Internal and external load monitoring in well-trained and professional cyclists

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Candidate declaration

I, ***Rodet-William Yila***, hereby declare that the work on which this dissertation/thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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Abstract

With the desire of inducing training adaptations in an athlete to facilitate an increase in performance capacity, as well as develop an increased resilience to fatigue, a sustained period of tolerable physiological stress is required. However, this adaptation is only possible when an adequate period of recovery is afforded to the athlete (Saw et al., 2016). An excessive training-induced stress imposed on an athlete, without being afforded an adequate recovery period, may result in an unwanted accumulation of fatigue, which can lead to a decrement in performance, as well an increased likelihood of sustaining an overuse injury or illness (Pyne & Martin, 2011). It should also, however, be noted that when the period of recovery is prolonged, it can also lead to a decrement in performance, as well as increase the likelihood of sustaining an overuse injury as the desirable training adaptations diminish over time in the absence of tolerable physiological stress (Mujika & Padilla, 2000).

The purpose of this dissertation was to determine whether the combination of a customised online questionnaire (Subjective Wellness Score, SWS) and a modified submaximal cycling test (Submaximal Fatigue Test, SFT) (internal and external training load monitoring tools) can be used in conjunction with an external training load monitoring tool (TrainingPeaks® Performance Management Chart™, PMC) to monitor the response to training in well-trained and professional cyclists with acceptable validity and reliability.

Pre-existing data, already uploaded onto two online registries, was retrospectively analysed. Data from 258 SFTs were analysed from 20 well-trained and professional cyclists, whereby objective and subjective data obtained from the SWS, SFT metrics and TrainingPeaks® PMC metrics was acquired from a continuous, longitudinal dataset. The first question formulated for this dissertation investigated whether the combination of the SWS and metrics of the SFT ($HR_{average}$ and RPE) are sensitive to changes in training load. The next question was to scrutinize the validity of the collected SWS questions, SFT metrics, and ETL metrics (of the PMC), and determine whether they are able to predict performance outcomes measured by the SFT (W/kg/RPE, RPE, TTE).

The results of the linear regression analysis for 'All Participants' (*n* = 20) reported the most significant correlation was found for TSB when compared to the SWS and SFT metrics, with statistically significant results for the variables of fatigue rating ($R^2 = 0.126$; $p < 0.001$), overall-feel rating ($R^2 = 0.026$; $p = 0.009$), and RPE ($R^2 = 0.051$; $p < 0.001$). The results of the multivariate analysis for TSS (7-day average), CTL, ATL, and TSB, for 'All Participants' (*n* =

20) indicated that TSB was found to have the strongest correlation with the SWS and SFT metrics ($R^2 = 0.197$; $F = 7.86$; $p < 0.001$). The most significant correlations were found for TSB when compared to the SWS and SFT metrics, with statistically significant results for the variables of overall-feel rating ($F = 12.37$; $p = 0.001$) and fatigue rating ($F = 28.11$; $p < 0.001$).

The results of the linear regression analysis for 'All Participants' ($n = 20$) reported the most significant correlations was found for the relative power output per unit of body mass per unit of RPE (W/kg/RPE) when compared to the SWS, $HR_{average}$ (of the SFT), and ETL metrics of the PMC, with statistically significant results for the variables of fatigue rating ($R^2 = 0.110$; $p < 0.001$), TSB ($R^2 = 0.065$; $p < 0.001$), composite score rating ($R^2 = 0.034$; $p = 0.003$), overall-feel rating ($R^2 = 0.032$; $p = 0.004$), and sleep rating ($R^2 = 0.016$; $p = 0.038$). In the multivariate analysis for the modelling of the performance outcome measures of the SFT (W/kg/RPE, RPE, and TTE), for 'All Participants' ($n = 20$), RPE was found to have the strongest correlation with the SWS, $HR_{average}$, and ETL metrics of the PMC ($R^2 = 0.207$; $F = 7.43$; $p < 0.001$). The most significant correlations were found for W/kg/RPE when compared to the SWS, $HR_{average}$, and ETL metrics of the PMC, with statistically significant results for the variables of overall-feel rating ($F = 11.06$; $p = 0.001$), fatigue rating ($F = 18.02$; $p < 0.001$), stress rating ($F = 8.23$; $p = 0.005$) sleep rating ($F = 4.61$; $p = 0.033$), and TSB ($F = 4.48$; $p = 0.035$).

Considering the findings in this research study, the two questions formulated for this thesis can be answered, whereby as it can be stated, with confidence, that the SWS and SFT metrics (overall-feel rating and fatigue rating) were sensitive to changes in the ETL metric of the PMC (TSB). It was also found that the SWS, $HR_{average}$, and ETL metrics of the PMC were able to a predict performance outcome measure of the SFT, yielding a correlation with W/kg/RPE. Furthermore, it should also be accepted that the combined use of a customised online questionnaire and a modified submaximal cycling test (SFT) can be used in conjunction with the TrainingPeaks® PMC to monitor the response to training in well-trained and professional cyclists with acceptable validity and reliability.

In closing, this study suggests that the concurrent use of the SWS, SFT and PMC is an effective and efficient method for coaches/sports scientist to monitor the cyclist's response to their encountered training load as the blend of subjective and objective training load metrics have been found to be sensitive to changes in fatigue status, with acceptable validity and reliability.

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CHAPTER ONE

Introduction

Background and research problem

Professional cycling has evolved tremendously over recent years. Whereby since its inception in the late nineteenth century, the sport has seen impressive growth in race participation numbers and number of races, television and media coverage and viewership, corporate partnership and sponsorship involvement, as well as prize money and other financial incentives (Mignot, 2016). These factors have culminated in an increase in competition amongst riders and busier race calendars, placing a greater emphasis on the need to focus on optimising training to enhance performance. It is due to this increased interest in cycling performance, where the need for cyclists and coaches to improve on their understanding of training methodology arises.

With the desire of inducing training adaptations in an athlete to facilitate an increase in performance capacity, as well as develop an increased resilience to fatigue, a sustained period of tolerable physiological (training-induced) stress is required. However, this adaptation is only possible when an adequate period of recovery (reduction of training-, emotional-, and environmental-induced stress) is afforded to the athlete (Saw et al., 2016). An excessive training-induced stress imposed on an athlete, without being afforded an adequate recovery period, may result in an unwanted accumulation of fatigue, which can lead to a decrement in performance, as well an increased likelihood of sustaining an overuse injury or illness (Pyne & Martin, 2011). It should also, however, be noted that when the period of recovery is prolonged, it can also lead to a decrement in performance, as well as increase the likelihood of sustaining an overuse injury as the desirable training adaptations diminish over time in the absence of tolerable physiological stress (Mujika & Padilla, 2000).

In recent years, there have been several concentrated efforts by sport scientists to ascertain what an ideal stress-recovery relationship should be, whereby a training load 'sweet spot' had been declared, via the employ of an acute-chronic workload ratio (Gabbett, 2016). The acute-chronic workload ratio computes the most recently completed workload (typically previous 7 days) against the average weekly historical workload (typically previous 4-6 weeks). This calculation utilises arbitrary units and is expressed as a ratio, and there are two main models for calculating the acute-chronic workload ratio: the rolling average model and the exponentially weighted moving average model. The exponentially weighted moving average model has been describe to be a more sensitive measure than the rolling average model as the exponentially weighted moving average model considers the decay in fitness via the adjusted weighting of historical workloads, therefore it is better suited to monitor changes in training load (Griffin et al., 2019). However, the shortcomings of these predictive models have been pointed out, whereby it has been suggested that the predictive model is unreliable and misleading (Impellizzeri et al., 2019).

Therefore, it should be considered that each athlete should have their training needs addressed on an individual basis, rather than on the assumption that every athlete responds to an imposed training load in the same way, and that their accumulated fatigue will dissipate at the same rate as another athlete's (Bouchard & Rankinen, 2001). In order for each athlete to have their individual training needs catered for, their response to the encountered training load needs to be monitored on a frequent basis as to enable the coach/sport scientist to detect positive and negative responses to the encountered training load. This will allow for the coach/sport scientist to make an informed decision on whether to increase the training-induced stress or whether they should allow for more recovery. The ability to improve the coach's/sport scientist's decision-making process is invaluable as it allows for optimal training loading throughout a training phase, as well as in the lead up to a competition or peaking phase (Smith, 2003).

There are several factors which should be considered when deciding on which method(s) should be used to monitor an athlete's training load and/or response. It is imperative that the chosen method is valid and reliable so that coaches, sports scientists and athletes can make accurate and informed decisions with regards to the prescription of training loads (Foster et al., 2017). In essence, the information generated in the monitoring report should not be distorted by noisy data. I.e., the measurement error, or within-subject reliability of a measurement, and the smallest worthwhile change associated with the measurement should allow the interpreter to correctly and reliably identify meaningful individual variation (Mann et al., 2014). Ideally, the method should also be non-aversive, quick and easy to use, and easy to interpret. The cost of the method is another factor which may influence its feasibility, whereby in most cases, an inexpensive method is preferred. Lastly, one of the most important factors to consider is whether the method will provide coaches, sports scientists, and athletes with valuable information which they can use in their decision-making process when prescribing periodised training programmes, making team selections, formulating peaking strategies, and implementing injury-prevention interventions (Bourdon et al., 2017).

With emphasis being placed on monitoring, it becomes important that coaches and sports scientists make use of the most appropriate methods to monitor their athlete's training. Subjective measures are typically based on interpretation and/or opinion (i.e. qualitative), whereas objective measures are impartial and generally insulated from bias (i.e. quantitative). The information obtained from objective measures can be used in conjunction with subjective methods to assist coaches and sports scientists in the decision-making process in a complimentary fashion.

This dissertation endeavours to provide coaches/sport scientists with the confidence needed to efficiently and effectively monitor the training load of an endurance sport athlete, particularly well-trained and professional cyclists.

Aims and objectives

The aims of this dissertation are to determine whether the combination of a customised online questionnaire (Subjective Wellness Score, SWS) and a modified submaximal cycling test (Submaximal Fatigue Test, SFT) (internal training load, ITL, and external training load, ETL, monitoring tools) can be used in conjunction with TrainingPeaks® Performance Management Chart™ (PMC) (ETL monitoring tool) to monitor the response to training in well-trained and professional cyclists with acceptable validity and reliability.

Two specific questions were formulated in order to attempt to bridge the gap between practically applied training load monitoring methods and novel scientific evidence:

- The first question formulated for this dissertation investigated whether the combination of the SWS and SFT metrics ($HR_{average}$, PO, RPE, and TTE) are sensitive to changes in ETL.
- The next question was to scrutinize the validity of the collected SWS questions, SFT metrics, and ETL metrics (of the PMC), and determine whether they are able to predict performance outcome measures of the SFT (W/kg/RPE, RPE, TTE).

Furthermore, several specific objectives were composed in order to adequately answer the aforementioned questions. These specific objectives are listed as follows, in sequential order:

- To assess the validity of an abridged questionnaire, which is customized to include the measures typically monitored in endurance sport athletes to allow for greater compliance from the athlete as the abridged questionnaire should not consume too much of their time, it should be minimally aversive, user-friendly, and easily accessible with the use of any smartphone or computer device with internet access.

- To assess the sensitivity and validity of a modified submaximal cycling test using a target power output while measuring the athlete's heart rate, rating of perceived exertion (RPE), and estimated time to exhaustion (TTE) for the prescribed power output. Changes in the relationship between these variables were subsequently assessed in comparison to the objective PMC (ETL metrics) as well as the subjective questionnaire data (ITL metrics).
- To correlate subjective questionnaire data, objective PMC metrics, and submaximal cycling test data (subjective and objective metrics) to assess which ITL metrics correlate with changes in the ETL metrics.
- To assess whether changes in the Subjective Wellness Score (SWS), $HR_{average}$ (for the SFT), and ETL metrics of the PMC (CTL, ATL, and TSB) correlate with performance outcome measures of the SFT (W/kg/RPE, RPE, and TTE).

CHAPTER TWO

Literature Review

Introduction

The rationale behind increasing training load before a targeted event is to induce physiological, neurological and biochemical adaptations which are associated with improved performance and increased resistance to fatigue. However, in order for this adaptation to take place, a sustained period of tolerable physiological stress, followed by adequate recovery, is required (Saw et al., 2016; Selye, 1950). A professional cyclist competing in the UCI World Tour is estimated to have 60 to 80 competition days in a season. The UCI World Tour series comprises of 38 cycling events, whereby the races range from 1-day, 2 to 3 days, and 1 to 3 weeks (Galán-Rioja et al., 2023). To add to the difficulties already faced by coaches and sport scientists involved in professional cycling, a Men's World Tour team may have 30 riders, whereby coaches and sport scientists are challenged with the responsibility of periodising each rider's individual training programme (a rider may be preparing for an event, recovering from a multistage race, or in the process of rehabilitating an injury), making team selections (smaller groups of 6-8 riders from a team may be competing in international events, on different continents around the world), and determining peaking and race strategies (each team will have riders who are climbing-, sprinting-, or time trial-specialists, and they are assigned specific tasked based on the topography of the race). Effective adjustments and manipulations to an individualised training programme, or changes to a peaking or race strategy, are challenging without accurate and impartial feedback. This emphasises the importance of the relationship between monitoring the response to training loads and periodisation in cycling.

As originally proposed by Eric Banister in 1980, performance can be modelled on assessments of fitness and fatigue (Banister & Calvert, 1980). In this model, when fitness is greater than fatigue, performance will be improved. Likewise, when fatigue is greater than fitness, there will be an expected decrement in performance (Pyne & Martin, 2011). Fitness is developed over a prolonged period of time when an athlete encounters a training-induced stress, thereby stimulating an adaptive response (Stone et al., 2007). Fitness is therefore slow to develop, and slow to dissipate. On the other hand, fatigue accumulates when adequate recovery is not afforded to the athlete during a training period, and it is conversely quick to occur and dissipate.

Therefore, an excessive amount of stress (physiological, emotional or environmental) encountered by an athlete in training, in the absence of adequate recovery, may lead to an excessive accumulation of fatigue, thereby possibly resulting in a decrement in performance (Pyne & Martin, 2011). Furthermore, a decrement in performance and increased likelihood of sustaining an overuse injury may also be the products of an excessively prolonged period of recovery, or a period of training whereby the encountered training-induced stress is grossly insufficient. This occurs as a result of the desirable training adaptations diminishing over time in the absence of tolerable physiological stress (Mujika & Padilla, 2000). The toxicology adage ‘the dose makes the poison’, accredited to Paracelsus, lends itself to the understanding that training-induced stressors are required to develop fitness, however, inappropriate prescription of the dose (excessive training load) may cause harm to the athlete (performance decrements, overuse injury or illness), and likewise, the affordance of adequate recovery is required to diminish fatigue, however, the prescription of excessively prolonged periods of recovery (dose) may cause harm to the athlete (performance decrements or overuse injury).

Work done by Stone and colleagues (Stone et al., 2007) expanded on Hans Selye’s original theory of the General Adaptation Syndrome (Selye, 1950). In the reviewed version, Stone *et al.* propose a Stimulus-Fatigue-Recovery-Adaptation theory, whereby it is suggested that training stimuli produce a general response, influenced by the overall magnitude of the training stress. In other words, a marginal training overload, accompanied with adequate recovery, will result in minimal improvements in physiological capacity (small magnitude “supercompensation”). While an excessive training overload, in the absence of adequate recovery, will result in performance decrements. This means that a progressive training overload, in the presence of sufficient recovery, is required to achieve the desired “supercompensation” of a large magnitude. This notion is fundamental when considering the primary objectives of a periodised training cycle. An athlete may experience acute (short-term) fatigue and temporary decrement in performance (24-48 hours) following an intense training session, or short period of intensive training, and following a short recovery period (24-48 hours), performance capacity will be restored – and possibly even slightly improved upon (small-magnitude “supercompensation”). If the period of intensified training is prolonged, the athlete would experience feelings of fatigue and decrements in performance for a period lasting several days to several weeks – however, in the presence of adequate recovery/reduction in training-induced stress, performance capacity is expected to rise above their initial baseline performance capacity (large-magnitude “supercompensation”) (Borresen & Lambert, 2008b; Lamberts, Swart, et al., 2010; Meeusen et al., 2013).

This positive stress-recovery response is the desirable outcome that a coach may plan for, therefore, this momentary stage of training-induced overreaching may be considered deliberate and is therefore known as functional overreaching. Conversely, when the period of intensified training is prolonged for an extensive period of time, the athlete would experience feelings of fatigue and decrements in performance, as with functional overreaching, however, the feelings of fatigue and decline in performance capacity could last from several weeks to a month, and due to the lack of adequate recovery/reduction in training-induced stress, performance capacity will only return to their initial baseline performance capacity (absence of "supercompensation") following a long-overdue recovery period (Ten Haaf et al., 2017). This negative stress-recovery response is not the desirable training outcome that a coach would plan for, therefore, this temporary stage of training-induced OR would be considered unwanted and is therefore referred to as non-functional overreaching.

Furthermore, if an athlete enters a stage of non-functioning overreaching and interventions are not made to promote recovery, or the period of intensified training is further prolonged, the athlete may be at risk of developing an overtraining syndrome, whereby the athlete may experience feelings of fatigue and decrements in performance for a long-term period (several months to a year), and a graded progression and re-integration back into intensified training is required before eventually returning back to their initial baseline performance capacity (Meeusen et al., 2013). While there is no known single cause and mechanism of the overtraining continuum, and athletes may present with or without related physiological and psychological signs and symptoms of maladaptation to training-induced stress, it would seem that the monitoring of stressors and symptoms are vital for preventing the shift towards non-functional overreaching and overtraining syndrome (Ten Haaf et al., 2017).

To contextualise the research questions that follow, a literature review has been done, firstly on training load, and secondly on the current practical methods of monitoring training load, specifically focusing on endurance sport, and specifically well-trained and professional cyclists. The literature review has been completed using a narrative style.

What is training load?

Training load (TL) is categorised as either internal or external load, and there are various measures of TL. Internal training loads (ITL) are the relative biological (both physiological and psychological) stressors exhibited by the athlete during training or competition. The use of heart rate (HR), heart rate variability (HRV), rating of perceived exertion (RPE), session rating of perceived exertion (sRPE), wellness questionnaires, sleep habits (e.g. sleep quality and sleep duration), training impulse (TRIMP) and derivatives thereof (Lucia's TRIMP; LuTRIMP), and oxygen consumption are examples of popular measures of ITL. External training loads (ETL) are objective measures of the work performed by the athlete during training or competition and imposed on the athlete, and these measures are assessed independently of internal workloads (Bourdon et al., 2017). Common examples of external training load include measures such as time, distance, movement repetition counts (e.g. pitches thrown, balls bowled, serves hit), power output (PO), speed, acceleration, global positioning system (GPS) parameters, time-motion analysis and neuromuscular function (e.g. jump test, isokinetic dynamometer, and plyometric push-up). Roos *et al.* have proposed the idea to differentiate between ETL and ITL as ETL being the encountered TL, and ITL being the response to the TL (Roos et al., 2013). In this sense, ITL can be regarded as the athlete's response to the encountered ETL.

There are several factors which should be considered when deciding on which method(s) should be used to monitor an athlete's TL and/or response (Halson, 2014; Roos et al., 2013). It is imperative that the chosen method is valid and reliable so that coaches, sports scientists and athletes can make accurate and informed decisions with regards to the prescription of training loads (Foster et al., 2017). The information generated in the monitoring report should not be distorted by noisy data. Therefore, the measurement error, or within-subject reliability of a measurement, and the smallest worthwhile change associated with the measurement should allow for the data interpreter to correctly and reliably identify meaningful individual variation (Halson, 2014; Mann et al., 2014). Ideally, the method should also be non-invasive, quick and easy to use, and easy to interpret. The cost of the method is another factor which may influence its feasibility, whereby in most cases, an inexpensive method is preferred. Lastly, one of the most important factors to consider is whether the method will provide coaches, sports scientists, and athletes with valuable information which they can use in their decision-making process when prescribing periodised training programmes, making team selections, formulating peaking strategies, and implementing injury-prevention interventions (Bourdon et al., 2017).

Current practical methods of monitoring training load

With emphasis being placed on monitoring, it becomes important that coaches and sports scientists make use of the most appropriate methods to monitor their athlete's training. Subjective measures are typically based on interpretation and/or opinion (i.e. qualitative), whereas objective measures are impartial and generally insulated from bias (i.e. quantitative).

Subjective measures allow the athlete to provide the coaching staff with an expression of how they feel from an emotional and psychological point of view. A systematic review found that subjective measures were more sensitive and consistent than objective measures in 22 of the 54 studies on TL monitoring (Saw et al., 2016). Subjective measures were also found to be more responsive than objective measures in detecting subtle changes. The lack of responsiveness, missing knowledge of practicality, or limited knowledge or understanding of analysis and interpretation does not, however, invalidate the importance of objective measures, but rather identify this as a limitation. The information obtained from objective measures can be used in conjunction with subjective methods to assist coaches and sports scientists in the decision-making process in a complimentary fashion.

Several internal and external load metrics are currently used in the sport of cycling:

Heart Rate (HR)

The use of heart rate (HR) to monitor and regulate training intensity can be dated back to the late 1930s, where a pair of German coaches and physicians used HR as parameters for the prescribed interval bouts. The introduction of radiotelemetric HR monitors in the early 1980s allowed for great advancements in the ease and accessibility of accurate ITL metrics, thereby increasing the interest in HR monitoring in the scientific community (Foster et al., 2017).

The autonomic nervous system is tasked with the regulation of constant haemodynamic adjustments, whereby the circulatory system is continuously working to meet physiological demands (Borresen & Lambert, 2008a). The autonomic nervous system comprises of the sympathetic nervous system and the parasympathetic nervous system. At rest, homeostatic disturbances are minimal, therefore, the parasympathetic nervous system dominates autonomic nervous system activity. However, during activity, sympathetic nervous system activity prevails – inhibiting parasympathetic nervous system activity, in order to govern the redistribution of blood to meet the metabolic demands of the skeletal muscle (Esco et al., 2010). Technological advancements have expanded the ability to easily and non-invasively monitor variations of HR metrics, such as heart rate recovery and heart rate variability (HRV).

Heart rate recovery is described as the rate at which HR declines following the cessation of activity, whereby there is an increase in parasympathetic nervous system activity, coupled with the reduction of sympathetic nervous system activity (Borresen & Lambert, 2008a). It is known that trained endurance athletes have a higher heart rate recovery than their untrained counterparts when exercising at the same absolute intensity (Du et al., 2005). It has also been shown that an increasing heart rate recovery, across a prolonged training period, is generally an indicator of an increase in fitness status, while a reduced heart rate recovery has been shown to be associated with a reduction in parasympathetic activity (and increased sympathetic activity, even at rest), which is therefore an indicator of fatigue (Lamberts, Swart, et al., 2010).

A normal sinus heart rate rhythm will display beat-to-beat variation in heart rate as a result of the interaction between multiple physiological mechanisms that regulate the heart rate, and HRV is determined by examining the beat-to-beat variations between R-R intervals (Bilchick & Berger, 2006). A higher resting HRV is typically associated with increased fitness, while a depressed resting HRV is typically an indication of a dysfunctional autonomic nervous system (Buchheit, 2014; Esco et al., 2010). When monitoring athletes over time, a decrease in HRV may be a result of negative adaptations to the encountered training stressors. However, a transient reduction in HRV, lasting between 24-48 hours, following relatively high training loads, prior to returning to normal HRV indices, coincides with the restoration of homeostasis, and could therefore be a sign of functional overreaching (Buchheit, 2014). The prolonged depression of HRV (longer than 48 hours) may be considered as a sign that the athlete is progressing along the overtraining continuum towards non-functional overreaching (Esco et al., 2010). Given the quadratic relationship between the parasympathetic influence on HR and HRV indices, it is important to keep in mind that HRV indices reflect the modulation in parasympathetic tone (Plews et al., 2013). Plews *et al.* have shown that at both low and high levels of vagal tone, HRV indices are reduced. This means that, while well-trained endurance athletes with low resting HR generally have high HRV indices, well-trained endurance athletes with low resting HR may also exhibit reduced HRV indices (Plews et al., 2013). It was also suggested by the same authors that both weekly and 7-day rolling averages were shown to provide better methodological validity compared with values taken on a single day (Plews et al., 2013).

As there are several confounding factors around the reliable and accurate interpretation of HRV indices, it is advised that an athlete establishes a longitudinal HRV profile, coaches and sport scientists are upskilled in the interpretation of HRV profiles, and that HRV is analysed over a longitudinal time period (weekly or 7-day rolling average) rather than a day-to-day analysis (Plews et al., 2013; Roos et al., 2013). Therefore, at this moment in time, heart rate recovery seems to be the more robust and reliable measure of cardiac function and fitness status, with reference to well-trained endurance athletes (J. Cornforth et al., 2014).

Submaximal Cycling Tests

It is widely accepted that maximal effort performance tests, such as the peak-power-output (PPO) test and time trials (TT), such as the 40-kilometre time trial (40km TT), have the ability to detect meaningful changes in training status in cyclists (Lamberts et al., 2009). However, the limitation with having to perform a maximal effort test is that it is aversive and may be disruptive to one’s training and/or racing schedule, thereby reducing the number of opportunities for a cyclist or coach to monitor the response to a training programme. Capostagno *et al.* conducted a systematic review investigating the current use of submaximal cycling tests to predict and monitor cycling performance, whereby only studies that included tests that were cycling-based, lasted less than 60 minutes, and were truly submaximal (and did not require a maximal effort or prolonged periods of high-intensity cycling) were reviewed (Capostagno et al., 2016). It was found that only two of the three submaximal cycling tests identified in the review had their reliability and validity investigated.

The Lamberts and Lambert Submaximal Cycle Test (LSCT) was one of the two submaximal cycling tests which has had its reliability and validity investigated, and this test incorporates a mix of variables (PO, HR and RPE) to assess the status of the autonomic nervous system and evaluate fatigue levels, as well as assess training status. The LSCT is comprised of three stages of increasing intensity, in which cyclists are required to ride at predetermined, fixed, percentages of their maximal heart rate (HR_{max}) (Lamberts et al., 2009, 2011). Stages 1 and 2 are both six minutes in duration, whereby the cyclist rides at 60 and 80% of HR_{max}, respectively, while stage 3 is three minutes in duration, whereby the cyclist rides at 90% of HR_{max}. RPE scores are recorded within the final 30 seconds of each stage, while HR, PO, and cadence are continuously recorded throughout the test. The cyclist’s 60-second heart-rate recovery is then recorded once the third stage has been completed, whereby they are instructed to stop pedalling, sit upright, and refrain from talking.

The other submaximal cycling test which has had its reliability and validity investigated was utilised in a study by Sassi *et al.*, whereby the relationship between blood lactate during submaximal constant workloads and perceived time to exhaustion was assessed (Sassi et al., 2006). This test begins with a 20-minute warm-up at 100 watts (W), before entering the submaximal cycling phase which utilises a constant workload of 60 to 85% of the cyclist PPO while maintaining a cadence of 94 to 98 revolutions per minute (RPM). Capillary blood samples were collected from the ear lobe at the fifth minute of the warm-up, at the fifth and tenth minutes of the target workload, as well as at exhaustion (defined as the inability to maintain the assigned cadence).

The submaximal nature of these tests negates the need to perform a maximal effort to determine meaningful changes in training status, and as a result these can be performed more frequently than maximal-effort tests. Cyclists can also utilise submaximal cycling-specific tests as a warm-up prior to a training session, which increases the ease of regular monitoring of the relationship between training load and symptoms of fatigue. The duration of the submaximal cycling tests described in the previously mentioned systematic review ranged from 17 to 58 minutes (Capostagno et al., 2016). While the LSCT is relatively quick and easy to administer, and it does not require capillary blood samples to determine lactate concentrations, the requirement of riding at 90% of HR_{max} for the final three minutes of a 17-minute test might pose as a slight challenge for some cyclists who are in the functional overreaching phase of their training (Capostagno et al., 2016).

Wellness & Recovery Questionnaires and Training Diaries

The practice of obtaining self-reported feedback from an athlete in the form of wellness and recovery questionnaires or having athletes log training diaries is relatively simple in theory. However, it has been suggested that the subjective information may need to be corroborated with physiological data (Borresen & Lambert, 2008b). While questionnaires and diaries may present as an inexpensive means of determining a subsequent response to a training session or competition, well-established questionnaires such as the Profile of Mood States (POMS) (Morgan et al., 1987), the Recovery-Stress Questionnaire for athletes (REST-Q-Sport) (Kellmann & Kallus, 2001), the Daily Analysis of Life Demands for Athletes (DALDA) (Rushall, 1990), and the Total Recovery Scale (TQR) (Kenttä & Hassmén, 1998), are time consuming. This poses a risk of reduced compliance in the case of an athlete not willing to take the time to complete the questionnaire accurately. While there isn't an abundance of research currently available, supporting the validity of abridged and time-efficient questionnaires, Le Meur *et al.* were able to successfully detect overreaching among endurance athletes by combining the use of a questionnaire (on the participant's pain, tiredness, and well-being) with the use of the Borg scale (to obtain feedback following a maximal running test effort) (Le Meur et al., 2013).

In addition, an athlete may manipulate the subjective feedback so that they are allowed to train even though they require more rest, or to be withdrawn from training even though they have recovered enough to train. A study by Roos *et al.* investigating the monitoring of training load in daily practice found that, in two focus group discussion sessions, coaches who work with elite athletes (95% of the 22 elite performance coaches) believed that the most important information gathered from self-reported questionnaires/training diaries pertained to personal comments regarding their training or health status (e.g. "My knees hurt") (Roos et al., 2013). Including open-ended questions in the questionnaire allows for the athlete to provide the coach with feedback which they might not have received had the questionnaire consisted of only closed-ended questions, allowing for static responses. It should, however, be noted that an athlete will only provide an in-depth response to a questionnaire when there is buy-in into the monitoring process, from both the athlete and the coach, as well as an established level of trust and honesty between the athlete and coach.

Furthermore, it was also noted by the elite performance coaches who formed part of the focus groups in the study by Roos *et al.* that coaches should make more of an effort to acknowledge and provide timeous feedback to the information offered by the athlete – which can be understood to indicate to the athlete that the coach is interested in their feedback, and that their feedback is being considered when planning the next training session.

Athletes should report their subjective well-being on a regular basis via the use of questionnaires and verbal communication with their coach or sports scientist in conjunction with objective measures. Coaches and sports scientists should also consider factors such as frequency of administration, time taken to complete the questions, sensitivity of the questionnaire, type of response required, time of day of completion and the amount of time required for appropriate feedback as these are all factors which will influence the level of compliance (Halson, 2014).

Power Output (PO)

The monitoring of ETL in endurance sports, such as cycling, has been greatly assisted by the widespread availability of relatively affordable technologies which allow for measurement of distance, speed, gradient, acceleration, cadence, and PO. Recently, the increased availability of personal cycling computers and power meters has made it easy for athletes and coaches to quantify training parameters, which provides a validated indication of the intensity of performance (Bouillod et al., 2022).

Cycling coaches or sports scientists can make use of commercially available software, such as TrainingPeaks® to analyse the cycling performance against parameters established by the cyclist in previous training sessions. Parameters such as functional threshold power (FTP), Training Stress Balance™ (TSB), Normalized Power™, Intensity Factor™, and Training Stress Score™ (TSS) are variables which have been introduced by TrainingPeaks® and are now widely used in the sport. TrainingPeaks® also provide a platform to view a summative report of fitness (chronic training load, CTL), fatigue (acute training load, ATL) and the athlete's readiness to perform based on the recorded data in the form of a Performance

Management Chart™ (PMC), thereby simplifying the presentation of training load in endurance sports (Coggan, 2022).

TSS is defined as a measure of the training load amassed during an individual session, whereby TSS is derived from the individual's relative training intensity, and duration of the session. In the case of endurance sports, TSS may be calculated from power, heart rate or rating of perceived exertion. Using cycling as an example, TSS is more commonly used to quantify the TL of a training session whereby the cyclist makes use of a power meter, and it can be calculated with the following equation:

$$TSS = [(s \times W \times IF) / (FTP \times 3{,}600)] \times 100$$

Whereby s is duration of the session (in seconds), W is Normalized Power™ for the session (in watts), IF is Intensity Factor™ for the session, FTP is the cyclist's functional threshold power (in watts), and 3,600 is the number of seconds in one hour (H. Allen & Coggan, 2019).

CTL, calculated as an exponentially weighted moving average of daily TSS values, typically computes the training loads from a window period of 21-42 consecutive days (3-6 weeks), therefore, it is essentially an indicator of an individual's fitness status. Whereas, ATL, calculated as an exponentially weighted moving average of daily TSS values, computes the training loads over a period of 5-10 consecutive days, therefore, it can be seen as an indicator of an individual's state of fatigue (H. Allen & Coggan, 2019). It has been shown in literature that the window periods (the period over which these two values decay mathematically, due to the exponentially weighted function of these two values) used to determine CTL and ATL may differ between sporting codes (Bourdon et al., 2017; Carey et al., 2017), whereby it may be more applicable for endurance sports to use longer window periods than team sports (e.g. the default time constant for CTL in TrainingPeaks® is set as 42 days).

The Training Stress Balance™ (TSB) parameter can be seen as an indicator of an individual's current level of freshness. TSB is calculated from the difference between an individual's developed fitness and accumulated fatigue. This is determined by evaluating the difference between the longer-term training loads (CTL) and the shorter-term training loads (ATL): form (TSB) = fitness (CTL) – fatigue (ATL). However, while it is acceptable to crudely compare TSB to the output of Banister's impulse-response model, it should be noted that, as a predictor of actual performance ability, the elimination of the positive adaptative and negative fatiguing factors means that TSB should rather be viewed as an indicator of how well the athlete has adapted to their recent training load, and therefore serve as an indicator of their "freshness". Thus, TSB can be used to express an individual's readiness to perform. It is also understood that performance depends not only on TSB, but also on CTL. This gives rise to the concept: form (performance potential) = fitness (CTL) + freshness (TSB) (H. Allen & Coggan, 2019).

Despite a number of recent studies which have validated TSS as a load measure in comparison to TRIMP and PO (Erp et al., 2019; Sanders et al., 2017), to date there has been no research validating the use of CTL, ATL and TSB to assess training status or fatigue.

Conclusion

In summary, a number of methods exist to quantify training status and fatigue and only some of these have been validated. Despite the validated methods, a gold-standard for monitoring training status and fatigue in endurance athletes is yet to be established (Borresen & Lambert, 2008b; Lambert & Borresen, 2010). A combination of submaximal, non-aversive internal and external load measures used in conjunction may provide an accurate and practically useful tool to monitor fatigue in cycling.

We have proposed that a combination of an abbreviated subjective question set, a modified submaximal cycling test, and the TrainingPeaks® PMC, can be used as a suitable method to monitor the response to encountered training loads in well-trained and professional cyclists. This thesis aims to determine whether a customised online questionnaire together with a modified submaximal cycling test, and an external training load monitoring tool (TrainingPeaks® PMC) can be used to monitor the response to training load in well-trained and professional cyclists with acceptable validity and reliability.

Two specific questions were formulated in order to attempt to bridge the gap between practically applied training load monitoring methods and novel scientific evidence. The first question formulated for this dissertation investigated whether the combination of the SWS and SFT metrics ($HR_{average}$, PO, RPE, and TTE) are sensitive to changes in ETL. The second question was to scrutinize the validity of the collected SWS questions, SFT metrics, and ETL metrics (of the PMC), and determine whether they are able to predict performance outcome measures of the SFT (W/kg/RPE, RPE, TTE).

CHAPTER THREE

Methodology

Participant recruitment

Well-trained and professional, male and female, cyclists between the ages of 18 and 45, who had already consented for their data to be captured in a research ethics database (HREC REF NO: R004/2018 and HREC REF NO: R037/2019) were included as participants of this retrospective study (HREC REF NO: R316/2020). Participants were able to withdraw from the study at any time had they wished to do so.

As part of the process to induct a participant into the research ethics database, each participant performed a graded exercise test in order to establish their PPO, whereby their maximal aerobic capacity (VO_{2max}) was extrapolated by means of respiratory gas analysis. The PPO test was performed at a starting work rate of 2.50 W/kg^{-1} body mass, after which the load of resistance was increased incrementally by 20 watts every minute until the participant was unable to sustain a cadence greater than 70 rpm or requested to terminate the test at their own volition due to exhaustion. During the graded exercise test, ventilation volume (V_E), oxygen uptake (VO_2) and CO_2 production (VCO_2) were measured over 15-second intervals using an online breath-by-breath gas analyser and pneumotach (COSMED Quark CPET, Rome, Italy). All persons who administered the graded exercise tests were competent facilitators of the assessment, and the participants were verbally encouraged to perform to maximal exhaustion. Peak power output was determined as the mean power output during the final minute of the PPO test, whereas VO_{2max} was determined as the highest recorded reading for a minimum of 30 seconds. These data were collected as part of each participant's standard high-performance assessment and were captured in the database.

Each participant's data from the previous cycling season was retrospectively analysed. The participant's FTP, or 1-hour mean maximal power (MMP), of the previous season was used as the target SFT power value for the analysis of TrainingPeaks® data (Louisville, Colorado, USA).

The participants performed a submaximal cycling test (Submaximal Fatigue Test, SFT) as well as a brief online questionnaire once each week, typically at the start of their training week. Once the participant completed the SFT as a part of their warm-up, they would immediately complete the abridged online questionnaire, which included subjective questions about their fatigue and wellness, as well as subjective questions about their perception of effort during the SFT (RPE and TTE). The data for all parameters from the participant's personal cycling computer were required to be uploaded to TrainingPeaks® and saved separately from the proceeding training session. All training sessions performed on a bike with their personal cycling computer (power meter) were recorded for a period of six months. All participants were informed about the importance of the zero-offset calibration of their power meters, and they were instructed to do the zero-offset calibration prior to each cycling session (including all training rides and races). The data for all parameters (power output, heart rate, cadence, speed, and distance) from their personal cycling computer were uploaded to TrainingPeaks® for all cycling training sessions (indoor or outdoor).

Exclusion Criteria

Participants who were unable to train in an unrestricted manner due to hospitalisation, or surgical procedures, were not eligible for the research study. Participants who suffered from chronic medical conditions, requiring them to take medication, which may alter metabolic response to exercise and exercise performance, were also excluded from the research study. Additionally, participants did not have their data included in the retrospective study if they had any pre-existing musculoskeletal injury or if they had ever been clinically diagnosed with overtraining syndrome.

Participants who did not have sufficient data from the previous cycling season to establish their FTP, or if they did not complete a minimum of 10 SFTs during six-month data capturing period, did not have their data included in the retrospective study.

Body composition assessment

Anthropometric measurements were measured in accordance to the International Standards for Anthropometric Assessments (International Society for the Advancement of Kinanthropometry, ISAK) methodology (Stewart et al., 2011). All persons who performed the assessments were skilled in the ISAK methodology. These data were collected as part of each participant's standard high-performance assessment and were captured in the database. Body composition was assessed and uploaded onto the database periodically. Participants statures (standing height) were measured, using a recently calibrated portable stadiometer (Seca scale, California, USA). Body mass was measured, using a recently calibrated portable scale (Seca scale, California, USA). Skinfold measurements were recorded with the use of a skinfold caliper (Harpenden skinfold caliper, West Sussex, UK) to determine the sum-of-seven skinfolds. The seven sites that were measured were the biceps, triceps, subscapular, supraspinale, abdomen, mid-thigh, mid-calf. The sum-of-seven skinfolds was recorded in millimetres (mm) and was used in conjunction with their stature (recorded in metres, m) and body mass (recorded in kilograms, kg) to compute their anthropometric profile (sum-of-seven skinfolds, mm, and body mass index, kg·m^2).

Submaximal Fatigue Test

Participants were requested to perform a submaximal fatigue test (SFT) on a weekly basis, typically at the start of their training week, however, in the instance of the training week starting with a rest day(s), the SFT was typically performed prior to a training ride whereby it was used as a warm-up. The SFT required the participant to complete a 3-minute effort, performed at a power output equivalent to their previous season's 1-hour MMP, which is essentially their FTP, as suggested by Borszcz (Borszcz et al., 2018). The participant could perform this effort as a warm-up for a training ride, in a self-selected gear, provided they were able to maintain a cadence of 80-90 rpm. HR was recorded continuously during the SFT. Once the 3-minute effort was completed, the participant was required to record their RPE (using Borg's 6-20 scale) (Foster, 1998), as well as their estimated time to exhaustion (TTE), on the online questionnaire. A performance outcome measure was then derived from the SFT data by expressing the average power output in relation to the participant's reported RPE and body mass (W/kg/RPE). The participant would then complete the remainder of the online questionnaire before completing the rest of their independently prescribed training session. As the SFT was performed as part of the participant's warm-up for their independently prescribed training session, the investigator had no influence on several factors which may influence the participant's performance outcomes. However, it was requested that the participants follow standard hydration and nutritional practices to ensure adequate preparation for SFT and their subsequent training session. The SFT was also typically performed at the start of the participant's training week, whereby participants followed the training schedule prescribed by their independent coach – thereby ensuring a time-of-day routine in the completion of the SFT. While it was not specified which of the participant's SFT were performed indoors and which were performed outdoors, each participant performed the SFT at a pre-determined workload, therefore the capping of power for the submaximal test allowed for participants to complete the SFT (and subsequent training session) in a manner that was appropriate to them at the time (indoors or outdoors), therefore improving compliance as it was minimally aversive, and would not be affected by seasonal changes in weather during the six-month data capturing period.

Following the conclusion of the training session, the participant was required to upload the data from their power meter and heart rate monitor onto TrainingPeaks®. The data for all parameters obtained by the participant's power meter during the SFT was required to be uploaded to TrainingPeaks® and saved separately from the proceeding training session. The data obtained by the participant's heart rate monitor during the SFT was required to be uploaded on TrainingPeaks® and saved separately from the proceeding training session, whereby the average heart rate for the last minute of the SFT was recorded as the SFT $HR_{average}$.

Performance Outcome Measures

The SFT yielded three performance outcome measures, namely, W/kg/RPE, RPE, and TTE. RPE and TTE provided an indication of the participant's perception of effort during the SFT, whereby RPE indicated their self-perceived rating of exertion for the task of maintaining the prescribed power output and cadence during the 3-minute effort, and TTE was their estimation of how long they believed that they could still maintain the prescribed power output and cadence for after the 3-minute effort. W/kg/RPE was a metric derived from the participant's relative power output per unit of body mass per unit of RPE. Therefore, W/kg/RPE was a measure of the participant's average power output during the 3-minute effort in relation to their reported RPE for the SFT and recorded body mass for that day.

Online questionnaire

The section of the online questionnaire which yielded a Subjective Wellness Score (SWS) comprised of four categories: overall-feel rating, fatigue rating, sleep rating, and stress rating. Each category was scored out of 25, whereby the investigators established an evenly weighted numerical value for the verbally anchored subjective rating system (Appendix A). The four parameters yielded a composite score out of 100 to produce the SWS. In addition to recording the RPE and TTE values for the SFT on the online questionnaire, participants also recorded their body mass on the online questionnaire.

Statistical Analysis

Data from 258 SFTs were analysed from a total of 20 well-trained and professional, male (Pauw et al., 2013) and female (Decroix et al., 2016), cyclists (n = 20). The SFT includes both objective ($HR_{average}$, PO, and body mass) and subjective (SWS, RPE and TTE) variables, while the TrainingPeaks® PMC included only objective (TSS, CTL, ATL, and TSB) variables. All objective and subjective data obtained from the SFT and TrainingPeaks® PMC were obtained from a continuous, longitudinal dataset. Microsoft Excel (version 16.72 for Macintosh, Microsoft Corporation, Redmond, Washington, United States) was used to compile all objective and subjective data obtained from the SFT and TrainingPeaks® PMC, and GraphPad

Prism (version 9.5 for Macintosh, GraphPad Software, San Diego, California, United States) was used to analyse the data and to calculate statistical significance.

Due to the lack of homogeneity in the data, a performance measure was derived from the SFT data by expressing the average power output in relation to the participants reported RPE and body mass (W/kg/RPE). In addition, Z-scores were established for all subjective (SWS, RPE and TTE) and objective (Positive-only $HR_{average}$, W/kg/RPE, TSS, CTL, ATL, and TSB) variables. The reason for converting the $HR_{average}$ Z-scores into positive values was that a baseline $HR_{average}$ value higher than the $HR_{average}$, for a particular SFT, would result in a negative $HR_{average}$ Z-score, whereby $HR_{average}$ cannot be expressed as a negative value. The Z-scores for each variable were established in order to normalise the data, as well as to consider the standard deviation for each participant's individual subjective and objective variable.

The participants were sub-divided into six analysis groups: 'All Participants' (n = 20), 'All Professionals' (n = 14), 'Well-trained Males' (n = 6), 'Professional Females' (n = 4), 'Professional Males' (n = 10), and 'All Males' (n = 16); all of the well-trained participants were male, and all of the female participants were professional, therefore these did not require sub-grouping. GraphPad Prism was used to conduct a one-way between sub-groups ANOVA to compare for statistical differences between participant characteristics. Post hoc comparisons using the Tukey-Kramer analysis was used to identify the statistical significance of the differences found between sub-groups. Simple and multiple linear regression models were analysed using GraphPad Prism and used to establish relationships between variables for all participants. A simple, as well as a multivariate, analysis of eight (8) dependent variables (composite SWS and each of the four components of the SWS, $HR_{average}$, RPE, and TTE Z-scores) was performed to establish relationships between these dependent variables and external training load metrics. Another set of simple and multivariate analyses, of nine (9) dependent variables, were also performed, comparing SWS (composite SWS and each of the four components of the SWS) and external training load metrics (ATL, CTL, TSB) to SFT Z-scores (RPE, W/kg/RPE, and TTE), was performed to establish relationships between both the subjective wellness data (SWS), objective SFT data, and external training load metrics. The multivariate analyses were also performed for each of the six sub-groups. All descriptive data are expressed as mean ± standard deviation, and statistical significance was accepted at $p < 0.05$. Correlation coefficients are presented as 95% confidence intervals (95% C.I.).

Ethical Considerations

This research study was performed in accordance with the principles of the Declaration of Helsinki (2013), ICH, and the laws of the Republic of South Africa. Prior to this research study, applications to create two online registries (HREC REF NO: R004/2018 and HREC REF NO: R037/2019) were submitted to, and approved by, the Human Research Ethics Committee (HREC) of the University of Cape Town's Faculty of Health Sciences. The research proposal (HREC NO: 316/2020) for this research study was submitted to, and approved by, the HREC of the University of Cape Town's Faculty of Health Sciences. As participants were pre-existing athletes already uploaded onto the SSISA HPC Athlete Monitoring database, they were already familiar with the online questionnaire (Appendix A). A copy of the original consent form from the participant's initial enrolment into the SSISA HPC Athlete Monitoring database (Appendix B) or the Cape Sports Medicine (UAE Team Emirates cycling) database (Appendix C) was stored in a secure facility, whereby only authorised personnel have access to the data and information for the designated scientific purposes. Participants were provided with study participation information forms (Appendix D).

All data and information collected during the study was stored on an online database registry, and hard copy documents of the participant's information and data capture forms (Appendix E) were stored in a secure, locked facility.

CHAPTER FOUR

Results

General descriptive characteristics

The participant characteristics are described in Table 1. The results of a one-way ANOVA between sub-groups are also reported in Table 1 to identify statistical differences between sub-groups, as well as the results of a post hoc test, whereby a Tukey-Kramer analysis was used to determine the level of statistical significance between the statistically different sub-groups.

The one-way ANOVA analysis found statistically significant differences ($p < 0.05$) between the sub-groups for body mass (F = 3,116; p <0.014), absolute VO_{2max} (F = 3,883; p <0.004), relative VO_{2max} (F = 2,899; p <0.020), relative PPO (F = 4,152; p <0.003), and absolute PPO (F = 4,659; p <0.001). No statistically significant differences were observed in age, height, sum-of-7 skinfolds, and BMI between the sub-groups.

The Tukey-Kramer post hoc test was able to identify the level of significance between the statistically significant differences, whereby statistically significant differences in body mass were found between the 'Well-trained Males' and 'Professional Females' sub-groups (p = 0.017), 'All Males' and 'Professional Females' sub-groups (p = 0.013), as well as between the 'Professional Females' and 'Professional Males' sub-groups (p = 0.043). A significant difference was found between the sum-of-7 skinfolds of the 'Professional Females' and 'Professional Males' sub-groups (p = 0.039). Statistically significant differences were also found in the comparison of absolute VO_{2max} between the 'All Males' and 'Professional Females' sub-groups (p = 0.004), as well as between the 'Professional Females' and 'Professional Males' sub-groups (p = 0.001). A statistically significant difference was found between the relative VO_{2max} of the 'Well-trained Males' and 'Professional Males' sub-groups (p = 0.042). The comparison of relative PPO between the 'Well-trained Males' and 'Professional Males' sub-groups yielded a statistically significant difference (p = 0.008), and the same was true in the comparison between the 'Professional Females' and 'Professional Males' sub-groups (p = 0.011). Statistically significant differences were also found between the absolute PPO of the 'All Males' and 'Professional Females' sub-groups (p = 0.002), as well as for the 'Professional Females' and 'Professional Males' sub-groups (p < 0.001). No statistically significant differences were observed in age, height, and BMI between any sub-groups. No statistically significant differences were observed in any of the characteristics between the 'All Professionals' and 'Well-trained Males' sub-groups.

Table 1: General descriptive characteristics

All Participants (***n*** **= 20)**	**All Participants** (***n*** **= 20)** **Mean ± SD**	**All Males** (***n*** **= 16)** **Mean ± SD**	**All Professionals** (***n*** **= 14)** **Mean ± SD**	**Well-trained Males** (***n*** **= 6)** **Mean ± SD**	**Professional Males** (***n*** **= 10)** **Mean ± SD**	**Professional Females** (***n*** **= 4)** **Mean ± SD**
Age (years)	28.65 ± 6.23	28.37 ± 6.98	27.50 ± 3.65	31.33 ± 10.03	26.60 ± 4.00	29.75 ± 0.50
Height (cm)	178.30 ± 8.36	180.68 ± 6.42	177.85 ± 9.03	179.33 ± 7.17	181.50 ± 6.16	168.75 ± 9.21
Body mass (kg)	**69.01 ± 7.83**	**71.65 ± 5.59 ‡**	**67.17 ± 7.94 ‡**	**73.31 ± 6.15 †**	**70.66 ± 5.60 #**	**58.45 ± 6.06 † ‡ #**
Sum-of-7 skinfolds (mm)	46.14 ± 13.25	42.66 ± 8.53	44.62 ± 15.04	49.70 ± 7.57	38.45 ± 6.68 #	60.05 ± 20.07 #
BMI (kg·m^2)	21.66 ± 1.44	21.94 ± 1.37	21.17 ± 1.26	22.79 ± 1.26	21.44 ± 1.24	20.51 ± 1.22
Absolute VO_{2max} (L/min)	**5.13 ± 0.78**	**5.43 ± 0.51 ‡**	**5.17 ± 0.91 ‡**	**5.04 ± 0.38**	**5.66 ± 0.48 #**	**3.97 ± 0.49 ‡ #**
Relative VO_{2max} (mL/kg/min)	**74.42 ± 7.92**	**76.05 ± 7.69**	**76.70 ± 7.37**	**69.08 ± 6.98 ○**	**80.23 ± 5.05 ○**	**67.87 ± 3.64**
Relative PPO (W/kg)	**6.51 ± 0.75**	**6.69 ± 0.71**	**6.76 ± 0.69**	**5.93 ± 0.56 ○**	**7.15 ± 0.32 # ○**	**5.79 ± 0.13 #**
Absolute PPO (W)	**450.00 ± 72.67**	**477.81 ± 47.30 ‡**	**457.14 ± 84.62 ‡**	**433.33 ± 31.25**	**504.50 ± 34.29 #**	**338.75 ± 36.6 ‡ #**

BMI = Body Mass Index, VO_{2max} = maximal aerobic capacity, PPO = Peak Power Output.

† *Well-trained Males vs. Professional Females*

‡ *All Males vs. Professional Females*

*Professional Females vs. Professional Males*

○ *Well-trained Males vs. Professional Males*

Boldface indicates a significant difference (p < 0.05).

Comparison of the SWS, SFT metrics, and PMC metrics.

Is there a correlation between the SWS and SFT metrics, and the ETL metrics of the PMC?

A simple linear regression analysis was performed in order to compare the SWS and SFT metrics to the ETL metrics of the PMC (TSS, CTL, ATL, and TSB). The results of the linear regression analysis for 'All Participants' (n = 20) is reported in Table 2, whereby the most significant correlations were found for TSB when compared to the SWS and SFT metrics, with statistically significant results for the variables of fatigue rating ($R^2 = 0.126$; $p < 0.001$), overall-feel rating ($R^2 = 0.026$; $p = 0.009$), and RPE ($R^2 = 0.051$; $p < 0.001$). ATL was found to have the next strongest correlations when compared to the SWS and SFT metrics, with statistically significant results for the variables of fatigue rating (R^2 = 0.061; p < 0.001) and $HR_{average}$ (for the SFT) (R^2 = 0.025; p = 0.010). TSS (7-day average) was found to have statistically significant correlations when compared to the SWS and SFT metrics, with statistically significant results for the variables of fatigue rating (R^2 = 0.053; p < 0.001) and RPE (R^2 = 0.019; p = 0.025). CTL was found to have weak correlations with the SWS and SFT metrics, whereby statistically significant results were found for the variables of $HR_{average}$ (R^2 = 0.026; p = 0.009) and TTE (R^2 = 0.017; p = 0.034). No statistically significant correlations were found for the variables of stress rating, sleep rating, and composite score rating.

Table 2: Linear regression analysis correlating the SWS and SFT metrics with the ETL metrics of the PMC for 'All Participants'

All Participants (n = 20)	**TSS**		**CTL**		**ATL**		**TSB**	
Variables	**R^2**	**p-value**	**R^2**	**p-value**	**R^2**	**p-value**	**R^2**	**p-value**
Overall-feel (Z-score)	0.013	0.065	0.000	0.950	0.010	0.096	0.026	**0.009**
Fatigue (Z-score)	0.053	**<0.001**	0.009	0.116	0.061	**<0.001**	0.126	**<0.001**
Stress (Z-score)	0.001	0.659	0.000	0.897	0.000	0.878	0.000	0.868
Sleep (Z-score)	0.001	0.704	0.001	0.570	0.003	0.375	0.004	0.333
Composite Score (Z-score)	0.004	0.311	0.005	0.251	0.004	0.285	0.005	0.273
Positive-only HR (Z-score)	0.001	0.698	0.026	**0.009**	0.025	**0.010**	0.002	0.527
RPE (Z-score)	0.019	**0.025**	0.001	0.692	0.005	0.232	0.051	**<0.001**
TTE (Z-score)	0.000	0.955	0.017	**0.034**	0.006	0.210	0.012	0.076

TSS = Average Training Stress Score (over the last 7-days), CTL = Chronic Training Load, ATL = Acute Training Load, TSB = Training Stress Balance, RPE = rating of perceived exertion, TTE = estimated time to exhaustion.

Boldface indicates a significant correlation (p < 0.05).

A multivariate analysis was performed to compare the SWS and SFT metrics to the ETL metrics of the PMC (TSS, CTL, ATL, and TSB). In the multivariate analysis for TSS (7-day average), CTL, ATL, and TSB, for 'All Participants' (n = 20) (Table 3), TSB was found to have the strongest correlation with the SWS and SFT metrics (R^2 = 0.197; F = 7.86; p < 0.001). ATL was found to have the next strongest correlation (R^2 = 0.125; F = 4.61; p < 0.001), while

TSS (7-day average) and CTL were found to have weak correlations with the SWS and SFT metrics ($R^2 = 0.087$; F = 3.06; $p = 0.003$ and $R^2 = 0.056$; F = 1.92; $p = 0.057$, respectively).

The most significant correlations were found for TSB when compared to the SWS, with statistically significant results for the variables of overall-feel rating (F = 12.37; $p = 0.001$) and fatigue rating (F = 28.11; $p < 0.001$). For ATL, when compared to the SWS and SFT metrics, significant correlations were found with fatigue rating (F = 15.53; $p < 0.001$) and $HR_{average}$ (for the SFT) (F = 7.89; $p = 0.005$). For TSS (7-day average), statistically significant results were found for the variables of overall-feel rating (F = 4.07; $p = 0.045$) and fatigue rating (F = 9.67; $p = 0.002$). For CTL, a significant correlation was found with $HR_{average}$ (F = 5.76; $p = 0.017$). No statistically significant correlations were found for the variables of stress rating, sleep rating, composite score rating, RPE, and TTE.

Table 3: Multivariate analysis correlating the SWS and SFT metrics with the ETL metrics of the PMC for 'All Participants'

All Participants (*n* = 20)	**TSS**		**CTL**		**ATL**		**TSB**	
Variables	**F-Value**	**P-Value**	**F-Value**	**P-Value**	**F-Value**	**P-Value**	**F-Value**	**P-Value**
Overall-feel (Z-score)	4.07	**P=0.045**	0.01	P=0.929	3.68	P=0.056	12.37	**P<0.001**
Fatigue (Z-score)	9.67	**P=0.002**	3.32	P=0.069	15.53	**P<0.001**	28.11	**P<0.001**
Stress (Z-score)	0.17	P=0.679	0.07	P=0.797	0.07	P=0.792	0.12	P=0.730
Sleep (Z-score)	0.41	P=0.522	0.68	P=0.410	2.14	P=0.145	2.56	P=0.111
Composite Score (Z-score)	0.44	P=0.508	0.16	P=0.692	0.07	P=0.790	0.03	P=0.859
Positive-only HR (Z-score)	0.05	P=0.816	5.76	**P=0.017**	7.89	**P=0.005**	2.05	P=0.154
RPE (Z-score)	3.54	P=0.061	0.15	P=0.703	1.37	P=0.244	3.23	P=0.073
TTE (Z-score)	1.64	P=0.202	3.38	P=0.067	2.81	P=0.095	0.08	P=0.782
Regression Model	3.06	**P=0.003**	1.92	P=0.057	4.61	**P<0.001**	7.86	**P<0.001**
Goodness of Fit (R^2); Degrees of Freedom	R^2=0.087; 257		R^2=0.056; 257		R^2=0.125; 257		R^2=0.197; 257	

TSS = Average Training Stress Score (over the last 7-days), CTL = Chronic Training Load, ATL = Acute Training Load, TSB = Training Stress Balance, RPE = rating of perceived exertion, TTE = estimated time to exhaustion.

Boldface indicates a significant correlation (p < 0.05).

Can the SWS, $HR_{average}$, and ETL metrics of the PMC predict performance outcome measures of the SFT?

Simple linear regression analyses were performed in order to compare the SWS, $HR_{average}$ (for the SFT), and the ETL metrics of the PMC (CTL, ATL, and TSB) to the performance outcome measures of the SFT (W/kg/RPE, RPE, TTE). The results of the linear regression analysis for 'All Participants' (*n* = 20) is reported in Table 4, whereby the most significant correlation was found for the relative power output per unit of body mass per unit of RPE (W/kg/RPE) when compared to the SWS, $HR_{average}$, and ETL metrics of the PMC, with statistically significant results for the variables of fatigue rating ($R^2 = 0.110$; $p < 0.001$), TSB ($R^2 = 0.065$; $p < 0.001$), composite score rating ($R^2 = 0.034$; $p = 0.003$), overall-feel rating ($R^2 = 0.032$; $p = 0.004$), and sleep rating ($R^2 = 0.016$; $p = 0.038$). The next strongest correlation was found for RPE, when compared to the SWS, $HR_{average}$, and ETL metrics of the PMC, with statistically significant results for the variables of fatigue rating ($R^2 = 0.131$; $p < 0.001$), TSB ($R^2 = 0.051$; $p < 0.001$), composite score rating ($R^2 = 0.030$; $p = 0.004$), and overall-feel rating ($R^2 = 0.033$; $p = 0.003$). TTE was found to have the weakest correlation when compared to the SWS, $HR_{average}$, and ETL metrics of the PMC, with statistically significant results for the variables of overall-feel rating ($R^2 = 0.033$; $p = 0.003$), fatigue ($R^2 = 0.024$; $p = 0.012$), $HR_{average}$ ($R^2 = 0.021$; $p = 0.018$), and CTL ($R^2 = 0.017$; $p = 0.034$). No statistically significant correlations were found for the variables of stress rating and ATL.

Table 4: Linear regression analysis correlating the SWS, $HR_{average}$, and ETL metrics of the PMC with the performance outcome measures of the SFT for 'All Participants'

All Participants (n = 20)	**W/kg/RPE**		**RPE**		**TTE**	
Variables	**R^2**	**p-value**	**R^2**	**p-value**	**R^2**	**p-value**
Overall-feel (Z-score)	0.032	**0.004**	0.033	**0.003**	0.033	**0.003**
Fatigue (Z-score)	0.110	**<0.001**	0.131	**<0.001**	0.024	**0.012**
Stress (Z-score)	0.001	0.566	0.002	0.502	0.004	0.289
Sleep (Z-score)	0.016	**0.038**	0.006	0.212	0.001	0.678
Composite Score (Z-score)	0.034	**0.003**	0.030	**0.004**	0.002	0.453
Positive-only HR (Z-score)	0.001	0.550	0.001	0.624	0.021	**0.018**
CTL	0.001	0.611	0.001	0.692	0.017	**0.034**
ATL	0.007	0.189	0.005	0.232	0.006	0.210
TSB	0.065	**<0.001**	0.051	**<0.001**	0.012	0.076

W/kg/RPE = relative power output per unit of body mass per unit of RPE, RPE = rating of perceived exertion, TTE = estimated time to exhaustion, CTL = Chronic Training Load, ATL = Acute Training Load, TSB = Training Stress Balance.
Boldface indicates a significant correlation ($p < 0.05$).

A multivariate analysis was performed to compare SWS, $HR_{average}$ (for the SFT), and ETL metrics of the PMC (CTL, ATL, and TSB) to the performance outcome measures of the SFT (W/kg/RPE, RPE, TTE). In the multivariate analysis for the modelling of the performance outcome measures of SFT (W/kg/RPE, RPE, and TTE), for 'All Participants' (n = 20) (Table 5), RPE was found to have the strongest correlation with the SWS, $HR_{average}$, and ETL metrics of the PMC ($R^2 = 0.207$; F = 7.43; $p < 0.001$). W/kg/RPE was found to have the next strongest correlation ($R^2 = 0.206$; F = 7.38; $p < 0.001$), and TTE was found to have the weakest correlation with the SWS, $HR_{average}$, and ETL metrics of the PMC ($R^2 = 0.124$; F = 4.01; $p < 0.001$).

The most significant correlations were found for W/kg/RPE when compared to the SWS, $HR_{average}$, and ETL metrics of the PMC, with statistically significant results for the variables of overall-feel rating (F = 11.06; $p = 0.001$), fatigue rating (F = 18.02; $p < 0.001$), stress rating (F = 8.23; $p = 0.005$) sleep rating (F = 4.61; $p = 0.033$), and TSB (F = 4.48; $p = 0.035$). For RPE, significant correlations were found with overall-feel rating (F = 12.14; p = 0.001), fatigue rating (F = 26.70; $p < 0.001$), and stress rating (F = 7.33; p = 0.007). For TTE, when compared to the SWS, $HR_{average}$, and ETL metrics of the PMC, significant correlations were found for the variables of overall-feel rating (F = 11.65; p = 0.001), fatigue rating (F = 4.01; p = 0.046), stress rating (F = 4.13; p = 0.043), sleep rating (F = 4.02; p = 0.046), and $HR_{average}$ (F = 5.76; p = 0.017). No statistically significant correlations were found for the variables of composite score rating, CTL, and ATL.

Table 5: Multivariate analysis correlating the SWS, $HR_{average}$, and ETL metrics of the PMC to the performance outcome measures of the SFT for 'All Participants'

All Participants (n = 20)	W/kg/RPE Z-score		RPE Z-score		TTE Z-score	
Variables	**F-Value**	**P-Value**	**F-Value**	**P-Value**	**F-Value**	**P-Value**
Overall-feel (Z-score)	11.06	**P=0.001**	12.14	**P=0.001**	11.65	**P=0.001**
Fatigue (Z-score)	18.02	**P<0.001**	26.70	**P<0.001**	4.01	**P=0.046**
Stress (Z-score)	8.23	**P=0.005**	7.33	**P=0.007**	4.13	**P=0.043**
Sleep (Z-score)	4.61	**P=0.033**	1.98	P=0.161	4.02	**P=0.046**
Composite Score (Z-score)	0.07	P=0.793	0.06	P=0.812	0.01	P=0.943
Positive-only HR (Z-score)	0.09	P=0.766	0.57	P=0.452	5.76	**P=0.017**
CTL	0.00	P=0.966	0.00	P=0.962	0.06	P=0.799
ATL	0.19	P=0.663	0.14	P=0.713	0.88	P=0.349
TSB	4.48	**P=0.035**	2.67	P=0.103	3.01	P=0.084
Regression Model	7.38	**P<0.001**	7.43	**P<0.001**	4.01	**P<0.001**
Goodness of Fit (R^2); Degrees of Freedom	R^2= 0.206; 256		R^2= 0.207; 256		R^2= 0.124; 256	

W/kg/RPE = relative power output per unit of body mass per unit of RPE, RPE = rating of perceived exertion, TTE = estimated time to exhaustion, CTL = Chronic Training Load, ATL = Acute Training Load, TSB = Training Stress Balance.
Boldface indicates a significant correlation (p < 0.05).

Sub-group analyses

In the multivariate analysis for TSS (7-day average), CTL, ATL, and TSB, for 'All Males' participants (n = 16), TSB was found to have the strongest correlation with the SWS and SFT metrics ($R^2 = 0.221$; F = 7.22; $p < 0.001$). ATL was found to have the next strongest correlation ($R^2 = 0.140$; F = 4.15; $p = 0.001$), while TSS (7-day average) and CTL were found to have weak correlations with the SWS and SFT metrics ($R^2 = 0.108$; F = 3.10; $p = 0.003$ and $R^2 = 0.070$; F = 1.92; $p = 0.058$, respectively). The most significant correlations were found for TSB when compared to the SWS and SFT metrics with statistically significant results for the variables of overall-feel rating (F = 9.62; $p = 0.002$) and fatigue rating (F = 6.79; $p = 0.001$). For ATL, when compared to the SWS and SFT metrics, significant correlations were found with fatigue rating (F = 4.68; $p = 0.032$), and $HR_{average}$ (F = 8.06; $p = 0.005$). For TSS (7-day average), a statistically significant result was found for the variables of fatigue rating (F = 5.02; $p = 0.026$). For CTL, a significant correlation was found with $HR_{average}$ (F = 6.22; $p = 0.014$). No statistically significant correlations were found for the variables of stress rating, sleep rating, composite score rating, RPE, and TTE.

The multivariate analysis conducted for the modelling of the performance outcome measures of the SFT (W/kg/RPE, RPE, and TTE), for 'All Males' participants (*n* = 16), W/kg/RPE and RPE were, equally, found to have the strongest correlations with the SWS, $HR_{average}$, and ETL metrics of the PMC ($R^2 = 0.206$; F = 5.86; $p < 0.001$ and $R^2 = 0.206$; F = 5.86; $p < 0.001$, respectively). TTE was found to have the weakest correlation with the SWS, $HR_{average}$, and ETL metrics of the PMC ($R^2 = 0.127$; F = 3.29; $p = 0.001$). The most significant correlations were found for W/kg/RPE when compared to the SWS, $HR_{average}$, and ETL metrics of the PMC, with statistically significant results for the variables of overall-feel rating (F = 14.05; $p < 0.001$), fatigue rating (F = 10.73; $p = 0.001$), sleep rating (F = 6.13; $p = 0.014$), and TSB (F = 5.86; $p = 0.023$). For RPE, significant correlations were found with overall-feel rating (F = 13.76; $p < 0.001$), fatigue rating (F = 15.17; $p < 0.001$), and sleep rating (F = 3.98; $p = 0.048$). For TTE, when compared to the SWS, $HR_{average}$, and ETL metrics of the PMC, significant correlations were found for the variables of overall-feel rating (F = 8.67; $p = 0.004$) and $HR_{average}$ (F = 4.71; $p = 0.031$). No statistically significant correlations were found for the variables of stress rating, composite score rating, CTL, and ATL.

In the multivariate analysis for TSS (7-day average), CTL, ATL, and TSB, for 'All Professionals' participants (*n* = 14), TSB was found to have the strongest correlation with the SWS and SFT metrics ($R^2 = 0.188$; F = 4.85; $p < 0.001$). ATL was found to have the next strongest correlation ($R^2 = 0.113$; F = 2.66; $p = 0.009$), while TSS (7-day average) and CTL were found to have weak correlations with the SWS and SFT metrics ($R^2 = 0.081$; F = 1.85; $p = 0.071$ and $R^2 = 0.055$; F = 1.21; $p = 0.295$, respectively). The most significant correlations were found for TSB when compared to the SWS and SFT metrics with statistically significant results for the variables of fatigue rating (F = 7.82; $p = 0.006$) and overall-feel rating (F = 5.53; $p = 0.020$). For ATL, when compared to the SWS and SFT metrics, significant correlations were found for sleep rating (F = 7.02; $p = 0.009$) and overall-feel rating (F = 5.05; $p = 0.026$). For CTL, a statistically significant correlation was found for sleep rating (F = 4.74; $p = 0.031$). ATL did not yield any statistically significant correlations when compared to the SWS and SFT metrics. No statistically significant correlations were found for the variables of stress rating, composite score rating, $HR_{average}$, RPE, and TTE.

The multivariate analysis conducted for the modelling of the performance outcome measures of the SFT (W/kg/RPE, RPE, and TTE), for 'All Professionals' participants (n = 14), W/kg/RPE was found to have the strongest correlation with the SWS, $HR_{average}$, and ETL metrics of the PMC ($R^2 = 0.201$; F = 4.63; $p < 0.001$). RPE was found to have the next strongest correlation with the SWS, $HR_{average}$, and ETL metrics of the PMC ($R^2 = 0.189$; F = 4.30; $p < 0.001$). TTE was found to have the weakest correlation with the SWS, $HR_{average}$, and ETL metrics of the PMC ($R^2 = 0.167$; F = 3.69; $p < 0.001$). The most significant correlations were found for RPE when compared to the SWS, $HR_{average}$, and ETL metrics of the PMC, with statistically significant results for the variables of fatigue rating (F = 11.08; $p = 0.001$) and overall-feel rating (F = 10.50; $p = 0.001$). For TTE, a significant correlation was found for the variable of overall-feel rating (F = 12.42; $p = 0.001$). For W/kg/RPE, significant correlations were found for the variables of overall-feel rating (F = 8.43; $p = 0.004$), fatigue rating (F = 8.21; $p = 0.005$), and sleep rating (F = 5.05; $p = 0.026$). No statistically significant correlations were found for the variables of stress rating, sleep rating, composite score rating, $HR_{average}$, CTL, ATL, and TSB.

In the multivariate analysis for TSS (7-day average), CTL, ATL, and TSB, for 'Professional Males' participants (n = 10), TSB was found to have the strongest correlation with the SWS and SFT metrics ($R^2 = 0.233$; F = 4.32; $p < 0.001$). TSS (7-day average) was found to have the next strongest correlation ($R^2 = 0.124$; F = 2.02; $p = 0.050$), while ATL and CTL were found to have weak correlations with the SWS and SFT metrics ($R^2 = 0.113$; F = 1.81; $p = 0.082$ and $R^2 = 0.050$; F = 0.74; $p = 0.653$, respectively). The most significant correlations were found for TSB when compared to the SWS and SFT metrics with statistically significant results for the variables of overall-feel rating (F = 4.23; $p = 0.042$) and fatigue rating (F = 4.44; $p = 0.037$). For TSS (7-day average), when compared to the SWS and SFT metrics, a significant correlation was found for fatigue rating (F = 5.14; $p = 0.025$). No statistically significant correlations for found for CTL or ATL when compared to the SWS and SFT metrics. No statistically significant correlations were found for the variables of stress rating, sleep rating, composite score rating, $HR_{average}$, RPE, and TTE.

The multivariate analysis conducted for the modelling of the performance outcome measures of the SFT (W/kg/RPE, RPE, and TTE), for 'Professional Males' participants (n = 10), W/kg/RPE was found to have the strongest correlation with the SWS, $HR_{average}$, and ETL metrics of the PMC (R^2 = 0.197; F = 3.08; p = 0.003). RPE was found to have the next strongest correlation with the SWS, $HR_{average}$, and ETL metrics of the PMC (R^2 = 0.174; F = 2.65; p = 0.008). TTE was found to have the weakest correlation with the SWS, $HR_{average}$, and ETL metrics of the PMC (R^2 = 0.172; F = 2.60; p = 0.009). The most significant correlations were found for TTE when compared to the SWS, $HR_{average}$, and ETL metrics of the PMC, with statistically significant results for the variables of overall-feel rating (F = 7.84; p = 0.006) and TSB (F = 4.56; p = 0.035). For RPE, a significant correlation was found for the variable of overall-feel rating (F = 8.13; p = 0.005). For W/kg/RPE, a significant correlation was found for the variable of overall-feel rating (F = 7.99; p = 0.006). No statistically significant correlations were found for the variables of fatigue rating, stress rating, sleep rating, composite score rating, $HR_{average}$, CTL, and ATL.

CHAPTER FIVE

Discussion

The aim of this thesis was to assess whether a combination of a customised online questionnaire (Subjective Wellness Score, SWS) and a modified submaximal cycling test (Submaximal Fatigue Test, SFT) (internal training load, ITL, and external training load, ETL, monitoring tools) can be used in conjunction with TrainingPeaks® Performance Management Chart™ (PMC) (ETL monitoring tool) to monitor the response to training in well-trained and professional cyclists with acceptable validity and reliability. This differs from similar studies in which, despite using participants of similar fitness status, they focused on different ITL and ETL metrics to monitor the response to training (Barbeau et al., 1993; Lamberts et al., 2014; Lamberts, Rietjens, et al., 2010; Otter et al., 2015; Sassi et al., 2006, 2008) and studies which have validated only TSS as a load measure in comparison to TRIMP and PO (Erp et al., 2019; Sanders et al., 2017).

The first major finding of this study was that when investigating the correlation between the SWS and SFT metrics with the ETL metrics of the PMC for 'All Participants', TSB was shown to be the most sensitive training load metric to changes in fatigue status. TSB was also the ETL metric (of the PMC) which had the strongest correlations with the SWS and SFT metrics for the three sub-groups that were additionally analysed ('All Males', 'All Professionals', and 'Professional Males'). TSB's relationship with the SWS and SFT metrics can be explained by the understanding that TSB is an ETL parameter that has been described as an indicator of an individual's current level of freshness, whereby TSB is derived from the difference between an individual's developed fitness and accumulated fatigue. Therefore, our findings support the notion that TSB can be used to express an individual's readiness to perform, or "freshness", as described by Coyne *et al.* and Allen & Coggan (H. Allen & Coggan, 2019; Coyne et al., 2022), thereby indicating that the SWS and SFT metrics are reliable measures of detecting changes in fatigue status.

Between ATL and TSS (7-day average), ATL was the ETL metric of the PMC that was found to be more sensitive to changes in fatigue status than TSS (7-day average), yielding a stronger statistically significant correlation to fatigue rating in the analyses of 'All Participants'. ATL is calculated as an exponentially weighted moving average (EWMA) of daily TSS, over a period of 7 days, whereby TSS is a 7-day rolling average (RA). This finding is supported by the understanding that EWMA is a more sensitive measure, and therefore more suitable for monitoring changes in training load (Griffin et al., 2019). CTL, however, did not correlate well with markers of fatigue status for any of the analysed sub-groups. CTL is also calculated as an EWMA of daily TSS, however, unlike ATL, its default time constant is set to 42 days. This finding suggests that fatigue is diminished relatively quickly (Stone et al., 1999) as the measure across a chronic time period does not retain a strong enough effect on the markers of fatigue.

The submaximal cycling test utilised in this study (SFT) was able to capture multiple variables ($HR_{average}$, PO, RPE, and TTE), from which the performance outcome measures of the SFT (W/kg/RPE, RPE, and TTE) were derived. The second major finding of this study, produced by the multivariate analysis conducted for the modelling of the performance outcome measures of the SFT, for 'All Participants', was that TSB was only significantly correlated with W/kg/RPE, but not RPE and TTE.

The statistically significant correlation between TSB and W/kg/RPE indicates that the relationship between PO and RPE (W/kg/RPE) is more sensitive to changes in fatigue status than RPE and TTE when interpreted as stand-alone metrics, i.e., in a fatigued state the participants either reduced their PO during the SFT (to below their target PO for the SFT), or alternatively, they recorded a higher RPE for the SFT (having maintained the target PO for the SFT). This finding revealed that the participant's inability to sustain the prescribed PO during the SFT, in conjunction with a greater perceived physical exertion during the SFT, is an indicator of the participant's muscular fatigue status (Allen et al., 2008), however, due to the complex nature in which muscular fatigue may originate at different levels of the motor pathways, further investigations are required in order to determine whether the failure to maintain the targeted PO can be categorised as muscular fatigue attributed to peripheral fatigue or central fatigue (Wan et al., 2017). Therefore, the process of coupling these two metrics enhances the sensitivity to changes in fatigue status, compared to monitoring RPE as a stand-alone measure. Furthermore, since TSB was found to be the most sensitive training load metric to changes in fatigue status, it suggests that the use of the SFT as a submaximal cycling test is valid for monitoring changes in fatigue status.

$HR_{average}$ was also found to have a good relationship with the ETL metrics of the PMC, ATL and CTL, as well as with the performance outcome measure of the SFT, TTE. This finding is consistent with that of the studies by Lamberts *et al.* which have investigated the reliability and validity of the Lamberts and Lambert Submaximal Cycle Test (LSCT), which incorporates PO, HR, and RPE (Lamberts et al., 2009, 2011). A systematic review stated that the use of multiple variables and multivariable analyses is likely to be the best and most sensitive way to monitor the response to training loads, predict cycling performance, and optimise training load prescription in cyclists (Capostagno et al., 2016).

Direct and simple closed-ended questions such as ‘How did you feel overall during the last week of training?’ and ‘How fatigued are you feeling after this week?’ were able to produce reliable indicators of fatigue status, whereby the responses to these questions yielded statistically significant correlations with TSB (ETL metric of the PMC) and W/kg/RPE (performance outcome measure of the SFT). Fatigue rating and overall-feel rating were therefore identified to be useful metrics to monitor fatigue status. Furthermore, fatigue rating was found to be the most meaningful variable of the SWS and SFT metrics, whereby statistically significant relationships were established with TSB, as well as with the performance outcome measure of the SFT, W/kg/RPE. Thereby supporting the notion that the use of a combination of subjective and objective measures instils confidence in the ability to detect changes in fatigue status (Halson, 2014).

Another finding of the study, also related to the ETL metrics of the PMC, was that while TSS (7-day average) and ATL yielded some statistically significant correlations with the SWS and SFT metrics (particularly with fatigue rating), aside from TSB, the ETL metrics of the PMC (CTL and ATL) offered little-to-no assistance in predicting performance outcome measures of the SFT (W/kg/RPE, RPE, TTE).

The findings of the multivariate analyses of the sub-groups ‘All Males’, ‘All Professionals’ and ‘Professional Males’ yielded similar results in that TSB was found to have the most significant correlations when compared to the SWS and SFT metrics, whereby the variables of overall-feel rating and fatigue rating were commonly found to produce the most statistically significant results in the respective investigations. The performance outcome measure of the SFT, W/kg/RPE, was found to frequently produce statistically significant correlations between the SWS, $HR_{average}$, (for the SFT), and ETL metrics of the PMC (CTL, ATL, TSB) in the ‘All Males’, ‘All Professionals’, and ‘Professional Males’ sub-groups, thereby furthermore highlighting similar trends between the investigated sub-groups. This discovery supports the idea that the findings in this study can be applied across various cycling disciplines, among well-trained and professional cyclists.

While this study was not able to demonstrate statistically significance amongst a female-only (‘Professional Females’) or the ‘Well-trained Males’ cohorts, due to the small sample sizes of these sub-groups (n = 4 and n = 6, respectively), the findings in this study did not lose any statistical significance by including the female participants in the analysis of the ‘All

Participants' and 'All Professionals' sub-groups, likewise, with the inclusion of the well-trained participants in the analysis of the 'All Participants' and 'All Males' sub-groups.

Although the SWS variables of stress rating, sleep rating, and composite score rating were all found to not be useful metrics to monitor fatigue status, a study by Le Meur *et al.* employed the use of an abridged questionnaire, whereby participants answered questions in three areas related to pain, tiredness, and well-being with the use of a visual analogic scale (Le Meur et al., 2013). The outcomes of that study were in line with the findings in our study, whereby it was shown that an abridged questionnaire, used in conjunction with other ITL and ETL metrics, can be administered to monitor the response to training load with acceptable validity. Interestingly, the SWS variables of stress rating, indicating the individual's self-perceived mood-state, and sleep rating, indicating the individual's self-perceived sleep quality for the previous night, did not yield statistically significant correlations between ITL and ETL measures, as it may have been expected, in line with previous findings (Gomes et al., 2013; Hamlin et al., 2019, 2021; Nobari et al., 2023; Walsh et al., 2021).

A longitudinal study by Hamlin et al. found a relationship between a number of subjective measures (of stress and self-perceived mood state) and odds of illness or injury (Hamlin et al., 2019). This study demonstrated that mood disturbances, sleep duration (but not sleep quality), and environmental stress (academic pressure) were the strongest contributors to illness and injury. These findings thereby corroborated previous work by Galambos and colleagues, who reported that subjective measures (mood disturbances and increased self-perceived life stress) were able to predict injury in elite athletes (Galambos et al., 2005). Additionally, work done by Gomes et al. demonstrated the worsening of symptoms of stress, as indicated by the greater number of responses of "worse than normal" in Part B of the DALDA, completed by the 10 youth tennis players during the four-week overloading training period (Gomes et al., 2013). This part of the questionnaire is closely associated with "symptoms", reflecting the individual's ability to cope with the imposed training-related stressors. However, despite this increase in the negative perception of stress, there was no significant change in the source of stress across the study's four-week overloading training period. Thereby, corroborating the findings in previous studies that have reported an increase in the "symptoms of stress" following an intensified period of training, which returned to the previous value following the reduction in training load (Achten et al., 2004).

Research performed by Nobari et al. concluded that the monitoring of sleep can be helpful in the early detection, diagnosis, and prompting of intervention before significant decrements in performance and health are observed (Nobari et al., 2023). This mechanism can be better understood by considering how sleep disturbances are frequently reported as one of the many symptoms of overreaching and overtraining (Walsh et al., 2021). Notably, a case study involving a talented female sprint cyclist by Walsh et al. reported a larger sleep deficiency (<6 hours per night, compared with 8-10 hours per night following full recovery) in the presence of signs of overtraining (i.e. persistent fatigue and underperforming over several months (Walsh et al., 2021). Furthermore, there is reason to believe that there is a relationship between sleep and rating of perceived exertion during training, evidenced by the findings of a study whereby it was interestingly found that on the days where the female participants reported increase sleep (≥8 hours for the previous night's duration of sleep), they also reported a trivial-to-small increase in perceived exertion during training ($p = 0.04$) and a small increase in overall training workload ($p = 0.04$), while only a non-significant increase in overall training workload was found in the male participants on days when they slept ≥8 hours (Hamlin et al., 2021).

The lack of statistically significant correlations between stress and sleep ratings and ITL and ETL measures observed in this current study does not refute the findings of previous research studies, whereby statistically significant correlations between mood disturbances and sleep duration, and measures of performance and/or illness and injury prediction were identified. It should rather be considered that our findings highlight the limitations in the over-simplification of monitoring complex and multifactorial variables, such as stress and sleep, when aiming to estimate or predict changes in proxies of performance.

While Le Meur *et al.* reported on their ability to successfully detect overreaching among endurance athletes via the use of an abridged questionnaire (Le Meur et al., 2013), the items of their questionnaire were focused on the participant's pain, tiredness, and well-being, coupled with a rating of their perceived effort. Therefore, these items did not definitively reflect the participant's mood state or rate their sleep quantity. It is therefore proposed that the use of an abridged questionnaire is a feasible, validated and reliable method of detecting signs of overreaching or overtraining in endurance athletes, however, the coach/sports scientist should be mindful that there is a possibility of the endurance athlete entering into a state of overreaching or overtraining in the absence of negative perceptions of stress or decreased sleep quantity.

CHAPTER SIX

Conclusion

The purpose of this dissertation was to determine whether the combination of a customised online questionnaire (Subjective Wellness Score, SWS) and a modified submaximal cycling test (Submaximal Fatigue Test, SFT) (internal and external training load monitoring tools) can be used in conjunction with an external training load monitoring tool (TrainingPeaks® Performance Management Chart™, PMC) to monitor the response to training in well-trained and professional cyclists with acceptable validity and reliability.

Two specific questions were formulated in order to attempt to bridge the gap between practically applied training load monitoring methods and novel scientific evidence. The first question formulated for this dissertation investigated whether the combination of the SWS and SFT metrics ($HR_{average}$, PO, RPE, and TTE) are sensitive to changes in ETL. In order to adequately answer this question, the objective of investigating the validity of the abridged questionnaire was posed. A customized online questionnaire (SWS) included the measures typically monitored in endurance sport athletes to allow for greater compliance from the athlete as the abridged questionnaire did not consume too much of their time, it was minimally aversive, user-friendly, and easily accessible with the use of any smartphone or computer device with internet access. Here it was found that the questions 'How fatigued are you feeling after this week?' (fatigue rating) and 'How did you feel overall during the last week of training?' (overall-feel rating) had the most statistically significant correlations with changes in the ETL metric of the PMC, TSB, as well as for the performance outcome metric of the SFT, W/kg/RPE. Another objective of this study was to correlate the SWS and SFT metrics with the ETL metrics of the PMC to assess which ITL metrics correlate with changes in the ETL metrics. The analyses performed concluded that there was a statistically significant relationship between TSB (an ETL metric of PMC) and fatigue rating and overall-feel rating (SWS variables), TSB (an ETL metric of PMC) and W/kg/RPE (a performance outcome measure of the SFT), and W/kg/RPE (a performance outcome measure of the SFT) and fatigue rating and overall-feel rating (SWS variables).

The next question was to scrutinize the validity of the collected SWS questions, SFT metrics, and ETL metrics (of the PMC), and determine whether they are able to predict performance outcome measures of the SFT (W/kg/RPE, RPE, TTE). The objective of determining the sensitivity and validity of the modified submaximal cycling test (SFT) was set out for the purpose of finding a sufficient answer for this question. The SFT utilised a target power output while measuring the athlete's heart rate, rating of perceived exertion (RPE), and estimated time to exhaustion (TTE) for the prescribed power output. Changes in the relationship between these

SFT metrics were subsequently assessed in comparison to the SWS variables, as well as the ETL metrics of the PMC. In this investigation, it was established that the relationship between power output and RPE (in the form of W/kg/RPE) is more sensitive to changes in fatigue status than RPE and TTE when these metrics are interpreted as stand-alone metrics as it was found that only changes in fatigue rating, overall-feel rating, and TSB had correlations with the performance outcome measure of the SFT, W/kg/RPE. Furthermore, the average heart rate ($HR_{average}$) for the duration of the SFT was found to correlate with ETL metrics of the PMC, ATL and CTL, and the performance outcome measure of the SFT, TTE.

Considering the findings in this research study, the two questions formulated for this thesis were answered, whereby it can be stated, with confidence, that the SWS and SFT metrics (overall-feel rating and fatigue rating) were sensitive to changes in the ETL metric of the PMC (TSB). It was also found that the SWS, $HR_{average}$, and ETL metrics of the PMC were able to a predict performance outcome measure of the SFT, yielding a statistically significant correlation with W/kg/RPE. Henceforth, it should also be accepted that the combined use of a customised online questionnaire and a modified submaximal cycling test can be used in conjunction with the TrainingPeaks® PMC to monitor the response to training in well-trained and professional cyclists with acceptable validity and reliability. It should also be noted that these findings contribute to the body of work pertaining to the current practices of monitoring training load in cyclists as the concurrent use of a customised questionnaire, a modified submaximal cycling test, and the ETL metrics of the PMC, as proposed in this research study, have yet to be reported on in previously published literature.

The discoveries made in this current study supports the opinion that fatigue is a complex and multifaceted phenomenon that has a variety of possible mechanisms (Halson, 2014), and as such, it is recommended that subjective and objective measures of training load are used in unison (Le Meur et al., 2013; Saw et al., 2016), thereby adapting a holistic approach to monitoring the response to training loads.

Practical application

The findings in this dissertation should provide coaches/sport scientists with the confidence needed to efficiently and effectively monitor the training load of an endurance sport athlete, particularly well-trained and professional cyclists. The most emphasis should, however, still be to promote clear and truthful channels of communication between the athlete and coach/sport scientist to ensure that data gathered from subjective feedback is accurate, useful and not misleading. The questions ‘How fatigued are you feeling after this week?’ and ‘How did you feel overall during the last week of training?’ have the greatest probability of establishing the athlete’s fatigue status, however, a coach/sport scientist should not disregard the athlete’s sleep rating (sleep quality and quantity) or stress rating (mood state) as these measures may still provide useful information that may affect the athlete’s readiness to perform, as well as serve as an indicator of an endurance athlete heading towards a state of overreaching or overtraining.

The use of the performance outcome measure of the SFT, W/kg/RPE, may prove to be highly beneficial for coaches/sports scientists as a cyclist in a fatigued state may reduce their power output during the SFT to below their target power output, and additionally, they may also record a higher RPE for the SFT.

The TrainingPeaks® PMC metric TSB was found to be the most useful ETL metric as the objective metric was sensitive to changes in fatigue status. It would, however, be worthwhile for the coach/sports scientist to furthermore establish the TSB range for which the athlete performs their best at, thereby ensuring that they are not too fatigued, or that they are underprepared due to a chronically low training load, in the lead-up to their competition.

In closing, this study suggests that the concurrent use of the SWS, SFT, and PMC is an effective and efficient method for coaches/sports scientist to monitor the cyclist’s response to their encountered training load as the blend of subjective and objective training load metrics have been found to be sensitive to changes in fatigue status, with acceptable validity and reliability.

Future research

This research study was not able to demonstrate statistically significance amongst a female-only (‘Professional Females’) or the ‘Well-trained Males’ cohorts, due to the small sample sizes of these sub-groups ($n = 4$ and $n = 6$, respectively). Therefore, increasing the sample sizes for the female-only and the well-trained sub-groups would circumvent this limitation to the study, and in doing so, furthermore contributing to the insights already reported on in this research study. The absence of objective performance outcomes (race data) was identified as another limitation of this study, therefore, a research study designed to specifically track a cycling season, with the inclusion of objective performance data, through structured testing and race data, could enhance the quality of knowledge gained from the investigation of the concurrent use of the SWS, SFT, and PMC to monitor the response to training load.

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Appendix

Appendix A – Online questionnaire

Fields marked with an * are required

First Name	Last Name

Email *

Today's Date

dd/mm/yyy

Please review your last week of training. Let me know highlights, low points, as well as how you felt during sessions during the week in general? (type)

How did you feel overall during the last week of training? (dropdown list)

Not Selected
Horrible
Extremely Poor
Poor
Bad
Below Average
Above Average
Good
Superior
Extremely Superior
Best

How fatigued are you feeling after this week? (dropdown list)

Not Selected
None
Very Low
Low
Average
High
Very High
Extreme

How stressed have you been this week? (dropdown list)

Not Selected
None
Very Low
Low
Average
High
Very High
Extreme

How would you rate your sleep quality and quantity this week? (dropdown list)

Not Selected
Horrible
Poor
Bad
Average
Good
Better
Best

Do you have any concerns, niggles or illness to report? (type)

Have you done an submaximal fatigue test (SFT) today? What was your RPE? (dropdown list)

Not Completed
6 No Exertion al all
7
8
9 Very Light
10
11 Light
12
13 Somewhat hard
14
15 Hard (Heave)
16
17 Very Hard
18
19 Extremely Hard
20 Maximal Exertion

If you have done a SFT, for how many minutes would you have been able to hold the prescribed 3 minute power? (dropdown list)

Did not complete
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
25
30
35
40
45
50
60
70
80
90
100
120
140
160

What was your weight this morning in kg? (type)

Any further comments? Please note any travel or other commitments (type)

Submit

Appendix B – SSISA HPC Athlete Monitoring database informed consent form

HIGH PERFORMANCE CENTRE
CONSENT FORM

I (print participant's name) ______________________________ hereby consent to participating in the physiological assessment and/or physical training on the following terms:

1. I have been informed about the procedures of the tests of the physical assessment and/or physical training, and understand what I will be required to do.
2. I understand that I will be participating in physical exercise some of which is at maximal intensity. I understand that there is always a small risk of injury associated with high-intensity exercise.
3. I understand that I can withdraw my consent, freely and without prejudice, at any time, terminating the physiological assessment and/or physical training.
4. I have told the personnel administrating the testing about any illness or physical defect I have that may contribute to the level of risk.
5. I understand that the information obtained from the physiological assessments, physical training and monitoring (via the SSISA HPC athlete monitoring database) will be treated confidentially with my right to privacy assured. However the information obtained may be used for scientific research purposes with my right to privacy retained.
6. I release the testing personnel from any liability for any injury or illness that I may suffer while undertaking the physical assessment and/or physical training, or subsequently occurring in connection with the assessment and/or physical training, or that is to any extent contributed to by it.
7. I accept however that the testing personnel will take every precaution to ensure that no incidents will occur.
8. I hereby provide my informed consent that my medical, training, race performance, and injury information may be used by the Sport Science Institute of South Africa's (SSISA) High Performance Centre (HPC) consultants who are cleared to access the data and their nominated research partners for research purposes only. I furthermore understand and acknowledge that all analysed, researched or published information will remain anonymous, and will be treated and handled with the utmost confidentiality.

Participant signature___________________ **Date**______________________

Participant's ID/Passport number: ……………………………………..

Investigator Contact Details: Rodet Yila (rodetyila@gmail.com / 076 197 4366)

This study was granted ethics approval from the Faculty of Health Sciences (FHS) Human Research Ethics Committee (HREC) at the University of Cape Town. If you have any complaints or queries that the investigator has not been able to answer to your satisfaction, you may contact Prof. Marc Blockman from the FHS HREC on (021) 406 6452.

Appendix C – Cape Sports Medicine (UAE Team Emirates cycling) database informed consent form

INFORMED CONSENT FORM

University of Cape Town /Cape Sports Medicine Database

UCT Division of Exercise Science & Sports Medicine

Department of Human Biology, Faculty of Health Sciences

University of Cape Town

Dear patient,

During the course of your treatment, information is collected regarding your symptoms, investigations that might be carried out and any treatments administered.

We are requesting your permission to store this information in a database which may be used at some time in the future for research purposes. The specifics of the research have not been established at this time.

Why is this database being formed?

Your data might provide researchers with important information relating to the optimal assessment and management of medical conditions and injuries.

What will happen if you take part?

Your information (as described above) will be stored in an electronic database. Your participation in this database will not influence how the information is collected or stored by the medical practice during the routine duties of the doctor treating you. It will also not influence your medical treatment in any way whatsoever. From time to time when a specific research study is designed and approved by the UCT Human Research Ethics Committee (HREC), relevant information from the database relating to your medical condition or injury may be extracted.

How your data will be shared with researchers:

When data is requested for a specific research project, a researcher will access your records and copy the important information relating to the study by filling in a research form or by copying this data into another electronic format such as an Excel spread sheet or similar document. During the transfer of this information your name and any details, which could identify you, will be removed from the data.

<u>What will happen to my data and test results?</u>

All information that is extracted from the database for research will remain confidential.
You retain the right at all times to request that your data be removed from the database.
All data that are extracted for research projects will be stored in a single password protected electronic database for a period of 48 months after which it will be erased.

<u>Will you receive any reward for taking part in this database?</u>

There is no financial compensation for participating in this database. However, any research studies generated from the database may improve medical management around the World.

<u>What happens if I refuse to take part?</u>

You are under no obligation to take part. If you decide not to take part, you will not be penalised.

<u>What if something goes wrong?</u>

There will not be any expected adverse effects as this study will only be an observation and will not affect any treatment you receive.

Questions or Concerns:

If at any time you have any questions about the database, please feel free to contact any of the individuals listed below. You are assured that all inquiries will remain confidential.

Dr Jeroen Swart

Physical Address: Sports Science Institute South Africa
Boundary Road, Newlands
Tel number: +27 (0) 21 6595644
Email: jeroen.swart@uct.ac.za

Professor Marc Blockman

Chairperson, Faculty of Health Sciences Human Research Ethics Committee
Tel number: (021) 4066492
E-mail: marc.blockman@uct.ac.za

By placing your signature below, it serves as confirmation that you have had adequate time to read through this information, that you have understood the consent form and that you are willing to participate in this database. You have the right to withdraw at any time and you may ask questions at any time. All information removed from the database for research will remain confidential, and you will not be identified in any research which is published. Your signature is confirmation that you have read this informed consent and agree to participate in this database and any research study that might be generated from this.

______________________	______________________	______________
Signature	Name (Please Print)	Date

Appendix D – Study participation information form

Study Participation Information Form

Internal and external load monitoring in well-trained cyclists

Dear Participant,

This research project will form part of a Masters degree in Exercise Science and Sports Medicine at the Department of Human Biology at the University of Cape Town. The research study being conducted will aim to determine whether a combination of the TrainingPeaks® Performance Management Chart, a modified submaximal cycling test and an abbreviated subjective question set as a suitable method to monitor competitive cyclists with acceptable validity and reliability.

All information obtained from this research study will be used to complete a dissertation which forms part of a Masters in Exercise Science (MSc Exercise Science), thereby assisting me in fulfilling the requirements for my thesis for the MSc Exercise Science degree.

This research project has been granted Ethical Approval by the Human Research Ethics Committee (HREC) of the University of Cape Town's Faculty of Health Science.

Please take your time to thoroughly read through this study participation information form before agreeing to participate in this research project. Please kindly take note of the factors which have been stated which may preclude you from being able to participate in this study. By agreeing to participate in this research project you confirm that, to the best of your knowledge, you meet the prerequisite criteria stated below, and have answered all pre-participation questions honestly.

What is the purpose of this research study?

The aim of this study is to determine whether a combination of the TrainingPeaks® Performance Management Chart, a modified submaximal cycling test and an abbreviated subjective question set as a suitable method to monitor competitive cyclists with acceptable validity and reliability. This should allow for greater compliance from the athlete as the submaximal cycling test may be used as a warm-up for a training ride, and the abridged questionnaire should not consume too much of their time, it should be minimally invasive, it should be user-friendly, and easily accessible with the use of any smartphone or computer device with internet access.

The findings of this study will allow coaches/sport scientists to efficiently and effectively monitor the training load of an individual sport athlete, particularly trained cyclists.

Why am I being asked to participate in this research study and how will my eligibility be decided?

You have been selected to participate in this research study as you are an athlete between the ages of 18-45, currently uploaded on either the SSISA HPC athlete monitoring or the Cape Sports Medicine (UAE Team Emirates cycling) database. Your eligibility to participate in the research study is based on the fact that you have at least one complete cycling season's worth of training data, already uploaded on the SSISA HPC athlete monitoring or Cape Sports Medicine (UAE Team Emirates cycling) databases:

Your eligibility to participate in the research study will be revoked for any of the following reasons:

- You are unable to train in an unrestricted manner due to illness, hospitalisation, or surgical procedures.
- You suffer from a chronic medical condition which requires the use of medication which may alter metabolic response to exercise and exercise performance.
- You do not have sufficient data from your previous cycling season.
- You do not own a personal power meter or heart rate monitor (chest-based strap) to use during every cycling training session.

How long will this research study take?

This research study will retrospectively analyse the data already uploaded onto the SSISA HPC athlete monitoring database and TrainingPeaks® over a period of six months.

What is required of me during my participation in this research project?

This research study will retrospectively analyse the data already uploaded onto the SSISA HPC athlete monitoring and Cape Sports Medicine (UAE Team Emirates cycling) databases and TrainingPeaks®, therefore, you will be fulfilling your requirements are a participant of this research study by uploading your data onto the aforementioned databases.

As per the usual practice of the SSISA HPC athlete monitoring/Cape Sports Medicine (UAE Team Emirates cycling) database, the online questionnaire must be completed and submitted once a week, ideally at the start of the training week, however, it is advised to save the weblink for the online questionnaire as a reminder, which should be set for a time which you should have free so that you can complete the online questionnaire in a honest manner without causing any inconvenience. You will also be required to perform the submaximal fatigue test (SFT) on a weekly basis, typically at the start of your training week, prior to the start of your training session (to be used as a warm-up). However, in the instance of your training week starting with a rest day(s), the SFT should only be performed prior to a training ride, whereby it can be used as a warm-up. Once you've completed the SFT, you will be required to record your RPE (using Borg's 6-20 RPE scale). The data for all parameters obtained by your power meter should be uploaded to TrainingPeaks® as soon as possible, whenever it is most convenient (however it is requested that the uploading of data is not neglected for longer than a week), and the data for all parameters obtained by your power meter during the SFT must be uploaded to TrainingPeaks® and saved separately from the proceeding training session or race.

<u>What happens if I decide that I no longer wish to continue participating in this research study?</u>

As your participation in this research study is completely voluntary, whereby there aren't any financial incentives for your participation, you will be able to reserve your right to withdraw from the research study at any point in time, with or without providing a reason for your decision to do so.

Furthermore, you will not be subjected to any form of persecution should you decide to withdraw from the study, and your decision to do so will be kept confidential, and the details of your participation in this research study will remain undisclosed to individuals who are not authorised to access the documents obtained during this research study.

The investigators reserve the right to withdraw participants from the research study if there is a mutual agreement between the investigators that the participant is no longer eligible for the research study. The participant may be withdrawn without warning, and the investigators do not have to disclose a reason for doing so.

<u>Are there any health risks associated with participating in this research study?</u>

As this research study is a purely observational study, analysing data gathered retrospectively, it would be considered to pose minimal risk to participants. Nevertheless, the research study is covered by an insurance policy taken out by the University of Cape Town (UCT). The insurer will pay for all medical costs, within reason, incurred during the treatment of your bodily injury, as defined in the South African Good Clinical Practice Guidelines 2006, which are based on the Association of the British Pharmaceutical Industry Guidelines. The insurer will pay without you having to prove that your participation in the assessment during the initial or follow-up visit for this research study was responsible for your bodily injury. You are entitled to request a copy of these guidelines from the investigators.

UCT will not be liable for any injury and/or bodily harm that you may sustain whereby it is a result of:

- Not following the instructions given to you by the investigator during any of the assessments or tests.
- Negligence on your behalf, whereby you fail to alert the investigators to any feeling of discomfort, concern, or pain during any of the assessments or tests.
- Injury and/or bodily harm sustained during a cycling training session or race.

If you sustain an injury and/or bodily harm and the insurer pays for the necessary medical costs, you will usually be asked to accept that insurance payment as full settlement of the claim for medical costs. However, accepting this offer of insurance cover does not mean that you forfeit your right to make a separate claim for other losses, based on negligence, in a South African court.

<u>What are the benefits of participating in this research study?</u>

The benefits of participating in this research study is that you will receive a body composition assessment free of charge, whereby a report of your body composition will be sent to you via e-mail, as well as a detailed report of your performance management chart (PMC™) derived from the data uploaded to TrainingPeaks®. You will also be educated on how to monitor your training, whereby the benefits of understanding the finer details of your training will only present at a later stage.

<u>What happens once the research study is over?</u>

Once the research study is complete, you will receive feedback on the findings of the research study. The raw data and hardcopy documents obtained during the course of the research study will be kept in a secure facility of a period of five years, whereby the documents will thereafter be destroyed. The data recorded on the online registry will remain online indefinitely, whereby only individuals who have been authorised to access the database for scientific research purposes will be able to view the data.

<u>Who can I contact to obtain more information about this research study and answer any questions with regards to the study?</u>

If at any point in time, you have any questions or concerns with regards to this research study, please feel free to contact any of the investigators listed below. Please be assured that all enquires will remain confidential.

The University of Cape Town's Faculty of Health Sciences Human Research Ethics Committee can be contacted on (021) 406 6338 in case you have any ethical concerns or questions about your rights or welfare as a participant in this research study. The HREC assigned reference number for the online registry is R004/2018.

Principle Investigator: Rodet-William Yila

Physical Address: Division of Exercise Science and Sports Medicine

Department of Human Biology, Faculty of Health Science

University of Cape Town

Sports Science Institute of South Africa

Boundary Road

Newlands, 7700

Cape Town, South Africa

Cell-phone Number: 076 197 4366

E-mail Address: rodetyila@gmail.com

Co-investigators: Dr. Jeroen Swart (jeroen.swart@uct.ac.za)

Prof. Mike Lambert (mike.lambert@uct.ac.za)

Dr. Michael Posthumus (mposthumus@ssisa.com)

Research Assistant: Matthew How (matthewhow94@gmail.com)

Appendix E – Participation information and data capture form

DATA CAPTURE FORM

Investigator: ______________________ Date: ________

Venue: ______________________

Participant details

Name: ____________ Surname: ______________ D.o.B: ________

Passport/I.D. number: ______________ Gender: ________ Age: ________

Medical history

Please state whether you suffer from any chronic medical conditions, requiring you to take any chronic medication, or if you are unable to train in an unrestricted manner due to illness, hospitalisation or surgical procedures.

____

____

____

Injury history

Please state whether you currently have any existing musculoskeletal injuries, or if you have ever been clinically diagnosed with overtraining syndrome.

____

____

____

Anthropomety Measurements

Stretch stature (m): ________ Body mass (kg): ________ BMI ($kg^{.}m^{2}$) = ________

Skinfolds (mm): ∑-of-6 (mm) = ________ Body fat (%) =

biceps = ________ supraspinale = ________

triceps = ________ abdomen = ________

subscapular = ________ mid-thigh = ________

iliac crest = ________ mid-calf = ________

Do you own a personal power meter and heart rate monitor (chest-based strap)? (circle) Y / N

I hereby confirm that the investigator conducted a familiarisation of the SSISA HPC Athlete Monitoring database, whereby the parameters of the wellness questionnaire were explained and the range of possible answers were verbally anchored. Furthermore, I was also kindly requested set a weekly-recurring reminder on my smartphone device, at a convenient time of the day, for me to complete the online questionnaire.

Signature of participant: Signature of witness: