S8</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>Hypochondroplasia</td>
<td>S6</td>
<td>3</td>
</tr>
</tbody>
</table>

a IPC Classification code; b Years competing as part of the national Paralympic swim team

4.3.2 Research Design

Swimmers completed 30 training sessions across a six-week home training period free from competition. Sessions were randomly selected by day and varied in nature from aerobic conditioning (14 sessions), anaerobic threshold (8 sessions) to $\dot{V}O_2$max (4 sessions) and high velocity work (4 sessions). Training zones and intensities were determined by step-test completed monthly with the swimmers as part of their ongoing physiological support programme and coach designed training sessions. The duration of daily water-based training sessions was typically between 90-110 min. Interrupted data and illness resulted in a total of 26 sessions (11 aerobic conditioning, 7 anaerobic threshold, 4 $\dot{V}O_2$max, and 4 high velocity work sessions) of complete data on each participant used in the final analysis.

4.3.3 Heart Rate

Heart rate was recorded continuously during each session using Freelap Cardio Swim heart rate monitors (Freelap timing systems, Switzerland) (Fig. 13). Any session where full data was not recorded was eliminated from the final analysis. Swimmers were asked to check their heart rate monitors flashed “ready” before the
session and the system was continuously monitored during the training sessions. Beat to beat interval was used for HR data recorded. Following each training session, the data was downloaded to a computer using the Freelap Cardio Software (Freelap timing systems, Switzerland).

Figure 13. Cardio swim heart rate monitor and as applied when worn during swimming (Freelap, USA).

4.3.4 Training Load

RPE was used to calculate TL using the method proposed by Foster et al., (1995). Approximately 15 minutes (Green et al., 2009) after every training session each swimmer was asked to rate the intensity of the session using the CR-10 RPE scale (Borg et al., 1985). Each session duration was recorded in minutes and multiplied by the RPE score given by each athlete (TL = duration x intensity). TL is expressed in AU.

4.3.5 Criterion Methods for Quantifying Internal Training Load

Following the protocol by Wallace et al., (2009) distance (m) completed in each swimming session was used as a criterion measure of external TL. Two HR-based methods for quantification of internal TL as previously described in Chapter 2 were used as criterion measures – Banister TRIMP (Banister, 1991), Edwards’ TRIMP (Edwards, 1993) and Lucia’s TRIMP (Lucia et al., 2003).
4.3.6 Statistical Analyses

All statistical analyses were performed using SPSS statistical software package v24 (SPSS Inc., Chicago, Illinois). All variables were normally distributed and satisfied equality of variances criteria according to Shapiro-Wilk and Levene tests (p ≥ 0.05). Pearson’s product moment correlation was used to examine the relationship between sRPE, HR based methods and distance and categorised as proposed by Hopkins et al., (2009): <0.10 (trivial), 0.10-0.30 (low), 0.31-0.50 (moderate), 0.51-0.70 (high), 0.71-0.90 (very high), 0.91-0.99 (near perfect) and 1.0 (perfect). Training session intensities were categorised as easy (RPE < 3), moderate (RPE 3-5) and hard (RPE > 5) based on coach perception (Wallace et al., 2009). A two-way Analysis of Variance (ANOVA) was used to examine differences in coach and athlete RPE scores for the three session intensity categories - easy, moderate and hard. Comparison of sRPE between coaches and athletes were analysed using Pearson’s product moment correlation. Effect sizes (ES) were calculated and classified as <0.2 (trivial), 0.2-0.4 (small), 0.4-0.7 (moderate) and >0.8 (large) (Cohen, 1988). Statistical significance was set at p ≤ 0.05 for all analyses.

4.4 Results

Individual correlations between HR based and sRPE TL were based on 26 individual sessions and group correlations were based on a total of 104 sessions. Analysis was extended to individual correlations in this study due to the differing disabilities and potential impact on results. Significant high correlations were observed between sRPE and Banister’s TRIMP (r = 0.68, p < 0.01), sRPE and Edward’s TRIMP (r = 0.66, p < 0.01) and sRPE and Lucia’s TRIMP (r = 0.74, p < 0.01) in all four swimmers (Table 4.2). Moderate correlations were observed between sRPE and distance measures but were lower than those observed with HR based measures.
Table 4.2 Individual correlations between sRPE, Banister's TRIMP, Edwards’ TRIMP, Lucia’s TRIMP and distance

<table>
<thead>
<tr>
<th>Subject</th>
<th>Banister’s TRIMP</th>
<th>Edward’s TRIMP</th>
<th>Lucia’s TRIMP</th>
<th>Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.65**</td>
<td>0.64**</td>
<td>0.64**</td>
<td>0.59*</td>
</tr>
<tr>
<td>2</td>
<td>0.79**</td>
<td>0.53*</td>
<td>0.76**</td>
<td>0.63*</td>
</tr>
<tr>
<td>3</td>
<td>0.65**</td>
<td>0.85*</td>
<td>0.86*</td>
<td>0.51**</td>
</tr>
<tr>
<td>4</td>
<td>0.64**</td>
<td>0.62**</td>
<td>0.69*</td>
<td>0.40</td>
</tr>
<tr>
<td>Mean</td>
<td>0.68</td>
<td>0.66</td>
<td>0.74</td>
<td>0.53</td>
</tr>
<tr>
<td>± SD</td>
<td>0.07</td>
<td>0.14</td>
<td>0.09</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Pearson product correlation results (r) *correlation significant at p ≤ 0.05 level. **correlation significant at p ≤ 0.01 level.

Evaluation of different session types revealed significant high to very high positive correlations between sRPE and Banister’s TRIMP, sRPE and Edward’s TRIMP and sRPE and Lucia’s TRIMP (Table 4.3) supporting the use of sRPE to quantify TL for all session types in Paralympic swimmers.

Table 4.3 sRPE, Banister's TRIMP, Edwards’ TRIMP and Lucia’s TRIMP correlation during different session types

<table>
<thead>
<tr>
<th>Session Type</th>
<th>Banister’s TRIMP</th>
<th>Edward’s TRIMP</th>
<th>Lucia’s TRIMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic</td>
<td>0.79**</td>
<td>0.73**</td>
<td>0.81**</td>
</tr>
<tr>
<td>Anaerobic threshold</td>
<td>0.67*</td>
<td>0.69*</td>
<td>0.69**</td>
</tr>
<tr>
<td>VO₂max</td>
<td>0.89**</td>
<td>0.82*</td>
<td>0.88**</td>
</tr>
<tr>
<td>High velocity</td>
<td>0.81*</td>
<td>0.77*</td>
<td>0.83**</td>
</tr>
</tbody>
</table>

*correlation significant at p ≤ 0.05 level. **correlation significant at p ≤ 0.01 level.

sRPE data of the four athletes and one coach were collected in 16 sessions (4 aerobic conditioning, 4 anaerobic threshold, 4 VO₂max and 4 high velocity sessions) during the investigation period. Following the protocol of Wallace et al., (2009) sessions were categorised into three intensities according to coach RPE rating (> 3 = easy, 3-5 = moderate and < 5 = hard). A two-way ANOVA indicated significant differences in sRPE between athletes and coach dependent upon the intensity of the training.
session \((F_{(2,108)} = 170.4, \ p < 0.001, \ \eta^2 = 0.75)\). The intended sRPE of the coach was lower than that of the athletes across all three training intensities (Fig. 14). Sessions deemed to be low intensity had the lowest correlation \((r = 0.43, \ p < 0.05)\) whilst moderate correlations were observed during moderate \((r = 0.58, \ p < 0.001)\) and harder intensity \((r = 0.64, \ p < 0.05)\) training sessions.

**Figure 14.** Comparison of athlete and coach sRPE TL during easy, moderate and hard training sessions.
Data presented as mean ± SE. * denotes significance at \(p \leq 0.05\). ** denotes significance at \(p \leq 0.01\)

### 4.5 Discussion

The aim of this study was to determine if the sRPE method for quantifying TL was a valid training monitoring tool for use with Paralympic swimmers. Results demonstrated positive high correlations between sRPE and HR based calculations of Banister’s TRIMP \((r = 0.64 - 0.79, \ p < 0.01)\), Edward’s TRIMP \((r = 0.53 – 0.85, \ p < 0.01)\) and Lucia’s TRIMP \((r = 0.64 – 0.86, \ p < 0.02)\) for quantifying internal TL. In addition, moderate to high correlations were observed between sRPE and the
criterion external load measure of distance \((r = 0.4 - 0.63, p < 0.05)\) but were lower than those observed with HR based measures.

Reliable HR measurement may not always be possible in a Paralympic athlete population as a result of diminished physiological response particularly in athletes with SCI or impairments of the autonomic nervous system (Paulson et al., 2013; Thiesen, 2012). While the four athletes who participated were not affected by an impairment which could impact HR readings, the purpose of this study was to determine a method to quantify internal TL applicable to all Paralympic athletes irrespective of disability or sport. sRPE has been suggested as the most suitable method of monitoring internal TL due to the high-intensity nature of the sport and the interference associated with water-based sport data collection (Wallace et al., 2009). During this study, HR data was interrupted due to technical problems on more than one occasion resulting in lost data for analysis and with HR based TRIMP equations depend on data collected during the full training session, interruption can result in missing significant data points.

sRPE has been shown to be a reliable method of quantifying TL in water-based sports where HR is not easily collected, including diving (Minganti et al., 2011), swimming (Wallace et al., 2009) and water polo (Lupo et al., 2014). Results from the current study support previous research in water-based sports, demonstrating that despite limitations of Paralympic swimmers due to disability, similar TL monitoring tools may be used across both AB and Paralympic populations. Amongst elite divers, Minganti et al., (2011) reported significant strong correlations between Edwards TRIMP and sRPE \((r = 0.71 - 0.96, p < 0.01)\), supporting the use of sRPE in quantifying TL. Lupo et al., (2014) also reported a strong correlation between sRPE and Edwards’ TRIMP \((r = 0.88, p < 0.05)\) in water polo players. Correlations from the current study are not as high as those previously reported by Minganti et al., (2011) and Lupo et al., (2014) but this may be due to the variance in session intensities across the period of data collection which were not specified in the published literature. Findings from the current study demonstrated sRPE and HR based TRIMP measures to be most strongly associated during high intensity sessions \((\dot{V}O_{2\text{max}} r = 0.82 - 0.88, p < 0.01)\) with the lowest association observed during anaerobic threshold sessions \((r = 0.67 - 0.79, p < 0.05)\).
Distance measures do not account for session intensity and as a result, sRPE has been proposed as a more sensitive measure particularly during high-intensity or intermittent training (Foster et al., 2001). Findings from the current study would support this, with poor to moderate correlations observed between sRPE and distance ($r = 0.4 - 0.63$, $p < 0.05$). Research has previously reported the average weekly training of Paralympic swimmers in terms of volume and intensity to be disability class dependent (Fulton et al., 2010). Given that varying disabilities can compete in the same class, it would seem more suitable for training to be prescribed based on disability rather than solely volume using distance. In contrast to distance, sRPE has been shown as a valid and simple use perceptual method of monitoring internal TL (Lovell et al., 2013) and allows for calculation and monitoring of derivative TL measures including training monotony, training strain and ACWR.

Mujika (2017), described three distinct measures of external TL – the planned load before the season, the daily load and the actual load completed by the individual athlete. To ensure accurate prescription of recovery, coaches must ensure the planned TL is equal to the perceived TL of the athlete. Results from the current study demonstrated a divergence between planned TL of the coach and perceived TL of the athlete which was dependent upon the session intensity. Lower intensity sessions had the lowest association between athlete and coach sRPE ($r = 0.43$, $p < 0.05$), whilst association improved as session intensity increased from moderate ($r = 0.58$, $p < 0.001$) to high intensity ($r = 0.64$, $p < 0.05$) sessions. Furthermore, coach sRPE values were lower than that of mean athlete values across the three session intensities. In contrast, amongst national level swimmers, Wallace et al., (2009) reported coach RPE scores to be lower than athletes at low intensity training sessions and coach RPE to be higher than athletes during high intensity training sessions. The difference in results with the current study may be a function of the study population and the fact the coach may have altered sessions for individual swimmers based on their disability, however it does indicate the TL designed was different to what was perceived. Results from the current study highlight the importance of anchoring sRPE use with athletes and coaches for a period of time before using as a TL monitoring tool. Coaches and athletes must also communicate during training sessions to ensure a synergy between the intended session TL and the actual load perceived by the athlete.
4.6 Conclusion

To the author’s knowledge this is the first study of its kind to validate the use of sRPE in quantifying TL in Paralympic swimmers. Based on the findings of this study it was concluded that sRPE may be implemented amongst Paralympic swimmers to reliably quantify TL during water-based training using a single measure. Furthermore, differences were observed between intended sessions intensity by the coach and actual intensity perceived by the athlete, particularly in sessions of low intensity thus highlighting the importance of coach and athlete communication during training sessions. A habituation period is recommended based on our results to ensure coaches and athletes are familiar with the sRPE method when using initially. Having determined sRPE to be a valid method for quantifying TL in Paralympic athletes, it is necessary to investigate its use longitudinally to ensure optimal TL and recovery prescription which will be examined and discussed in Chapter 5 (study 3).
Chapter 5. Longitudinal Monitoring of Athletic Response to Training and Incidence of Illness and Injury in Paralympic Swimming
5.1 Abstract

The purpose of this study was to examine the athletic response to training using sRPE and subjective wellness measures and the relationship with incidence of injury and illness across a 48-week training and competition season in Paralympic swimmers. Having previously investigated subjective wellness measures in Paralympic footballers, this study expanded the number of markers used to include sleep quality, sleep quantity, mood, energy and muscle soreness. Four Paralympic swimmers recorded the five subjective wellness on a daily basis across a 48-week 2015/2016 season. Multi-level analysis identified illness occurrence was associated with increases in weekly TL (22%), cumulative 2wk TL (16%) and ACWR (24%) in the preceding week. A 28% increase in training monotony was observed to be significantly associated with injury. TL variables for Paralympic swimmers which when monitored may reduce the number of training days lost to illness and injury have been identified as well as TL variables which are not associated with injury or illness and may be excluded from monitoring including training strain, chronic TL and cumulative 3wk and 4wk TL. Chronic TL should be included for calculation of ACWR only and not as a stand-alone TL measure. Spearman correlation analysis identified a moderate association between weekly TL and subjective wellness markers of sleep quality ($r_s = -0.69$, $p = 0.002$) and sleep quantity ($r_s = -0.64$, $p < 0.01$) and between ACWR and sleep quality ($r_s = -0.72$, $p = 0.04$) and sleep quantity ($r_s = -0.61$, $p < 0.01$) highlighting the importance of sleep monitoring in Paralympic swimmers. Despite moderate associations evident in Paralympic footballers between TL variables and subjective wellness markers, no other relationships were identified in Paralympic swimmers. Muscle soreness showed no association with TL measures and may not be necessary for inclusion in athlete monitoring of Paralympic swimmers. Markers such as mood and energy also showed no association with TL variables in the current study. However, given the low number of athletes involved in the current study, future research may be needed over multiple seasons to fully examine the response of wellness markers to changes in TL. Thus, it is recommended these markers be included in future investigations of Paralympic sports longitudinally before deciding as scientific research has suggested disruptions in scores for subjective markers including mood may be an early sign of poor recovery or NFOR.
5.2 Introduction

González-Boto et al., (2008) suggest competitive level swimmers are subjected to an elevated TL due to high training frequency and intensity. A review by Ross et al., (2013), reported a daily athlete monitoring system incorporating a validated questionnaire or RPE and physiological parameters provides the most reliable TL information. However, research is required to establish the suitability of different monitoring tools for each specific sport and the athletes involved ensuring adequate and reliable depiction of the training response. Amongst national competitive swimmers, self-reported measures of sleep, recovery, fatigue and heart rate variability were observed to be sensitive to changes in TL across a fifteen-month investigation period (Crowcroft et al., 2017). However, a recent review by Dyer and Deans (2017), reported scientific research to date into Paralympic swimming, and more specifically those swimmers with missing limbs has shown significant biomechanical and physiological differences when compared to AB swimmers. Thus, application of TL research from AB swimming to Paralympic swimming may not be appropriate and warrants further investigation.

Burgess (2017) has suggested the subjective wellness markers used in custom-designed questionnaires are specific to each sport and their athletes. Various sleep indices including sleep quality, duration and phase of sleep have been identified as essential aspects which impact the restorative ability of sleep in promoting recovery (Samuels, 2009); therefore, inclusion of sleep quality and duration in athlete monitoring provides further insight into athlete sleep than monitoring sleep quality alone. Having reviewed the results and observed a dose-response relationship between sleep quality and TL in Paralympic footballers (Chapter 3, Study 1), this study examined sleep as both sleep quality and sleep quantity. Research has also reported on the sensitivity of the marker for muscle soreness to changes in TL (Gastin et al., 2013; Buccheit et al., 2013). Muscle soreness scores have previously been shown to respond negatively to increases in TL over short periods of 3-10 days in collegiate level swimmers (Morgan et al., 1988; O’Connor et al., 1991), thus longitudinal response to changes in TL warrants investigation and this measure was also included. Subjective wellness measures were limited during Study 1 to ensure daily compliance, however based on the results observed and published research by Gastin et al., (2013) suggesting compliance is unaffected with up to ten daily
measures, the research expanded the focus to five subjective wellness measures. Furthermore, Taylor et al., (2012) suggest subjective scores for muscle soreness in TL monitoring give insight into the recovery state of the athlete.

Despite widespread use of athlete monitoring practices, a paucity of information remains in the published scientific research investigating its use within Paralympic athletes. In a previous study with Paralympic footballers (Chapter 3, Study 1), three subjective wellness measures of sleep, energy and mood were shown to significantly decrease during periods of illness with no changes during periods of injury. Furthermore, a negative relationship was observed between TL and subjective wellness markers. Increases in TL measures of weekly TL, cumulative 2wk and 3wk TL and ACWR were shown to be significantly associated with illness in the following week amongst Paralympic footballers. Unfortunately, no relationship was determined between TL variables and incidence of injury. Therefore, the aim of this study was to apply sRPE TL and its associated metrics to an additional Paralympic athlete population of Paralympic swimmers, to determine the relationship with incidences of illness and injury and establish the variables to monitor as part of an athlete monitoring system. Secondly, additional subjective wellness markers of muscle soreness and sleep quantity were examined as part of the investigation to determine the relationship between TL, subjective wellness markers and illness and injury across a training season.

5.3 Methods

5.3.1 Participants

Four elite Paralympic swimmers (1 male, 3 females; age 19 ± 4 yrs, body mass 48.5 ± 7.6 kg) participated in this study. The four swimmers represented the full Irish swim team preparing for and competing at the Rio 2016 Paralympic Games. All testing protocols formed part of the on-going physiological support programme, delivered through the Sport Ireland Institute and Paralympics Ireland, which swimmers were fully familiar with prior to participating in the study. All participants were fully informed of the requirements and potential risks and benefits of participation and provided written informed consent before commencement of data
collection. All experimental procedures were approved by University of Limerick, Faculty of Education and Health Sciences Ethics Committee.

5.3.2 Research Design

Data was collected across the 2015/2016 training season (48 weeks). During the season, TL data was analysed daily and weekly by the researcher in the role as team physiologist to assist with individual athlete TL monitoring and training prescription. TL was calculated for all training completed and included swimming training, strength and conditioning sessions, rehabilitation training, mobility and stretching work and any general conditioning sessions of running, cycling, or other. Swimmers were familiar with the load monitoring recording having completed the process over a familiarisation period of six weeks prior to commencement of the 2015/2016 season and been instructed in its use by the researcher.

5.3.3 Training Load

sRPE having previously been shown as a valid measure for use in Paralympic swimmers, (see Chapter 4: Study 2), was used to quantify TL. Approximately 15 minutes after each training session each athlete was required to rate the intensity of the session according to the CR-10 RPE scale (Borg et al., 1985). Each session duration was recorded in minutes and multiplied by the RPE score given by each swimmer (TL = session duration x intensity). TL was expressed in AU.

5.3.4 Training Load Measures

TL was used to calculate training monotony (weekly TL mean/SD) and training strain (training monotony x weekly TL) (Foster, 1998). The mean weekly TL represented acute workload and a 4-week rolling average represented the chronic workload - ACWR was calculated by dividing acute workload by the chronic workload (Blanch and Gabbett, 2016). Two, three and four-week cumulative TL and week-to-week changes were also calculated as they have been previously associated with increased injury risk previously (Rogalski et al., 2013).
5.3.5 Injury and Illness

Any incidence of injury or illness across the season was recorded in the individual monitoring file and self-reported to the team doctor or physiotherapist. Injury was defined as any pain, tightness or impairment that restricted full participation in training or competition (Clarsen et al., 2013). Illness was defined as any medical issue reported to the team doctor that resulted in the swimmer missing training or where training to be modified (Mountjoy et al., 2015). During any period of injury or modified training, swimmers were required to record all cross-training or rehabilitation training sessions. Individual athlete files were accessible by medical and physiotherapy staff who could flag injury or illness in the event the athlete had not recorded.

5.3.6 Subjective Markers of Wellness

In an expansion from the previous study described in Chapter 3 (study 1), swimmers recorded five subjective markers of wellness – sleep quality, sleep duration, energy, muscle soreness and mood daily. Data was entered each morning with swimmers subjectively rating each variable using an analogue scale ranging from 1 (poor state of well-being) to 5 (good state of well-being) (Appendix C).

5.3.7 Statistical Analyses

Multilevel modelling using Multilevel Models Project MLn (Rasbash et al., 2009) were used to investigate longitudinal training and subjective wellness data with injury and illness occurrence. Multilevel analysis is an extension of multiple regression. Data was not normally distributed determined by significant (p ≤ 0.05) Shapiro-Wilk and Levene tests, therefore non-parametric statistics were used in analysis. Spearman correlations were calculated to determine the relationship between TL measures and subjective wellness markers using SPSS statistical software package v24 (SPSS Inc., Chicago, IL). Cohen’s standard was used to evaluate the correlation coefficient to determine the strength of the relationship: <0.19 very weak, 0.20-0.39 weak, 0.40-0.59 moderate, 0.60-0.79 strong and >0.8
very strong (Cohen, 1988). Statistical significance was set at \( p \leq 0.05 \) for all analyses.

### 5.4 Results

One hundred and ninety-two observations for weekly TL, ACWR, training strain, training monotony, chronic TL, cumulative 2wk, 3wk and 4k TL were recorded across the 48-week season. A total of 7 injuries and 19 incidences of illness were observed during this time.

Mean TL measures for each swimmer are presented in Table 5.1. All TL measures are calculated from the sRPE TL quantified for each training session.

#### Table 5.1 Training load measures of four Paralympic swimmers across a 48wk season.

<table>
<thead>
<tr>
<th>Swimmer</th>
<th>Training Monotony</th>
<th>Training Strain</th>
<th>ACWR</th>
<th>Chronic TL</th>
<th>2wk cumulative TL</th>
<th>3wk cumulative TL</th>
<th>4wk cumulative TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.30</td>
<td>4404.0</td>
<td>1.01</td>
<td>3360</td>
<td>6753</td>
<td>10169</td>
<td>13439</td>
</tr>
<tr>
<td>2</td>
<td>1.33</td>
<td>4541.8</td>
<td>1.01</td>
<td>3542</td>
<td>6885</td>
<td>10232</td>
<td>13466</td>
</tr>
<tr>
<td>3</td>
<td>1.25</td>
<td>4196.9</td>
<td>0.99</td>
<td>3276</td>
<td>6459</td>
<td>9597</td>
<td>12656</td>
</tr>
<tr>
<td>4</td>
<td>1.64</td>
<td>6382.8</td>
<td>1.00</td>
<td>3793</td>
<td>7468</td>
<td>11125</td>
<td>14725</td>
</tr>
</tbody>
</table>

Data presented as means. TL variables calculated from sRPE for each training session.

For the 48-week season, the first 17-weeks were used as macro one pre-season with the remaining 31-weeks considered in-season. Due to the Paralympic Games held in September 2016, the season allowed for a longer pre-season macro period. Mean ± SD weekly TL during pre-season was 3303 ± 584 AU and during in-season was 3471 ± 1026 AU (Fig. 15).

A typical training week consisted of seven to nine pool sessions of approximately two hours duration (14-18 hours weekly) and two gym sessions of one-hour duration (2 hours weekly). Individual swimming programmes were prescribed based upon swimming class; with higher classed swimmers completing the higher training hours.
Cumulative TL was calculated for two, three and four weeks with mean weekly values across the training season $6892 \pm 1594$ AU, $10260 \pm 2100$ and $13531 \pm 2713$ AU respectively. Individual weekly totals for 2, 3 and 4wk cumulative TL are described in Fig. 16. Weekly ACWR was also examined with a 4-week rolling average calculated to represent chronic load and divided into weekly TL (Fig. 17).

Figure 15. Mean weekly TL for Paralympic swim team across a 48-week season
Data presented as mean ± SE. Weekly TL calculated as sum across seven days of sRPE TL. Pre-season period indicated in red, in-season period indicated in blue.
Figure 16. Cumulative TL of 2, 3 and 4 weeks for Paralympic swimmers across a 48-week season
Data presented as means. Cumulative loads calculated from sRPE weekly TL.
Figure 17. Weekly ACWR across the season in four Paralympic swimmers
5.4.1 Subjective Wellness Markers

In agreement with the findings from Chapter 3 (Study 1), a negative relationship was observed between weekly TL and sleep quality (Table 5.2). Additionally, results showed a further negative relationship between weekly TL and sleep quantity ($r_s = -0.648, p < 0.01$). A negative relationship was also identified between ACWR and both sleep quality ($r_s = -0.716, p = 0.04$) and duration ($r_s = -0.612, p < 0.01$).

In disagreement with the findings amongst Paralympic footballers which showed a relationship between weekly TL and training monotony with mood and energy, results amongst Paralympic swimmers did not identify any relationship between TL measures and the subjective wellness measures of mood, energy or muscle soreness (Table 5.2). No association was observed between subjective wellness markers and cumulative TL measures, indicating changes in scores for sleep quality and duration are more sensitive to changes in acute TL measures of weekly TL and ACWR.

<table>
<thead>
<tr>
<th>Sleep Quality</th>
<th>Sleep Duration</th>
<th>Mood</th>
<th>Energy</th>
<th>Muscle soreness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekly TL</td>
<td>-.691*</td>
<td>-.648**</td>
<td>.048</td>
<td>.025</td>
</tr>
<tr>
<td>Training monotony</td>
<td>.015</td>
<td>-.099</td>
<td>.067</td>
<td>.107</td>
</tr>
<tr>
<td>Cumulative 2wk TL</td>
<td>-.037</td>
<td>-.220**</td>
<td>.038</td>
<td>.057</td>
</tr>
<tr>
<td>Cumulative 3wk TL</td>
<td>-.005</td>
<td>-.165*</td>
<td>.038</td>
<td>.097</td>
</tr>
<tr>
<td>Cumulative 4wk TL</td>
<td>.039</td>
<td>-.145*</td>
<td>.075</td>
<td>.102</td>
</tr>
<tr>
<td>ACWR</td>
<td>-.716*</td>
<td>-.612**</td>
<td>-.044</td>
<td>-.080</td>
</tr>
<tr>
<td>Chronic TL</td>
<td>.069</td>
<td>-.158*</td>
<td>.118</td>
<td>.176*</td>
</tr>
</tbody>
</table>

*denotes data significant at $p \leq 0.05$ ** denotes data significant at $p \leq 0.01$.

In agreement with Chapter 3, Study1, results showed sleep quality scores were strongly correlated with scores for energy ($r_s = 0.68, p < 0.01$), muscle soreness ($r_s =$
0.61, p < 0.01) and mood ($r_s = 0.73, p < 0.01$), further demonstrating the importance of sleep for athlete perception of wellness scores.

Multilevel analysis identified a significant decrease in scores for muscle soreness (40%) indicating higher muscle soreness perceived by the athlete during periods of injury compared to periods of no injury. Minimal changes were observed in wellness markers of sleep quality, sleep duration and mood but none were found to be significantly different (Table 5.3).

Table 5.3 Multilevel regression analysis of subjective wellness markers for four Paralympic swimmers and periods of injury during a 48-week training season.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sleep Quality</th>
<th>Sleep Duration</th>
<th>Energy</th>
<th>Mood</th>
<th>Muscle Soreness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed explanatory variables</td>
<td>Estimate</td>
<td>S. Error</td>
<td>Estimate</td>
<td>S. Error</td>
<td>Estimate</td>
</tr>
<tr>
<td>Constant (a)</td>
<td>3.2</td>
<td>0.2</td>
<td>8.8</td>
<td>0.1</td>
<td>2.9</td>
</tr>
<tr>
<td>Injury (Δa)</td>
<td>-0.2</td>
<td>0.2</td>
<td>-0.2</td>
<td>0.3</td>
<td>-0.2</td>
</tr>
<tr>
<td>% Change</td>
<td>6%</td>
<td>2%</td>
<td>0%</td>
<td>10%</td>
<td>40%</td>
</tr>
</tbody>
</table>

Values are means ± SE. Subjective wellness marker scores during periods of no injury were used as constant, indicated by (a) and compared to scores during periods of injury indicated by (Δa). * denotes significant changes from periods of no injury.

In agreement with the findings amongst Paralympic footballers (Chapter 3, Study 1), multilevel analysis identified significant decreases in scores for sleep quality (29%), mood (16%) and energy (17%) during periods of illness (Table 5.4) compared to periods of good health. For the additional subjective wellness markers used in this study, incidences of illnesses were also associated with significant decreases in scores for sleep duration (19%) and muscle soreness (40%) (Table 5.4).
# Table 5.4 Multilevel regression analysis of subjective wellness markers of four Paralympic swimmers and periods of illness across the 2015/2016 training season

<table>
<thead>
<tr>
<th>parameter</th>
<th>sleep quality</th>
<th>sleep duration</th>
<th>energy</th>
<th>mood</th>
<th>muscle soreness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant (a)</td>
<td>3.5</td>
<td>0.2</td>
<td>9.0</td>
<td>0.1</td>
<td>3.0</td>
</tr>
<tr>
<td>Illness (∆a)</td>
<td>-1.0*</td>
<td>0.1</td>
<td>-1.7*</td>
<td>0.2</td>
<td>-0.5*</td>
</tr>
<tr>
<td>% Change</td>
<td>29%</td>
<td>19%</td>
<td>17%</td>
<td>16%</td>
<td>40%</td>
</tr>
</tbody>
</table>

Values are means ± SE. Subjective wellness marker and resting heart rate scores during periods of no illness were used as constant, indicated by (a) and compared to scores during periods of illness indicated by (∆a). * denotes significant changes from periods of no illness.

## 5.4.2 Training Load Measures

In agreement with Study 1, multilevel analysis identified increases in TL measures of weekly TL (743.9 (241.1) AU), 2wk cumulative TL (1073 (366) AU) and ACWR (0.24 (0.06)) were significantly associated with illness in the following week amongst Paralympic swimmers compared to periods of good health and normal training. A 22% increase in mean weekly TL to 4148 AU was associated with the 7-day period prior to illness compared to mean weekly TL of 3405 AU during periods of good health. In contrast to results with Paralympic footballers, no changes were observed in training monotony or cumulative 3wk TL prior to periods of illness (Table 5.5 and 5.6).

In the week prior to reported periods of illness, cumulative 2wk TL totalled 7861 AU, significantly higher (16%) than mean values of 6788 AU during periods of good health and normal training. Furthermore, values for ACWR were also significantly increased (24%) in the week preceding reported illness (Table 5.6).
### Table 5.5 Multilevel regression analysis of TL measures (TL, monotony, strain and chronic TL) of four Paralympic swimmers and periods of illness across the 2015/2016 training season

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Training Load</th>
<th>Monotony</th>
<th>Strain</th>
<th>Chronic TL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>S. Error</td>
<td>Estimate</td>
<td>S. Error</td>
</tr>
<tr>
<td>Constant(a)</td>
<td>3405</td>
<td>110</td>
<td>1.38</td>
<td>0.07</td>
</tr>
<tr>
<td>Illness ((\triangle \text{a}))</td>
<td>743*</td>
<td>241</td>
<td>0.04</td>
<td>0.08</td>
</tr>
<tr>
<td>% Change</td>
<td>22%</td>
<td>3%</td>
<td>2%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Values are means ± SE. TL measures during periods of no illness were used as constant, indicated by (a) and compared to values in the seven days prior to onset of illness indicated by (\(\triangle \text{a}\)). * denotes significant changes from periods of no illness.

### Table 5.6 Multilevel regression analysis of TL measures (cumulative 2, 3, 4wk TL and ACWR) of four Paralympic swimmers and periods of illness across the 2015/2016 training season

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cumulative 2wk TL</th>
<th>Cumulative 3wk TL</th>
<th>Cumulative 4wk TL</th>
<th>ACWR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>S. Error</td>
<td>Estimate</td>
<td>S. Error</td>
</tr>
<tr>
<td>Constant(a)</td>
<td>6788</td>
<td>09</td>
<td>10203</td>
<td>302</td>
</tr>
<tr>
<td>Illness ((\triangle \text{a}))</td>
<td>1073*</td>
<td>366</td>
<td>838</td>
<td>481</td>
</tr>
<tr>
<td>% Change</td>
<td>16%</td>
<td>8%</td>
<td>6%</td>
<td>24%</td>
</tr>
</tbody>
</table>

Values are means ± SE. TL measures during periods of no illness were used as constant, indicated by (a) and compared to values in the seven days prior to onset of illness indicated by (\(\triangle \text{a}\)). * denotes significant changes from periods of no illness.

An additional finding from this study was identification of the TL measure of training monotony to be significantly higher (28%) in the week preceding injury (0.38 (0.12) AU) in Paralympic swimmers (Table 5.7). This is in contrast to the results amongst Paralympic footballers where no significant changes were observed in TL measures prior to injury.
Table 5.7 Multilevel regression analysis of TL measures (TL, monotony, strain and chronic TL) of four Paralympic swimmers and periods of injury across the 2015/2016 training season

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Training Load</th>
<th>Monotony</th>
<th>Strain</th>
<th>Chronic TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant (a)</td>
<td>3475 ± 100</td>
<td>1.37 ± 0.08</td>
<td>4901.2 ± 449.6</td>
<td>3498 ± 102</td>
</tr>
<tr>
<td>Injury (Δa)</td>
<td>99 ± 394</td>
<td>0.38* ± 0.12</td>
<td>284.9 ± 865.2</td>
<td>72 ± 188</td>
</tr>
<tr>
<td>% Change</td>
<td>3% ± 28%</td>
<td>6% ± 2%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± SE. TL measures during periods of no injury were used as constant, indicated by (a) and compared to values in the seven days prior to incidence of injury indicated by (Δa). * denotes significant changes from periods of no injury.

In contrast to periods preceding reports of illness, no other TL measures were found to be significantly different prior to injury occurrence (Table 5.8).

Table 5.8 Multilevel regression analysis of TL measures (cumulative 2, 3, 4wk TL and ACWR) of four Paralympic swimmers and periods of injury across the 2015/2016 training season

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cumulative 2wk TL</th>
<th>Cumulative 3wk TL</th>
<th>Cumulative 4wk TL</th>
<th>ACWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant (a)</td>
<td>6896 ± 191</td>
<td>10296 ± 285</td>
<td>13578 ± 381</td>
<td>1.00 ± 0.02</td>
</tr>
<tr>
<td>Injury (Δa)</td>
<td>71 ± 596</td>
<td>287 ± 772</td>
<td>22 ± 989</td>
<td>0.08 ± 0.10</td>
</tr>
<tr>
<td>% Change</td>
<td>1% ± 3%</td>
<td>0% ± 8%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± SE. TL measures during periods of no injury were used as constant, indicated by (a) and compared to values in the seven days prior to onset of illness indicated by (Δa).

5.4.3 Summary of Results

Amongst Paralympic swimmers, increases in TL measures of weekly TL (22%), cumulative 2wk TL (16%) and ACWR (24%) were found to be significantly
associated with incidence of illness in the following week. Mean weekly TL of 4148 AU was significantly associated with illness in the following week compared to 3405 AU during periods of good health. A 24% increase in ACWR was also significantly associated with illness in the following week. Results observed between weekly TL and 2wk cumulative TL with incidence of illness agree with the findings reported in Paralympic footballers. No association was identified with cumulative 3wk TL in Paralympic swimmers which disagrees with the results of Study 1. Additionally, ACWR was identified as a significant measure to be included in athlete monitoring for Paralympic swimmers.

A further addition of this study was the identification of a TL variable significantly associated with incidence of injury. Increases in training monotony (28%) were found to be significantly associated with injury occurrence in the following week. Findings amongst Paralympic footballers were unable to identify a relationship between any TL measure and injury occurrence.

Amongst both Paralympic footballers and swimmers, chronic TL and cumulative 4wk TL showed no association with injury or illness, and no relationship was identified with subjective wellness markers supporting the earlier statement that its use should be limited to calculation of ACWR and not as a stand-alone TL measure.

Scores for all subjective wellness markers of sleep quality, sleep duration, mood, energy and muscle soreness were significantly lower (16-40%) during periods of illness compared to periods of good health. During periods of injury, scores for muscle soreness were observed to be significantly lower (40%) compared to periods of no injury. Minimal changes (0-10%) were identified in other subjective wellness markers with none significantly different.

In agreement with the findings from Chapter 3 (Study 1), a dose-response relationship was observed between weekly TL and subjective wellness markers of sleep quality and sleep duration. No relationship was identified between TL measures and wellness measures of energy or mood, a direction contrast to the findings from study 1. Furthermore, while no relationship between subjective wellness markers and training monotony was observed in this study, an increase in ACWR was associated with decreases in scores for both sleep measures.
Finally results from this study present the quantified TL of Paralympic swimmers across a 48-week training season in preparation for competition at the Rio 2016 Paralympic Games. A 17-week pre-season macro period presented a mean ± SD weekly TL of 3303 ± 584 AU whilst during the 31-week in-season period, TL equated to 3471 ± 1026 AU.

5.5 Discussion

The goal of a multi-faceted athlete monitoring system is to closely follow indicators of maladaptation to training which may impact on performance and intervene to prevent such maladaptation from continuing (Soligard et al., 2016; Schwellnus et al., 2016). Thus, this is the first investigation into the athlete response of Paralympic swimmers to training and the relationship with incidence of injury and illness across a training season. Following on from the results reported in Paralympic footballers (Chapter 3, Study 1), additional subjective wellness markers of sleep duration and muscle soreness were included in this research study. Results demonstrated a moderate relationship between weekly TL and ACWR with subjective wellness markers of sleep quality and sleep quantity only. Contrary to findings observed in Study 1, no relationship was identified between TL measures and subjective wellness markers of energy, mood or muscle soreness. TL measures of weekly TL, cumulative 2wk TL and ACWR were shown to be significantly greater in the week preceding illness compared to periods of good health. Additionally, training monotony was observed to be significantly higher prior to incidence of injury. Findings from the current study highlight the importance of regular TL monitoring in Paralympic swimmers and identifies specific TL monitoring variables associated with incidence of both illness and injury.

A major finding of this research study is the quantification of TL for Paralympic swimmers across a 48-week training season in preparation for the 2016 Rio Paralympic Games. Elite-level swimmers complete demanding training practices in order to develop the appropriate physiological and biomechanical capabilities specific to the sport (Pyne and Sharp, 2014). Previous research has reported Paralympic swimmers weekly training mileage to range 38-52 km in preparation for performance at Paralympic Games (Edmonds et al., 2015), however no sRPE TL were specified in this study. Results from the current study showed a mean weekly
TL of 3303 ± 584 AU and 3471 ± 1026 AU during pre-season and in-season periods respectively for the four Paralympic swimmers. Furthermore, using sRPE has determined variables including monotony, strain and ACWR across the training season. Successful performance is dependent upon coaches and support staff devising training plans that provide both an adequate training stimulus and associated recovery which can be challenging for Paralympic athletes due to limitations associated with physical disability. Consequently, this TL data adds to the current scientific research on Paralympic swimmers, needed by coaches to effectively profile both the sport and the athletes.

The training schedule of elite swimmers, particularly early morning training, has been reported to restrict the quality and duration of sleep (Sargent et al., 2014), highlighting the need to include sleep as a variable in the monitoring of Paralympic swimmers. Results from the current study demonstrated a moderate negative relationship between weekly TL and scores for sleep quality ($r_s = -0.69, p < 0.05$) and duration ($r_s = -0.65, p < 0.01$) as well as between ACWR and sleep quality ($r_s = -0.716, p < 0.05$) and duration ($r_s = -0.612, p <0.01$). Amongst elite synchronized swimmers, significant reductions in both sleep quality and duration were previously reported alongside increased fatigue and impaired performance during a period of FOR (Schaal et al., 2015). However, this research reported changes over a short four-week period only. Samuels (2008) reported sleep quality, sleep duration and phase of sleep as key aspects impacting on the restorative abilities of sleep. Despite similar values evident for sleep quality and duration with weekly TL, it is recommended to continue monitoring both variables. Disturbance in sleep quality has been highlighted as an early sign of poor recovery or NFOR in athletes (Meeusen et al., 2016) whilst sleep duration can inform on norm values during periods of disturbance such as prior to competition (Juliff, Halson and Peiffer, 2015). Strong positive correlations were also observed in the current study between scores for sleep quality and energy ($r_s = 0.68, p < 0.01$), mood ($r_s = 0.73, p < 0.01$) and muscle soreness ($r_s = 0.61, p < 0.01$) demonstrating the impact of sleep on other subjective wellness markers. Following the recommendations of published research and the findings from the current study, both sleep quality and duration should be included in a multi-faceted athlete monitoring system.
No other relationships were identified between TL and subjective wellness measures amongst Paralympic swimmers. This is in direct contrast to results from Paralympic footballers (study 1) which identified a moderate to strong relationship between weekly TL and subjective wellness measures of sleep quality, mood and energy. Inclusion of the muscle soreness variable in the monitoring of Paralympic swimmers has shown to be unnecessary given that no relationship was observed with any TL variables. Results from the current study disagree with previous research showing a negative response to increases in TL in collegiate level swimmers (Morgan et al., 1988; O’Connor et al., 1991), however this research was conducted over brief periods of 3-10 days and not longitudinally. Therefore, results would suggest it should be removed from athlete monitoring for Paralympic swimmers as it does not provide any additional information on the athletic response to coaches or support staff. Physiological demands between Paralympic football and swimming are different, most notably the fact that swimming is water-based activity and non-weight bearing, therefore it may warrant investigation as a variable in Paralympic football or other Paralympic sports in future research. Results from the current study also disagree with previous research which demonstrated a disturbance in mood scores in response to increases in TL (González-Boto et al., 2008). Additionally, amongst Paralympic footballers, scores for mood showed moderate negative association with both weekly TL and training monotony. Given that the same measurement scale was used with both athlete groups, it is possible the difference in training program design contributed to the lack of relationship evident between subjective wellness markers and TL variables. With just four Paralympic swimmers representing the full national team across the 48-week study period, coaches and support staff had more contact time with the athletes and could make daily adjustments to TL if deemed necessary and as a result, fluctuations in daily wellness scores in response to changes in TL may have been limited. Mood disturbance has previously been highlighted as an early sign of poor recovery or NFOR in athletes (Meeusen et al., 2013 and recommended for inclusion in athlete monitoring (Halson, 2014a; Soligard et al., 2016). Therefore, despite the results from the current study it is recommended to continue monitoring mood as part of an athlete monitoring system for Paralympic swimmers for additional training seasons in order to examine the relationship between mood and TL variables before removing.
Early research by Foster (1998) demonstrated 84% of illnesses in athletes could be explained by a preceding spike in TL. In agreement with these findings, results from the current study showed a 22% increase in weekly TL (744 (241) AU) to be significantly associated with illness. Furthermore, a 16% increase in cumulative 2wk TL and a 24% increase in ACWR were also significantly associated with reports of illness in the following week amongst Paralympic swimmers. Findings from the current study agree in part with those observed amongst Paralympic footballers (Chapter 3, Study 1) for weekly TL and cumulative 2wk TL. Jones et al., (2017) has previously reported that athletes who are subjected to spikes in TL without sufficient recovery are exposed to an extended period of immuno-suppression placing them at higher risk of illness. Results investigating Paralympic athletes agree, given that weekly TL and cumulative 2wk TL were significantly associated with incidence of illness in both Paralympic swimmers and footballers and would support the inclusion of both variables in an athlete monitoring system.

An additional finding of the current study was the relationship between injury occurrence and a sRPE variable. Of the eight TL variables examined, training monotony was the single measure observed to be significantly higher (28%) in the week preceding injury. Foster et al., (1995) previously reported high monotony scores (> 2.0 AU) to increase the injury and illness risk in athletes. From the current study, a mean monotony score of 1.75 AU was significantly associated with injury compared to mean values to 1.37 AU during periods of good health. Lower TL due to the disabilities of Paralympic swimmers may contribute to the lower monotony range associated with injury. However, results are in contrast with those observed amongst Paralympic footballers which did not identify any TL variables associated with injury. Schwellnus et al., (2016) suggests monitoring variables may be sport specific. Findings from the current study would support this statement given the disparity found between two athlete groups of swimmers and footballers. Despite this, the current study has identified variables for inclusion in an athlete monitoring system that are associated with both illness and injury for practitioners and coaches of Paralympic swimmers.
5.6 Conclusion

The current study is the first of its kind to longitudinally examine the response of Paralympic swimmers and incidences of injury and illness across a training season. Illness occurrence was associated with increases in TL, cumulative 2wk TL and ACWR in the preceding week whilst injury incidence was associated with an increase in training monotony in the preceding seven days. This research has identified TL variables for Paralympic swimmers which when monitored may reduce the number of training days lost to illness and injury.

Results have also identified variables which are not associated with injury or illness and support the findings from Paralympic footballers and may be excluded from monitoring including training strain, chronic TL and cumulative 4wk TL. Furthermore, cumulative 3wk TL showed no association with incidence of injury or illness in Paralympic swimmers and may also be excluded from monitoring in this athlete population. Chronic TL should be included for calculation of ACWR only and not as a stand-alone TL measure.

Acute TL measures of weekly TL and ACWR were shown to be significantly associated with subjective wellness markers of sleep quality and sleep duration, highlighting the importance of sleep monitoring in Paralympic swimmers. Despite moderate associations evident in Paralympic footballers between TL variables and subjective wellness markers, no other relationships were identified in Paralympic swimmers. Muscle soreness showed no association with TL measures and may not be necessary for inclusion in athlete monitoring of Paralympic swimmers. However, given that swimming is water-based and non-weight bearing, the use of muscle soreness as a subjective wellness marker should be investigated in other sports before removal as it may inform coaches and support staff on the athletic response of those in weight bearing sports.

Markers such as mood and energy also showed no association with TL variables in the current study. However, given the low number of athletes involved in the current study, future research may be needed over multiple seasons to fully examine the response of wellness markers to changes in TL. Thus, it is recommended these markers be included in future investigations of Paralympic sports longitudinally.
before deciding as scientific research has suggested disruptions in scores for subjective markers including mood may be an early sign of poor recovery or NFOR.

A limitation of the current study is the low number of athletes with future research needed to possibly investigate multiple seasons as the population of national Paralympic swimmers is not as extensive as other national Paralympic sports teams.

This research has now identified subjective markers of TL which can be included in the athlete monitoring systems of Paralympic swimmers and footballers. Objective measures of TL, such as salivary biomarkers, are also recommended to ensure full depiction of the athletic response to training. Therefore, further investigation is required to examine the salivary biomarker responses to TL in Paralympic swimmers and their suitability for inclusion in a multi-faceted athlete monitoring system.
Chapter 6. Salivary Biomarker Monitoring and Training Load in Elite Paralympic Swimmers during Training and Competition

As per the peer-reviewed paper published in *International Journal of Sports Physiology and Performance*.

6.1 Abstract

Objective measures of internal TL such as salivary biomarkers have been recommended for use alongside subjective wellness markers for effective athlete TL monitoring (Burgess, 2017). The aim of this study therefore was to examine the relationship between TL and salivary biomarkers IgA, AA and cortisol across a 16-week preparation phase and 10-day competition phase in Paralympic swimmers. Four Paralympic swimmers provided bi-weekly saliva samples during three training phases – 1) normal training, 2) intensified training, 3) taper as well as daily saliva samples in the 10-day Paralympic competition (2016 Paralympic Games). TL was measured using sRPE. Multi-level analysis identified a significant increase in sIgA (64%, (94.98 (27.69) µg.ml\(^{-1}\)), sAA (66%, (45.78 (19.07) µg.ml\(^{-1}\))) and salivary cortisol (49%, (7.92 (2.17) nM)) during intensified training concurrent with a 38.3% increase in TL. During taper phase, a 49.5% decrease in TL from the intensified training phase resulted in a non-significant decrease in sIgA, sAA and salivary cortisol; however, all three remained higher than baseline levels. A further significant increase was observed during competition in sIgA (168.69 (24.19) µg.ml\(^{-1}\), sAA (35.86 (16.67) µg.ml\(^{-1}\)) and salivary cortisol (10.49 (1.89) nM) despite a continued decrease (77.8%) in TL from taper phase. During the three training phases, results demonstrate a dose-response relationship between TL and salivary biomarkers, thus supporting their use as an objective measure of internal TL in Paralympic swimmers. Performance during major competition such as Paralympic Games induces a stress response in athletes despite a noticeable reduction in TL. Due to the elevated stress response observed, modifications to individual post-race recovery protocols may be required to enable athletes to maximise performance across all ten days of competition.
6.2 Introduction

Responses to athletic stress are highly individualised (Halson, 2014a), thus athlete monitoring is utilised to understand the individual response to a training stimulus. According to Fry et al., (1991) multi-faceted athlete monitoring should be applied to effectively evaluate training response and include physiological, psychological, biochemical and immunological markers. Having established sRPE to be a valid method to quantify TL in Paralympic swimmers (Chapter 4, Study 2) and determining the appropriate subjective wellness markers for inclusion in daily monitoring (Chapter 5, Study 3), the aim of the current study was to examine the response of salivary biomarkers to TL and competition in Paralympic swimmers.

It has been proposed that in order to fully quantify the training stress and subsequent response of the individual athlete, a combination of internal and external TL measures should be utilised (Bourdon et al., 2017). One such monitoring tool that has emerged over recent years is salivary monitoring – non-invasive saliva measures which can be analysed for immunological and stress biomarkers including sIgA, sAA and salivary cortisol. These salivary biomarkers provide an effective, non-invasive, easily accessible monitoring tool and can be measured quickly and repeatedly in both laboratory and field settings (Papacosta and Nassis, 2011). The non-invasive collection of salivary samples ensures the suitability for inclusion in a multi-faceted athlete monitoring system, in an attempt to fully understand the athletic response to training. Regular monitoring of controlled resting levels of salivary biomarkers has been recommended to determine individual reference data as variations within and between subject groups imply that the stress response to TL, competition and additional external stressors is highly individual (Neville, Gleeson and Folland, 2008). Furthermore, the emergence of a validated point of care test for sIgA, sAA and salivary cortisol has allowed for quick analysis of salivary biomarkers in the training and competition field (Edmonds et al., 2015). Given the sensitivity of immune function to physiological and psychological stressors, immune and stress salivary biomarkers may assist in monitoring the athletic responses to training and competition demands.

sIgA is the predominant immunoglobulin secreted at mucosal surfaces and has a primary role in defence against infection of the upper respiratory tract (Schroeder and Cavacine, 2010). According to Tiollier et al., (2005), monitoring immune
function through sIgA provides a marker of the athletic response to training and recovery. In a study assessing sIgA and illness in elite swimmers during a seven-month training period, Gleeson et al., (1999) reported the median concentration of sIgA to be significantly lower in athletes who reported with higher incidence of upper respiratory tract infection (URTI) \((r_s = -0.51, p = 0.01)\). Changes in sIgA levels may also indicate periods of excessive training or inadequate recovery (Libicz et al., 2006). Previous research has shown sAA to acutely respond to stressors both physiological and psychological (Chatterton et al., 1996), with the response appearing to peak rapidly at the onset of a stressor before returning to baseline levels within 30-60 minutes (Kivlighan and Granger, 2006). A negative correlation was reported between sAA and TL in swimmers over a 21-week period (Diaz et al., 2013) whilst Edmonds et al., (2015) suggest sAA response may be a more sensitive tool than heart rate variability (HRV) to TL of varying intensities. Cortisol levels have been shown to increase concurrently with TL in swimmers (O’Connor et al., 1989) while in rugby union players increases were observed following an international level game and remained elevated above pre-game levels fourteen hours later (Cunniffe et al., 2010).

Despite the shift in focus from rehabilitative participation to elite level sport, research into Paralympic sport has lagged behind the large body of scientific investigation of AB athletes. TL and athletic response must be monitored in a bid to fully understand the training and recovery needs of this highly individual athletic population. Thus far, this research has determined the suitability of sRPE and subjective wellness markers of sleep quality and duration, mood, energy, muscle soreness in monitoring TL and reducing risk of injury and illness in Paralympic athletes. However, multi-faceted athlete monitoring requires both objective and subjective data to fully depict the athlete response (Bourdon et al., 2017). Therefore, the aim of this study is to examine the salivary biomarker responses to TL in Paralympic swimmers. Furthermore, the study will aim to determine the stress response in participation of major competition and the impact on the individual athlete.
6.3 Methods

6.3.1 Participants

Four elite Paralympic swimmers (1 male, 3 female, age 19 ± 4 yrs, body mass 48.5 ± 7.6 kg) selected for competing at Rio 2016 Paralympic Games participated in this study. The athletes had been competing regularly in international competitions for at least 2 years. All four athletes had competed and reached finals in the World Championships in the previous 12 months. Testing protocols formed part of the on-going physiological support programme which swimmers were familiar with before participation in this study. All participants were fully informed of the requirements and potential risks and benefits of participating with a written informed consent completed before commencement of data collection. All experimental procedures were approved by University of Limerick Ethics Committee.

6.3.2 Experimental Design

Athletes were monitored throughout a twelve-month training period in the run-up to the 2016 Paralympic Games. Four periods of collection were established in the 16 weeks before the Paralympic Games:

1) a baseline non-competition period of 4 weeks (11 samples)

2) an intensified training period of 2 weeks (6 samples)

3) a taper phase of 10 days (4 samples)

4) a competition period of 10 days (10 samples).

No samples were collected during the first seven days upon arrival in Brazil in order to reduce any impact of travel fatigue and jet lag on salivary biomarker response. During the non-competition periods, salivary data was collected twice weekly to determine a baseline hormonal profile whilst daily samples were made during the Paralympic Games competition to depict the salivary hormone response when competition stress would be highest.
6.3.3 Salivary Data

In order to control for any waking responses and dietary influences, saliva samples were collected in the morning, 30 minutes after waking, before breakfast and before any physical exercise had been undertaken. Sampling was kept to a consistent one-hour time block for each athlete to minimise impact of circadian variation on salivary biomarkers. Swimmers were instructed not to brush their teeth before providing the saliva sample. Salivary samples were collected using an IPRO (Soma Bioscience, Wallingford, UK) oral fluid collector (OFC) kits (Fig. 18).

![Figure 18. IPRO oral fluid collector kit (Soma Bioscience)](image)

The ease of sample collection using the IPRO OFC kits allowed athletes to collect their saliva sample at home. The sampling protocol was followed in accordance with manufacturer's guidelines. The OFC is placed in the mouth and collects 0.5mL of saliva in one sample (Fig. 19). A volume indicator within the swab handle changed colour to indicate when sufficient saliva volume has been collected.

![Figure 19. Saliva sample collection using the IPRO OFC kit (Soma Bioscience)](image)
The swab was then removed from the mouth and placed into the IPRO OFC buffer. The duration of collection time was less than 60s. The buffer contains extraction agents to draw the target analytes from the swab into the buffer. Samples were analysed using an IPRO lateral flow device (LFD) with separate cartridges used to analyse IgA/AA and cortisol. The IPRO device has been considered reliable through comparison of two saliva samples collected concurrently \( (r = 0.89, \ p < 0.01 \text{ and } CV = 9.4\%) \) and valid through comparison against ELISA analysis \( (r = 0.93, \ p < 0.01) \) in measuring sIgA (Coad et al., 2015). For sAA, test re-test reliability was conducted through re-testing of samples \( (CV = 13.2\%) \) and validity against ELISA analysis \( (r = 0.87, \ 95\% CI 0.78-0.92) \) (Dunbar et al., 2015). Dunbar et al., (2013) reported test re-test reliability \( (r = 0.93, \ p < 0.05) \) and validity through comparison against ELISA analysis \( (r = 0.79, \ p < 0.01) \) of the IPRO device in measuring salivary cortisol. Two drops of buffer mix from the collector kit were added to the sample window on the LFD cartridges. After a standing time of 10 min, sample intensity is measured in an IPRO LFD reader and a quantitative value given.

### 6.3.4 Training Load

TL was calculated using sRPE as proposed by Foster et al., (1995) and validated in Chapter 4 (Study 2). Approximately 15 minutes after every training session (Kraft et al., 2015) swimmers were asked to rate the intensity of the session using the CR-10 RPE scale (Borg et al., 1985). The total session duration including warm-up and cool-down was recorded in minutes and multiplied by the RPE score given by each athlete \( (\text{TL} = \text{duration} \times \text{intensity}) \). TL is expressed in AU.

### 6.3.5 Statistical Analysis

Mean and standard error were calculated for TL, salivary IgA, alpha-amylase and cortisol levels collected during the four training phases. Data was analysed using multilevel modelling approach using Multilevel Models Project MLn (Rasbash et al., 2009) to investigate longitudinal (repeated measures) data. Multilevel analysis is an extension of multiple regression. A random intercept model with 2 levels was created for IgA, AA and cortisol separately – time (level 1) nested within athlete.
(level 2). Analysis was used to identify changes in mean values of three salivary biomarkers across the four identified time periods.

6.4 Results

Mean TL and salivary biomarkers levels during the four training phases are presented in Fig. 20.

Figure 20. TL, salivary cortisol, sIgA and sAA across four training phases in Paralympic swimmers
Data mean ± SE. Salivary IgA (µg.ml⁻¹), salivary cortisol (nM), salivary alpha-amylase (µg.ml⁻¹) and TL across the four training phases (1=baseline, 2=intensified training, 3=taper, 4=competition). * indicates significant change (p ≤ 0.05) between baseline and intensified training periods (phase 1 and 2). ** indicates significant change (p ≤ 0.05) between baseline and competition periods (phase 1 and 4)
Significant within-athlete differences were observed for sIgA (11253.38 (1497.10) µg.ml\(^{-1}\)), sAA (5341.12 (710.64) µg.ml\(^{-1}\)) and salivary cortisol (68.08 (9.19) nM) between the three training and one competition phases researched, demonstrating the individual response and needs of the athletes (Fig. 21).

![Graphs showing training load and salivary biomarker responses](image)

**Figure 21. Individual TL and salivary biomarker responses in four Paralympic swimmers during three training phases**

Data presented as means and shows responses of sIgA, sAA and salivary cortisol across three training phases of normal training, intensified training and taper. Multi-level analysis identified significant within-athlete differences in salivary biomarker levels showing the sensitivity of the measures to changes in TL whilst no significant between-athlete differences were observed.

The multi-level analysis (Table 6.1) identified a significant increase of 64% in levels of sIgA (94.98 (27.69) µg.ml\(^{-1}\)), 66% increase in sAA (45.78 (19.07) µg.ml\(^{-1}\)) and a 49% increase in salivary cortisol (7.92 (2.17) nM) from baseline to intensified training. Increases were concurrent with a 38.3% increase in TL during this period.
Table 6.1 Multilevel analysis of salivary levels for the four swimmers competing at the 2016 Paralympic Games.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>sIgA</th>
<th>sAA</th>
<th>Salivary cortisol</th>
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Values are means ± SE. Baseline training salivary levels were used as constant, indicated by (a) and compared to levels during three other training phases indicated by (△a). Changes from baseline in all three salivary markers were significant at intensified training phase and again during competition phase. *denotes significance from baseline. The between-subject variances (at level 2) were not significant but the within subject variances (at level 1) were all significant.

During taper phase, a 49.5% decrease in the TL from the intensified training phase resulted in a decrease of sIgA (28.5%), sAA (14%) and salivary cortisol (25.5%) levels. However, all three biomarker levels remained higher than baseline levels though this was not found to be significant.

Further significant increases in sIgA of 113% (168.69 (24.19) µg.ml⁻¹), 52% sAA (35.86 (16.67) µg.ml⁻¹) and 64% salivary cortisol (10.49 (1.89) nM) were observed during competition phase compared to baseline. Increases in all three biomarkers occurred despite a continued decrease of 77.8% in TL from taper phase.
No changes between race and rest day mean levels of sIgA (380.62 µg.ml$^{-1}$ vs 379.77 µg.ml$^{-1}$) were observed. In contrast, significant differences were observed between race and rest days mean levels of salivary cortisol (31.14 ng vs. 23.95 nM) and sAA (138.62 vs 82.81 µg.ml$^{-1}$), further demonstrating an elevated stress response associated with participating in a Paralympic Games.

6.5 Discussion

The present study was designed to examine TL and the associated stress response through the measurement of three salivary biomarkers in four Paralympic swimmers during training and performance in major competition. sIgA, sAA and salivary cortisol were shown to respond to changes in TL across the training season during phases of normal, intensified and taper training. During a period of intensified training, a 38.3% increase in TL was associated with significant increases in all three salivary markers while a subsequent decline in TL of 49.5% during a taper phase coincided with significant decreases in sIgA, sAA and salivary cortisol. Interestingly, despite a further 77.8% reduction in TL from taper phase, during the Paralympic Games salivary biomarkers were significantly increased from baseline demonstrating an induced psychophysiological stress response in all four Paralympic swimmers.

The emergence of a validated point of care test for sIgA, sAA and salivary cortisol has allowed the quick analysis of salivary biomarkers (Edmonds et al., 2015). Longitudinal studies amongst elite endurance athletes have shown sIgA levels to decrease in response to increases in training volume and duration, with a decline contributing to the increased risk of illness in athletes (Neville et al., 2008). In contrast, findings from the current study observed a significant increase of 64% in sIgA from baseline during intensified training period correlating with a 38.3% increase in TL. In a study investigating high school basketball players, Tharp (1991) reported a 25.1 µg.ml$^{-1}$ increase in mean sIgA levels across a season and suggested chronic training may result in increases in resting IgA levels providing further protection from infection risk. Supporting this Gleeson and Walsh (2012) reported that moderate exercise can actually increase sIgA concentrations thus decreasing the risk of URTI. The four athletes participating in the current study were 4-5 weeks away from competition during the intense training camp after a long training season.
and combined with sufficient recovery may explain why no decreases occurred in sIgA. Following this, a taper phase characterised by a gradual decrease in training volume and increase in intensity resulted in a drop in TL and a subsequent decline in levels of sIgA, sAA and salivary cortisol. Individual data showed a decline in sIgA during the taper phase in two swimmers and an increase in two swimmers, however, no illness was reported amongst the group during this time. An increase in sIgA has previously been suggested to be attributable to increased sympathetic nervous system activation in response to competition (Tanner and Day, 2017), thus may account for the increases observed in two of the Paralympic swimmers in this research.

Athletic competition has been shown to induce a stress response in athletes (Kivlighan and Granger, 2006; Diaz et al., 2013; Edmonds et al., 2015; Chennaoui et al., 2016). Findings from this study demonstrated a significant increase in sAA levels during competition compared to baseline and are in line with those reported by Edmonds et al., (2015) who observed a prolonged elevation in sAA for up to 48 hours following a weekend of elite level competition in disability swimmers. Furthermore, Diaz et al., (2013) compared sAA levels before and after a race event during competition and on a control day in swimmers and reported higher levels during competition which were attributed to increased psychological and physical stress. The increase in sAA in the current study during the competition phase can be potentially attributed to two stressors – an elevation from increased competition performance as well as the psychological stress of participating in a major competition.

Salivary cortisol has been extensively researched as an indicator of training stress. In the current study, it was identified that during the intensified training phase an increase in TL of 38% from baseline induced a stress response in athletes and resulted in a significant increase in salivary cortisol levels. Furthermore, a decrease in salivary cortisol during the taper phase was accompanied by a decline in TL of 49.5%. However, further decreases in TL during the competition phase were not associated with additional declines in salivary cortisol levels as would have been expected with a decrease in training stress. A study in soccer players showed a reduction in cortisol during recovery periods compared to periods of intense training (Filaire et al., 2003). The present study showed similar findings with a mean decrease in salivary cortisol levels during taper phase following an increase during
the intensified training phase. In contrast, salivary cortisol levels actually increased significantly again from baseline to their highest levels during the competition phase at a point where TL was lowest. The continued increase in salivary cortisol levels during this competition phase may be explained by an elevated psychological stress response induced by performance in a major competition such as the Paralympic Games.

According to Kellmann (2010) heightened stress levels in athletes can limit the ability to recover and require additional recovery activities. Results from this study indicate post-race recovery must account for not just the physiological stress on the body as a result of racing, but also the individual physiological and psychological stress response to major competition. Additional recovery modalities, including nutritional intervention, enhanced sleep both quality and quantity and increased post-race swim down may be necessary to meet the increased recovery demand of athletes and assist in maximising performance across all days of competition. Furthermore, findings by Edmonds et al., (2016) showed increased sAA levels in Paralympic swimmers in response to competitive performance continue even with light recovery training and further support the need to recognise the increased recovery needs of athletes. Results from the current study also highlight the large inter-individual differences in salivary biomarker responses of athletes. Significant within athlete differences were observed for sIgA (11253.38 (1497.10) µg.ml\(^{-1}\)), sAA (68.08 (9.19) µg.ml\(^{-1}\)) and salivary cortisol (5341.12 (710.64) nM) between the four training and competition phases examined, further highlighting the individual response and needs of athletes.

### 6.6 Conclusion

This study aimed to examine responses of sIgA, sAA and salivary cortisol to training and performance in major competition. All three salivary biomarkers were shown to respond to changes in TL with increases during more intense training and decreases during taper. Performance in major competition was shown to induce a psychophysiological stress response in athletes. Significant increases in sAA and salivary cortisol levels were observed during competition compared to baseline despite relatively low TL. Thus, it is reasonable to associate the response with increased psychological stress of participating in a competition as significant as the Paralympic Games. Given the significant changes observed in response to TL, it is
recommended to include salivary biomarkers as a measure within a multi-faceted monitoring system for Paralympic athletes. Findings of this study support the use of salivary biomarkers as an objective measure of quantifying athletic response and can be combined with subjective variables of sRPE and subjective wellness markers in Paralympic athletes.
Chapter 7. Research Summary, Limitations, Conclusions and Future Recommendations
7.1 Research Summary

This research investigated TL monitoring tools for inclusion in a multi-faceted athlete monitoring system for Paralympic athletes and their association with incidence of illness and injury. Longitudinal athlete monitoring is essential to ensure adequate evaluation of the individual athlete response to demands of training and competition (Kellman, 2002). Having identified sRPE as a single measure of TL for all Paralympic athletes regardless of disability, its application was examined in two athlete populations – ten Paralympic footballers and four Paralympic swimmers. Increases in TL measures of weekly TL (11%), training monotony (36%), cumulative 2wk (11%) and 3wk TL (8%) and ACWR (29%) were identified to significantly increase in the week preceding illness occurrence in Paralympic footballers.

In Paralympic swimmers increases in weekly TL (22%), cumulative 2wk TL (16%) and ACWR (24%) were significantly higher in the week preceding illness occurrence. Despite a 3% increase in TL measures, no significant associations were identified with injury occurrence in Paralympic footballers. In contrast, a 28% increase in training monotony was significantly associated with injury in Paralympic swimmers. Findings from this research have identified specific TL variables associated with incidence of injury and illness, which should be monitored in Paralympic footballers and swimmers as part of multi-faceted athlete monitoring system. Additionally, TL variables which are not associated with illness or injury in either population have been identified as chronic TL, cumulative 4wk TL and training strain, and can be removed from athlete monitoring of Paralympic swimmers and footballers.

Subjective wellness markers have been supported as a simple yet informative tool for monitoring TL (Saw et al., 2015) and have been suggested to show negative athlete response to TL before objective measures (Coutts et al., 2007). However, these markers and their subsequent responses have yet to be investigated amongst Paralympic athletes. Based on a thorough review of the scientific literature, pertinent subjective wellness markers of sleep quality and duration, mood, energy and muscle soreness were identified and their response to changes in TL then investigated. Scores for subjective wellness sleep quality, mood and energy were shown to be significantly lower during periods of illness compared to periods of good health in
Paralympic footballers while amongst Paralympic swimmers scores for sleep quality, sleep duration, mood, energy and muscle soreness were all significantly lower during periods of illness. Muscle soreness scores were the only subjective wellness marker to be significantly lower during periods of injury amongst Paralympic swimmers compared to periods of good health. Negative correlations were observed between TL and sleep quality in Paralympic footballers and sleep quality and duration in Paralympic swimmers, highlighting the importance of sleep monitoring in Paralympic athletes.

Finally, salivary biomarkers were examined in response to changes in TL and competition as an objective measure of internal TL monitoring. During three training phases, a dose-response relationship was observed between TL and three salivary biomarkers, supporting their use as an objective measure of internal TL. An elevated stress response was identified during performance in major competition despite a noticeable reduction in TL and highlights the possible modifications which may be needed in post-race recovery protocols to maximise competition performance.

7.2 Study Limitations

- A limitation of this research is not collecting data regarding the injury occurrence, location of injury and nature of injury to further inform on TL responses and potential injury surveillance of Paralympic athletes.
- The low number of athletes in the Paralympic swimming research is a research limitation, despite the four athletes representing the full national team.
- In the salivary biomarkers research amongst Paralympic swimmers, a limitation was the absence of a psychological assessment measure, for example POMS or RESTQ-Sport to understand the stress impact of competition participation on athletes.

7.3 Summary of Key Findings

The over-arching aim of this research was to determine if a multi-faceted athlete monitoring system for use with Paralympic athletes could identify the individual
response to training, competition and recovery, and the relationship with incidence of illness and injury. A number of conclusions can be drawn from the four studies including:

- **sRPE** is a valid method to quantify internal TL in Paralympic swimmers (Table 4.2) and can be utilised by coaches and support staff. However, coach-RPE was shown to be lower than that of the athletes across training sessions of easy, moderate and hard intensities and may require a period of familiarisation between coaches and athletes as well as clear communication to discuss sessions when used initially.

- TL measures associated with illness occurrence are different amongst Paralympic swimmers and footballers. Increases in TL, cumulative 2wk TL and ACWR were observed in the week preceding illness in Paralympic swimmers (Table 5.5 and 5.6). Increases in TL measures of weekly TL, training monotony and cumulative 2wk and 3wk TL and ACWR were significantly associated with illness in the following week amongst the ten Paralympic footballers (Table 3.2 and 3.3).

- TL measures associated with incidence of injury also vary in each sport investigated. Despite a 3% increase in TL measures prior to injury occurrence, none were found to be significantly associated with injury in Paralympic footballers. In contrast, a 28% significant increase in training monotony was observed in the week preceding injury in Paralympic swimmers (Table 5.7).

- Results have highlighted the importance of sleep monitoring in Paralympic footballers and the impact of increased TL measures on sleep quality scores. Acute TL measures of weekly TL and training monotony were shown to be significantly associated with subjective wellness marker scores of sleep quality, energy and mood, therefore changes may indicate maladaptive TL responses quickly.

- The subjective wellness marker muscle soreness showed no association with TL measures and may not be necessary for inclusion in athlete monitoring of Paralympic swimmers.

- Subjective wellness markers of mood and energy showed no association with TL measures in Paralympic swimmers.
Salivary biomarkers are an objective measure of internal TL and respond to changes in TL across a season in Paralympic swimmers (Fig. 20).

Participation in major competition has been shown to induce a psychophysiological stress response in Paralympic swimmers despite a decline in TL (Table 6.1) Coaches and support staff should recognise the stress response associated with participation in major competition despite decreasing TL. Post-race recovery must account for not just the physiological stress on the body as a result of racing but also the individual psychological and physiological stress response to major competition. Additional recovery modalities, for example nutritional interventions, increased sleep and increased post-race recovery may be required to meet increased recovery demand of athletes.

7.4 Practical Applications

Based on the findings from this research, a number of practical applications for athlete monitoring in Paralympic sports are presented including:

- Increases in weekly TL of 11% in Paralympic footballers and 22% in Paralympic swimmers were significantly associated with illness. Therefore, weekly TL should be included in an athlete monitoring system for either Paralympic sport to reduce the risk of illness amongst athletes.

- Increases in cumulative 2wk TL of 12% in Paralympic footballers and 16% in Paralympic swimming were also significantly associated with illness in the following week and should also be included in an athlete monitoring system to reduce the risk of illness.

- For Paralympic footballers, monitoring of 3wk cumulative TL is also recommended given that this research has highlighted an 8% increase was significantly associated with illness in the following week.

- For Paralympic swimmers, inclusion of ACWR in athlete monitoring is recommended for reducing risk of illness as increases of 24% were observed in the week preceding reported illness.

- Regarding injury, this research observed an increase in training monotony of 28% to be significantly associated with injury amongst Paralympic
swimmers, thus should be included in an athlete monitoring system to reduce the risk of injury.

- Results have indicated TL variables which are not associated with illness or injury and may be excluded from monitoring systems of Paralympic footballers and swimmers including training strain, chronic TL and cumulative 4wk TL. In Paralympic swimmers, no association was observed between illness or injury and cumulative 3wk TL either and would suggest this may also be excluded from monitoring of this athlete population. Chronic TL should be determined for use in ACWR calculations and not as a stand-alone TL measure.

- Subjective wellness markers including sleep quality, mood and energy are sensitive to changes in TL and should be included in a multi-faceted athlete monitoring system for Paralympic footballers.

- Muscle soreness as a subjective wellness marker was not observed to have any association with changes in TL, illness or injury in Paralympic swimmers. Findings from this research suggest its inclusion does not add further knowledge to the coach or support staff on the athletic response to training. However, future research should examine its response in weight bearing sports given that swimming is a water-based, non-weight bearing sport which may have influenced results.

- Athletes should prioritise sleep particularly during periods of intense or heavy training in both Paralympic footballers and swimmers.

- sRPE can be utilised amongst Paralympic swimmers as a valid tool to quantify internal TL.

- Salivary biomarkers can be utilised as an objective measure of internal TL sensitive to changes in TL across a training season.

- Coaches and support staff should recognise the stress response associated with participation in major competition despite decreasing TL as measured using salivary biomarkers. Additional recovery modalities may be required to meet the increased recovery demands of athletes.
7.5 Future Recommendations

Having established suitable monitoring tools for use with Paralympic swimmers and footballers, this research observed the variables for inclusion in athlete monitoring system are different. Therefore, future studies should investigate similar monitoring tools for use in additional Paralympic sports and athletes to determine the most suitable for their athlete populations.

- Longitudinal research in Paralympic footballers (Chapter 3, Study 1) and Paralympic swimmers (Chapter 5, Study 3) identified a moderate association between TL variables and subjective wellness measures of sleep quality, mood and energy. Future research may examine additional subjective wellness markers including fatigue, muscle soreness or general well-being which may further inform coaches and support staff on early maladaptive responses of Paralympic footballers.

- Additional research is warranted to examine the relationship between TL measures and injury to fully understand the injury patterns in Paralympic footballers.

- Subjective wellness markers of mood and energy showed no association with TL variables in Paralympic swimmers. However, given the low number of athletes who participated in the study, future research may be needed over multiple seasons to fully examine the response to changes in TL.

- Muscle soreness was not observed to respond to changes in any TL variable investigated in Paralympic swimmers. However, given that swimming is a water-based, non-weight bearing sport, the use of muscle soreness as a subjective wellness marker should be investigated in other sports before removal as it may inform coaches and support staff on the athletic response of those in weight bearing sports.

- Salivary biomarkers IgA, AA and cortisol were observed to respond to changes in TL over a 16-week period during three training phases (Chapter 6, Study 4). Future research should examine their response longitudinally and determine the relationship with subjective wellness markers.

- Participation in major competition was shown to induce a significant stress response in Paralympic swimmers (Chapter 6, Study 4) with implications for
recovery protocols. Research should examine the individual stress response to other competition to determine the psychophysiological impact on athletes.

- According to Kellmann (2010) heightened stress levels in athletes can limit the ability to recover and may require modifications to recovery protocols particularly during competition. Results from Chapter 6 (Study 4) have demonstrated the stress response in athletes during major competition and future research is warranted to examine the implications of this stress response on recovery protocols.
References


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Appendices
Appendix A: Sample of Completed TL Monitoring Excel File

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Note: The table above represents a sample of completed TL monitoring Excel file, with data entries for each week.
Appendix B: Sample of Completed Daily Wellness File

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Average: John Doe
Total: 45.68
Calories: 3295.4

Next Day:
- Exercise
- Healthy Eating
- Sleep 7-8 hours

Day Before:
- Exercise
- Healthy Eating
- Sleep 7-8 hours

Last Day:
- Exercise
- Healthy Eating
- Sleep 7-8 hours
Appendix C: Analogue Scales for Subjective Wellness Markers used with Paralympic Swimmers

<table>
<thead>
<tr>
<th>SLEEP, ENERGY, MOOD RATING SCALES</th>
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<tbody>
<tr>
<td><strong>SLEEP:</strong></td>
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<tr>
<td>1: VERY POOR</td>
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<tr>
<td>2: POOR</td>
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<tr>
<td>3: AVERAGE</td>
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<tr>
<td>4: GOOD</td>
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<tr>
<td>5: VERY GOOD</td>
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<tr>
<td><strong>ENERGY:</strong></td>
</tr>
<tr>
<td>1: EXTREMELY TIRED</td>
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<tr>
<td>2: MORE TIRED THAN USUAL</td>
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<tr>
<td>3: NORMAL</td>
</tr>
<tr>
<td>4: FRESH</td>
</tr>
<tr>
<td>5: VERY FRESH</td>
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<tr>
<td><strong>MOOD:</strong></td>
</tr>
<tr>
<td>1: VERY STRESSED/UNHAPPY</td>
</tr>
<tr>
<td>2: SLIGHT STRESS/UNHAPPY</td>
</tr>
<tr>
<td>3: AVERAGE</td>
</tr>
<tr>
<td>4: RELAXED/GOOD MOOD</td>
</tr>
<tr>
<td>5: GREAT MOOD</td>
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<tr>
<td><strong>MUSCLE SORENESS:</strong></td>
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<tr>
<td>1: VERY SORE</td>
</tr>
<tr>
<td>2: ABOVE AVERAGE SORENESS</td>
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<tr>
<td>3: SLIGHT/ AVERAGE SORENESS</td>
</tr>
<tr>
<td>4: VERY SLIGHT SORENESS</td>
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<tr>
<td>5: NO SORENESS</td>
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Appendix D: Participant Information Sheet for Study 1

Participant Information Sheet

Use of an athlete monitoring system in Paralympic Footballers during preparation for Rio 2016

What is the project about?
This research aims to investigate the use of an athlete monitoring system in Paralympic footballers during the preparation for Rio 2016. Training load monitoring will be used in conjunction with subjective wellness markers to determine the individual response of each athlete to training and to maximise recovery from training and competition.

What will I have to do?
Your participation will not require any more than that which forms part of the current physiology service provided by Paralympics Ireland.

Training Load monitoring:
After each training session you will be required to record the session duration in minutes along with a rating for each session’s intensity using the scale provided. This data will be recorded on the excel file set up for you.

Subjective Wellness monitoring:
In the excel file set up for you, you will be asked to record a score daily for the following variables – sleep quality, energy and mood. This can be rated using the scales provided. You will also be asked to note any illness or injury.

What are the benefits?
Linking these measures of training load and wellness will enable individual data to be fed back to coaches on how you are responding to training. It will also give an indication of your recovery profile and what is required for you to sufficiently recover from different forms of training sessions.
What are the risks?
There are no risks greater than what you would expect from your normal exercise or training session.

What if I do not want to take part?
You can stop taking part in the research study at any time. Should you feel at any stage that you want to stop taking part in the study, then this is dealt with in a sensitive and confidential manner.

What happens to the information?
The information gathered from the study will be handled in complete confidence. Results of the participants as well as their confidentiality are the first priority of the researchers carrying out the study. When the study is finished, information will be kept on my (Ciara Sinnott-O’Connor) computer that is password-protected.

Who else is taking part?
The other Paralympic Ireland panel footballers who are currently aiming to qualify for Rio 2016.

What if something goes wrong?
In the unlikely event that something goes wrong, the testing procedure will immediately stop and the PESS department emergency procedures will be followed.

What happens at the end of the study?
At the end of the study the information will be used to present results but the information will be completely anonymous. All subject detail/information and data will be held by the principal investigator (Dr Giles Warrington) for up to 7 years on a password-protected computer at UL.

What if I have more questions or do not understand something.
If you do not understand any aspect of the research please contact either of the researchers and discuss any questions that you might have. It is important that you feel completely at ease during the research.

What if I change my mind during the study?
Should you feel at any stage that you want to stop being a participant in the research, you are free to stop and take no further part.

Thank you for taking the time to read this information sheet.

Principal Investigator
Dr Giles Warrington, PESS Dept. University of Limerick, Tel (061) 234903
Email: giles.warrington@ul.ie
If you have any concerns about this study and wish to contact someone independent, you may contact:

The EHS Research Ethics Contact Point of the Education and Health Sciences Research Ethics Committee, Room E1003, University of Limerick, Limerick.
Appendix E: Participant Consent for Study 1

PARTICIPANT CONSENT

Use of an athlete monitoring system in Paralympic Footballers during preparation for Rio 2016

Should you agree to participate in this study please read the statements below and if you agree to them, please sign the consent form.

- I have read and understood the participant information sheet.
- I understand what the project is about, and what the results will be used for.
- I understand that what the researchers find out in this study may be shared with others but that my name will not be given to anyone in any written material developed.
- I am fully aware of what I will have to do, and of any risks and benefits of the study.
- I know that I am choosing to take part in the study and that I can stop taking part in the study at any stage without giving any reason to the researchers.

After considering the above statements, I consent to my involvement in this research project.

Name: (please print): __________________________

Signature: ________________________________ Date: ______________

Investigator’s Signature ______________________________ Date: ______________
Participant Information Sheet

Use of an athlete monitoring system in Paralympic swimmers during preparation for Rio 2016: A Case Study

What is the project about?
This research aims to investigate the use of an athlete monitoring system in Paralympic swimmers during the preparation for Rio 2016. Training load monitoring will be used in conjunction with salivary biomarkers and subjective wellness monitoring to determine the individual response of each athlete to training and to maximise recovery from training and competition.

What will I have to do?
Your participation will not require any more than that which forms part of the current physiology service provided by Paralympics Ireland. Swimming step test data will be collated at a scheduled camp held at the National Aquatic Centre Dublin. Heart rate data will be collected during identified training sessions and you will be required to wear the Freelap Cardio HR system.

Step Test:
Using the 7x200m protocol, blood lactate, heart rate, rate of perceived exertion, recorded times and stroke rates will be recorded for each target time step.

Training Load monitoring:
After each training session you will be required to record the session duration in minutes along with a rating for each session’s intensity using the scale provided. This data will be recorded on the excel file set up for you.

Subjective Wellness monitoring:
In the excel file set up for you, you will be asked to record a score daily for the following variables – sleep quality, sleep duration, energy, mood, muscle soreness and general wellness. This can be rated using the scales provided. You will also be asked to note any illness or injury.
**Salivary Biomarkers:**
This is a procedure which will be new to you. You will be asked to provide a sample of saliva using a small collection device (IPRO Oral Fluid Collector). You will place the collector in your mouth for 60s and a sample of 0.5mL of saliva will be collected. A colour change indicator in the swab will indicate when the adequate volume of saliva has been collected. This data will be collected weekly before your training session, on a day proceeding a recovery day. The sample will be collected at the same time each week.

What are the benefits?
Linking these measures of training load and wellness will enable individual data to be fed back to coaches on how you are responding to training. It will also give an indication of your recovery profile and what is required for you to sufficiently recover from different forms of training sessions.

What are the risks?
There are no risks greater than what you would expect from your normal exercise or training session.

What if I do not want to take part?
You can stop taking part in the research study at any time. Should you feel at any stage that you want to stop taking part in the study, then this is dealt with in a sensitive and confidential manner.

What happens to the information?
The information gathered from the study will be handled in complete confidence. Results of the participants as well as their confidentiality are the first priority of the researchers carrying out the study. When the study is finished, information will be kept on my (Ciara Sinnott-O’Connor) computer that is password-protected.

Who else is taking part?
The four Paralympic Ireland panel swimmers who are currently aiming to qualify for Rio 2016.

What if something goes wrong?
In the unlikely event that something goes wrong, the testing procedure will immediately stop and the PESS department emergency procedures will be followed.

What happens at the end of the study?
At the end of the study the information will be used to present results but the information will be completely anonymous. All subject detail/information and data will be held by the principal investigator (Dr Giles Warrington) for up to 7 years on a password-protected computer at UL.

What if I have more questions or do not understand something.
If you do not understand any aspect of the research please contact either of the researchers and discuss any questions that you might have. It is important that you feel completely at ease during the research.

**What if I change my mind during the study?**
Should you feel at any stage that you want to stop being a participant in the research, you are free to stop and take no further part.

Thank you for taking the time to read this information sheet.

**Principal Investigator**
Dr Giles Warrington, PESS Dept. University of Limerick, Tel (061) 234903
Email: giles.warrington@ul.ie

**Other investigator**
Ciara Sinnott-O’Connor
Postgraduate Student
PESS Department
087-6358580
csoconnor@instituteofsport.ie

*If you have any concerns about this study and wish to contact someone independent, you may contact:*

*The EHS Research Ethics Contact Point of the Education and Health Sciences Research Ethics Committee, Room E1003, University of Limerick, Limerick.*
Appendix G: Participant Consent for Study 2, 3 and 4

USE OF AN ATHLETE MONITORING SYSTEM IN PARALYMPIC SWIMMERS DURING PREPARATION FOR RIO 2016: A CASE STUDY

Should you agree to participate in this study please read the statements below and if you agree to them, please sign the consent form.

- I have read and understood the participant information sheet.
- I understand what the project is about, and what the results will be used for.
- I understand that what the researchers find out in this study may be shared with others but that my name will not be given to anyone in any written material developed.
- I am fully aware of what I will have to do, and of any risks and benefits of the study.
- I know that I am choosing to take part in the study and that I can stop taking part in the study at any stage without giving any reason to the researchers.

After considering the above statements, I consent to my involvement in this research project.

Name: (please print): __________________________

Signature: __________________________ Date: ____________

Investigator’s Signature __________________________ Date: ____________

EHSREC No: __________________________
Appendix H: Conference Publications


Abstract Title: Salivary Biomarkers and Training Load in Training and Major Competition: A Case Study of 4 Paralympic Swimmers

Authors: C. Sinnott-O’Connor 1,2,3, T. Comyns 1, A. Nevill 1,4, G. Warrington 1

Affiliations: 1 University of Limerick, 2 Paralympics Ireland, 3 Sport Ireland Institute, 4 University of Wolverhampton

Introduction: Responses to training stress are highly individualised with athletes recovering from the same training stimulus differently (1). Stress response can also be attributed to competition where increased physiological and psychological stress can negatively impact on performance and recovery. Salivary biomarkers are easily accessible and non-invasive measures which can be quantified quickly and repeatedly (2). Saliva contains both immunity and stress biomarkers such as immunoglobulin A (IgA), alpha-amylase (AA) and cortisol (cort) which have been used to monitor training and competition stress responses (3, 4). To understand the training/recovery needs of Paralympic athletes and the impact of major competition, this case study examined training loads and salivary biomarker responses in preparation for and during the Rio 2016 Paralympic Games.

Methods: Four Paralympic swimmers provided bi-weekly saliva samples during three distinct phases of training (baseline, intensified training and taper) with daily saliva samples collected in the 10-day Paralympic competition phase. Saliva samples were analysed for IgA, AA and cort using an IPRO (IPRO Interactive, Wallingford, UK) oral fluid collector (OFC) kits. Training loads were measured during all four phases using session-RPE method proposed by Foster et al. (5).

Results: Compared to baseline training, significant increases in mean concentrations of IgA, AA and cort were observed during intensified training in line with increases in mean training load (Table 1). Salivary IgA did not decrease in response to increased training load suggesting swimmers were not immuno-compromised during the intensified training phase (Fig. 1). In response to competition all three biomarkers values were further increased from baseline during the Paralympic Games despite training load decreasing during this phase (Fig. 1). Mean training load decreased during taper and competition and in response salivary biomarkers decreased during taper but significantly increased during competition.
Discussion: The results demonstrate that performance in major competition such as Paralympic Games induces a stress response in athletes. Previous research has identified a significant increase in sAA in response to competition (3). Similarly, the findings from this case study demonstrated a significant response in sAA levels during competition period compared to baseline. With a decrease in training stress in
this phase it is reasonable to associate the response with increased psychological stress of participating in a competition as significant as a Paralympic Games. Despite widespread research examining salivary biomarkers in athletic populations, little research has been conducted on the immunological and stress hormones in response to major competition and training stress in Paralympic athletes. Findings from this case study suggest that coaches and support staff should recognise the stress response associated with participation in major competition despite training loads decreasing. More intense recovery protocols may be necessary as competition progresses to enable athletes to optimally perform across all ten days of competition.

References:
Abstract submitted and presented at All-Ireland Postgraduate Conference 2017, Carlow.

Salivary Biomarkers and Training Load in Training and Major Competition: A Case Study

Ciara Sinnott-O’Connor1,2,3, Tom Comyns1, Alan Nevill1,4, Giles Warrington1

1 University of Limerick, 2 Paralympics Ireland, 3 Sport Ireland Institute, 4 University of Wolverhampton

Introduction: Athletic stress responses can be attributed to training and competition where increased physiological and psychological stress can negatively impact on performance and recovery. Salivary biomarkers are easily accessible and non-invasive measures which can be quantified quickly and repeatedly.1 Saliva contains immunity and stress biomarkers including immunoglobulin A (IgA), alpha-amylase (AA) and cortisol which assist in monitoring training and competition stress responses.2 To understand the training and recovery needs of Paralympic athletes and the impact of major competition, this case study examined training loads (TL) and salivary biomarker responses in preparation for and during the Rio 2016 Paralympic Games.

Methods: Four Paralympic swimmers (age 19 ± 3.9 sp, body mass 48.5 ± 7.6 kg) provided bi-weekly saliva samples during three training phases (baseline, intensified training and taper) with daily samples collected during 10-day Paralympic competition. Saliva samples were analysed for IgA, AA and cortisol using an IPRO oral fluid collector kit. TL was measured during all four phases using session-RPE method.

Results: Multi-level analysis identified a significant increase in IgA (94.98 (27.69)), AA (45.78 (19.07)) and cortisol (7.92 (2.17)) from phase 1 to phase 2 concurrent with a 38.3% increase in TL (Fig. 1). During phase 4 TL decreased by 49.5% accompanied by decline in all three biomarkers towards baseline. A further significant increase was observed during competition in IgA (168.69 (24.19)), AA (35.86 (16.67)) and cortisol (10.49 (1.89)) despite a continued decrease in training load from phase 3.

Conclusion: Performance in major competition can induce a stress response in athletes. During Paralympic competition significant increases were observed in AA and cortisol levels compared to baseline and with a decrease in TL, it is reasonable to associate the response with increased...
psychological stress of participation in major competition. Findings from this case study would suggest coaches/support staff should recognise the stress response associated with participation in major competition despite decreases in TL. More intense recovery protocols may be necessary as competition progresses to enable athletes to optimally perform across all ten days of competition.

Reference:


Appendix 1: Peer Reviewed Journal Publication

Due to copyright restrictions the full text of this article is not included in the electronic version of this thesis

International Journal of Sports Physiology and Performance
2018 13 (7), PP.839-843
Salivary Biomarkers and Training Load During Training and Competition in Paralympic Swimmers
Ciara Sinnott-O’Connor, Thomas M. Comyns , , Alan M. Nevill, Giles D. Warrington
https://doi.org/10.1123/ijspp.2017-0683