

**Interactions between training load, submaximal heart rate, and
performance in endurance runners**

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Dedicated to the runners of South Africa. You all have been my study participants, athletes, friends, and mentors. My time in South Africa was greatly enriched by your presence. Thank you for your time, energy, enthusiasm, and kindness.

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Declaration

Declaration

I, Rebecca Elin Johansson, hereby grant the University of Cape Town free license to reproduce the above thesis, in whole or in part, for the purpose of research. I declare that this thesis is my own unaided work, both in concept and execution, and that apart from the normal guidance from my supervisor, I have received no assistance. I declare that neither the substance nor any part of this thesis has been in the past, or is being, or is to be submitted for a degree at this University, or any other University. This thesis is presented for examination in fulfillment of the requirements for the degree of Doctor of Philosophy.

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- a. Johansson R, Adolph S, Swart J, Lambert M. The accuracy of GPS sport watches in measuring distance in an ultramarathon running race. (Accepted for publication in the International Journal of Sports Science & Coaching).

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List of Abbreviations

ACT	Activity Watch
ACWR	Acute Chronic Workload Ratio
ATL	Acute Training Load
AUC	Area Under the Curve
CEL	Cell Phone
CI	Confidence Interval
CTL	Chronic Training Load
CV	Coefficient of Variation
DALDA	Daily Analysis of Life Demands for Athletes
ES	Effect Size
EWMA	Exponentially Weighted Moving Average
FINISHER	Fartlek run using speed and heart rate
GFR	Garmin Forerunner Series
GFX	Garmin Fenix Series
GPS	Global Positioning System
GXT	Garmin Forerunner XT Series
HR	Heart Rate
HRR	Heart Rate Recovery
HRV	Heart Rate Variability
IAAF	International Association of Athletics Federations

List of Abbreviations

ICC	Intraclass Correlation Coefficient
IF	Intensity Factor
IQR	Interquartile Range
PLR	Polar Series
Q	Quartile
RPE	Rating of Perceived Exertion
rTSS	Running Training Stress Score
SD	Standard Deviation
sRPE	Session Rating of Perceived Exertion
STO	Suunto Series
SWC	Smallest worthwhile change
Sy.x	Standard deviation of the residuals
TEM	Typical Error of Measurement
TERE	Train Easy Race Easy
TERH	Train Easy Race Hard
THRE	Train Hard Race Easy
THRH	Train Hard Race Hard
TOM	TomTom Series
TSS	Training Stress Score
Vs.	Versus

Measuring Units

Measuring Units

beats/min	beats per minute
cm	centimetre
h	hour(s)
km	kilometres
km/h	kilometres per hour
m	metres
min	minute(s)
s	second(s)

Definition of Terms

Competitive recreational runner: An athlete who partakes in running training and racing as a recreational endeavor. He or she competes in marathon and ultramarathon distance running events. There is no minimum or maximum training requirement.

Endurance running event: A running-specific event. For the contents of this thesis the distance is defined as ≥ 21 -km in distance.

Marathon: A running distance of 42.2-km.

Ultramarathon: A running distance of > 42.2 -km.

Well-trained competitive recreational runner: An athlete who partakes in running training and racing as a recreational endeavor. He or she runs at least 40-km per week with a frequency of at least three runs per week. The well-trained competitive recreational runner competes in endurance running events approximately once every two months.

Thesis Abstract

Background: The popularity of endurance running events has rapidly increased in recent years with more recreational runners entering the field. How recreational runners train is not well known. Understanding this and the relationship between training and performance in this group of runners is important for prescribing appropriate training to maximise performance and decrease the risk of injury. This forms the underlying theme throughout this thesis.

Aim: The broad aims of this thesis were to better understand the *ad libitum* training habits of well-trained competitive recreational runners and to determine the relationships between performance, training load, and submaximal heart rate (HR) in this cohort.

Methods: Five inter-related studies were performed to: 1) determine relationships between 56-km race performance and pacing ($n = 7,327$) in competitive recreational runners; 2) determine relationships between 56-km race performance, pacing, and training load in competitive recreational runners ($n = 69$); 3) determine the accuracy of GPS sport watches in measuring distance ($n = 255$); 4) develop a feasible and reliable submaximal running test, and 5) determine relationships between performance on a submaximal running test, training load, and submaximal HR in well-trained competitive recreational runners ($n = 29$).

Main findings: A group of well-trained competitive recreational runners performed 44 ± 22 km/week (median \pm IQR) in a six-month time frame while training *ad libitum*. This group had a wide range of inter-individual differences in training load performed even when considering participants who had the same relative marathon performance. The same group of well-trained competitive recreational runners maintained most of their training over a six-month period in a range of 0.81 – 1.14 for the acute: chronic workload ratio (ACWR). When the ACWR values reached > 1.50 , it was mainly due to participation in endurance running races (≥ 21 -km). When looking at relative weekly changes in training load, the maximum increase was 30% with only two

Abstract

participants having maximum increases of $\leq 10\%$. The increases in load were predominantly short term (one to two weeks). Submaximal HR had a negative linear relationship with performance in 21% of the study participants. In those participants, poor performances were associated with a higher submaximal HR. Training load was only related to changes in performance in one participant.

Conclusion: This thesis confirms that no single variable can provide the necessary information on how to adjust training load to maximise performance. Athletes, coaches, and sports scientists need to have a holistic view of stress exposure and how this affects the body. Although we can only speculate, when the participants had a poor performance it may have been due to factors such as lack of motivation, fatigue, mental stress, dehydration, and/or sleep deprivation. It is important for runners, coaches, and sports scientists to approach the training load – recovery balance as being unique for each athlete. Even in a homogenous group of well-trained competitive recreational runners, their *ad libitum* training load is widely varied and was not associated with performance or ability level. The balance should be adjusted over time based on the athlete's symptoms.

Chapter 1: Background and thesis topic

Background

It was a cold, winter's day in Wisconsin. The trails were covered in snow that crunched under our feet as we ran along the Shoreline trail. My classmate, Garrett, and I were escaping the lab for a two hour run. My lungs were burning from the cold air, and I couldn't feel my toes. Garrett was training for a 100-mile running race, and I was rebounding from yet another overuse injury.

Our focus in the lab was vascular physiology in obese humans. The physiology was intriguing, but the lab chatter was most always centred around upcoming races, how we planned to squeeze in training, and how it wasn't fair that the pros got to 'run all day'. "What if we got to think about training all day as our job? Wouldn't that be awesome?" asked Garrett. "Yea, I guess it would be," I replied. I was half listening as Garrett rambled on as he always did on our runs. It was a seemingly mundane moment in time, but the conversation was oddly burned into my memory for years as I finished my Master's degree and struggled to find a way forward.

In my 15 years as a competitive swimmer, I had always wondered about the correlation between training and performance. At galas, instead of goofing off with my teammates I would watch every heat and think, "all of us do the same workouts at practice - why did some perform so well at the competition and others did not?"

And then my journey as a recreational athlete in triathlon and ultramarathon running began. The training load for athletes of even the same finishing time were drastically different. Some ultramarathon runners swore that high mileage was key. Others contributed their success to strength and cross training combined with low running mileage. Instead of joining one 'camp' or the other, I developed an intense curiosity in learning more about these people. In December 2014, I wrote an article for *Trail Runner Magazine*, "Do More With Less," where I profiled successful ultramarathon runners whose training load was considered low. I started to dig into the scientific literature on training load

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and performance in endurance sport for the article and found a lack of scientific evidence.

Garrett's comment no longer seemed mundane in my mind. I wanted and needed to understand more about training load and how it relates to performance. Seven years after that cold winter's day run in Wisconsin, this PhD thesis, "*Interactions between training load, performance, and submaximal heart rate in endurance runners*" represents the product of a small but significant moment.

Thesis Topic

The popularity of endurance running events has rapidly increased in recent years (Andersen, 2019; "2014 annual marathon report," 2014). The demographics of participants are becoming older ("2014 annual marathon report," 2014; Hoffman, Ong, & Wang, 2010) and they have slower finishing times (Andersen, 2019; "2014 annual marathon report," 2014) than in previous decades. How these runners train and the relationships between training and performance are currently not well known. It is important to understand the relationships between training load and performance to decrease the risk of injury and maximise performance. This forms the underlying theme throughout this thesis.

Before the experimental work is presented, the literature relating to the various aspects of the thesis are discussed in Chapter 2. Then in Chapter 3, we explored the relationships between training load, performance, and pacing in competitive recreational runners. For the contents of this thesis, competitive recreational runners are defined as athletes who partake in running training and racing as a recreational endeavor. They compete in marathon and ultramarathon distance running events. There is no minimum or maximum training requirement. Well-trained competitive recreational runners are defined as athletes who partake in running training and racing as a recreational endeavor. They run at least 40-km per week with a frequency of at least three runs per week. The well-trained

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competitive recreational runners compete in endurance running events approximately once every two months.

To gain a good understanding of how runners train and perform we need daily observations of training data over many weeks and months. The use of global positioning systems (GPS) devices is superior to training journals or questionnaires in this regard. Field research allows for the collection of ecologically valid data. Journals or questionnaires where runners self-report their training can have inherent error (Borresen & Lambert, 2006). Over time, this can lead to a large error in results and faulty conclusions. Measuring training distance and intensity using a GPS device can provide objective data about training. The use of GPS sport watches has rapidly increased in recent years among runners, and the Global wearable technology market is expected to grow at a compound annual growth rate of 17.66% over the forecast period of the years 2019-2024 (Wearable Technology Market - Growth, Trends, and Forecast 2019 - 2024, 2019). Using GPS data can provide sports scientists with objective data such as running route, running speed captured every one – three seconds, elevation profile, temperature, and running cadence. Whether GPS sport watches are a valid tool to measure running distance is not well known and is explored in Chapter 4.

Submaximal tests have been used in endurance sports to provide information about training status (Lamberts, Swart, Capostagno, Noakes, & Lambert, 2010; Mann, Lamberts, & Lambert, 2014; Vesterinen et al., 2014). The goal is to provide insight into how an athlete is responding to training, their race-readiness, and if adjustments to training need to be made. A brief summary of submaximal tests and measurement outcomes they provide is explored in Chapter 2. Submaximal running tests should be simple, easy to conduct in the field, low cost, and minimally invasive to the athlete. The development of our novel submaximal running test called the Fitness Fatigue Index using Speed and Heart Rate (FFIniSHR) and the testing of its reliability is presented in Chapter 5.

Chapter 1

Markers of internal training load to help determine training status have been used in many previous research studies (Aubry et al., 2015; Bellenger et al., 2016, 2017; Brink et al., 2013; Hedelin et al., 2000; Lamberts et al., 2010). Markers of internal load may include resting heart rate (HR), submaximal HR, HR recovery (HRR), HR variability (HRV), session rating of perceived exertion (sRPE), subjective fatigue and/or stress questionnaires. A summary of these markers and their uses is provided in Chapter 2. We focused on submaximal HR due to its superior sensitivity to change (Buchheit, 2014); its ease of use in the field; runners having access to chest strap HR monitors; and that it could be incorporated into the FFINISHR test with simultaneous performance measures. Putting all the pieces together, we explored the interactions between training load, submaximal HR, and performance in Chapter 6.

There are several practical applications that arise from this research. These are discussed in Chapter 7. In particular the discussion centres on how coaches, runners, and sports scientists can use the findings to apply the relationships between training load and performance, and how to use HR as a training aid.

The specific research questions addressed in this thesis are listed below.

Research Questions

Question #1

What are the relationships between 56-km race performance, pacing, and training load in competitive recreational runners and well-trained competitive recreational runners?

The relationships between 56-km race performance and pacing in competitive recreational runners were explored in Chapter 3.1.

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This was further developed in Chapter 3.2 by exploring the associations between training load, 56-km race performance, and pacing in competitive recreational runners.

The relationships between training load and marathon race performance in well-trained competitive recreational runners were explored in Chapter 6.3.

Question #2

Are GPS sport watches an accurate tool to calculate external training load?

This question was addressed in Chapter 4 where the accuracy of GPS sport watches in measuring running distance was assessed.

Question #3

What is the 'noise' around HR measurements during the **FINISHER** running test?

In Chapter 5, we determined the typical error of measurement of the **FINISHER** test.

Question #4

What are the *ad libitum* training habits of well-trained competitive recreational runners? What is the variation in training load; do they have spikes in training load and, if so, what is the reason for the spikes? Do they adhere to small progressions in training load $\leq 10\%$?

In Chapter 6.1, we described the *ad libitum* training habits of a group of well-trained competitive recreational runners for a six-month time frame. We also described inter-individual differences in training load.

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In Chapter 6.2, we described the range of the acute: chronic workload ratios (ACWR) over a six-month period. We pinpointed when there were spikes in the ACWR and reasons for these spikes. We also calculated relative weekly changes in training load.

Question #5

What is the relationship between training load, submaximal HR, and performance using the **FINISHER** test?

In Chapter 6.4, we determined associations between training load, HR, and performance in a group of well-trained competitive recreational runners.

The literature review in the following chapter will discuss definitions, background, and gaps in the literature surrounding the topics presented in the above research questions.

Chapter 2: Literature Review

Literature Review

This literature review provides background information related to the five questions listed in the introduction. The review begins with a description of the studies on the demographics of the recreational runner and then delves into running performance and factors associated with pacing during a race. Then there is a discussion on external training load and the methodology used in this thesis to calculate training load. The accuracy of Global Positioning Systems (GPS) devices used to calculate distance are also discussed. The next section discusses markers of internal training load and how they relate to performance and changes in external training load. Finally, a summary and list of gaps in the literature is presented.

Defining today's recreational runner

Performance Level

There has been a rapid increase in the number of competitors in endurance running events the last 30-40 years. For example, in the United States of America, the number of marathon finishers has increased from 143,000 in 1980 to 541,000 in 2013 ("2014 annual marathon report," 2014). According to the 2018 global marathon report, there was a 49% increase in participation in marathon races from the years 2008 – 2018 (Andersen, 2019). At the ultramarathon distance, the number of finishes in the world increased from 63,833 to 643,204 from the years 2000 – 2019 ("DUV ultra marathon statistics," 2020). In South Africa, the Two Oceans Marathon had 3,770 entrants in 1984, approximately 10,000 entrants by the year 2004 ("Old Mutual Two Oceans Marathon History since 1970") and nearly 14,000 entrants in 2019. Despite the increase in the number of marathon finishers, the median finishing time slowed by approximately 40 minutes in both males and females ("2014 annual marathon report", 2014) from 1980 – 2013. The 2018 global marathon report showed finishing times had slowed by four minutes from 2008 – 2018 (Andersen, 2019). These results indicate most of the increase in participation in endurance running events can be attributed to an increase in the number of recreational runners.

Training Volume

There are common training themes for endurance running events such as “consistency, overload, proper rest or recovery, and individualisation” that have persisted for decades (Pate, 1976). However, recreational runners in the 1970’s training for marathons or ultramarathons averaged training loads of up to 160 km/week (Pate, 1976). The famed Arthur Lydiard system of training popularised in the 1970’s advocated consistent running loads of 160 km/week in preparation for marathons (Lydiard, 1978). In comparison, a subset of runners who completed the 2017 Two Oceans Marathon (56 km) averaged 59 ± 24 km/week (mean \pm SD) in the peak weeks of training leading up to the race. Leyk and colleagues (2009) surveyed training habits of over 6,000 marathon runners in Germany. The average frequency of training was approximately four runs per week, and the average distance was 45 – 50 km/week. These results suggest that contemporary recreational runners may likely train less than the recreational runners in the 1970’s. Training advice should be tailored with these facts in mind.

Demographics

In the last 40 years, the profile of the average recreational runner has become older. A study of 161-km ultramarathon finishers spanning the years 1977 – 2008, showed the mean age of finishers increased across time (Hoffman et al., 2010). This was due to an increase in finishers in the 40 – 59 year age groups, and a decrease in the number of finishers in the younger than 40 year age category (Hoffman et al., 2010). The “median ages of men and women finishing marathons increased from 34 and 31 years old in 1980 to 40 and 36 years old in 2007 respectively (“2014 annual marathon report,” 2014).”

Importance of studying recreational runners

The sport of endurance running impacts positively on the economy and has meaningful health benefits for the participants. For example, race organisers, running clubs, coaches, and shoe and apparel companies benefit economically

from having a large running participation. The consequences of endurance running are known to impact health including a decreased risk of developing cardiovascular disease (Cornelissen & Fagard, 2005), an improved metabolic profile, and healthy weight maintenance (Donnelly et al., 2009). In contrast to the health benefits associated with running, there are also negative health consequences. For example, there is a relatively high risk of overuse injury associated with running. Twenty-five percent of runners may be injured at any given time, and approximately 50% of runners experience an injury that requires that they stop training for a period of time in any given year (Fields, Sykes, Walker, & Jackson, 2010).

Contemporary recreational runners are older (Hoffman et al., 2010), slower ("2014 annual marathon report", 2014), and may likely train less (Leyk et al., 2009) than the runners in the 1970's (Pate, 1976). Runners with this profile are increasingly participating in endurance running events. With more recreational runners entering endurance races, it is important to create an optimal balance of training and recovery in this group to decrease the risk of injury and improve performance.

Defining performance and its relationship to pacing

Running Performance

Running performance is defined as how fast a runner completes a time trial or race. Performance can also refer to an athlete's ranking at an event. Tracking performance through stages of training allows coaches and runners to adjust training programmes based on how they perform in the test. To adequately track performance the distance should be appropriate to repeat on a regular basis (weekly, fortnightly, or monthly). The distance should also allow for a maximal effort. When these factors are considered, a common distance used is a one, three, or 5-km time trial or alternatively, a workout that includes a maximal effort of at least three minutes.

Endurance runners typically target one to three races per year where they plan their training programme to peak at the event(s). The race distances for recreational endurance runners may include the following: 5-km, 10-km, 21.1-km, 42.2-km, or > 42-km (ultramarathon distance). Runners may participate in additional races throughout the year where the goal is preparation for a target race. Runners may not target peak performances at preparation races. Recreational runners spend much time and effort preparing for peak performances. Thus, it is important to balance training and recovery continually to optimise the performance and reduce the risk of getting injured.

Pacing in ultramarathons

Pacing is important when running ultramarathon distances (> 42.2-km). Pacing is defined as a subjective and learned strategy in changing speeds throughout a race (Lambert et al., 2004). Pacing goals to maximise endurance running performance involve maintaining an even pace by minimising the slowing down in the second half of the race. Pacing is learned and must be practiced in training to increase chances of running at goal pace during a race. Strategic and effective pacing can lead to faster finishing times, decreased injury rates, and improved recovery after the race (Diaz, Fernández-Ozcorta, & Santos-Concejero, 2018; Knechtle, Rosemann, Zingg, Stiefel, & Rüst, 2015; March et al., 2011; Renfree, Crivoi do Carmo, & Martin, 2015; Tan, Tan & Bosch, 2016).

Pacing strategy and finishing time

Finishing times in ultramarathons vary more than two-fold. In the 2016 Two Oceans Marathon, finishing times ranged from 3h 13min to the cut-off of 7h. Knowing how fast, medium, and slow runners pace themselves in ultramarathon races can contribute to more effective training. Previous research showed faster runners maintain more even pacing compared to slower runners across 100-km and 161-km (Lambert et al., 2004; Tan et al., 2016). Also at the marathon distance, faster runners had more consistent pacing (March et al. 2011). This study also showed that older runners and females have more even pacing versus

(vs.) younger runners and males (March et al. 2011). However, it is important to note that in these pacing studies, the races were completed on relatively flat terrain.

External Training Load

Definition

An athlete's training involves completing workout sessions defined by a specific duration, intensity, and frequency. The combination of these factors is defined as the external training load (Wallace et al., 2009). The external training load is the dose of training an athlete performs without any regard to how he or she responds to that training. External load is measured in units of time, speed, and number of sessions, and is generally expressed in arbitrary units using the formula; $\text{load} = \text{duration} \times \text{intensity}$.

Training Stress Score

The training stress score (TSS) is a novel way to calculate external load. This method was created by Andy Coggan to calculate external training load in cyclists (Allen & Coggan, 2006). The calculation for cycling is;

$$\text{TSS} = \text{time (seconds)} \times \text{Normalised Power} \times \text{Intensity Factor (IF)} / (3,600 \text{ seconds} \times \text{Functional Threshold Power}).$$

[IF = Normalized Power / Functional Threshold Power (maximum power output that can be sustained for one hour)].

The formula has been transformed for use in running;

$$\text{running TSS (rTSS)} = \text{duration (hours)} \times \text{IF}^2 \times 100 \text{ (McGregor, Weese, \& Ratz, 2009)}.$$

Running pace is used instead of power output to calculate the IF. The intensity factor for running is the ratio of running speed in relation to running speed at lactate threshold (maximum running speed that can be sustained for one hour).

Acute Training Load, Chronic Training Load, and the Acute: Chronic Workload Ratio

Banister's performance model predicted an athlete's "fitness" and "fatigue" and investigated the balance between the two constructs to predict performance (Bannister, Calvert, Savage, & Bach, 1975; Banister & Calvert, 1980; Banister, 1991). The volume and intensity of a training session contribute to "fitness" and "fatigue" independently. A fatigue response from a training session is evident immediately (Morton, 1997). A fitness response is not realised immediately and requires successive training sessions to increase (Morton, 1997). The rate of decay of "fitness" and "fatigue" is also unique. Fatigue decays at a faster rate than fitness with no successive training sessions. Fitness takes longer to realise but also takes longer to decay (Morton, 1997). With this concept in mind, "fitness" is related to chronic training load (CTL) and is typically represented as a 28-day rolling average of training load. "Fatigue" is related to acute training load (ATL) and is typically represented as a seven-day rolling average of training load (Gabbett, 2016; Murray, Gabbett, Townshend, Hulin, & McLellan, 2016).

The fitness-fatigue model has evolved to consider that there are more than one fitness and fatigue after-effects (Chiu & Barnes, 2003). Specific systems of the body such as the neuromuscular and cardiovascular system show unique fitness and fatigue after-effects from exercise training (Chiu & Barnes, 2003). In addition, there are inter- and intra-individual differences in the dose-response relationship of training and its associated "fitness" and "fatigue" (Morton, 1997).

The acute: chronic workload ratio (ACWR) is defined as the ATL divided by the CTL. This ratio provides information on the athlete's current workload vs. the workload he or she has been prepared for, and, in part, aims to predict

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performance (Banister, 1975, 1980; Hulin, 2014). Ideally, an athlete should enter an important competition with high CTL values and low ATL values.

The daily ACWR can be expressed as rolling averages or exponentially weighted averages. The rolling average includes the average of the previous seven or 28-day period. Exponentially weighted moving averages (EWMA) are calculated using the following formula (Williams, West, Cross, & Stokes, 2017);

$$EWMA_{today} = Load_{today} \times \lambda_a + ((1 - \lambda_a) \times EWMA_{yesterday})$$

$\lambda_a = 2 / (N + 1)$; N = the chosen time decay constant. There has been debate about whether the risk of injury is described better by either ACWR with rolling averages or EWMA (Buchheit, 2017; Drew, Blanch, Purdam, & Gabbett, 2017; Lolli et al., 2017, 2018; Menaspà, 2017; Murray, 2016). Neither method (ACWR with rolling averages or EWMA) has previously been described in a group of recreational runners in relation to performance.

The ACWR has been studied mainly in the context of team sports in relation to risk of injury (Gabbett, 2016; Hulin, 2014, 2016; Murray, 2016). Gabbett (2016) suggested the 'sweet spot' for ACWR in training is 0.8-1.3, while ACWR values ≥ 1.5 is associated with increased risk of injury. These conclusions were based on three studies involving cricket, rugby, and soccer (Hulin, 2014, 2016; Ehrmann, 2016). There has recently been controversy around the methodology used to create the ACWR 'sweet spot' and 'danger zone' thresholds (Impellizzeri, 2019). He points out the danger in researchers "using this quadratic relation as a reference model to fit their data instead of examining the best model" (Impellizzeri, 2019). There is a lack of research regarding the ACWR in endurance sports. As a start it is important to understand the range of ACWR values recreational runners perform while training for endurance races. ACWR values in endurance sports is likely different than team sports. Further it will vary depending on the specific endurance sport and demographics of the study cohort. Load tolerance for spikes or troughs will be unique to sport and group.

Use of GPS devices

Objective measures of tracking changes in training load have the potential to be more accurate compared to subjective measurements. Subjective recall using training diaries, for example, has recall bias which is a potential for error. For example, a study of recreational runners showed that 24% of the participants overestimated the amount of training they were doing and 17% underestimated the training amount (Borresen, & Lambert, 2006b). Tracking training load using Global Positioning Systems (GPS) devices eliminates the recall bias and has the potential to record distance accurately; this depends however on the type of GPS device. This method has the potential to be simple, non-invasive, and automated. However, as discussed by Cardinale and Varley (2017), there are an increasing number of wearable devices on the market and many have not been validated.

In the last approximately 10 years, GPS device use in running has rapidly increased. In the year 2004, there was an average of 31 Google searches per day for “Garmin Forerunner”, and by 2018 this search number had doubled to 63 per day (Google Trends). Nielsen et al. (2013) determined the measurement error of the Garmin Forerunner® 110 GPS watch. The error while running on a flat path with a clear view to the sky was 0.8%. In an urban area with buildings the error was 1.2%, and in a forest the error was 6.2%. These results suggest coaches, runners, and sports scientists can use GPS sport watches to accurately track training load particularly in road runners providing they account for the error associated with the measurement. However, Nielsen et al. (2013) only tested one specific GPS sport watch. The measurement error in other brands and/or models of watches is currently not known. As coaches and athletes make training decisions based on external load measured by these devices, understanding their validity is important. There is currently a gap in the literature concerning measurement error in a range of brands and models of GPS sport watches.

Markers of internal training load: definitions and history of studies

A primary goal of coaches and athletes is to have a method to evaluate how an athlete is responding to a training programme (Foster, Rodriguez-Marroyo, & de Koning, 2017). In the 1920's and 1930's interval training was used to track progress and improve performances in runners. By the 1980's, heart rate (HR) monitors allowed coaches, athletes, and sports scientists to monitor physiological responses to training (Foster et al., 2017). This allowed sports science to evolve in the area of internal training load and training monitoring. Measuring internal training load is important in determining how an athlete is adapting to a given workload. The definition and various internal load markers are discussed below.

Definition

Internal training load is defined as the physiological or subjective response to a given external workload (Alexiou & Coutts, 2008; Halson, 2014). Internal load can be measured several different ways including submaximal and maximal HR (Foster et al., 2017), HR recovery (HRR) (Aubry et al., 2015), HR variability (HRV) (Bellenger et al., 2016), rating of perceived exertion (RPE) (Borg, 1973, 1982, 1998), session RPE (sRPE), (Foster et al., 2001, 2017), subjective questionnaires (Saw, Main, & Gustin, 2016), and biochemical markers (Garrett, Eston, & Norton, 2018). Although there are several methods to measure internal training load, many of them have low validity, reliability, and/or are not sensitive to change or are poorly correlated with changes in performance. In addition, cost and applicability must be considered when decisions are made about selecting a method to measure internal training load (Gomes et al., 2013; Halson, 2014; Taylor, Chapman, Cronin, Newton, & Gill, 2012).

Overreaching and Overtraining

When acute external training loads are high relative to the time to recover, athletes can experience short-term decrements in performance (Meeusen et al., 2013). The duration of recovery, which may vary from a few days to many

months influences the classification of the condition. The condition is known as overreaching and is divided into functional or non-functional overreaching (Halson & Jeukendrup, 2004). For example, functional overreaching leads to short term impairments in performance where recovery takes days to weeks (Meeusen et al., 2013). With adequate recovery, athletes often undergo supercompensation where performance is better than baseline (Meeusen et al., 2013). Functional overreaching is sometimes used as a strategy by coaches who plan for the rebound in performance after a period of reduced training to coincide with competition (Stanley, Peake, & Buchheit, 2013).

Non-functional overreaching leads to short term impairments in performance that may last weeks or months (Birrer, Lienhard, Williams, Röthlin, & Morgan, 2013, Meeusen et al., 2013). Following acute recovery, athletes do not show a supercompensation effect. There are no advantages associated with non-functional overreaching and coaches should regulate training and recovery to avoid this condition (Meeusen et al., 2013). Athletes who show signs of non-functional overreaching are not adapting to the training load (Meeusen et al., 2013). They either need to reduce the training load, increase rest and recovery or both.

Overtraining leads to long-term decrements in performance, and recovery can take months to years (Meeusen et al., 2013). This can be a serious medical condition, and presents with symptoms including depression, extreme fatigue, lack of appetite, and an inability to complete training sessions.

Heart Rate Measurements

The autonomic nervous system transmits messages from the central nervous system to peripheral organs (Freeman, Dewey, Hadley, Myers, & Froelicher, 2006). There are two branches of the autonomic nervous system including the sympathetic and parasympathetic branches. They work in balance to help maintain homeostasis in a wide range of stressors and conditions. The two branches act on the sinoatrial node of the heart to alter HR (Freeman et al.,

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2006). The sympathetic branch acts to increase HR while the parasympathetic branch decreases HR (Robinson et al., 1966). As a person transitions from rest to exercise, HR increases due to a withdrawal of the parasympathetic nervous system and an increase in the sympathetic nervous system (White & Raven, 2014). During exercise, the rise in HR and stroke volume acts to increase cardiac output, thereby increasing blood flow to active skeletal muscles (Victor, Seals, & Mark, 1987).

Heart rate is measured in beats per minute using a HR monitor or by manually counting pulses over a specified time. There is a linear relationship between HR and steady state work rate (Hopkins, 1991; Robinson, Hume, & Hopkins, 1991). The day-to-day variation in HR in a lab-controlled setting is approximately six beats per minute (Lamberts et al., 2004) or 6.5% (Bagger, Petersen, & Pedersen, 2003). Heart rate can be affected by variables including ambient temperature, exercise duration, altitude, hydration, plasma volume, diurnal variations, and training state (Achten & Jeukendrup, 2003; Robinson et al., 1991). If these variables are controlled, the accuracy of measuring and interpreting HR improves (Lambert et al., 1998). Factors such as ambient temperature and hydration are difficult to control when testing in the field but recording HR early on in the exercise session helps minimise the effect from these factors (Coyle & Gonzalez-Alonso, 2001).

Submaximal Heart Rate

“Depending on exercise intensity, at least three to four minutes of exercise are required for HR to reach steady state during submaximal exercise” (Cerretelli & Di Prampero, 1971). In a review, the coefficient of variation for submaximal HR measures at a fixed workload was approximately 3% and the smallest worthwhile change was approximately 1% (Buchheit, 2014). Heart rate recorded at submaximal intensities was associated with the athlete’s effort level (Eston & Williams, 1988). With increases in aerobic fitness, sympathetic tone decreases and parasympathetic tone increases at the same absolute exercise intensity, and a lower HR has been observed (Borresen & Lambert, 2008;

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Bosquet et al., 2008). Several research studies have reported decreases in submaximal HR with endurance training (Hedelin et al., 2000; Skinner et al., 2003; Uusitalo, 2001; Wilmore et al., 2001). Further, correlations between decreases in submaximal HR and improvements in high intensity exercise performance have been found (Lamberts et al., 2010).

Vesterinen et al. (2104) conducted a combined field and laboratory study to determine the changes in the HR-Running speed relationship with changes in training load. They calculated a HR-Running speed index that represented the absolute difference between the actual and theoretical running speed at any given HR. The formula includes the average speed and HR during a training run, standing HR, maximum HR, and peak speed from a maximal run test. The authors showed significant improvements in the relationship with 28 weeks of a marathon training programme. Changes included a lower HR at similar running speeds or the same HR at faster running speeds.

A limitation of this methodology was that the authors only used two points to create each runner's regression: (i) a predicted standing HR, and (ii) a HR associated with maximal treadmill running speed. The slope of the line can vary depending on the two data points. While the concept of creating an individualised line of HR/running speed for runners was novel, the methodology was lacking. A more sophisticated method of determining the HR/running speed relationship needs to be determined so it can be related to changes in performance and/or acute and chronic changes in training load.

Past research has also used submaximal HR as a tool to detect symptoms of overreaching. Hedelin et al. (2000) found decreased submaximal HR in a group of canoeists after six days of overload training (50% increased training load). A systematic review reported overreaching resulted in a small but significant decrease in submaximal HR, particularly in interventions longer than two weeks (Bosquet et al., 2008). Bellenger et al. (2017) studied a group of male cyclists after two weeks of overload training. Performance in 5-min and 60-min time trials decreased, and submaximal HR decreased.

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Two days after a 56-km running race, Siegl et al. (2017) found decreased HR at 70% of peak treadmill running speed in 93% of their participants. Interestingly, at 85% of peak treadmill speed 64% of participants had decreased HR, 14% had no change, and 21% had an increase in HR. This confirms the importance of a submaximal running test having a range of intensities.

In contrast to the above studies (Bellenger et al., 2017; Hedelin et al., 2000; Seigl et al., 2017), Brink et al. (2013) found an increased submaximal HR was associated with overreaching in a group of young soccer players. The players who had an elevated HR during the submaximal field test showed a disturbed stress-recovery balance while reaction time was maintained.

Submaximal HR has also been used to predict sickness in athletes (Buchheit et al., 2013). The researchers used submaximal HR to predict sickness at a high altitude training camp for soccer players (Buchheit et al., 2013). They found an association between an increase in HR greater than 4% in response to an increase in training load the previous day and sickness the next day.

There is a lack of research regarding relationships between HR, performance, and changes in training load in already well-trained runners. There appears to be agreement in the literature that when an untrained individual becomes trained, submaximal HR at the same intensity decreases. There also seems to be agreement in the literature that a large increase in training load in well-trained athletes, either through a race or an overload training period of one-two weeks, is associated with decreases in submaximal HR. The decrease in HR can be attributed to increases in plasma volume (Buchheit, Laursen, Haddad, & Ahmaidi, 2009). However, the increases in training load seen in those studies is rarely ecologically valid. Acute fatigue may be associated with a decrease in HR, but how it is associated with smaller, more ecologically valid increases in training load is unknown. There is a gap in the literature concerning the relationships between HR, performance, and changes in training load in well-trained runners.

Considering the accuracy and simplicity of collecting submaximal HR data in the field, the technique is underused by sports scientists. Much research emphasis is placed on HRR and HRV. However, the application of those techniques by runners and coaches is not wide. Jason Koop, a running coach and director of coaching at Carmicheal Training Systems, listed metrics worth tracking in running (*“What training data is worth tracking in ultrarunners?”* 2019). Heart rate variability was listed in the section of *“not recommended to track.”* He cited compliance issues and performance contradictions as the reasons. So, despite a wealth of laboratory studies, if the measurement is not implemented in practice the worthiness of the measure decreases. Submaximal HR does not require any additional time from the athlete before or after the training session. In addition, a well-designed workout repeated on a weekly basis can easily be included as part of the athlete’s training programme without any major disruption.

Maximal and Peak Heart Rate

Maximal and peak heart rate has been shown to decrease with overreaching. Bellenger et al. (2017) showed a 5% decrease in peak HR during a 5-min time trial and a 12% decrease in peak HR during a 60-min time trial after two weeks of overload training. Similarly, Hedelin et al. (2000) found decreased maximal HR in a graded maximal exercise test after six days of overload training. One possible mechanism for the decrease in maximal HR is an increase in plasma volume (Zavorski, 2000). A study found plasma volume and maximal HR were negatively related with an 8-day training regimen in trained individuals (Convertino, 1983). Maximal HR is not an ideal method to track internal load in athletes. If a runner currently has a poor balance of training and recovery, performing a session that requires maximal HR requires a high motivation level to complete the workout and will further increase fatigue.

Heart Rate Recovery

Heart rate recovery (HRR) is defined as the difference in heart rate from the time exercise stops to 60 seconds after stopping exercise. It reflects the withdrawal of the sympathetic nervous system and upregulation of the parasympathetic

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nervous system after the cessation of exercise (Buchheit, 2007). There is controversy in the research results with some studies showing an improved (greater number heartbeats) HRR with overreaching (Aubry et al., 2015; Thomson, Bellenger, Howe, Karavirta, & Buckley, 2016), and other studies showing a decrement in HRR (smaller number heartbeats) with overreaching (Borresen & Lambert, 2007; Lamberts et al., 2010).

Aubry et al. (2015) found overreaching was associated with improved HRR in a group of well-trained male triathletes. There was a control group and a group that underwent overload in training. The overload group showed an increase in HRR and fatigue; decrease in peak power output; and a decrease in maximal HR. It is important to note the overload group was in a functional overreaching state. After a two-week taper, their performances were improved. Another research study (Thomson et al., 2016) found similar results in a group of male cyclists and triathletes. After two weeks of heavy training, the athletes showed improved HRR; a decrease in time trial performance; and a decrease in maximal HR.

A group of researchers (Mann, Platt, Lamberts, & Lambert, 2015) measured HRR after an ultramarathon race (Comrades Marathon, 87-km). They found an improved HRR two to four days after the race. However, the runners had an increased RPE during the 20-min submaximal running test (70% VO_2 max). They acknowledged this was a paradoxical finding and recommended “that changes in HRR should be considered in the context of other factors, such as recent training load and RPE during submaximal exercise (Mann et al., 2015).”

Siegl et al. (2017) tested runners seven days pre and two days post a 56-km road running race (Two Oceans Marathon). All runners displayed an improved HRR two days after the race. These studies support an improved HRR with acute fatigue, particularly if the fatigue is induced by a high acute load. After an endurance event such as an ultramarathon, plasma volume temporarily increases which causes increased stroke volume and decreased HR (Neumayr et al., 2005; Overgaard, Lindstrøm, Ingemann-Hansen, & Clausen, 2002).

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In contrast to the above studies, Borresen and Lambert (2007) and Lamberts et al. (2010) found either a decreased HRR after hard training or individual variability suggesting HRR cannot be used as a diagnostic tool for overreaching by itself. For example, HRR decreased in a group of trained recreational runners that significantly increased training load from week one to week two (Borresen & Lambert, 2007). It is interesting to note these participants trained *ad libitum*. The training stimulus was not as great as the studies that showed increased HRR after hard training (Aubry et al., 2015; Thomson et al., 2016). However, this study (Borresen & Lambert, 2007) has more ecological validity as athletes rarely increase their load as much as the above studies (Aubry et al., 2015; Thomson et al., 2016). In the study of Lamberts et al. (2010) a group of well-trained cyclists underwent a four-week high intensity training intervention. The participants were divided into two groups. The first group displayed a continual increase in HRR. They also showed an increase in peak power output, an improved time in a 40-km time trial, and an increase in the power output during the 40-km time trial. An increase in HRR was associated with improved performances. This finding was in contrast to other studies (Aubry et al., 2015; Mann et al., 2015; Thomson et al., 2016) that showed increased HRR was associated with decreased performances. The second group showed an initial increased HRR, but it then decreased by the end of the four-week intervention. They showed no change in peak power output, a slower 40-km time trial, but an increase in power output during the time trial. This study (Lamberts et al., 2010) suggests that a decreased HRR can be a sign of non-functional overreaching. Commenting on the complexity of HRR interpretation, Lehmann (Lehmann, Foster, Dickhuth, & Gastmann, 1998) proposed an improved HRR is associated with acute fatigue, while a decrement in HRR is associated with a chronic fatigue state.

The negative aspects associated with measuring HRR is it requires additional time from the athlete after the training session is complete. The methodology requires athletes to sit quietly upon completing the session to get an accurate HRR reading (Dupuy, 2012). When considered on a daily basis in a field setting, this may be difficult for runners.

Heart Rate Variability

The autonomic nervous system regulates cardiac responses to physical and psychological stimuli through the interaction of the sympathetic and parasympathetic nervous systems (Dong, 2016; Fatisson, Oswald, & Lalonde, 2018). A dominant sympathetic nervous system is reflected by a relatively constant time interval between heart beats. This reduced variability between heart beats can negatively impact the immune system, self-regulation, and psychosocial abilities (Fatisson et al., 2018). The time interval varies as the parasympathetic nervous system becomes more dominant. A greater variability between heart beats means the heart has the ability to adequately react to stressors (Fatisson et al., 2018). This variation in time interval between each heart beat is known as heart rate variability (HRV).

The research on HRV as a monitoring tool has shown that when comparing athletes vs. sedentary people, athletes have higher HRV at rest and during exercise due to increased parasympathetic tone (Auburt et al., 1996). Also, standing HRV at rest increased with two weeks of intensified training in a group of male runners and triathletes (Bellenger et al., 2016b). Performance on a 5-km time trial decreased after the intensified training. Surprisingly, HRV remained increased even after a 10-day taper. However, performance improved after the 10-day taper.

A systematic review summarized the controversial results around HRV (Bellenger et al., 2016a). In studies showing improved performances, there was a small increase in HRV at rest and a moderate increase in post-exercise HRV. Studies with decreased performances also showed a small increase in HRV at rest and an increase in post-exercise HRV. The studies included in the review utilised isolated measures of HRV which have larger variability compared to weekly averages or seven-day rolling averages (Buchheit, 2014). Bellenger et al. (2016a) concluded that using HRV in isolation would be difficult in detecting changes in training status.

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In contrast to these results, another research group (Plews, Laursen, Kilding, & Buchheit, 2012) found HRV decreased in a case study of a non-functional overreached elite triathlete. There was no change in HRV in the control case study. Plews et al. (2012) used a seven-day rolling average of the natural log of the root mean square of the successive differences (\ln rMSSD) to determine changes in HRV.

Vesterinen et al. (2016) performed a study using individual endurance training prescription using HRV. The HRV guided training group did not perform high intensity sessions if changes in HRV were larger than the smallest worthwhile change. This group showed improvements in a 3-km time trial after 12 weeks of training (four weeks at baseline, eight weeks of intensified training), while the control group did not. This study suggests HRV can be used to guide training load.

In contrast to the findings of Vesterinen et al. (2016), another research study (Coates, Hammond, & Burr, 2018) found same day resting HRV measures did not predict declines in performance and decreased maximal HR after three weeks of overload training in a group of cyclists. They concluded that resting HRV measurements should not be used to guide training load.

There are several protocols for measuring HRV. For example, research has recorded HRV at rest in a supine posture (Buchheit et al., 2010), seated posture (Buchheit et al., 2013; Kiviniemi, Hautala, Kinnunen, & Tulppo, 2007), and/or standing posture (Kiviniemi et al., 2007; Wallace, Slattery, & Coutts, 2014). Other studies have recorded HRV during sleep (Boullosa et al., 2013; Vesterinen et al., 2013). There are also different ways to calculate HRV. For example, studies have measured the differences between calculating daily HRV vs. 7-day rolling averages of HRV (Le Meur et al., 2013; Plews et al., 2012, 2013). These studies show that results vary depending on the method chosen. This is likely one of the causes for the contradictions in the research about HRV and decreases its ecological validity (Quintana, Alvaras, & Heathers, 2016). It has a larger measurement error compared to submaximal HR making it difficult for athletes

to interpret the measurement on their own. Many factors can affect HRV such as posture, respiration rate, mood, stress, and sleep. The difficulty of controlling all these factors contribute to the relatively large measurement error (Buchheit, 2014; Fatisson et al., 2018). This reduces the practical application of HRV.

Rating of Perceived Exertion

Athletes can use the rating of perceived exertion (RPE) scale as a subjective measure of their exercise intensity. This scale has two versions, a 15-point category scale and 10-point category ratio (CR) scale (Borg 1973, 1982, 1998). The 15-point scale was designed to reflect a linear increase in exercise intensity (Borg, 1982). The scale spans from 6 – 20 and was developed to be approximately associated with HRs from 60 – 200 beats/min (Borg, 1982). The CR-10 scale spans from 0 – 10 with numbers anchored by verbal expressions (Borg, 1982). It was designed to be simple and understandable by a larger population. Rating of perceived exertion scales are easy to use, inexpensive, non-invasive, and are proven to be valid and reliable in many settings. Previous research has found a significant relationship between RPE and average HR during submaximal running in elite male runners (Robinson et al., 1991). Rating of perceived exertion has also been used to monitor training status (Lamberts, Swart, Noakes, & Lambert, 2011). A higher RPE rating at the same exercise intensity may be indicative of early signs of overreaching. Based on the circumstances the training-recovery balance can be adjusted accordingly.

Despite the positive features of using RPE, it is a subjective rating with inherent error. For example, RPE can be affected by mood (Parfitt & Eston, 1995), exercise history (Parfitt, Markland, & Holmes, 1994), and physiological condition (Russell, 1997). A meta-analysis found the relationship between RPE and HR to strengthen as fitness level of the participant increased (Chen, Fan, & Moe, 2002). In addition, the multiple definitions of physical effort, multiple scales as well as instructions can all affect measurement validity (Halperin and Emanuel, 2019). Due to the error associated with the subjective measurement, RPE should be used in combination with an objective measure for monitoring responses to

training.

Session RPE

The sports scientist, Carl Foster, combined an adapted RPE scale and duration of exercise to assess training load. The formula for session training load involves multiplying the duration of the training session (minutes) by the session rating of perceived exertion (sRPE) (Foster et al., 2001). The sRPE is a rating scale of 0-10, with the numbers anchored by verbal expressions which are similar to the expressions in the 10-point (CR) scale (Borg 1973, 1982, 1998). The sRPE gauges how hard the athlete found the training session. Athletes record their rating 30 minutes after the workout. Using this formula for training load, coaches and sports scientists can track acute and chronic changes in load across an extended period of time. They can also measure whether the intended intensity of the session matches the athlete's perceived intensity after the training session. If the intended and perceived intensity do not match on a consistent basis, it indicates an athlete is not adapting well to the current training load or the prescribed training load needs to be reconsidered.

The sRPE method is both a valid and reliable (Foster, 2006) indicator of exercise intensity (Foster, 2006; Haddad, 2013; Haddad et al., 2013, 2014; Haddad, Chaouach, Castagna, Wong, & Chamari, 2012). In a study by Foster (2006), there was a significant correlation between sRPE and % VO_2 max ($r^2=0.71$), % HR max ($r^2=0.74$), and % HR reserve ($r^2=0.71$) for 30 minutes of cycling exercise at three different intensities. In the same study, there was also a significant correlation between repeated bouts of cycling exercise for sRPE ($r^2=0.77$). Using sRPE to track changes in internal training load is simple, inexpensive, and practical (Haddad, Padulo, & Chamari, 2014). Although sRPE has positive attributes, it does leave room for subjective error similar to RPE. Subjective ratings can be affected by mood, personality, physiological condition, and experience level (Morgan, 1973, 1994).

Subjective Questionnaires

Some sports scientists argue that subjective questionnaires are more sensitive to detect symptoms of overreaching in athletes than objective data such as HR (Saw, Main, & Gustin, 2016).

Saw et al. (2016) completed a systematic review comparing the effectiveness of subjective and objective measures. To be included in the review both measures had to be collected concurrently. In the studies that met these criteria, subjective self-reported measures reflected changes in training load with increased sensitivity and consistency compared to objective measures.

Subjective and objective markers were discussed in a paper that provided practical tools coaches can use to monitor fatigue in athletes (Borresen & Lambert, 2006). Subjective markers discussed were sRPE, the Profile of Moods States questionnaire, the Daily Analysis of Life Demands for Athletes questionnaire (Rushall, 1990), and the muscle soreness questionnaire. Although it is time-consuming for the athlete to complete questionnaires it provides the coach with information about factors that may affect their training sessions. Recreational athletes in particular spend only one – two hours per day training, while 22 – 23 hours of the day are dedicated to work, family, and sleeping. The information in the questionnaires gives context to how their training session went.

A negative aspect of questionnaires is the amount of time they take to complete. The data need to be recorded on a frequent (daily or multiple times per week) basis, and this may affect the compliance. Athletes may not complete many of required surveys which would lead to missing data points and possible faulty conclusions. Another possibility is the athletes completing the surveys too long after finishing the training session. This could lead to recall bias and faulty information.

Biomarkers

Several biomarkers have been measured in relation to increases in training load in athletes. However, none have been adopted as a practical method to monitor athletes. This may be attributed to them being expensive and time consuming. They do however provide insight into possible physiological mechanisms for overreaching and/or overtraining. Frequently tested biomarkers include cortisol, creatine kinase, testosterone, and the testosterone: cortisol ratio. Their definitions and associations with training load are provided below.

Cortisol is a hormone that mobilises fuel stores such as carbohydrate and fat and can also suppress the immune system (Armstrong & Vanheest, 2002; Brownlee, Moore, & Hackney, 2005). Greenham, Buckley, Garrett, Eston, & Norton (2018) conducted a systematic review including 42 studies. For inclusion, research studies had to include well-trained male athletes older than 18 years. Biomarkers were collected at rest before and after the intensified training period. The authors (Greenham et al., 2018) found no significant change in blood cortisol concentration in response to intensified training. There was no change in cortisol in athletes that showed an improvement or decrement in performance after intensified training. Blood cortisol increased moderately in studies that reported no change in performance.

Creatine kinase is an enzyme that aids in the breakdown of creatine phosphate to form one molecule of adenosine triphosphate during exercise (Apple, 1992). Creatine kinase is an intramuscular enzyme, but can leak into the blood when there is a change in membrane permeability. This can occur following muscle damage (Apple, 1992). The authors of the systematic review (Garrett et al., 2018) found no significant change in blood creatine kinase activity in response to intensified training. One example of intensified training was three weeks of doubled training mileage in long distance runners (Apple, 1992). The results were consistent in both athletes that showed an improvement or decrement in performance after intensified training. However, studies have shown increases in plasma creatine kinase activity following a large overload stimulus such as an

ultramarathon (Burgess & Lambert, 2008; Noakes, Kotzenberg, McArthur, & Dykman, 1983).

Testosterone is a hormone that aids in the growth of skeletal muscle (Brownlee et al., 2005). There was no significant change in blood testosterone in response to intensified training (Garrett et al., 2018). The results were consistent in both athletes that showed an increase or decrease in performance after intensified training.

The free circulating testosterone: cortisol ratio is a marker of a person's physiological anabolic/catabolic balance (Urhausen, Gabriel, & Kindermann, 1995). A decrease in this ratio (increase in catabolic state) has been found during increased training load and competitions (Budgett, 1998; Urhausen et al., 1995). One study (Filaire, Bernain, Sagnol, & Lac, 2001) found no relationship between decreases in performance and changes the testosterone: cortisol ratio. Hough, Corney, Kouris, and Gleeson (2013) found decreases in the testosterone: cortisol ratio after 11 days of overload training. This was linked to increased fatigue and burnout scores. However, there were no differences in RPE or HR responses to the cycle test pre and post-increased training load and no changes in time to fatigue during the test (Hough et al., 2013).

Although these biomarkers are useful to scientists who study mechanisms, they are not practical for widespread use among recreational athletes. In addition to low feasibility, the above-mentioned studies suggest the markers are not sensitive to changes in training load or performance.

A Multifactorial Approach

A few sports scientists have tried to understand overreaching better by using a multifactorial approach. Although this type of study is more invasive and time-consuming for the participant, it provides useful information. For example, Le Meur et al. (2013) used blood markers of fatigue, submaximal and maximal HR, running biomechanics, and cognitive performance to determine overreaching in

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a group of well-trained triathletes. The markers associated with determining overreaching were a decreased submaximal and maximal HR and decreased blood lactate at submaximal and maximal intensities during an incremental treadmill running test. In addition, cognitive performance decreased, and perceived fatigue increased at exhaustion in the overreached group.

Another group of researchers (Schmikli, Brink, De Vries, & Backx, 2011) used a combination of submaximal HR, running speed, the Profile of Moods State questionnaire, and blood markers of fatigue to determine nonfunctional overreaching in a group of elite soccer players and middle-distance runners. The group used field tests specific to soccer and running to determine a state of non-functional overreaching. When the soccer players displayed elevated HR on two consecutive field tests (spaced two weeks apart) they were allocated to the overreached group. The runners had to display a performance decrement at controlled submaximal HRs. The researchers also observed increased anger and depression scores as well as decreased blood levels of cortisol in the overreached group.

A multifactorial approach is a good way to learn more about the associative value of a combination of internal training load measurements. It is also a good approach to use with professional sports teams and athletes. The stakes of maintaining a good balance of training and recovery are higher for professional athletes, and they also have more time and dedication to complete several training load measurements. However, the feasibility of a multifactorial approach greatly decreases in a field setting with recreational athletes because they generally have limited time and are typically less invested in their performance results compared to professional athletes.

Summary

In the last 30 – 40 years, the profile of the recreational runner has changed. Now they are older, slower and it may be reasonable to suggest they train less (Leyk

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et al., 2009; Hoffman et al., 2010; “2014 annual marathon report,” 2014). However, more runners are participating in endurance running events (Andersen, 2019; “2014 annual marathon report,” 2014). We need a more in depth understanding of how this type of runner trains. This information will enable coaches and sports scientists to advise this type of runner about training to maximise performance and decrease injury risk.

An athlete’s training involves completing workout sessions defined by a specific duration, intensity, and frequency. The combination of these factors is defined as the external training load (Wallace et al., 2009). The ACWR provides information about spikes and troughs in training. It also provides insight about athlete preparedness before competition. Coaches and sports scientists can tailor training advice according to the ACWR to optimise performance and decrease injury risk. There is a gap in the literature describing the ACWR in endurance sports.

The use of GPS sport watches has rapidly increased with endurance runners. It provides an opportunity to collect large amounts of training load data free from recall bias or compliance. There is a lack of research regarding the accuracy of GPS sport watches.

Internal training load measures provide information about how an athlete is responding and adapting to training. Submaximal HR is an accurate and feasible way to calculate internal training load. When untrained individuals increase aerobic fitness, submaximal HR decreases (Hedelin et al., 2000; Skinner et al., 2003; Uusitalo, 2001; Wilmore et al., 2001). Submaximal HR also decreases when already trained athletes are exposed to an overload, such as a large increase in training load or an ultramarathon race (Bellenger et al., 2017; Le Meur et al., 2013; Siegl et al., 2017). A decreased submaximal HR is also associated with decreased performances. However, there is a gap in knowledge about possible relationships between decreases in performance, submaximal HR, and more ecologically valid changes in training load. More specifically, the gaps in the current literature include:

- 1) How do well-trained competitive recreational runners train? What is the contribution of training volume and intensity? How much does their training load vary in a period of several months?
- 2) How does the ACWR change over time with *ad libitum* training in well-trained competitive recreational runners? Do they adhere to small progressions in training load $\leq 10\%$?
- 3) What is the measurement error in a range of brands and models of GPS sport watches?
- 4) What are the possible relationships between changes in performance, submaximal HR, and training load? Specifically, are there any relationships with ecologically valid changes in training load in well-trained competitive runners?

These questions will be addressed in the experimental sections that follow. Each study will have a brief introduction, methods section, results and discussion. The findings from these studies will be consolidated in the final section of the thesis (Chapter 7).

Chapter 3: Relationships between training load,
performance, and pacing at the Two Oceans Marathon

**Study 1: Relationships between performance and pacing at the 2016
Two Oceans Marathon**

Introduction

Pacing is defined as how an athlete distributes his or her energy throughout an exercise task such as a race and has been shown to affect endurance running performance (Lambert et al., 2004). Previous research has found faster runners maintain more even pacing compared to slower runners during endurance running races ranging from 12-km to 161-km in distance (Esteve-Lanao, Larumbe-Zabala, Dabab, Alcocer-Gamboa, & Ahumada, 2014; Hanley, 2014; Hoffman, 2014; Lambert et al., 2004; March, Vanderburgh, Titlebaum, & Hoops, 2011; Renfree & Gibson, 2013; Tan et al., 2016).

Changes in gradient during a race lead to large changes in energy expenditure, and the ability to maintain consistent pacing is more difficult than on level terrain. Runners tend to change speed on hilly terrain to maintain consistent energy expenditure. For example, in a 9-km course, research participants ran 14% faster on downhill sections compared to level terrain and 23% slower on uphill sections (Townshend, Worringham, & Stewart, 2010). Compared to races with level terrain, pacing on hilly terrain may be regulated conservatively in anticipation of topographic difficulties (Kerhervé, Cole-Hunter, Wiegand, & Solomon, 2016). Running at too high of a relative effort can lead to premature fatigue and slower overall race times.

While there is research on pacing in flat road races (March et al., 2011; Renfree & Gibson, 2013) and mountain trail ultramarathons (Hoffman, 2014; Kerhervé et al., 2016), there is a lack of research in hilly road ultramarathons where the pacing could be unique. Trail races, although typically hilly, have variations in ground surface not applicable to road races. In addition, the gradient of climbs in mountain trail races is often much larger than hilly road races. Understanding pacing under these conditions is important for elite and recreational runners. For example, at the elite level, championship events are held in different sites each year with unique topography. Understanding and adopting the ideal pacing strategy during events with hills will contribute to a better performance. At the recreational level, it is important for coaches, athletes, and sports scientists to

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understand how different race profiles may alter the effect of performance level on pacing. Given runners' pacing strategies change with hilly terrain, the aim of this study was to determine the influence of performance level on pacing in a hilly ultramarathon course.

Methods

Experimental approach to the problem

This descriptive field study occurred at the 2016 Two Oceans Marathon. The 56-km course is a road run over hilly terrain with approximately 800 meters of cumulative vertical gain (Figure 3.1.1). The race has a cutoff time of seven hours. Race results and split times of all finishers ($n = 8,945$) were accessed via the Two Oceans Marathon public website ("Two Oceans Marathon," n.d.). The age and previous number of races completed for participants were accessed from the race entry registration information. The Two Oceans Marathon database is registered with the Human Research Ethics Committee at the University of Cape Town (HREC REF R009/2016). All study participants gave informed consent for their race data to be used for research. The data of 1,618 runners were excluded from analysis due to missing split times. In total, 7,327 competitors were included in the analyses. Splits included times when runners crossed timing mats at the start, 28-km, 42-km, 50-km, and finish points. Electronic timing mats and chips were provided by RaceTec ("RaceTec," n.d.). The race route is measured by an International Association of Athletics Federations (IAAF) accredited course measurer. Runners were subdivided into four quartiles (1-4) based on finishing time. Quartiles 1, 2, 3 and 4 (Q1, Q2, Q3, Q4) comprised the first, second, third and fourth quartile finishers respectively.

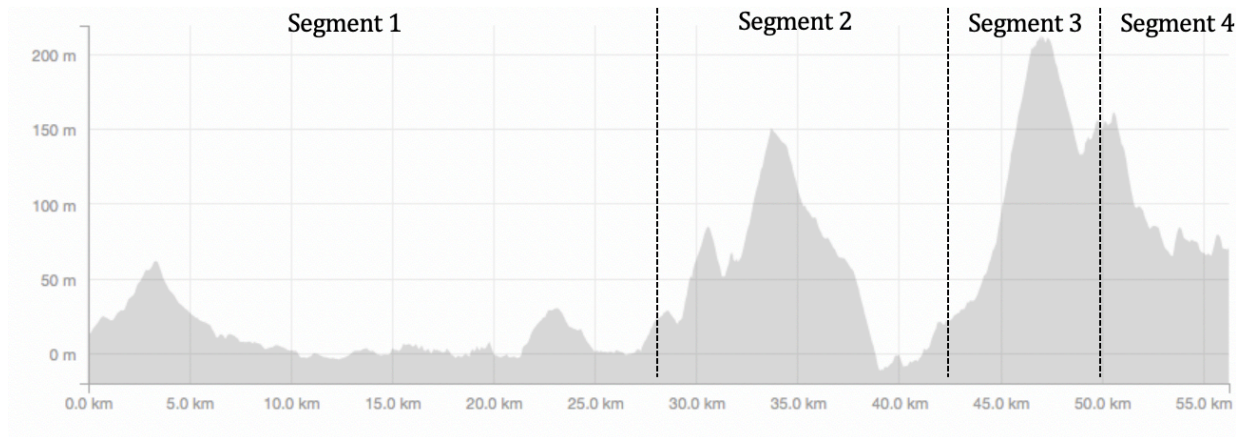


Figure 3.1.1. The Two Oceans Marathon course profile.

Participants

The distribution of finishing times was skewed to the left with a median finishing time of 5 h 59 min (Figure 3.1.2). The characteristics of the competitors are shown in table 3.1.1. The range of mean finishing times from Q1 – Q4 was 4 h 50 min \pm 28 min (mean \pm SD) (Q1) to 6 h 47 min \pm 7 min (Q4).

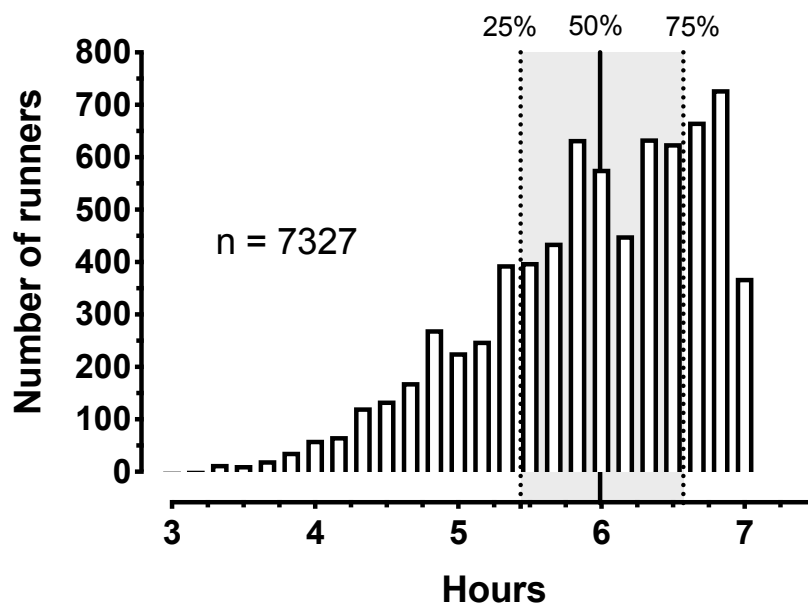


Figure 3.1.2. Distribution of finishing times.

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Table 3.1.1. Characteristics of finishers at the 2016 Two Oceans marathon (56-km) split into quartiles.

	<u>Q1</u>	<u>Q2</u>	<u>Q3</u>	<u>Q4</u>	<u>Mean</u>
n	1832	1832	1832	1831	7327
Age (yr)	39±8 ^{b,c,d}	42±9 ^d	42±9 ^d	43±10	42±9
Ultras*	5±5	5±6 ^{c,d}	4±5	4±5	5±5
Time (min)	290±28 ^{b,c,d}	345±10 ^{c,d}	379±9 ^d	407±7	355±46
Speed (km/h)	11.7±1.3 ^{b,c,d}	9.7±0.3 ^{c,d}	8.9±0.2 ^d	8.3±0.2	9.6±1.5
<u>Speed (km/h)</u>					
S1	13.0±1.6 ^{2,3,4}	11.2±0.7 ^{2,3,4}	10.0±0.6 ^{2,3,4}	9.3±0.5 ^{2,3,4}	10.8±1.7
S2	11.2±1.4 ³	9.2±0.5 ^{3,4}	8.4±0.4 ^{3,4}	7.7±0.4 ^{3,4}	9.1±1.6
S3	10.1±1.5 ⁴	8.5±0.7 ⁴	7.7±0.5 ⁴	7.2±0.4 ⁴	8.4±1.4
S4	11.2±1.5	9.6±0.8	8.7±0.7	8.1±0.6	9.4±1.5
<u>Normalised</u>					
<u>Run Speed (%)</u>					
S1	111±6 ^{2,3,4}	111±6 ^{2,3,4}	112±6 ^{2,3,4}	113±5 ^{2,3,4}	112±6
S2	96±4 ³	94±4 ^{3,4}	94±4 ^{3,4}	93±4 ^{3,4}	94±4
S3	86±7 ⁴	87±7 ⁴	87±5 ⁴	87±5 ⁴	87±6
S4	96±8	99±8	98±8	98±7	98±8

* *Ultras* – number of previous Two Oceans ultramarathon races completed.

Speed (km/h) – average speed for the 56-km race.

S1 = segment 1 (0 – 28-km), S2 = segment 2 (28 – 42-km), S3 = segment 3 (42 – 50-km), S4 = segment 4 (50 – 56-km).

Normalised Run Speed = (segment speed/mean overall race speed)*100.

All data are presented as mean ± SD.

^{2,3,4} p < .01 segment 1 vs. segments 2, 3, & 4 respectively.

^{b,c,d} p < 0.01 Q1 vs. Q2, Q3, and Q4 respectively.

Procedures

Mean running speed (km/h) for the four segments available (0 - 28-km, 28 - 42-km, 42 - 50-km, 50 - 56-km) was calculated using split and race times for each individual runner. In accordance with previously published research (Renfree, Crivoi do Carmo, & Martin, 2016), normalised running speed for each segment was calculated by expressing each split segment as a percentage of mean overall race speed.

All results are expressed as mean \pm standard deviation (mean \pm SD). Characteristics for each quartile of finishing group were compared using a one-way analysis of variance. Due to the distribution of the data being skewed, and presence of unequal variances, non-parametric statistical analyses were performed. A Friedman's test was used to determine the effect of race distance on running speed within each quartile. A Kruskal-Wallis Test was used to determine differences in relative speed between quartiles at each running segment. The Kruskal-Wallis test statistics were transformed into effect sizes (Cohen, 2008; Fritz, Morris, & Richler, 2012). The thresholds for determining magnitudes of the transformed effect sizes were: *trivial* ($d \leq 0.2$), *small* ($d = 0.21$), *moderate* ($d = 0.6$), and *large* ($d = 1.2$) (Hopkins, Marshall, Batterham, & Hanin, 2009).

Results

The normalised running speed for the entire group is shown in figure 3.1.3. Throughout the race, runners decreased their running speed until the final 6-km (50 – 56-km) when runners increased their relative running speed. The course profile (Figure 3.1.1) may be a contributing factor to this observation.

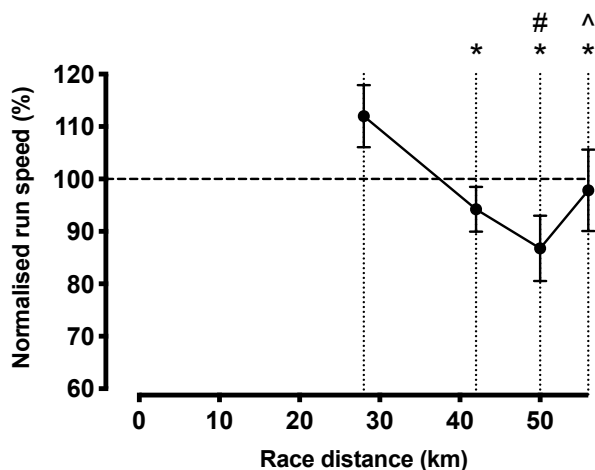


Figure 3.1.3. Data are presented as mean \pm SD. Normalised running speed at each running segment for the combined group ($n = 7327$). The first, second, third, and fourth data points represent the mean running speed from 0 – 28 km; 28 – 42 km; 42 – 50 km; and 50 – 56 km respectively.

* $p < 0.001$ vs. segment 1. # $p < 0.001$ vs. segment 2. ^ $p < 0.001$ vs. segment 3.

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When runners were split into quartiles based on finishing times (Figures 3.1.4A - 4D) all groups decreased their running speed until the final 6-km of the race (50 – 56-km) when all groups increased their running speed. Runners in Q3 & Q4 ran relatively faster than runners in Q1 & Q2 in the first half of the race (approximately 110m/105m vertical gain/loss) ($p < 0.001$) (Q1 vs. Q3 $d = 0.27$; Q1 vs. Q4 $d = 0.41$; Q2 vs. Q3 $d = 0.22$; Q2 vs. Q4 $d = 0.36$; Q3 vs. Q4 $d = 0.13$) (Figure 3.1.5A and Table 3.1.1). Runners in Q4 ran relatively faster than runners in Q3 in the first half of the race ($p = 0.001$, $d = 0.13$). However, the difference is considered *trivial*. When all statistics are considered, runners in Q3 & Q4 ran relatively faster than runners in Q1 in the first half of the race. The difference is considered *small*. Runners in Q4 also ran relatively faster than runners in Q2 in the first half of the race. The difference is considered *small*.

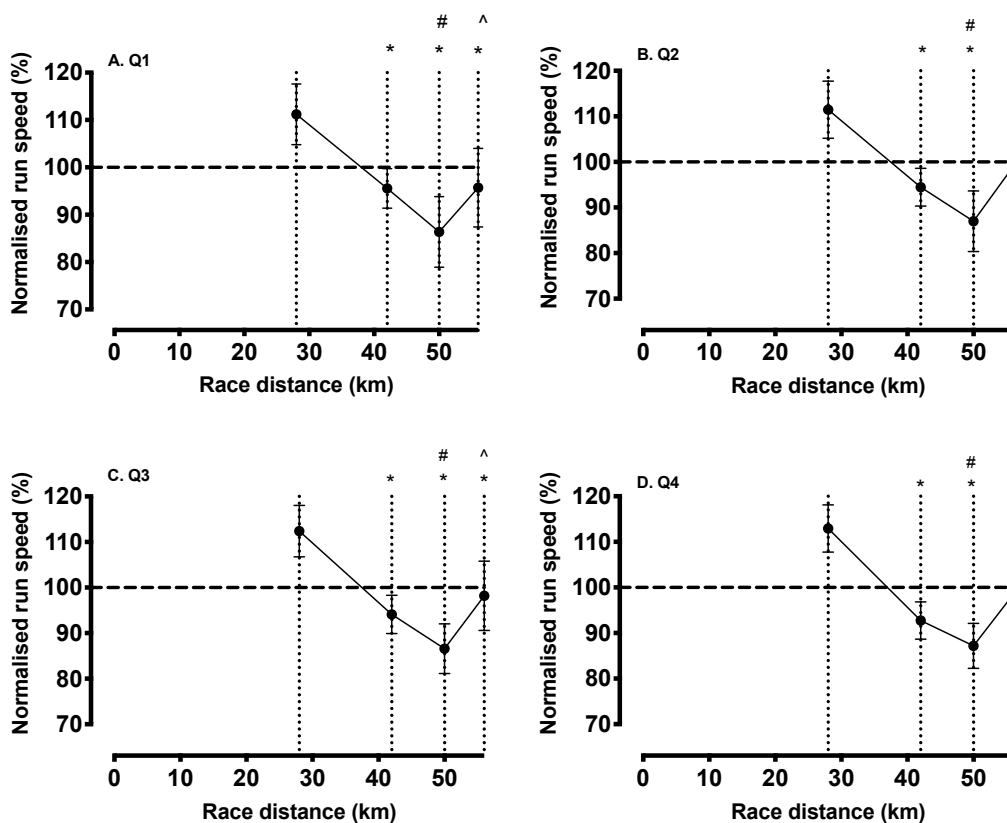


Figure 3.1.4A – 4D. Data are presented as mean \pm SD. Normalised running speed at each segment for Q1 – Q4 respectively. The first, second, third, and fourth data points represent the mean running speed from 0 – 28 km; 28 – 42 km; 42 – 50 km; and 50 – 56 km respectively. **A)** $n = 1832$; **B)** $n = 1832$; **C)** $n = 1832$; **D)** $n = 1831$.

* $p < 0.001$ vs. segment 1. # $p < 0.001$ vs. segment 2. ^ $p < 0.001$ vs. segment 3.

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For segment 2 (28 – 42-km) (approximately 240m/230m vertical gain/loss), runners in Q1 ran relatively faster than runners in Q2, Q3, & Q4 ($p < 0.001$, $d = 0.27, 0.38, 0.81$ respectively) (Figure 3.1.5B, Table 3.1.1). Runners in Q2 ran relatively faster than runners in Q3 & Q4 ($p = 0.011, < 0.001$ & $d = 0.10, 0.50$ respectively). However, the difference between runners in Q2 and Q3 is considered *trivial*. Runners in Q3 ran relatively faster than runners in Q4 ($p < 0.001$, $d = 0.39$). When all statistics are considered, runners in Q1 ran relatively faster than runners in Q2, Q3, & Q4 from the 28 – 42-km mark of the race. The differences are considered *small* for Q1 vs. Q2 & Q3, and *moderate* for Q1 vs. Q4. Runners in Q2 ran relatively faster than runners in Q4 for segment 2, and the difference is considered *small*. Runners in Q3 ran relatively faster than runners in Q4 for segment 2, and the difference is considered *small*.

For segment 3 (42 – 50-km) (approximately 235m/100m vertical gain/loss), runners in Q4 ran relatively faster than runners Q1 ($p = 0.028$, $d = 0.09$) (Figure 3.1.5C, Table 1). Runners in Q2 ran relatively faster than runners in Q3 ($p = 0.003$, $d = 0.12$). Runners in Q4 ran relatively faster than Q3 ($p = 0.001$, $d = 0.13$). However, all of the above differences are considered *trivial*. When all statistics are considered, runners in all quartiles ran at similar relative speeds from the 42 – 50-km mark of the race.

For segment 4 (50-56 km) (approximately 55m/125m vertical gain/loss), runners in Q2, Q3, and Q4 ran relatively faster than runners in Q1 ($p < 0.001$, $d = 0.43, 0.31, 0.32$ respectively) (Figure 3.1.5D, Table 3.1.1). Runners in Q2 ran relatively faster than runners in Q3 & Q4 ($p = 0.006$, $d = 0.11$, $p = 0.020$, $d = 0.10$ respectively). However, the differences between Q2 and Q3 & Q4 were considered *trivial*. When all statistics are considered, runners in Q2, Q3, & Q4 ran relatively faster than runners in Q1 in the final 6-km of the race. The differences are considered *small*.

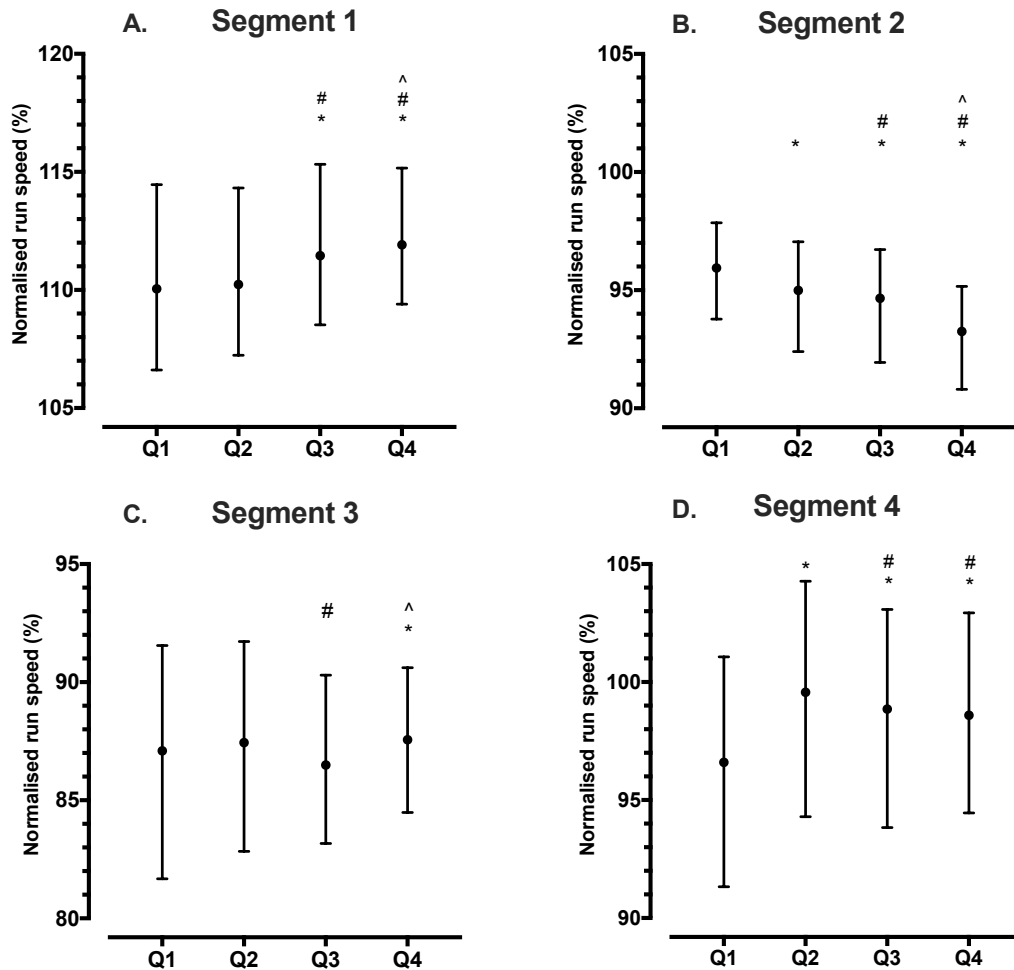


Figure 3.1.5A-5D. Data are presented as median \pm IQR. Normalised running speed for Q1 - Q4 at each segment respectively. Q1: n = 1832; Q2: n = 1832; Q3: n = 1832; Q4: n = 1831.

A: * $p < 0.001$ vs. Q1; # $p < 0.001$ vs. Q2; ^ $p < 0.001$ vs. Q3.

B: * $p < 0.0001$ vs. Q1; # $p = 0.011$ Q3 vs. Q2, $p < 0.001$ Q4 vs. Q2; ^ $p < 0.001$ vs. Q3.

C: * $p = 0.028$ vs. Q1; # $p = 0.003$ vs. Q2; ^ $p = 0.001$ vs. Q3.

D: * $p < 0.0001$ vs. Q1; # $p = 0.006$ Q3 vs. Q2; $p = 0.020$ Q4 vs. Q2.

When all runners' relative decrease in speed in the second half vs. first half of the race was plotted, the median decrease was 20% (Figure 3.1.6). This relatively large decrease in speed is likely due to the course profile. The two major climbs of the race occur in the second half. Runners in Q3 & Q4 slowed down more in the second half compared to runners in Q1 & Q2 ($p < 0.001$) (Table 3.1.1). The difference between Q1 & Q2 compared to Q4 was considered *small* ($d = 0.30$, $d = 0.31$ respectively). Runners in Q4 slowed down more in the second half compared to runners in Q3 ($p < 0.001$). The difference between Q1 vs. Q3; Q2 vs.

Q3; and Q3 vs. Q4 were all considered *trivial* ($d = 0.17, d = 0.18, d = 0.13$). When considering all statistics, runners in Q1 & Q2 slowed down less in the second half compared to runners in Q4. The differences are considered *small*.

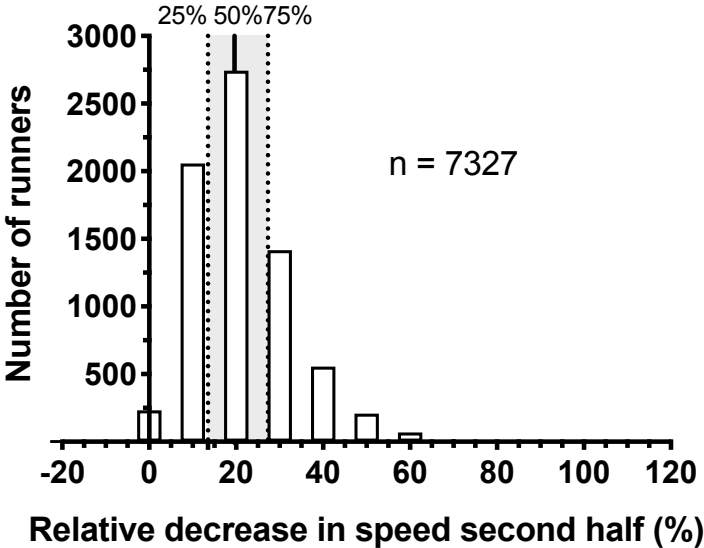


Figure 3.1.6. Distribution of relative decrease in speed in the second half of the race.

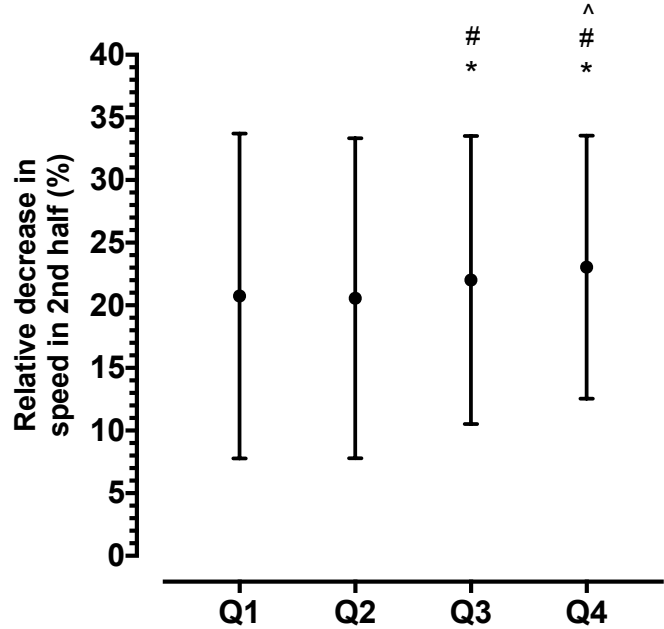


Figure 3.1.7. Data are presented as median \pm IQR. Relative decrease in running speed in the second half of the race for Q1 – Q4. Q1: $n = 1832$; Q2: $n = 1832$; Q3: $n = 1832$; Q4: $n = 1831$.

* $p < 0.001$ vs. Q1. # $p < 0.001$ vs. Q2. ^ $p = 0.001$ vs. Q3.

Discussion

The conclusions of this study include: 1) When the race is split into first half vs. second half, runners in Q1 & Q2 displayed more even pacing when compared to Q4 competitors, but this difference is considered *small*; 2) In the first half of the race Q4 competitors run at a relatively faster speed compared to Q1 & Q2 competitors. Q3 competitors run at a relatively faster speed compared to Q1 competitors. All of these differences are considered *small*; 3) From the 28 – 42-km mark, which includes the first major climb, Q1 competitors run relatively faster than Q2, Q3, & Q4 competitors. Q2 and Q3 competitors also run relatively faster than Q4 competitors. The differences are considered *small* in all cases except for Q1 vs. Q4 which is considered *moderate*; 4) All groups run at a similar relative speed from the 42 – 50-km mark. This section of the race includes the second major climb; and 5) From the 50-km mark – finish, Q1 competitors run at a relatively slower speed compared to Q2, Q3, & Q4 competitors. All of these differences are considered *small*. Conclusions one – three are similar to previous research on courses with relatively level terrain at the 42-km and 100-km distances (March et al., 2011; Renfree et al., 2016). However, conclusions three – five indicate the slower competitors' relative speed is similar or faster than the faster competitors in the final 14-km of the race.

Energy Expenditure

It is important to consider the specific course profile when interpreting the results. The Two Oceans Marathon includes two significant climbs. The first climb (uphill and downhill) occurs from the 29 – 38-km mark in the race. Runners climb approximately 180 m in 5-km. The second climb occurs from the 40 – 46-km mark in the race, and runners climb approximately 215 m in 4-km. The faster runners were running at a faster relative speed compared to slower runners from the 28 – 42-km mark which includes the first climb, while runners in all quartiles ran at similar relative speeds from the 42 – 50-km mark which includes the second climb. The pacing on the first climb was different and could have impacted the pacing on the second climb in the faster runners. In support of this, a previous study found a large range of energy expended on the downhill

section of a running course of 65 – 94% of ventilatory threshold (Townshend et al., 2010). This suggests some athletes run downhill at a high relative effort while others use the downhill as recovery. In our study, it may be possible that faster runners were running downhill close to their ventilatory threshold while slower runners were running at an easier relative effort.

Psychological Differences

Previous research has shown psychological factors may influence pacing in endurance running events. Deaner, Addona, & Hanley (2019) found runners who scored high for risk-taking in pace slow more during the race at the marathon distance. This held true even after controlling for other factors that may affect pace such as amount of training and experience level. It is possible that the Q4 runners took a greater risk in pacing in the first half due to concern for making the cut off time of seven hours. The mean finishing time for the Q4 competitors was only 13 minutes faster than the cutoff time so this may be a reasonable speculation.

When considering all available segments, it is possible that the Q1 competitors took on a greater risk in pacing from the 28 – 42-km mark of the race. This may have contributed to the slower competitors running at a similar or faster relative speed in the final 14-km of the race.

Experience Level

Previous research has found a higher level of experience and more repetitions of an event improves pacing across a range of activities (Ansley, Lambert, Schabort, St Clair Gibson, & Noakes, 2004; Deaner, Carter, Joyner, & Hunter, 2015). For example, Deaner et al. (2015) found experienced runners pace more evenly than inexperienced runners at the marathon distance. Ansley et al. (2004) found a more consistent pacing profile in the second and third repetition of a 4-km cycling time trial compared to the first time trial.

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One potential reason for the small differences in pacing in the current study is that runners in all quartiles had similar previous experience at the race (Table 3.1.1). Runners in Q1 & Q2 had previously completed the Two Oceans Marathon an average of five times, while runners in Q3 & Q4 had completed the course four times previously on average. Although Q2's experience level was significantly greater than Q3 & Q4 ($p < 0.01$), this difference was considered *trivial* ($d = 0.1$).

When considering the small differences between runners in Q4 vs. Q1 and Q2 runners in the first vs. second half, there is a greater number of Q4 runners with only one previous Two Oceans Marathon compared to Q1 & Q2 runners (Figure 3.1.8A, B, & D). This lack of experience may have played a part in the small but significantly slower relative speed in the second half of the race for the Q4 competitors.

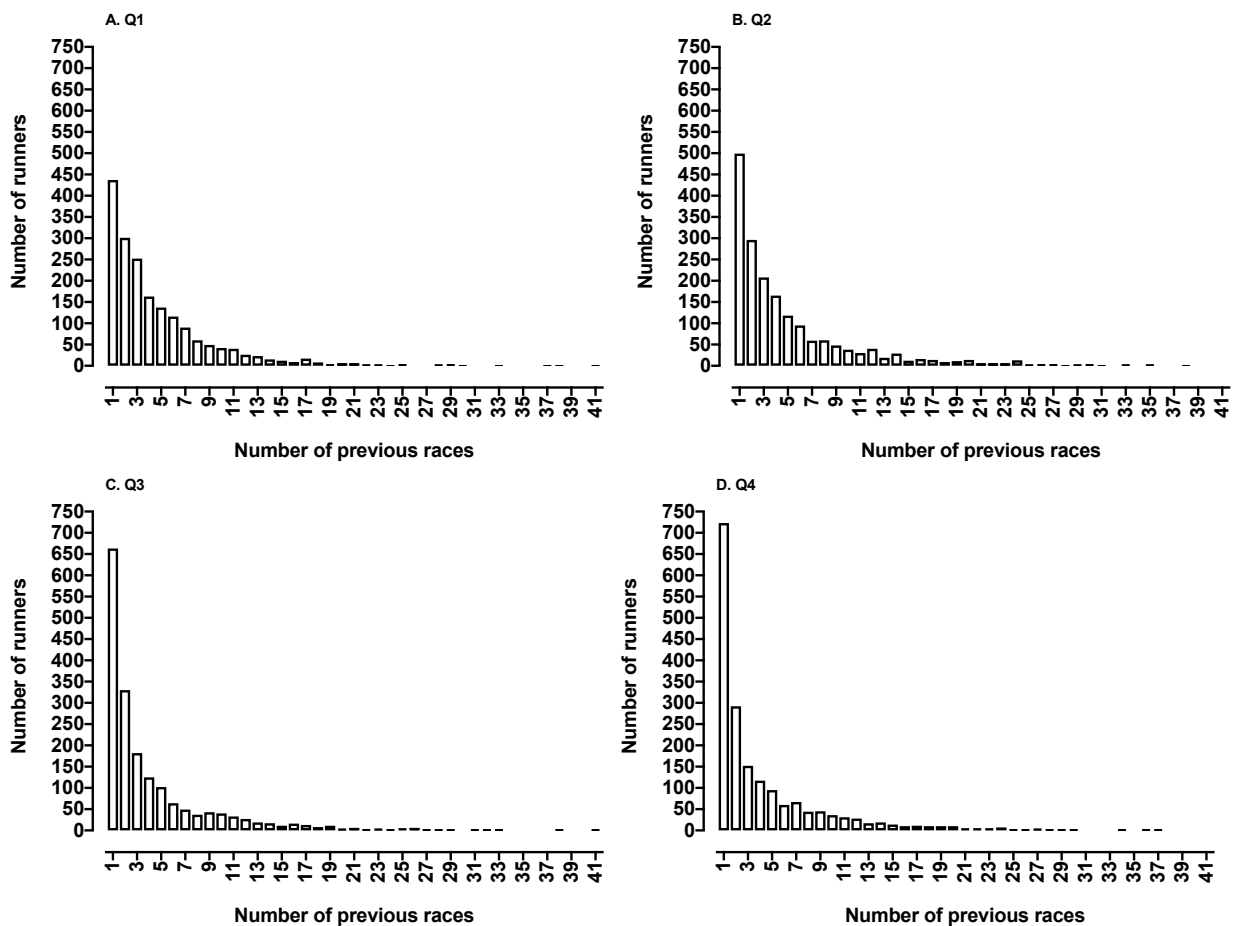


Figure 3.1.8A-D. Frequency distribution for previous number of completed Two Oceans Marathons for Q1-Q4 respectively. **A)** $n = 1832$; **B)** $n = 1832$; **C)** $n = 1832$; **D)** $n = 1831$.

Limitations

A limitation of the study is the lack of knowledge regarding runners' pacing strategy and/or goals before race day. Our conclusions are based on their pacing on the race day. We could not account for confounding variables that may have affected them on race day. The study would be strengthened if runners were surveyed about their expected times and pacing strategy before the race. However, due to the retrospective nature of the study, this was not possible.

Another limitation of the study is the lack of knowledge regarding whether runners' chose to run with an official race pacesetter. The Two Oceans Marathon offers pacesetters to come in slightly faster than the following finishing times: 5 h; 5 h 15 min; 5 h 30 min; 5 h 45 min; 6 h; 6 h 10 min; 7 h. Runners who choose to run behind a pace setter may benefit from a reduction in air resistance (Pugh, 1970) and may have a psychological advantage perhaps through motivation from the pace setter (Zouhal et al., 2015).

Finally, it is important to consider that participants across the quartiles would have experienced the same course but may have experienced different weather depending on finishing time. The temperature ranged from 16 – 20 degrees Celsius from 6am – 12pm on race day ("timeanddate," n.d.). It is possible that temperature and/or wind may have affected pacing in the slower runners differently than the faster runners.

Conclusion

In conclusion, the fastest two quartiles of finishers slow down less in the second half of the race compared to the slowest quartile. When examined in each of the four available segments, this difference is attributable to Q1 and Q2 competitors running relatively faster from the 28 – 42-km mark which includes the first of two major climbs in the race. The small pacing differences may be due to differences in energy expenditure or different decision-making regarding how hard to run different sections of the course. The slower runners may be able to eliminate the small but significant decline in relative speed in the second half by

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adopting a slower start. Runners should not be influenced by other competitors' pace at the beginning of endurance races, as this can lead to sub-optimal pacing.

Taken as a whole, all differences were considered *trivial* or *small* except for Q1 vs. Q4 in segment two (28 – 42-km) which was considered *moderate*. Compared to previous research, the competitors at the Two Oceans Marathon run at more similar relative speeds. This could be due to similar previous race experiences across the groups. Future research should consider determining possible relationships between training load, race performance, and pacing. This would provide information about whether training may impact runners' ability to maintain similar speeds throughout a race.

**Study 2: Relationships between training load, performance, and
pacing at the 2017 Two Oceans Marathon**

Introduction

An athlete completes training in preparation for a competition. This training load is often adjusted to maximise performance. Coaches and athletes cannot appropriately adjust load unless they accurately quantify the training load. External training load is an objective measure of the work that an athlete performs (Borresen & Lambert, 2009). In running this includes distance, speed, and frequency. Despite the importance of quantifying training load, many sports science studies lack a proper training description. This limits their application and makes it difficult to compare the effects of training between studies (Hopkins, 1991).

Previous research describing the training load performed by athletes has determined relationships between training load and performance (Borresen & Lambert, 2009). For example, one study (Mujika, 2014) described the training of a world-class triathlete in preparation for the London 2012 Olympic Games. Other research studies have described training intensity distribution and periodisation in world-class cross-country skiers and orienteers (Seiler & Kjerland, 2006; Tønnessen et al., 2015). Mujika et al. (1995) determined the relationships between training load and performance in high level swimmers. These studies ultimately help athletes, coaches, and sports scientists to enhance training effectiveness and improve performances.

However, all the above-mentioned studies focussed on elite level athletes. The practical applications may not be translatable to recreational level athletes. With rapid increases in participation in endurance running events (Andersen, 2019; "2014 annual marathon report," 2014) it is important for runners, coaches, and sports scientists to understand how recreational runners train and how training load in this group of athletes relates to performance.

The aim of this study was therefore to: 1) quantify training load in a group of competitive recreational runners in preparation for a 56-km road

ultramarathon; and 2) determine the relationships between training load, performance, and pacing during the race.

Methods

Training & Race Data

The Two Oceans Marathon is a 56-km road race held in Cape Town, South Africa. The race was previously described in detail in Ch.3.1. The 2017 race was held on 15 April. Participants in the study were recruited from the Two Oceans Marathon list of registered runners (approximately 10,000 entrants). All study participants provided informed consent for their race results and Global Positioning Systems (GPS) files from their training to be accessed for the research study. Training data of study participants (n = 69) were accessed via the SmartBeat Technologies research database which runners joined by linking their Strava (www.strava.com) account to the database. The Two Oceans Marathon and SmartBeat Technologies databases are registered with the Human Research Ethics Committee at the University of Cape Town (HREC REFS: R009/2016; R037/2016).

Summaries of each training run were downloaded from the SmartBeat Technologies database. Information from each training run included: average speed; maximum speed; average pace; maximum pace; distance; elapsed time; elevation gain; date of run; type of workout; name of workout; and description of workout. Runners used the following GPS devices: Garmin® (n = 38); Suunto® (n = 7); TomTom® (n = 13); Polar® (n = 4); cell phone (n = 1); unknown (n = 6).

Calculations

Training load was calculated using a running training stress score (rTSS) (McGregor et al., 2009). The formula for $rTSS = \text{duration (hours)} * \text{intensity factor (IF)}^2 * 100$. The duration is time spent running in hours. The intensity factor for running is the ratio of running speed in relation to running speed at lactate threshold. In this study, running speed for a best 10-km race in the

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previous 12 months was used as an estimate of speed at lactate threshold (Kumagi et al., 1982; Perez, I., Perez, D., Gonzalez, & Esteve-Lanao, 2012).

If participants did not have a best 10-km time from the previous 12 months ($n = 40$), a best time from a 5-km, 8-km, 12-km, 21-km, or 42-km race from the previous 12 months was taken and entered into the Pete Riegel race time projection model (Riegel, 1981). The equation is $T_2 = T_1 * (D_2/D_1)^{1.06}$ where T_2 is the predicted time; T_1 = race time for known distance; D_2 = predicted distance; D_1 = distance for known race time.

To get an overall training value for each participant, area under the curve (AUC) rTSS for each participant was calculated for the 42 days before the race. This was done using GraphPad Prism (GraphPad Software, San Diego, California USA, www.graphpad.com) which computes AUC using the trapezoid rule ("How to: Area under the curve," 2019). Only the days where participants had rTSS values greater than zero were included in the AUC calculation. Relative race performances were calculated by dividing the mean race speed by runners' best 10-km race speed in the last 12 months.

Participants' data were analysed first as a combined group. Fifty of the participants were male and 19 were female. The average age of the participants was 38 ± 7 years (mean \pm SD) (Table 3.2.1). Then the runners were split into four groups: train hard race hard (THRH); train easy race hard (TERH); train hard race easy (THRE); and train easy race easy (TERE) and the data from each group were compared. The groups were created by calculating the 45% and 55% percentiles of the 6-week AUC rTSS and relative performances on race day. For example, the participants in the top 45th percentile for training load and relative performance were grouped into THRH. The participants in the bottom 55th percentile for training load and relative performance were grouped into TERE.

The thresholds for AUC rTSS and relative performance for each group are as follows:

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- THRH: AUC rTSS \geq 2039 & relative performance \geq 82%; n = 21.
- THRE: AUC rTSS \geq 2039 & relative performance \leq 79%; n = 8.
- TERH: AUC rTSS \leq 1969 & relative performance \geq 82 %; n = 7.
- TERE: AUC rTSS \leq 1969 & relative performance \leq 79%; n = 19.

Table 3.2.1. Participant characteristics for each group & combined group analyses.

	<u>THRH</u>	<u>THRE</u>	<u>TERH</u>	<u>TERE</u>	<u>Group</u>
n	21	8	7	19	69
Age (yr)	42 \pm 8	39 \pm 10	36 \pm 10	37 \pm 5	38\pm7
Ultras*	5 \pm 7	1 \pm 1	1 \pm 1	3 \pm 5	3\pm6
Time (min)	335 \pm 46	334 \pm 52	339 \pm 47	373 \pm 32*	349\pm43
Rel Perf (%)	87 \pm 2	76 \pm 4*	85 \pm 2	72 \pm 5*#	80\pm7
10-km (min)	51.8 \pm 6.8	44.8 \pm 6.2*	51.8 \pm 4.8	48.3 \pm 4.8	49.5\pm6.2

* *Ultras* – number of previous Two Oceans ultramarathon races completed.

Time = 56-km race time in minutes. Rel Perf = relative performance. Percentage of best 10-km race speed in the last 12 months. 10-km = best 10-km race time in minutes in the last 12 months.

THRH = Train hard race hard; THRE = Train hard race easy; TERH = Train easy race hard; TERE = Train easy racy easy.

Data are presented as mean \pm SD.

* p < 0.05 vs. THRH. # p < 0.05 vs. TERH.

Statistical Analyses

Statistical analyses to test for normality were done using SPSS version 25 (SPSS, Inc., Chicago, IL USA). All remaining statistical analyses were done using GraphPad Prism software (GraphPad Software, San Diego, California USA, www.graphpad.com). A Shapiro-Wilk test was used to determine normality of daily rTSS, IF, duration, and AUC rTSS. Due to the presence of non-normal distribution for daily rTSS, IF, and duration, non-parametric statistical analyses were performed, and results are expressed as median \pm interquartile range (IQR).

Characteristics for each group were compared using a one-way analysis of variance. A Friedman's test was used to determine: 1) if AUC rTSS changes over time as a combined group; 2) if running duration and IF change over time within each of the four groups; and 3) group differences in duration, IF, and pacing. Multiple comparisons were corrected using Dunn's method. A Kruskal-Wallis Test was used to determine group differences in AUC rTSS and variation in pacing splits. Linear regression analyses were used to determine relationships between performance, training load, and pacing.

Results

Distributions

The distribution of relative performances and finishing times are both skewed (Figures 3.2.1A - B). The distribution for relative performances is skewed to the left ($p = 0.01$) and the distribution for finishing times is non-normal ($p = 0.02$). The median relative performance was 81% with an IQR of 11%. The median finishing time was 5h 52min with an IQR of 1h 7min.

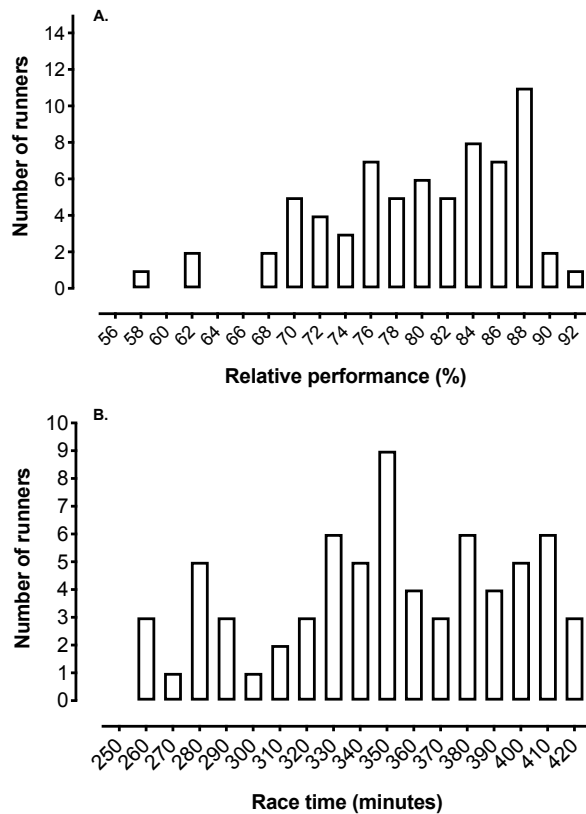


Figure 3.2.1A-B. Frequency distribution for **A)** relative race performance & **B)** absolute race time. n = 69.

Analyses with all participants

Area under the curve rTSS was calculated for the 6-week time frame before the race as well as the AUC rTSS for each week (Figure 3.2.2A - B). The median AUC was 2002 with an IQR of 1571 – 2664. The variation in 6-week training load was approximately 13-fold ranging from 341 – 4488 (Figure 3.2.2A). The median distance per week performed was 51 km/week with an IQR of 37 – 68 km/week. There was a significant change in AUC rTSS over time ($p < 0.01$). Training load was reduced in the one week before the race compared to weeks two – six. In addition, there was a significant increase in training load from five weeks before race day to four weeks before (Figure 3.2.2B).

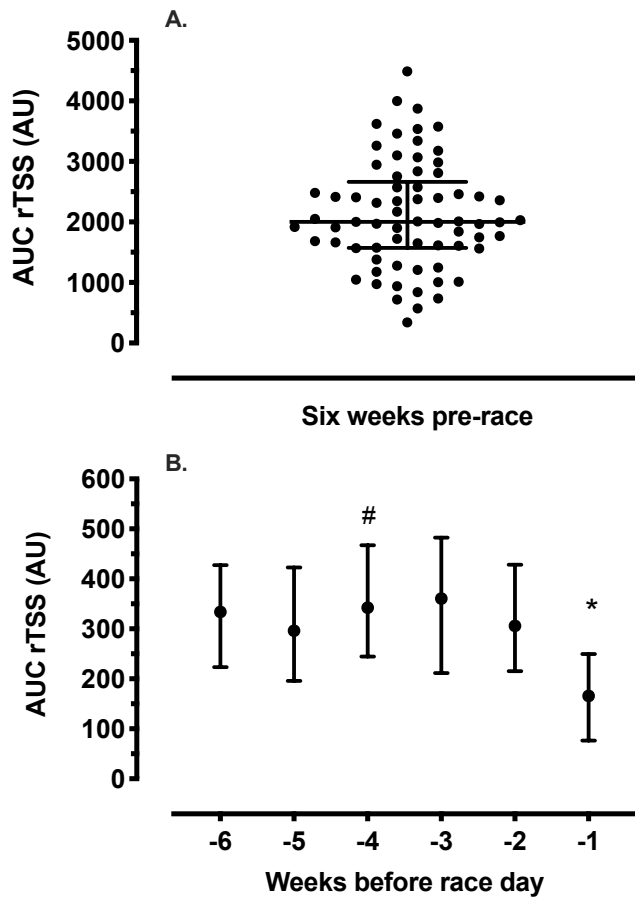


Figure 3.2.2A-B. Data are presented as median \pm IQR. **A)** Scatter dot plot for Area Under the Curve (AUC) for running training stress score (rTSS) for the six weeks prior to race. **B)** Weekly AUC rTSS for the six weeks before race day.

* $p < 0.01$ vs. all other weeks. # $p < 0.05$ vs. week -5. $n = 69$.

There was a significant positive relationship between relative race performance and the 6-week training load AUC leading up to the race ($p < 0.01$) (Figure 3.2.3). Runners with better relative performances on race day had higher training load for the six weeks before race day.

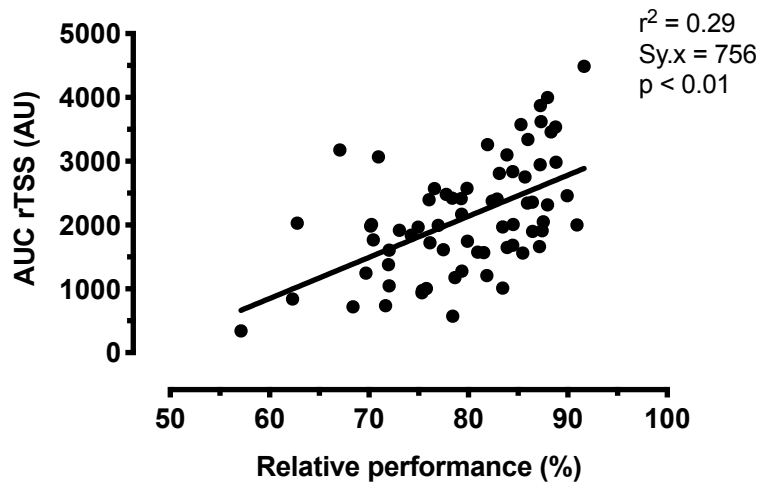


Figure 3.2.3. Relationship between relative race performance and area under the curve (AUC) for running training stress score (rTSS) for the six weeks before race day. $Sy.x$ = standard error of estimate. $n = 69$.

Grouped analyses

When 6 -week training load was compared between the four groups, the TERH and TERE groups had lower AUC rTSS values compared to the THRH group. The TERE group also had lower AUC rTSS values compared to the THRE group (Figure 3.2.4).

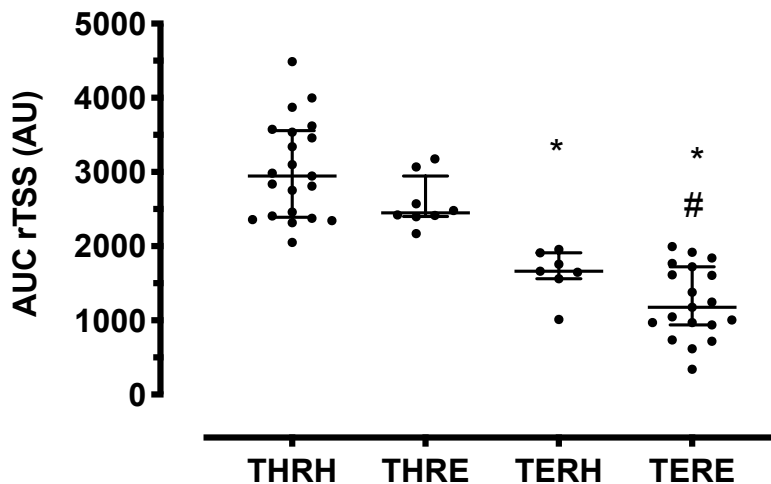


Figure 3.2.4. Data are presented as median \pm IQR. Area under the curve (AUC) for running training stress score (rTSS) for six weeks before race day in each group. THRH = train hard race hard ($n = 21$); THRE = train hard race easy ($n = 8$); TERH = train easy race hard ($n = 7$); TERE = train easy race easy ($n = 19$).

* $p < 0.01$ vs. THRH. # $p < 0.01$ vs. THRE.

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Weekly running duration and average weekly IFs for each group were calculated (Figures 3.2.5A-H). Between group analyses for running duration showed the TERE group had lower running time in the 6-weeks prior to race day compared to the THRH and THRE groups ($p = 0.02$) (Figure 3.2.5D). Between group analyses for IF showed the THRE and TERE groups had lower average IFs compared to the THRH group ($p < 0.05$) (Figure 3.2.5F & 5H).

Within group analyses showed an effect of time on running duration for the THRH, THRE, and TERE groups. The THRH group showed reduced running time in the one week prior to race day compared to all other weeks ($p < 0.05$) (Figure 3.2.5A). The THRE group showed reduced running time in the one week prior to race day compared to the 4th week prior to the race ($p < 0.01$) (Figure 3.2.5B). The TERH group showed similar running time each week prior to the race. The TERE group showed reduced running time in the one week prior to race day compared to the six – four weeks before race day ($p < 0.01$) (Figure 3.2.5D).

Within group analyses showed no effect of time on average IF. This suggests each group runs at similar relative running speed for each of the six weeks leading up to race day.

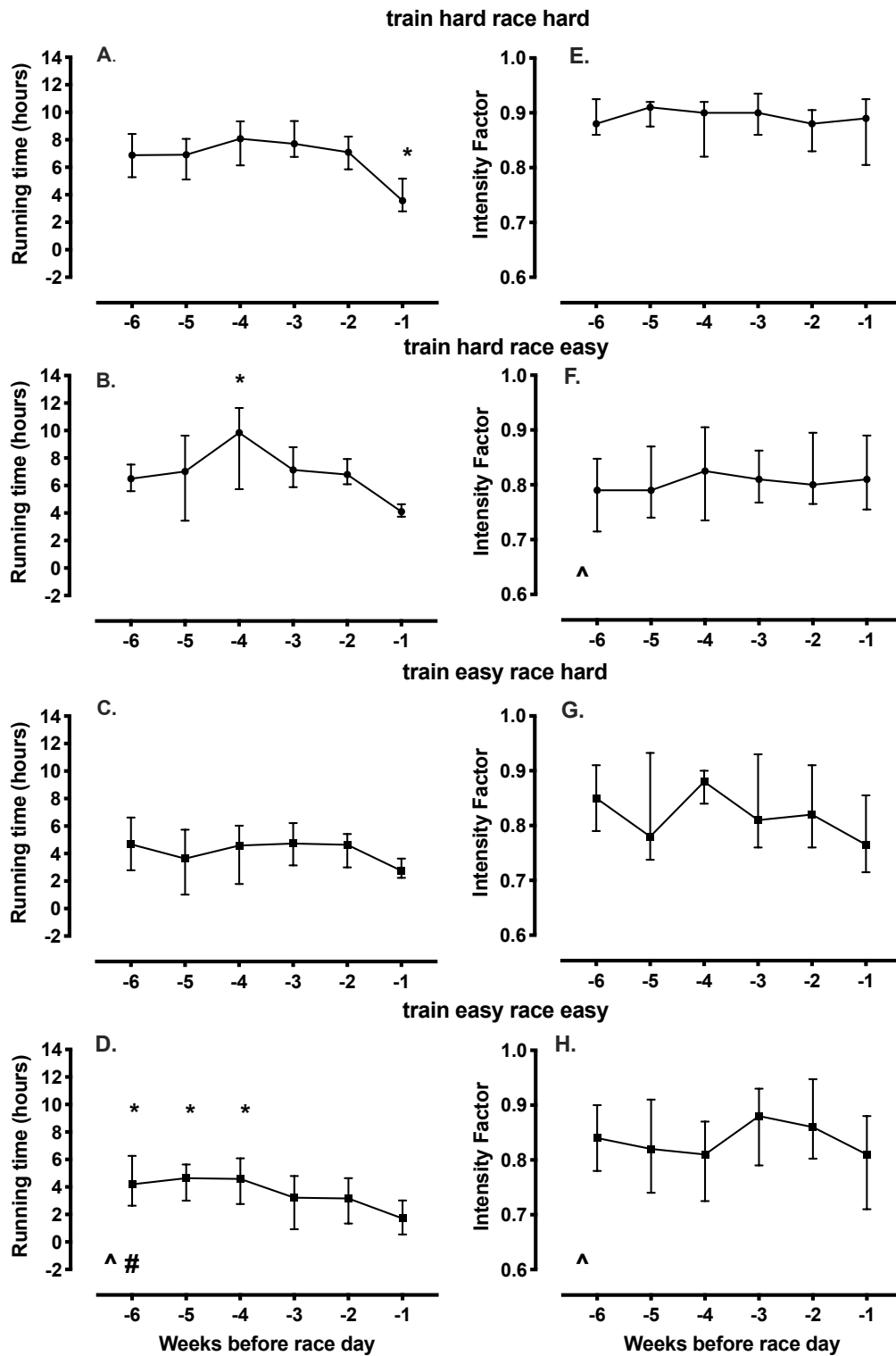


Figure 3.2.5A-H. Data are presented as median \pm IQR. Train hard race hard n = 21; train hard race easy n = 8; train easy race hard n = 7; train easy race easy n = 19.

A-D) Running duration per week in each group. \wedge p = 0.02 vs. train hard race hard. # p = 0.02 vs. train hard race easy. **A)** * p < 0.05 vs. all other weeks; **B)** * p < 0.01 vs. week -1; **D)** * p < 0.01 vs. week -1; **E-H)** Average Intensity Factor per week in each group. \wedge p < 0.05 vs. train hard race hard.

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Table 3.2.2. Weekly AUC rTSS, duration, & IF for each group & combined group analyses.

	<u>THRH</u>	<u>THRE</u>	<u>TERH</u>	<u>TERE</u>	<u>Group</u>
<u>AUC rTSS</u>					
-6	453±194	359±118	321±141	236±10 [^]	334±203
-5	444±174	364±203	275±183	200±121 [^]	296±227
-4	497±189	433±270	378±219	222±183 [^]	343±222#
-3	536±163	453±107	358±200	173±196	360±270
-2	454±144	396±117	339±151	173±185	306±212
-1	249±110*	231±70	188±131	84±91	166±174*
<u>Duration (h)</u>					
-6	6.8±3.1	6.5±1.9	4.7±3.8	4.2±3.6 [^]	5.3±3.3
-5	6.9±3.0	7.0±6.2	3.6±4.7	4.6±2.6 [^]	5.4±3.7
-4	8.1±3.2	9.8±5.9*	4.6±4.2	4.6±3.3 [^]	5.7±4.8
-3	7.7±2.6	7.1±2.9	4.7±3.1	3.2±3.9	6.3±4.1
-2	7.1±2.3	6.8±1.8	4.6±2.4	3.2±3.3	5.4±3.8
-1	3.6±2.4*	4.1±0.9	2.8±1.4	1.7±2.5	2.9±2.4*
<u>Intensity</u>					
<u>Factor</u>					
-6	.88±.07	.79±.13	.84±.10	.82±.13	.86±.13
-5	.91±.05	.79±.13	.77±.12	.79±.13	.87±.14
-4	.90±.10	.83±.17	.88±.10	.78±.15	.85±.13
-3	.90±.08	.81±.10	.78±.11	.86±.17	.86±.13
-2	.88±.08	.80±.13	.81±.12	.88±.16	.84±.12
-1	.89±.12	.81±.14	.77±.11	.81±.20	.85±.15

AUC rTSS = area under the curve running training stress score per week. Duration = running duration hours per week. Intensity Factor = average running intensity per week as a ratio of best 10-km race speed.

-6; -5; -4; -3; -2; -1 = 6; 5; 4; 3; 2; & 1 week before race day respectively.

THRH = train hard race hard (n = 21); THRE = train hard race easy (n = 8); TERH = train easy race hard (n = 7); TERE = train easy race easy (n = 19); Group (n = 69).

Data are presented as median ± IQR.

* p < 0.05 vs. all other weeks. ^ p < 0.01 vs. week -1. # p < 0.05 vs. week -5.

Pacing

There was a negative linear relationship between relative race performance and the coefficient of variation (CV) of running splits throughout the race (Figure 3.2.6A). Runners with a better relative race performance, displayed more even pacing throughout the race. When examined as between group differences, the TERE group displayed greater variation in pacing compared to the THRH and TERH groups ($p < 0.01$; $p = 0.03$ respectively) (Figure 3.2.6B, Table 3.2.3).

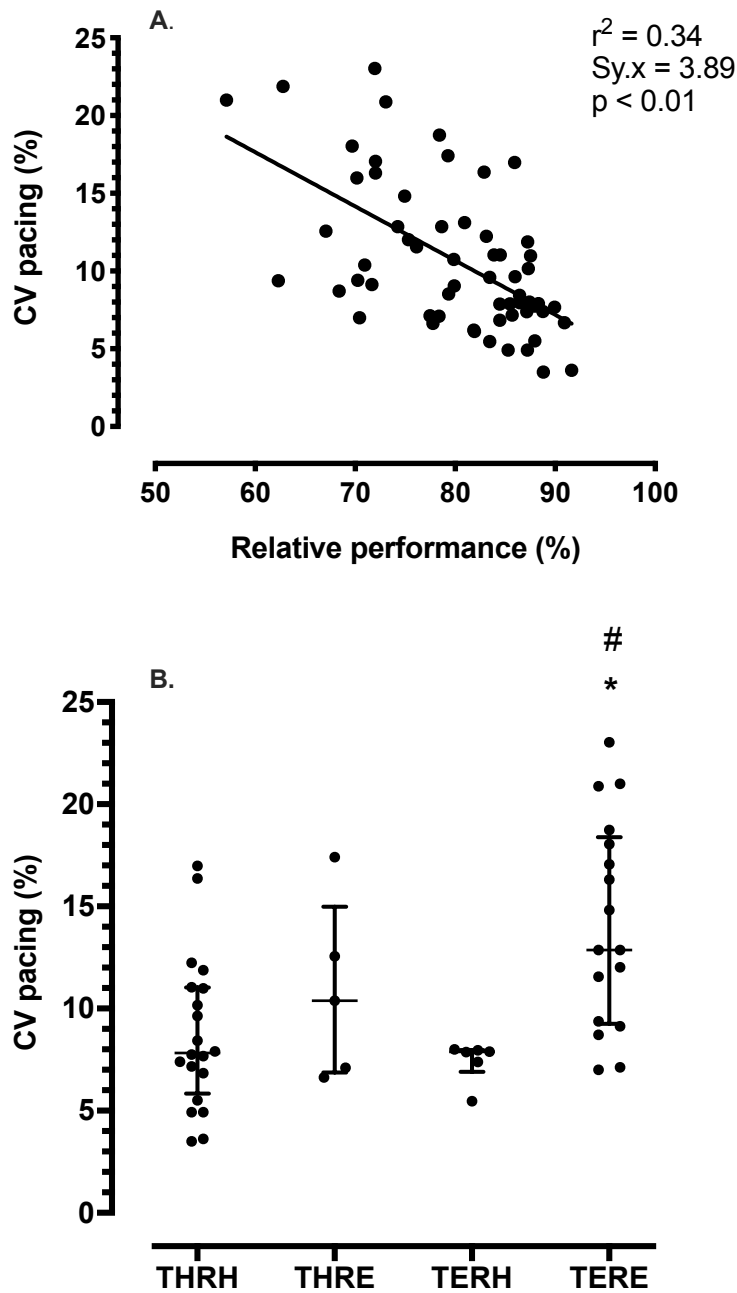


Figure 3.2.6A-B. CV = coefficient of variation **A)** Relationship between relative race performance and CV in available running splits (n = 60). Sy.x = standard error of estimate **B)** Data are presented as median \pm IQR. THRH = train hard race hard (n = 20); THRE = train hard race easy (n = 5); TERH = train easy race hard (n = 6); TERE = train easy race easy (n = 17).

* p < 0.01 vs. THRH; # p = 0.03 vs. TERH.

Only participants with pacing splits available were included in the analysis.

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Table 3.2.3. Normalised running speed at each of the available five segments & CV of available splits for each group & combined group analyses.

	<u>THRH</u>	<u>THRE</u>	<u>TERH</u>	<u>TERE</u>	<u>Group</u>
<u>Normalised</u>					
<u>Run Speed (%)</u>					
S1	108±7	109±10	108±1	114±11	110±6
S2	106±4	106±5	107±2	111±8	107±6
S3	98±3 ^{a,b}	98±6	98±2 ^a	96±4 ^{a,b}	97±3^{a,b}
S4	89±6 ^{a,b}	90±8 ^a	89±3 ^{a,b}	82±8 ^{a,b}	88±7^{a,b,c}
S5	101±8 ^{a,d}	98±5	101±5	95±11 ^{a,b,d}	98±8^{a,b,d}
CV splits (%)	7.8±4.5	10.4±5.5	7.9±0.4	12.9±8.7*#	9.4±5.5

Normalised run speed = run speed as a percentage of speed for the entire race. CV splits = coefficient of variation of running speed across the five segments.

THRH = train hard race hard (n = 20); THRE = train hard race easy (n = 5); TERH = train easy race hard (n = 6); TERE = train easy race easy (n = 17); Group (n = 60).

S1 = Segment 1 (0 – 16-km); S2 = Segment 2 (16 – 28-km); S3 = Segment 3 (28 – 42-km); S4 = Segment 4 (42 – 50-km); S5 = Segment 5 (50 – 56-km).

Data are presented as median ± IQR.

* p < 0.01 vs. THRH. # p = 0.03 vs. TERH. ^{a, b, c, d} p < .05 vs. segments 1, 2, 3, & 4 respectively.

Discussion

The main conclusions of the current study include: 1) This group of competitive recreational runners perform a wide-range of training loads in the six weeks prior to a 56-km ultramarathon; 2) There is an increase in training load from the fifth week to the fourth week prior to race day, and there is no decrease in training load until the one week prior to the race; 3) Runners divided into groups for comparison had differences in training duration and intensity; and 4) Runners with better relative performances complete higher training loads and display more even pacing during the race compared to lower performing runners.

Wide range in training load

The 6-week AUC training load in this group varied approximately 13-fold. When analysed as distance run, this represents a range of 12 – 112 km/week (59 ± 24 km/week (mean \pm SD)) in training. Competitive recreational runners today are training with less volume than in the 1970's and 1980's when coaches were advocating running loads of 160 km/week in preparation for marathons (Lydiard, 1978; Pate, 1976). This group trained less than a group training for the same race in 1997 (Lambert & Keytel, 2000). A survey was sent out to the top 10 finishers in each age group and found that males ran 108 ± 45 km/week and females ran 83 ± 22 km/week. It is possible this difference in training load is due to the 1997 dataset only including top finishers.

Our mean results are in line with Leyk et al. (2009) who found an average distance of 45 – 50 km/week in preparation for the marathon distance. Their data was taken from 108 marathon races and included any runner who completed the race. It is important to consider possible reasons for the relatively low training volume in comparison to training advice from the 1970's (Pate, 1976). It may be possible that the runners have relatively low load tolerance due to other commitments such as full-time work and family. It is also possible that the training loads advocated in the 1970's and 1980's were too high. Due to a lack of applied research at the time, we are uncertain about the compliance to the training advice. Runners and coaches should consider that mean distances in preparation for marathon and 56-km race distances for this population of runners were 45 – 59 km/week. This will help them set realistic training targets that can be adjusted at an individual level. When taking into account the wide range in training load, this indicates some competitive recreational runners may be under-prepared for an ultramarathon race, while others may be adequately prepared. On the other hand, the 'train easy' runners may be unable to adapt to a higher training load and may be more susceptible to overuse injuries.

Changes in training load over time

When analysed as a combined group, the training load increased from the fifth week to the fourth week before the race. Load remained high until one week before the race when it decreased significantly. This indicates that the combined group of runners completed their biggest training weeks in the fourth, third, and second week before the race. The reduction in training load the one week before the race represents the taper period. Research has shown that planned reductions in training volume can lead to improvements in aerobic capacity and performance (Hickson, Kanakis, Davis, Moore, & Rich, 1982; Hickson, Foster, Pollock, Galassi, & Rich, 1985; Mujika, Chatard, Padilla, Guezennec, & Geysant, 1996). Previous research on tapering suggests that a 12 – 14-day reduction in training load is optimal (Banister, Carter, & Zarkadas, 1999; Morton, 1997). It is interesting to note that this cohort did not decrease load until the one week before the race. It is possible that competitive recreational runners may not require as long of a taper as elite level athletes, because their overall training loads are significantly lower. With less overall stress, there may be a shortened recovery time needed for supercompensation to occur (Cunanan et al., 2018). It is also possible that had the runners performed a 12 – 14-day taper, their results may have been better.

Differences in running duration and intensity

The intensity factor remained the same throughout the six weeks leading up to race day. Previous research suggests exercise intensity should be maintained during a taper (Hickson et al., 1982, 1985; Mujika, 2010; Wittig, Houmard, & Costill, 1989; Wittig, McConell, Costill, & Schurr, 1992). This suggests that this group follows recommended tapering techniques regarding intensity.

The pattern of the training load was different when participants were split into four groups for comparison. The THRH group had higher running duration compared to the TERE group, and higher running intensity than the TERE and THRE groups. The THRH group did not decrease their running duration until one week before the race, and IF remained similar for all six weeks. The running

duration pattern is in contrast to the other groups. The THRE group had higher running duration in the fourth week before the race vs. the one week before, but similar duration in all other weeks. This means that in the third and second weeks before the race, the THRE group trained similar to the one week before which is not in line with suggested training principles. It is possible this group did not perform as well on race day due to a poor tapering strategy. The TERH group trained with similar duration and intensity for all six weeks. This suggests this group may not have followed a structured training programme and did not complete a taper. The TERE group had higher running duration in the sixth – fourth weeks before the race vs. the one week before. This is similar to the THRE group, where the training load was similar for the three weeks before the race.

Relationships between training load, performance, and pacing

This was a heterogenous group of competitive recreational runners from the perspective of training load. There was no performance or minimum training requirement as a prerequisite for inclusion in the study. The only requirement was that they were registered to run the 56-km race. The Two Oceans Marathon does require all 56-km entrants to run a qualifying marathon within the eight months before race day. We determined relationships between training load and 56-km race performance. Our results indicate a higher training load is associated with better relative performances on race day. This is in accordance with previous research (Bale, Rowell, & Colley, 1985; Knechtle, Knechtle, Rosemann, & Senn, 2011; Lambert, 2000). Runners should aim to safely increase training load to increase chances of improving performance. However, it is important to take individual variability into account. Some runners may not be able to manage increases in load due to injury prevalence, poor running biomechanics, and/or a highly demanding career or other stressors (Collette, Kellmann, Ferrauti, Meyer, & Pfeiffer, 2018; McEwen, 1998; Rushall, 1990).

The pacing results are consistent with previous research showing that better performers have more even pacing at races (Esteve-Lanao et al., 2014; Hanley, 2014; Hoffman, 2014; Lambert et al., 2004; Renfree & Gibson, 2013; Tan et al., 2016). The TERE group displayed a significantly higher variation in pacing splits

compared to the THRH and TERH groups. When examined as individual segments, this variation was due to the TERE group running too fast in the first two segments of the race (start – 28-km), which negatively impacted their relative speed on the final three segments (28 – 56-km). The TERE group should be advised on the benefits of a conservative pacing strategy for races.

Limitations

The study time frame was only six weeks in duration. This is a relatively short time frame and does not capture the entire training preparation for the race. Runners' race preparation was likely anywhere from 12 – 20 weeks in duration. However, we can assume that in the six weeks prior to the event, we captured the taper period and possibly the peak week(s) of training for the race.

Secondly, the only requirement of the study was that runners be registered to run the 56-km Two Oceans Marathon. There is a possibility that some runners did not run the race at their maximal effort. Some runners may have completed the race with a friend with a lower ability level or run the race as preparation for a future race.

Thirdly, we are only able to report on external training load measures in this cohort. The interpretation of the data would have been enhanced had we also had a measure of internal training load. Although most of the research participants had wrist-based heart rate monitors, we decided not to use these data because we were concerned about the accuracy of the measurement of heart rate. For this reason, we focused on external training load measures.

Finally, the intensity factors were calculated using average running speed for each training session. We recognize that if runners completed speed work in a session with recovery running between, using the average speed for the entire session is a limitation. Due to the large number of participants and nearly 8,000 GPS files analysing segments of each file was not feasible.

Despite these limitations the results from this study provide novel information about competitive recreational runners preparing for an ultramarathon.

Conclusion

In conclusion, competitive recreational runners have a wide range of training loads as they prepare for an ultramarathon. The profile of runners in this group who perform relatively better can be described as runners who:

- (i) complete higher training loads;
- (ii) display a one-week taper with a reduction in training volume while maintaining running intensity, and
- (iii) pace more evenly during the race.

This study provides needed information regarding how competitive recreational runners train in preparation for an endurance running event. It also provides information on relationships between training load, performance, and pacing. Future studies should quantify both external and internal training load in recreational runners for a period of 12 weeks or longer. In addition, since data were collected from runners' GPS sport watches, future research should determine the validity of the devices in measuring distance.

Chapter 4: The accuracy of GPS sport watches in measuring distance in an ultramarathon running race

Introduction

Wearable technology has, in the last decade, become increasingly popular with endurance runners. Wearables were estimated to represent a \$6-billion industry in 2016 (Düking, Hotho, Holmberg, Fuss, & Sperlich, 2016) with a projected \$25-billion industry in the year 2019 (Koytcheva, 2015). A large category of wearables give information about distance and speed traveled using Global Navigation Satellite Systems such as Global Positioning Systems (GPS) (Cummins, Orr, O'Connor, & West, 2013; Schutz and Chambaz, 1997). To obtain the best possible GPS readings, a high-sampling frequency, open areas free from obstructions such as tall buildings, and clear skies are required (Baranski & Strumillo, 2012; Cummins et al., 2013). Endurance runners have several GPS sport watch brands to select such as Garmin®, Polar®, Suunto®, and TomTom®. Within these brands there are several existing models e.g. Garmin Forerunner® 620, Suunto Ambit® 3. It is important to evaluate the reliability and accuracy of these GPS sport watches for coaches and sports scientists to accurately measure performance and track training load. To date, most research regarding the accuracy of GPS devices is related to team sports such as rugby and football, and primarily focus on the accuracy in measuring high intensity changes in speed (Akenhead, French, Thompson, & Hayes, 2014; Aughey, 2011; Barbero-Álvarez, Coutts, Granda, Barbero-Álvarez, & Castagna, 2010; Cardinale & Varley, 2017; Chambers, Gabbett, Cole, & Beard, 2015; Malone, Lovell, Varley, & Coutts, 2017). The GPS devices used in team sports are unique in their specifications and cannot be directly compared to GPS sport watches used in endurance running. There has also been research regarding the validity and reliability of wearable devices to measure heart rate (HR) (Abt, Bray, & Benson, 2018), step counts, energy expenditure and sleep (Diaz et al., 2015; Ferguson, Rowlands, Olds, & Maher, 2015). However, only one study in a systematic review (Evenson, Goto, & Furberg, 2015) reported on the validity of a wearable in measuring distance (Takacs et al., 2014). There is currently a lack of research on the accuracy of GPS sport watches in the field of endurance running. With these gaps in mind, the aim of the current study was to determine the accuracy of various GPS sport watches in measuring distance throughout a hilly 56-km running race.

Methods

Race Data

The Two Oceans Marathon is a 56-km road race held in Cape Town, South Africa (Figure 4.1A-B). The course has previously been described in detail in Ch. 3.1. The 2017 race was held on 15 April. The weather during the allotted race time ranged from 14 - 24 degrees Celsius with sunny and clear skies (“timeanddate,” n.d.). Participants in the study (n = 281) were recruited from the Two Oceans Marathon list of registered runners (approximately 10,000 entrants). All study participants provided informed consent for their race results and GPS files to be accessed for the research study. Race results and segment times of study participants in the 2017 race were accessed via the race’s public website (“Two Oceans Marathon,” n.d.). GPS device files from participants were accessed via the SmartBeat Technologies research database (“Smartbeat,” n.d.), which runners joined by linking their Strava (“Strava,” n.d.) account to the database. The Two Oceans Marathon and SmartBeat Technologies databases are registered with the Human Research Ethics Committee at the University of Cape Town (R009/2016; R037/2016). Segment times were recorded when runners crossed timing mats at the 16-km, 28-km, 42.2-km, 50-km, and finish (56-km) points. The segment from the start to the 16-km mat was excluded from analysis since runners recorded various distances in this segment depending on their assigned starting batch (batches A-E; with a time range of 1min 24s to 6min 32s to cross the first timing mat).

Figure 1A.

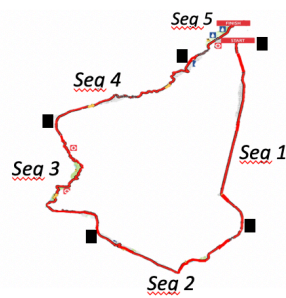


Figure 1B.

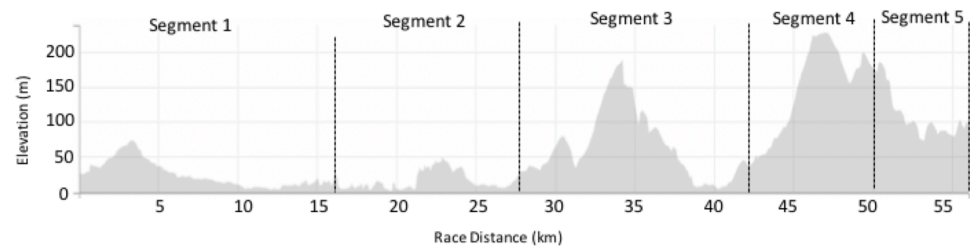


Figure 4.1 **A.)** Two Oceans Marathon 56-km race route. **B.)** Two Oceans Marathon 56-km race profile. Segment 1 (0-16 km), 2 (16-28 km), 3 (28-42.2 km), 4 (42.2-50 km), and 5 (50-56 km) are designated with dashed lines.

GPS devices

Runners were divided into eight categories depending on their GPS device brand (Table 4.1). Participants provided their own GPS devices. Eight categories defined by the GPS device brand are included (Table 4.1). Because approximately 2/3 of the participants had Garmin® devices, they were divided into groups according to three unique models. The categories include Garmin Fenix® series (GFX), Garmin XT® series (GXT), Garmin Forerunner® series (GFR), Activity watches (ACT), Suunto® (STO), TomTom® (TOM), Polar® (PLR), and cell phones (CEL). All participants in the CEL category used the Strava application to record their race. Eight of the 14 CEL participants used the Strava iPhone app, and six used the Strava android app.

Table 4.1. Number of participants and finishing time of GPS Sport Watch categories.

<u>Device category</u>	<u>Number of participants</u>	<u>Race time (h:min:s)</u>
GFX	34	5:52:31 ± 44:39
GXT	58	5:42:50 ± 42:28
GFR	67	5:45:04 ± 50:46
ACT	10	6:12:12 ± 35:13
STO	20	5:42:33 ± 40:46
TOM	44	6:02:58 ± 40:24
PLR	8	5:42:38 ± 52:28
CEL	<u>14</u>	6:04:10 ± 36:42
	255	

GFX = Garmin Fenix series (1, 2, 3); GXT = Garmin XT series (305, 310, 735, 910, 920); GFR = Garmin Forerunner series (25, 35, 220, 225, 230, 235, 610, 620, 630); ACT = Activity Watches (Garmin VivoActive, Fitbit Surge, Samsung Gear 2 & 3, Apple Watch); STO = Suunto (Ambit 2, 2R, 2S; Ambit 3 Sport, Peak, Run; Spartan). TOM = TomTom (Runner 1, 2, 3; Multisport); PLR = Polar (M400, V800); CEL = Cell Phones (iPhone, Samsung, Sony).

Data are presented as mean ± SD.

Analysis of GPS device error

Participants were instructed to start their GPS device at the same time as the starting gun. They were also instructed to set their GPS sampling frequency to “best” for their watch. Their race times were recorded as they crossed timing mats at the following race distances: 16-km, 28-km, 42.2-km, 50-km, and 56-km. Electronic timing mats and chips were provided by RaceTec (www.racetec.co.za). Timing chips were attached to the runners’ shoes using their shoelaces. The race route is measured by an International Association of Athletics Federations (IAAF) accredited course measurer. The times runners crossed the timing mats were used to identify the corresponding time points in the GPS file. For example, the Two Oceans race measures a distance of 12-km in segment two of the race (from 16 to 28-km). The Two Oceans database reports runner x crosses the 16-km mat at 1h 11min 17s and the 28-km mat at 2h 2min 26s. These time points were identified in the GPS file and the GPS measured

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distance between these time points was calculated. Runners who had no split times available in the race results or who failed to complete the 56-km race were excluded from analysis (n = 26). Forty-three participants successfully completed the race but had one or more missing split times. They were included in the analysis for the segments that split times were available for.

A relative error was calculated by taking the course distance segment (d_{course}) subtracted from the GPS device segment distance (d_{GPS}) divided by the average of the two values (relative error = $d_{GPS} - d_{course} / \text{average } d_{GPS}, d_{course}$). An error in metres was calculated by taking the course distance segment subtracted from the GPS device segment distance (metres error = $d_{GPS} - d_{course}$). The sign of the error (over or under) was included in both calculations.

Statistical Analyses

All statistical analyses were done using GraphPad Prism software (GraphPad Software, San Diego, California USA, www.graphpad.com). Participant race times for each GPS category are expressed as mean \pm standard deviation (mean \pm SD) and were compared using a Kruskal-Wallis test.

Due to the presence of unequal variances, non-parametric statistical analyses were performed, and all GPS results are expressed as median \pm Interquartile Range (IQR). A Kruskal-Wallis test was used to determine differences in relative and distance errors between GPS device categories for segment two (16 – 28-km), segment three (28 - 42.2-km), segment four (42.2 – 50-km), segment five (50 – 56-km), and the 16-56-km points. Multiple comparisons were corrected by controlling the false discovery rate via the two-stage step-up method of Benjamini, Krieger, and Yekutieli (2006).

Results

The GPS device categories and mean race times for each category are presented in table 4.1. The average finishing times of runners in the different categories were not different between groups (p = 0.20).

The data for segment one were not analysed because of the varying time it took participants to cross the start line after the start of the race. For segment two (16 - 28-km), the GXT, GFR, & TOM devices had lower relative ($p = 0.001$; < 0.001 ; < 0.001 respectively) and distance errors ($p = 0.001$; $p = 0.001$; $p < 0.001$ respectively) compared to the GFX devices (Figure 4.2A, Table 4.2, Table 4.3). GXT, GFR, & TOM devices also had lower relative and distance errors ($p < 0.001$) compared to CEL devices (Figure 4.2A, Table 4.2, Table 4.3).

For segment three (28 - 42.2-km), all device categories except for CEL had lower relative (GXT, GFR, STO, TOM $p < 0.001$; ACT $p = 0.024$; PLR $p = 0.005$) and distance errors (GXT, GFR, STO, TOM $p < 0.001$; ACT $p = 0.023$; PLR $p = 0.004$) compared to the GFX (Figure 4.2B, Table 4.2, Table 4.3). All device categories except for GFX and ACT had lower relative errors (GXT, GFR, TOM $p < 0.001$; STO $p = 0.001$; PLR $p = 0.017$) and distance errors (GXT, GFR, TOM $p < 0.001$; STO $p = 0.001$; PLR $p = 0.017$) compared to CEL (Figure 4.2B, Table 4.2, Table 4.3). TOM had a lower relative error ($p = 0.030$) vs. ACT (Figure 4.2B, Table 4.3).

For segment four (42.2-50 km) the GXT, GFR, and TOM devices had higher relative ($p < 0.001$) and distance errors ($p < 0.001$) vs. GFX (Figure 4.2C, Table 4.2, Table 4.3). All device categories except for PLR and GFX had significantly different relative (GXT, GFR, TOM $p < 0.001$; ACT $p = 0.005$; STO $p = 0.016$) and distance errors (GXT, GFR, TOM $p < 0.001$; ACT $p = 0.004$; STO $p = 0.013$) vs. CEL (Figure 4.2C, Table 4.2, Table 4.3). The STO and PLR devices had lower relative (STO $p = 0.005$; PLR $p = 0.024$) and distance errors (STO $p = 0.006$; PLR $p = 0.020$) vs. TOM. The GXT and GFR watches had higher relative ($p = 0.012$, $p = 0.001$ respectively) and distance errors ($p = 0.010$, $p = 0.001$ respectively) vs. STO. GFR had a higher relative ($p = 0.011$) and distance ($p = 0.010$) error vs. PLR (Figure 4.2C, Table 4.2, Table 4.3).

For segment five (50 - 56-km) GXT, GFR, and TOM devices had lower relative ($p = 0.003$; $p = 0.003$; $p = 0.002$ respectively) and distance errors ($p = 0.002$;

p= 0.004; p= 0.001 respectively) compared to the CEL devices (Figure 2D, Table 2, Table 3).

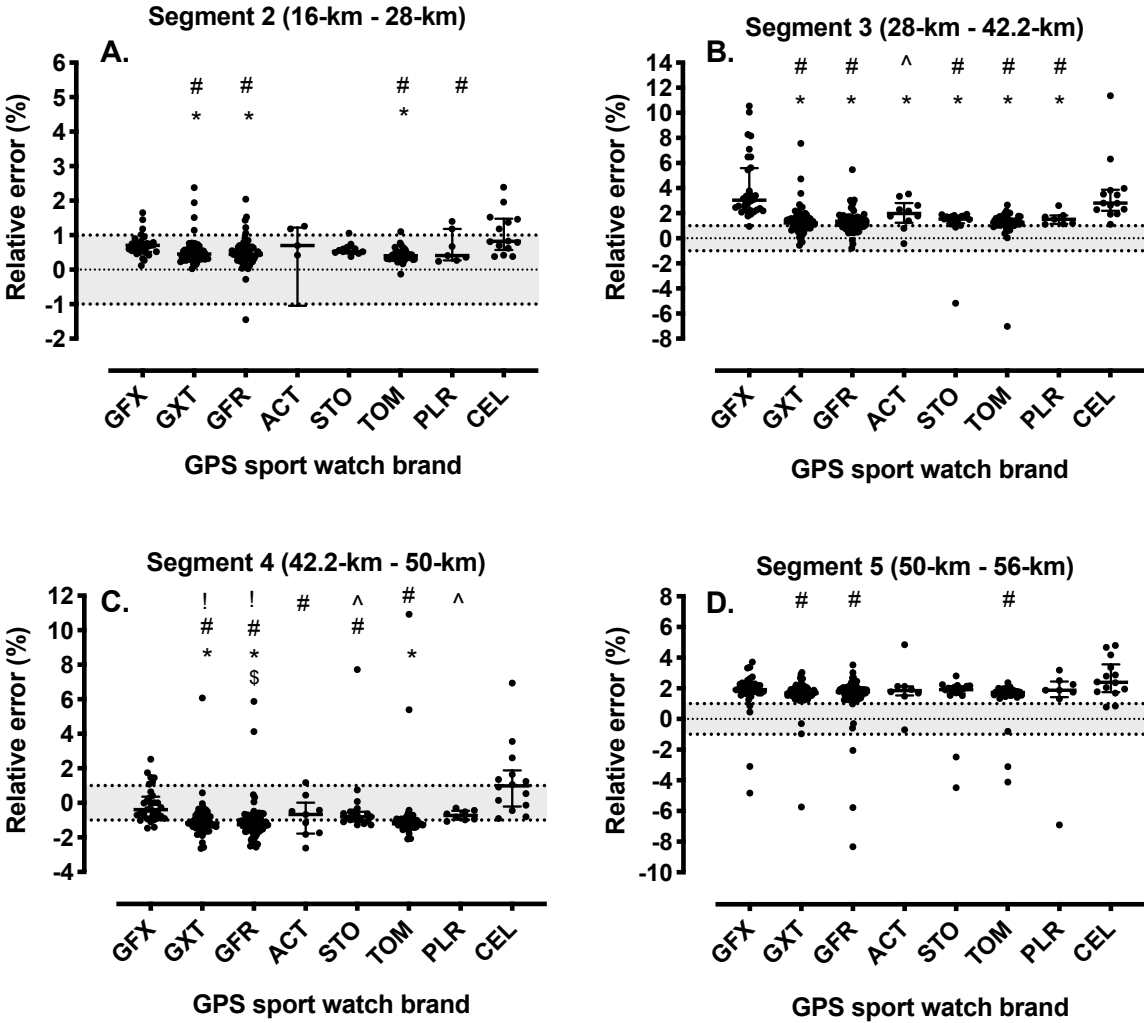


Figure 4.2A-D. Relative error of GPS measured distance vs. IAAF measured distance for segment 2, 3, 4, & 5 respectively. **A.)** n = 223; **B.)** n = 248; **C.)** n = 246; **D.)** n = 238.

GFX = Garmin Fenix series; GXT = Garmin XT series; GFR = Garmin Forerunner series; ACT = Activity Watches; STO = Suunto; TOM = TomTom; PLR = Polar; CEL = Cell Phones.

* p < 0.05 vs. GFX. # p < 0.05 vs. CEL. ^ p < 0.05 vs. TOM. ! p < 0.05 vs. STO. \$ p < 0.05 vs. PLR.

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Table 4.2. The absolute distance between the GPS sport watch measurement for a given segment(s) vs. the IAAF course measurement.

	<u>GFX</u>	<u>GXT</u>	<u>GFR</u>	<u>ACT</u>	<u>STO</u>	<u>TOM</u>	<u>PLR</u>	<u>CEL</u>
Segment 2 (m)	80±30	50±30*#	50±40*#	80±90	60±10	50±20*#	50±70	100±100
Segment 3 (m)	640±480	370±120*#	390±90*#	480±150*	420±80*#	380±60*#	420±80*#	600±210
Segment 4 (m)	-230±90	-290±50*#!	-300±50*#!\$	-250±100	-260±40#^	-290±30*#	-260±40^	-120±130
Segment 5 (m)	120±40	100±30#	110±40#	110±30	120±30	100±20#	110±40	150±90
Segment 2 – Segment 5 (m)	640±320	240±210*#	240±120 *#	380±280	290±70*#	240±80*#	280±160*#	760±510

Data are presented as median ± IQR. Segment 2 = 16 – 28 km; segment 3 = 28 - 42 km; segment 4 = 42 – 50 km, segment 5 = 50 km - 56 km; segment 2 – segment 5 = 16 km – Finish (40 km).

GFX = Garmin Fenix series; GXT = Garmin XT series; GFR = Garmin Forerunner series; ACT = Activity Watches; STO = Suunto; TOM = TomTom; PLR = Polar; CEL = Cell Phones.

* p < 0.05 vs. GFX. # p < 0.05 vs. CEL. ^ p < 0.05 vs. TOM. ! p < 0.05 vs. STO. \$ p < 0.05 vs. PLR.

Table 4.3. The relative difference between the GPS sport watch measurement for a given segment(s) vs. the IAAF course measurement.

	GFX	GXT	GFR	ACT	STO	TOM	PLR	CEL
Segment 2 (%)	0.7±0.3	0.5±0.3*#	0.4±0.4*#	0.7±2.3	0.5±0.1	0.4±0.2*#	0.4±0.9	0.8±0.9
Segment 3 (%)	3.0±3.4	1.2±0.9*#	1.3±0.7*#	2.0±1.6*^	1.5±0.6*#	1.3±0.5*#	1.5±0.7*#	2.8±1.7
Segment 4 (%)	-0.4±1.3	-1.2±0.7*#!	-1.3±0.8*#!\$	-0.7±1.8#	-0.8±0.6#^	-1.2±0.4*#\$\$	-0.7±0.5	-1.0±2.1
Segment 5 (%)	1.9±0.7	1.7±0.5#	1.7±0.7#	1.9±0.6	1.9±0.5	1.7±0.3#	1.9±1.0	2.4±1.8
Segment 2 – Segment 5 (%)	1.6±0.9	0.6±0.6*#	0.6±0.3*#	0.9±1.2	0.7±0.2*#	0.6±0.3*#	0.7±0.7*#	1.9±1.5

Data are presented as median ± IQR. Segment 2 = 16 – 28 km; segment 3 = 28 - 42 km; segment 4 = 42 – 50 km, segment 5 = 50 km - 56 km; segment 2 – segment 5 = 16 km – Finish (40 km).

GFX = Garmin Fenix series; GXT = Garmin XT series; GFR = Garmin Forerunner series; ACT = Activity Watches; STO = Suunto; TOM = TomTom; PLR = Polar; CEL = Cell Phones.

* p < 0.05 vs. GFX. # p < 0.05 vs. CEL. ^ p < 0.05 vs. TOM. ! p < 0.05 vs. STO. \$ p < 0.05 vs. PLR.

When relative errors were calculated for 16 - 56-km, GFX and CEL had higher relative errors compared to all other devices except for ACT (GFX vs. GXT, GFR, TOM respectively p < 0.001; GFX vs. STO p = 0.004; GFX vs. PLR p = 0.012) (CEL vs. GXT, GFR, TOM respectively p < 0.001; CEL vs. STO p = 0.004; CEL vs. PLR p = 0.009) (Figure 4.3, Table 4.3). GXT, GFR, TOM, and STO had errors within the IAAF acceptable course measurement error of 1% (shaded area Figure 3). PLR had six out of eight participants that fell within the shaded area; CEL had two out of 14 participants; and GFX had two out of 29. When analysed as distance differences GFX and CEL had higher errors compared to all other devices except for ACT (GFX vs. GXT, GFR, TOM respectively p < 0.001; GFX vs. STO p = 0.004;

GFX vs. PLR $p = 0.012$) (CEL vs. GXT, GFR, TOM respectively $p < 0.001$; CEL vs. STO $p = 0.003$; CEL vs. PLR $p = 0.009$) (Table 4.2).

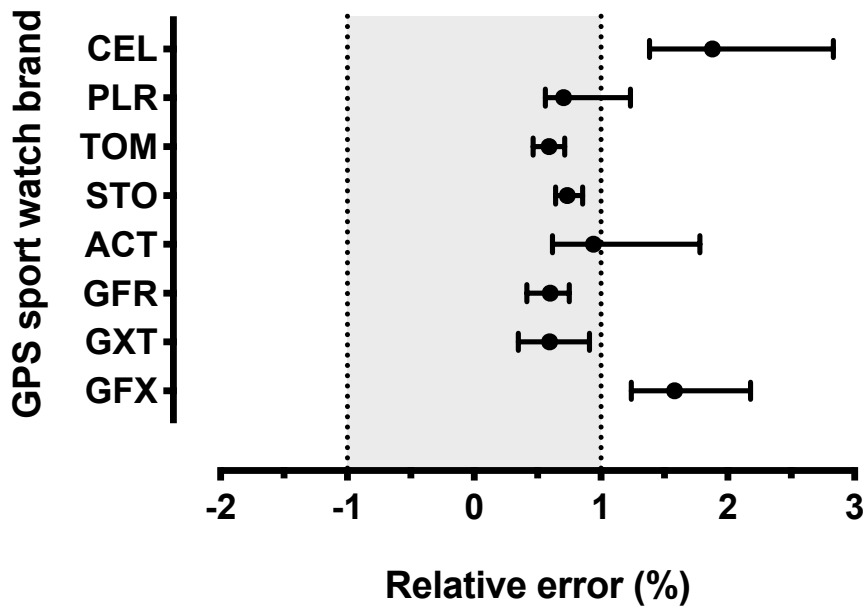


Figure 4.3. Data are presented as median \pm IQR. Relative error of GPS measured distance vs. IAAF measured distance for segment 2 - segment 5 (16 - 56-km). The shaded region represents the $\pm 1\%$ IAAF course measurement error. $n = 212$.

GFX = Garmin Fenix series; GXT = Garmin XT series; GFR = Garmin Forerunner series; ACT = Activity Watches; STO = Suunto; TOM = TomTom; PLR = Polar; CEL = Cell Phones.

Discussion

This study has three main findings: 1) GPS devices recorded distance within $0.6 \pm 0.3 - 1.9 \pm 1.5\%$ (median \pm IQR) accuracy; 2) GXT, GFR, STO, TOM, PLR have lower overall errors compared to CEL and GFX; and 3) The errors appear to be greater in the hilly sections of the race with more turns (segments three, four, and five) compared to the flatter and straighter section (segment two).

When considered in context, the relative error for segment two to the finish of the race (a distance of 40-km) was lower than previous research using a GPS sport watch (Nielsen et al., 2013). Nielsen et al. (2013) showed the error in measuring distance using a Garmin Forerunner® 110 ranged from 0.8 to 6.2% (mean). The results from our study reflect better accuracy. This could be due to advancements in technology and GPS units since 2013 when the Nielsen paper was published.

The cell phone category displayed a higher error compared to most other categories. Eight participants had iPhones, and six participants had phones with android operating systems. Different brands may have unique GPS units. However, when iPhones were compared to cell phones with android operating systems there was no difference in relative error for the 16 – 56-km segment ($p = 0.57$). There has also been research about the accuracy of different running applications on cell phones (Bauer, 2013). All the study participants in the CEL category used the Strava running application therefore this possibility was eliminated. The placement of the GPS device on the body can affect accuracy. GPS sport watches are usually worn on the wrist with a clear view of the sky. In contrast cell phones can be held or worn on the arm with a case and strap, in a shorts pocket, or in a waistband. The placement of the cell phone may have contributed to the large IQR of the CEL category.

The Garmin Fenix® category also displayed a higher error compared to most other categories. The 3rd edition of the Garmin Fenix® series (31 out of 34

participants in this category had the Garmin Fenix 3) is the first one to offer GPS and Global Navigation Satellite Systems (GLONASS) (Hofmann-Wellenhof, Lichtenegger, & Wasle, 2007). The recent incorporation of GLONASS into GPS sport watches increases the availability of surrounding satellites. However, there is currently no research comparing the accuracy of GPS vs. GPS combined with GLONASS in the devices included in our study. Simply increasing the availability of surrounding satellites does not guarantee improved GPS accuracy. There are many factors to consider such as the quality of the GPS chipset in the device as well as quality of the manufacturer algorithm. Future research should investigate these areas further.

The next finding was that the error appears to change depending on the segment of the race course. For example, the medians in the TomTom[®] category for segments two, three, four, and five are 0.4%, 1.3%, -1.2%, and 1.7% respectively. This change in error could be due to changes in course elevation, turns, and/or tree cover. Segment two is relatively straight and flat with approximately 100 m of elevation change while segments three, four, and five include larger changes in elevation (approximately 465 m, 300 m, 150 m respectively) and more turns. Nielsen et al. (2013) tested the accuracy of the Garmin Forerunner[®] 110 in measuring distance covered in three different settings. The relative error on a flat path with a clear view of the sky was 0.8%. In an urban area with buildings the error was 1.2%, and in a covered forest area the error was 6.2%. Segments four and five include significant tree cover compared to the other segments which may have affected the accuracy. In addition, segments three and four include stretches of road surrounded by mountains on one or both sides which can also affect accuracy. A professional product tester found an average GPS sport watch error of 1% on a 1.6 km straight path with a clear view of the sky; 1.7% around a 400 m track; and 1.7% on a 0.84 km loop route through a mix of open area and tree cover (Rainmaker, 2011). In line with this, there is a possibility the turns in segments 3, 4, and 5 (Figure 4.1A) affected the accuracy in measuring distance.

Limitations

A limitation of the study is that the distance between course markings can only be guaranteed to 1% according to the IAAF regulations. This limitation was considered in the analysis and interpretation. Another limitation to consider is that when a course is measured according to IAAF regulations, the measurer take the shortest possible route when navigating turns (“The measurement of road race courses”, 2008). This is to ensure that runners complete at least the measured distance in the race. It is possible that some runners took turns wider than the shortest route possible which may have affected the distance covered. Consideration should be given to the various software and firmware within devices as both can affect GPS accuracy. Because we do not know which software version participants had on their devices on race day, it is not possible for us to speculate about this. Regardless of whether we categorised by brand, hardware, or software there would have been cross-over between hardware and software. The main aim of our study was to determine if GPS sport watches are a feasible and valid tool to measure distance. We feel reporting results by brand has more practical applications for sports scientists, coaches, and athletes as firmware is not included in the marketed specifications of the devices. Another limitation of the study includes the lack of control of device settings such as amount of free memory, and sampling rate which can affect accuracy. However, the possibility of runners choosing a low sampling rate is low as the battery life using GPS for 29 out of 38 devices is 10 hours or more. With a race cut-off time of seven hours, having to alter the sampling rate to extend battery life would not be a likely occurrence in this race. Finally, the lack of control of the placement of the GPS device is a limitation of this study, particularly in the CEL category. While GPS sport watches are predominantly worn on the wrist with a clear view of the sky, cell phones are often placed in a case and worn around the arm or in a waist pocket. Although this limitation needs to be considered when interpreting the results, it has practical implications as it is not feasible for runners to carry cell phones without a case and/or strapping it to an arm or placing in a pocket.

Conclusion

The conclusions of this study are: 1) GPS sport watches are a valid and feasible way to measure performance and track training load; 2) GXT, GFR, STO, TOM, PLR devices have lower overall errors compared to CEL and GFX devices; 3) The error appears to be greater in segments with more elevation and turns (segments three, four, and five of the race) compared to the flatter and straighter section (segment two). The GPS sport watches in this study have an accuracy of 0.6 ± 0.3 to $1.9 \pm 1.5\%$ (median \pm IQR) in reporting distance covered. This indicates that GPS sport watches are a valid and feasible method for sports scientists and coaches to measure performance and track training load. However, the small error associated with each brand needs to be considered when data are interpreted. Sports scientists, coaches, and runners should also consider that error may be influenced by changes in elevation, non-linear movement, tree cover, and cloud cover.

Chapter 5: Development of the **FINISHER** Test & testing its reliability

Study 1: Development of the FINISHER test

Introduction

Submaximal running tests are used in the sport of running to help determine training status (Borresen & Lambert, 2007; Vesterinen et al., 2016). A poor performance during a test can indicate either a lack of fitness or increased fatigue levels in the athlete. A good performance can indicate a positive adaptation to training and good race preparedness. Ideally the test should have the ability to be completed regularly in the field rather than in a laboratory setting. It should also require minimal equipment, be easy to interpret, and not cause disruption to the athlete's training. It should also be able to detect small changes in training status. A well-designed test should fit into a training programme as either part of a warm up or in place of a training session that can be repeated on a weekly, fortnightly, or monthly basis.

The aim of this study was to develop a submaximal running test designed to measure fitness and fatigue. The objective was to determine a protocol that established an accurate relationship between heart rate (HR) and running speed. Furthermore, all the prerequisites described above needed to be incorporated into the design of the test.

Methods

The submaximal running test evolved after a series of trials and pilot studies. In the first trial we tested four different submaximal tests. The same participant (the author) was used for each test. Testing occurred from 16 May, 2016 – 8 August, 2016. The Global Positioning Systems (GPS) device used was a Suunto Ambit® 2 with a Garmin® chest strap HR monitor. The different tests are described below:

Five x three minutes

This test involved running for three minutes at each of the following five intensities: “very easy, easy, moderate, hard, and very hard.” Each three-minute interval was conducted on separate but sequential testing days. A five-minute

running warm up was performed before completing the designated three-minute interval. The interval was performed at the same time of day and the five intervals were completed from a Monday – Friday. Similar sleep patterns were maintained through the five weekdays. Testing on Saturdays and Sundays was avoided due to the possibility of the effect of a change in sleep pattern on cardiovascular control (Ewing, Neilson, Shapiro, Stewart, & Reid, 1991). The test was completed on a flat road route. Completing each interval on separate days was done to avoid possible effects that a preceding interval would have on a following one. This test was completed twice to determine if results were repeatable. Minutes one – three (the final two minutes of each interval) for speed and HR were used for analysis.

Three x three minutes

This test involved running for three minutes at the following three intensities: “easy, moderate, and very hard.” All three intervals were completed in a single session. A five-minute running warm up was performed before completing the test. An easy two minutes of jogging was performed between each three-minute interval. This test was completed on a flat road route. Including the warm up, the test took 18 minutes to complete. Minutes one – three of each interval for speed and HR were used for analysis.

Eight x 1-km

This test involved running eight x 1-km of increasing effort level on an outdoor track. The effort level was based on a modified Borg CR-10 rating of perceived exertion (RPE) scale (Figure 5.1.1). The intensity levels included: RPE 1, RPE 3, RPE 4, RPE 5, RPE 6, RPE 7, RPE 8, & RPE 9. After each 1-km interval, the participant rested until HR returned to approximately 110 beats/min. Once HR reached approximately 110 beats/min, the next interval was started. The test took 1h 24min to complete. The first 60 seconds of each interval were excluded from analysis.

1 - 10 Borg Rating of Perceived Exertion Scale	
0	Rest
1	Really Easy
2	Easy
3	Moderate
4	Sort of Hard
5	Hard
6	
7	Really Hard
8	
9	Really, Really, Hard
10	Maximal: Just like my hardest race

Figure 5.1.1. Modified Borg 10-point Rating of Perceived Exertion scale

Seven x three minutes

This test involved running for three minutes at the following order of intensities: RPE 1, RPE 3, RPE 4, RPE 5, RPE 6, RPE 8, & RPE 9 (Figure 5.1.1). A five-minute running warm up was performed before completing the test. An easy two-minute jog was performed between each three-minute interval. The test was completed on a flat road route. The entire test including the warm up took 38 minutes to complete. Minutes one – three of each interval for speed and HR were used for analysis.

Statistical Analyses

The average, standard deviation, and coefficient of variation for speed and HR of each interval were calculated. Linear regression analyses were used to create the lines of best fit and calculate correlation coefficients. A two-way analysis of variance was used to determine differences in predicted HR at a range of speeds between the various tests.

Results

The results from each test are provided in Table 5.1.1. The range in running speeds and HR for each test is shown in Table 5.1.2.

The coefficient of variation for speed within each test was an average of 4% for the five x three min test #1 and #2, and an average of 3% for the three x three min test, eight x 1-km test, and seven x three min test. The coefficient of variation for HR was an average of 3% for the five x three min #1 test, the three x three min test, and the eight x 1-km test. It was an average of 2% for the five x three min #2 test and the seven x three min test.

The tests with the highest correlation coefficients were the three x three min test and the eight x 1 km test ($r^2 = 0.97$). The five x three min #2 test and seven x three min test had coefficients of $r^2 = 0.90$, and the five x three min #1 test had a coefficient of $r^2 = 0.84$.

The equation of the best fit line for each test was used to calculate predicted HR for the following speeds: 8 km/h, 10 km/h, 12 km/h, and 14 km/h. The predicted HR's for the three x three min test, eight x 1-km test, and seven x three min test were significantly higher than the five x three min test #1. The predicted HR's for the eight x 1 km test and seven x three min test were significantly higher than the five x three min test #2. Finally, the predicted HR's for the seven x three min test were significantly higher than the three x three min test.

Figure 5.1.2 provides a graphical representation of the various running tests. Heart rate is plotted as a function of running speed. Linear regression analysis is used to draw a line of best fit. The equation of the best fit line can be used to predict HR's at specific running speeds that can be compared to sequential tests.

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Table 5.1.1. Running speed, heart rate (HR), line of best fit, r^2 value, $Sy.x$, and predicted HR for each running test.

	<u>5 x 3min #1</u>	<u>5 x 3 min #2</u>	<u>3 x 3 min</u>	<u>8 x 1 km</u>	<u>7 x 3 min</u>
<u>Speed (km/h)</u>					
1	8.5±0.2 (2%)	9.1±0.3 (3%)	10.3±0.3 (2%)	6.0±0.2 (3%)	6.0±0.2 (3%)
2	10.5±0.7 (6%)	9.8±0.4 (4%)	11.6±0.3 (3%)	9.0±0.2 (2%)	9.0±0.2 (2%)
3	11.3±0.4 (3%)	11.5±0.2 (2%)	13.0±0.5 (4%)	10.2±0.4 (4%)	10.2±0.4 (4%)
4	12.8±0.6 (5%)	12.5±0.6 (4%)	N/A	10.2±0.4 (4%)	11.1±0.3 (3%)
5	13.9±0.6 (5%)	14.4±0.7 (5%)	N/A	11.1±0.3 (3%)	11.3±0.3 (2%)
6	N/A	N/A	N/A	11.3±0.3 (2%)	12.6±0.5 (4%)
7	N/A	N/A	N/A	12.6±0.5 (4%)	13.1±0.4 (3%)
8	N/A	N/A	N/A	13.1±0.4 (3%)	N/A
<u>HR</u>					
<u>(beats/min)</u>					
1	129±4 (3%)	141±6 (4%)	151±5 (3%)	116±3 (3%)	120±3 (3%)
2	141±7 (5%)	140±4 (3%)	159±9 (5%)	148±5 (4%)	140±3 (2%)
3	164±3 (2%)	165±2 (1%)	177±2 (1%)	157±5 (3%)	151±7 (4%)
4	170±2 (1%)	167±3 (2%)	N/A	156±5 (3%)	171±5 (3%)
5	168±3 (2%)	176±4 (2%)	N/A	163±4 (2%)	165±3 (2%)
6	N/A	N/A	N/A	165±5 (3%)	178±4 (2%)
7	N/A	N/A	N/A	171±4 (4%)	178±2 (1%)
8	N/A	N/A	N/A	174±4 (2%)	N/A
<u>Line of best fit</u>					
	$y = 8.2x + 61.3$	$y = 7.4x + 73.6$	$y = 9.3x + 53.8$	$y = 8.0x + 72.4$	$y = 7.8x + 75.7$
<u>r^2 value</u>					
	0.84	0.90	0.97	0.97	0.90
<u>$Sy.x$ value</u>					
	8.32	5.72	3.37	3.43	7.69
<u>Predicted HR</u>					
<u>@speeds</u>					
<u>(beats/min)</u>					
			*	*#	*#^
8 km/h	127	133	128	136	138
10 km/h	143	148	147	152	154
12 km/h	159	162	165	168	169
14 km/h	176	177	184	184	185

Data are presented as mean \pm SD. $Sy.x$ = standard deviation of estimate. Coefficient of Variation is in parentheses.

* $p < 0.05$ vs. 5 x 3 min #1. # $p < 0.05$ vs. 5 x 3 min #2. ^ $p = 0.01$ vs. 3 x 3 min

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Table 5.1.2. Range of speed and heart rate within each respective test's set of intervals.

Range	<u>5 x 3min #1</u>	<u>5 x 3 min #2</u>	<u>3 x 3 min</u>	<u>8 x 1 km</u>	<u>7 x 3 min</u>
Speed (km/h)	5.4	5.3	2.7	7.1	7.1
HR (beats/min)	39	35	26	58	58

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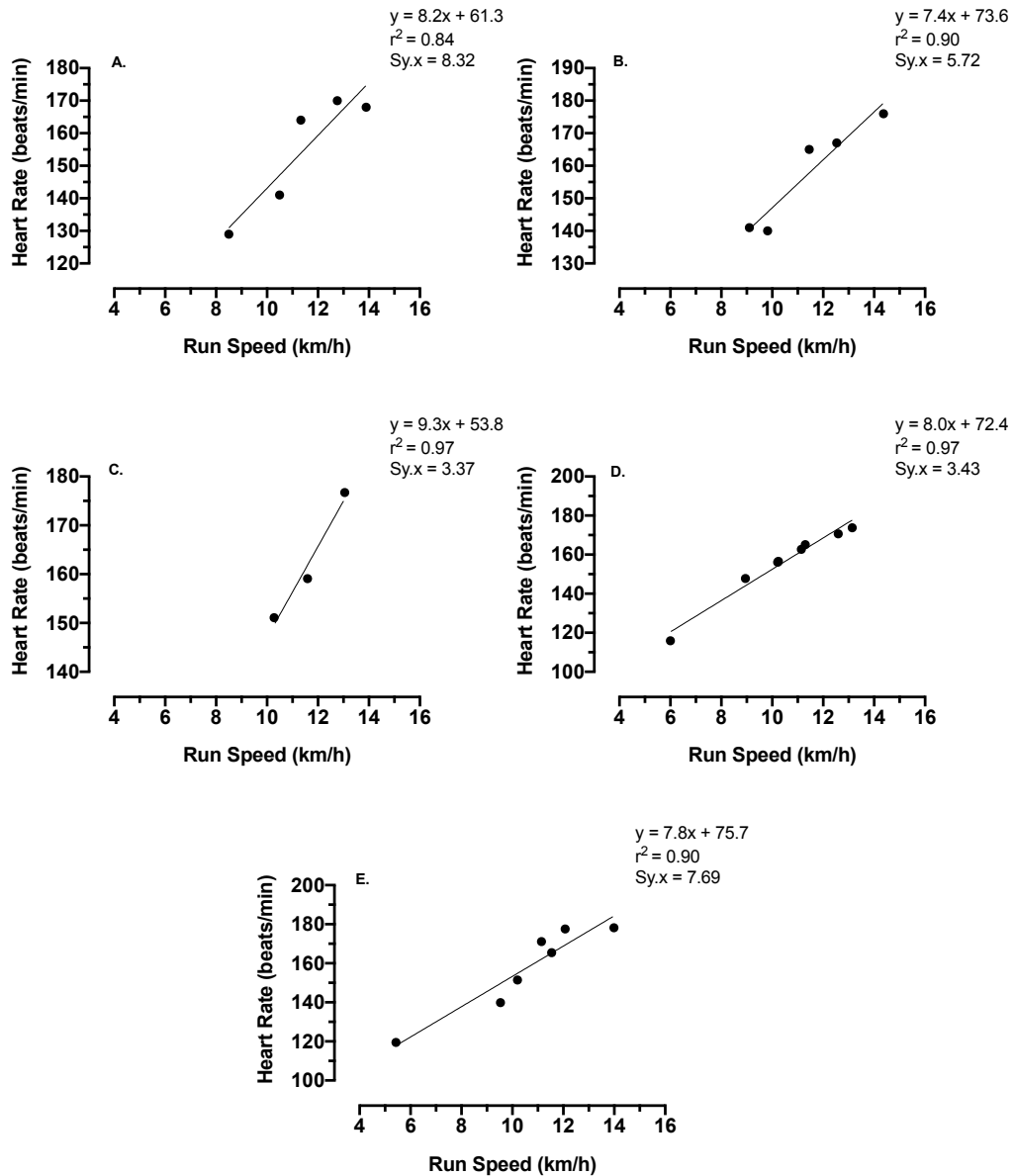


Figure 5.1.2A-D. Heart rate as a function of running speed for: **A)** 5 x 3 min #1; **B)** 5 x 3 min #2; **C)** 3 x 3 min; **D)** 8 x 1 km; & **E)** 7 x 3 min.

The line of best fit is drawn. $Sy.x$ = standard deviation of estimate.

Discussion

This study demonstrates that after considering all factors the seven x three min test is most feasible for use in future research studies. We used a process of elimination which is explained below.

Five x three minute test

The main benefit of this test was that it only requires 8 minutes of time from athletes on any given day. It also eliminated any effect one interval can have on a following one such as cardiovascular drift (Achten & Jeukendrup, 2003). However, this test has low feasibility. There is biological variability day-to-day that can affect the test results (Achten & Jeukendrup, 2003; Lambert et al., 1998). Participants would have to strictly control diet, sleep, and training patterns for the five-day testing period. While this may be possible for a short period, there is a good chance the participants would not be compliant over a long period and this would lessen the accuracy of the measurements and not provide an accurate portrayal of current training status.

Three x three minute test

This test also requires little time from athletes (18 min). Other positive attributes of the test are that it can be included as part of a warm up before a longer workout for endurance athletes, and athletes can perform the entire test in one session. The major drawback to this test is the low number of intensities, which resulted in the smallest range in running speeds (2.6 km/h) and HR (26 beats/min). The line of best fit was derived from only three data points. This could lead to inaccuracies in comparing multiple speeds and HR's when the test is repeated on a regular basis for an extended time period.

Eight x 1-km test

A positive outcome was that the test had a wide range of intensities and a longer interval duration (~4.5 min to 10 min). Also because of the rest periods, the effect of one interval on the following interval were minimised. However, negative factors to consider were that the test was difficult to perform and time-consuming (1 h 24 min). As a consequence, the test would cause disruption to an athlete's training programme. Athletes would unlikely be willing to complete this running test on a regular basis, thus its feasibility is low.

Seven x three min

This test provided a wide range of intensities and was less time-consuming to complete compared to the eight x 1-km test (38 min vs. 1h 24min). The range in running speeds was 7.1 km/h and range in HR was 58 beats/min. The three min interval is shorter than the 1-km intervals, and a two-minute easy jog between intervals is more feasible for runners to perform compared to resting. An optimal interval duration for achieving a high physiological load is three – five min (Seiler & Sjørnsen, 2004). In addition, a two-min active recovery period during an interval training session has been found to be sufficient in achieving a stable performance (Seiler & Hetlelid, 2005). When comparing predicted HRs at the same running speeds using the line of best fit, the HRs from the seven x three min test were closest to the HRs on the 8 x 1 km test compared to the five x three min and three x three min tests (Table 5.1.1).

Predicted HRs were calculated for the same absolute speeds for comparison between tests using the lines of best fit (Table 5.1.1). The HR values for the five x three min test were significantly different than the values for the eight x 1-km test. The predicted HR's calculated using the line of best fit from both the three x three min test and the seven x three min test were similar to the eight x 1-km test (Table 5.1.1). We ultimately chose the seven x three min test because it could be used as a workout by itself- this is useful for recreational runners. It also provided more intensities to fit into the regression equation. This increased the confidence of the best fit line and reduced assumptions between data points.

Conclusion

In conclusion the seven x three min test is the most practical test for athletes to perform on a regular basis in a field study. It represents a wide range of intensities, can be performed as a fartlek workout as part of an athlete's training programme, and is easily understood by the athletes. Henceforth this test will be known as the fartlek run using speed and heart rate, or the **FINISHER** test. The following studies will determine the reliability of the **FINISHER** test as well as possible associations with performance and training load.

Study 2: Testing the reliability of the FINISHER Test

Introduction

As discussed in the previous study, submaximal running tests are used in the sport of running to help determine training status (Borresen & Lambert, 2007; Vesterinen et al., 2016). These tests can help coaches adjust training load to maximise performance and reduce the risk of overuse injuries. The goal of adjusting training load is to ensure an adequate balance between training load and recovery. If an adequate balance is not achieved, the athlete may display symptoms of undertraining or fatigue associated with non-functional overreaching or ultimately overtraining syndrome (Meeusen et al., 2013).

In the pilot study (Ch. 5.1), we developed a feasible submaximal running test (Fartlek run using speed and heart rate (**FINISHER**) test) using running speed and heart rate (HR) as the two variables of interest. Running speed is considered a measure of external training load. It is the work that the athlete performs during the test. Heart rate is a variable representing internal training load. It is a physiological response to the work performed during the test and has a positive linear relationship with exercise intensity (Arts & Kuipers, 1994). Heart rate and running speed have previously been used in research in monitoring training adaptation in runners (Vesterinen et al., 2014). The researchers found that after a 28-week training programme, participants' HR decreased at similar running speeds; or running speed increased at similar HR values. However, as discussed in the literature review in Chapter 2, their method of creating the HR-running speed line used only two points- resting and maximal values and has inherent inaccuracy as a result.

Heart rate can be measured during exercise with a monitor strapped around the chest (Karvonen & Vuorimaa, 1988). Chest strap monitors are widely sold as a package along with Global Positioning Systems (GPS) sport watches and used in the field by recreational runners. It is important to understand the day-to-day variation in submaximal exercising HR to determine the smallest worthwhile change (SWC). Previous research has found day-to-day variation to be approximately six beats/min during submaximal exercise in a controlled, indoor

environment (Brisswalter & Legros, 1994; Lamberts et al., 2004). It is unknown what the day-to-day variation in submaximal HR is in an uncontrolled, outdoor setting.

There are certain variables to consider in day-to-day variation in HR in a field study. Factors such as duration of exercise, temperature, altitude, hydration, time of day, and training status may affect HR (Achten & Jeukendrup, 2003; Lamberts et al., 2004; Robinson et al., 1991). These variables should be controlled for as closely as possible to improve accuracy (Lambert et al., 1998). Participants should be encouraged to perform the test the same time each day to eliminate changes in HR due to circadian cycles (Reilly, Robinson, & Minors, 1984). They should also be encouraged to perform the test on the same route and keep their diet and hydration similar on testing days. If there is adverse weather such as extreme heat, cold or wind, testing should be avoided.

Many tests used to assess athletes are not suitable for regular monitoring due to excessive measurement error, large expense, being time-consuming, needing laboratory facilities or because the test is high intensity and therefore interferes with training. The **FINISHER** running test has been designed to consider and avoid these points. For example, the test can be performed in the field and takes 38 minutes to complete. The test is submaximal and can be incorporated into a training session. However, before a test is used in a long-term training study, the feasibility and reliability of the test should be established (Impellizzeri & Marcora, 2009). While it may be argued that the **FINISHER** running test is feasible, the reliability, and by inference the measurement error, has not been determined. Therefore, the aim of the study was to determine the reliability of the **FINISHER** running test.

Methods

Participants

Eleven runners volunteered to participate in the study (Table 5.2.1). Nine of the participants were male and two participants were female. Participants were required to run a minimum of two – three times per week and have averaged at least 25 km/week for the preceding six months. They had to be able to run 10-km in ≤ 51 minutes. All participants had to be injury free for a minimum of six months leading up to study enrolment. The study was approved by the University of Cape Town Human Research Ethics Committee (HREC REF: 093/2017), and all participants provided informed consent prior to study participation.

Table 5.2.1. Participant Characteristics.

Age (yr)	32 \pm 7
Mass (kg)	73 \pm 15
Height (cm)	179 \pm 10
Competitive (yr)	6 \pm 4
Distance/wk (km)	45 \pm 16
Best Time (mm:ss)	42:07 \pm 4:56

Competitive = number of years the athlete has been competitive. Distance/wk = the average distance ran per week in the last 6 months. Best Time = fastest 10 km time achieved in the last 12 months: mm = minutes; ss = seconds.

Data are presented as mean \pm SD (n = 11).

Study Design

Study participants performed a total of four **FINISHER** tests on separate days. The first test served as a familiarisation test. Participants were given the choice

of either performing the test four times within five days or alternatively to do the familiarisation test one week, and tests #two – four within a five-day time period the following week. Participants were instructed to: avoid caffeine a minimum of two hours prior to each running test; maintain consistent sleeping and training patterns for all testing days; perform the test at the same time of day (within one hour) for each of the four trials; not to perform the test if temperature or wind was drastically different compared to previous trials; and perform the test on the same route each time (a flat outdoor running surface such as sidewalk, road, or a track). Participants completed the Daily Analysis of Life Demands for Athletes questionnaire (DALDA) (Rushall, 1990) and an evaluation of fatigue and muscle soreness questionnaire (Lamberts et al., 2004) on each day they completed a **FINISHER** run test. The purpose of the questionnaires was to ensure there were no changes in stress, fatigue, or muscle soreness throughout the study duration.

The protocol for the **FINISHER** test is described in Ch. 5.1. In brief, participants performed a five-minute running warm up, directly followed by seven x three-minute intervals with two minutes of easy jogging between intervals. The intervals were completed in the following order of rating of perceived exertion (RPE) intensities: RPE 1, RPE 3, RPE 4, RPE 5, RPE 6, RPE 8, and RPE 9 (Borg, 1998) (Figure 5.2.1).

1 - 10 Borg Rating of Perceived Exertion Scale	
0	Rest
1	Really Easy
2	Easy
3	Moderate
4	Sort of Hard
5	Hard
6	
7	Really Hard
8	
9	Really, Really, Hard
10	Maximal: Just like my hardest race

Figure 5.2.1. Modified Borg 10-point Rating of Perceived Exertion scale

Participants used their personal GPS sport watches and chest strap HR monitors for the study (Suunto Ambit[®] 3, n = 2; Suunto Ambit[®] 2, n = 2; Garmin Forerunner[®] 70, n = 3; Garmin Forerunner[®] 920XT, n = 1; Garmin Fenix[®] 2, n = 1; Garmin Fenix[®] 3, n = 1; TomTom Cardio Runner[®], n = 1). The accuracy of these devices in reporting distance was determined in Chapter 4. GPS files were accessed via the Smartbeat Research Database (HREC REF: R 037/2016) for analysis of running speed and HR.

Statistical Analyses

Runs #two – four were used for analysis. The average HR (beats/min) and running speed (km/h) for minutes one – three (the final two minutes) of each of the seven intervals was calculated. Heart rate was plotted as a function of running speed, and bivariate linear regression analysis was used to describe the line of best fit for the relationship between running speed and HR. The average

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slope (m), constant (c), and r^2 value were calculated using the lines of best fit for runs #two, three, and four.

A Friedman's Test was used to determine changes over time for the perceived fatigue and muscle soreness ratings as well as the number of "a" (worse than normal) responses on the DALDA questionnaire.

The equations for the best fit lines were used to calculate predicted HR values at three set running speeds (11, 12, 13 km/h) for each trial. The predicted HR values were used to calculate the typical error of measurement (TEM), coefficient of variance (CV_{TEM}), and an intraclass correlation coefficient (ICC) using the excel spreadsheet, "reliability from consecutive pairs of trials," downloaded from www.sportsci.org (Hopkins, 2000). All measures of reliability are expressed with 90% confidence intervals (90% CI). Magnitudes of standardised effects were determined using Cohen's Effect Sizes (ES) with the following thresholds: trivial: ≤ 0.2 , Small: $> 0.2 - < 0.6$; moderate: $\geq 0.6 - < 1.2$; and large ≥ 1.2 (Hopkins et al., 2009). Effect size was calculated between trials, averaged and multiplied by Cohen's effect sizes for the smallest change (0.21), moderate change (0.6), and large change (1.2) ($HR = (standardized\ effect\ size \times ES) \times 100$). The smallest worthwhile change (SWC) was calculated to coincide with an ES of 0.21, 0.6 and 1.2 respectively. The TEM was compared to the SWC at different levels to determine the appropriate and practical SWC.

Results

The slopes (m) of the regression equations ranged from 4.35 – 10.19 (Table 5.2.2). The constants (c) ranged from 31.25 – 102.05, and the r^2 values ranged from $r^2 = 0.71 - 0.98$ (Table 5.2.2).

The TEM was the same (three beats/min) for predicted HR at all three set speeds (11, 12, & 13 km/h) (Table 5.2.3). The SWC in HR for the **FINISHER** test is three beats/min, while a moderate change is eight beats/min, and a large change is 15

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- 17 beats/min (Table 5.2.3). The intraclass correlation coefficient between the trials at 11 km/h was $r = 0.93$; at 12 km/h it was $r = 0.96$; and at 13 km/h it was $r = 0.96$ (Table 5.2.3).

A graphical representation of regression analysis between two running trials is shown in figure 5.2.2. The data points represent all participants' predicted HR at 11 km/h between two consecutive running tests.

Table 5.2.2. The average parameters of the Linear Regression Equation ($y = mx + c$) for each participant.

Participant	m	c	r ²
1	4.35 ± 1.93	89.12 ± 26.24	0.77 ± 0.24
2	8.11 ± 1.05	69.97 ± 10.93	0.97 ± 0.02
3	7.18 ± 0.95	54.94 ± 10.95	0.96 ± 0.02
4	7.20 ± 0.44	57.11 ± 12.32	0.86 ± 0.10
5	4.69 ± 1.35	102.05 ± 18.35	0.71 ± 0.27
6	4.94 ± 0.31	100.10 ± 1.74	0.97 ± 0.04
7	8.46 ± 0.52	41.73 ± 9.33	0.98 ± 0.01
8	9.06 ± 0.58	53.23 ± 8.38	0.91 ± 0.02
9	8.63 ± 0.29	31.25 ± 3.44	0.93 ± 0.02
10	8.40 ± 1.28	56.42 ± 12.06	0.82 ± 0.09
11	10.19 ± 4.89	44.92 ± 60.64	0.91 ± 0.02

Data are presented as mean ± SD. y = heart rate, x = running speed, m = slope; c = constant; r^2 = Pearson correlation coefficient squared

Table 5.2.3. Summary of Reliability Statistics for Predicted Heart Rate at 11, 12, and 13 km/h.

Running Speed (km/h)	Heart rate (beats/min)				CV _{TEM} % (CI)	ICC (CI)
	TEM (CI)	SWC	MC	LC		
11	3 (3 - 5)	3	8	16	0.30 (0.23 - 0.43)	0.93 (0.84 - 0.98)
12	3 (2 - 4)	3	8	17	0.24 (0.19 - 0.35)	0.96 (0.89 - 0.98)
13	3 (2 - 4)	3	8	15	0.24 (0.19 - 0.35)	0.96 (0.89 - 0.98)

(90% CI). TEM = typical error of measurement; CV_{TEM} = Coefficient of variation; CI = confidence interval; SWC = smallest worthwhile change; MC = moderate change; LC = large change; ICC = Intraclass Correlation Coefficient. n = 11.

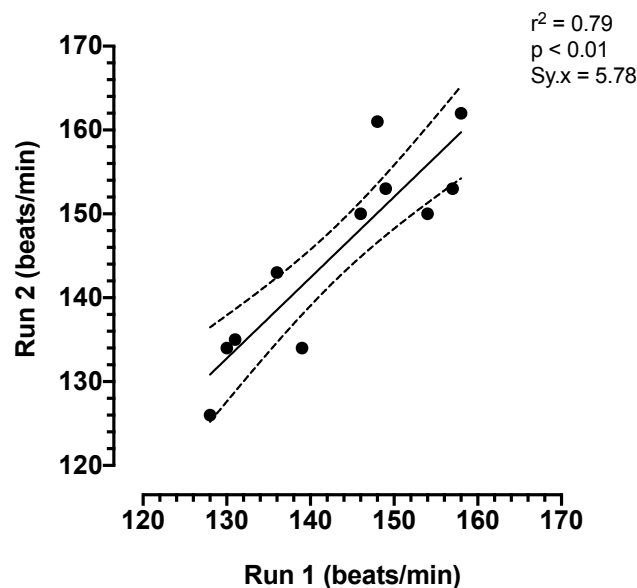


Figure 5.2.2. Example of between test reliability comparing Run 1 vs. Run 2 at 11 km/h for all participants. Line of best fit is drawn (solid line) along with 90% CI limits (dotted lines). Sy.x = standard deviation of estimate.

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The questionnaires for perceived muscle soreness and life demands were analysed for each running test. There was no change in perceived fatigue or muscle soreness across the run test trials (Figure 5.2.3A-B; $p = 0.88$, $p = 0.94$ respectively). There was no change in the number of “a” scores on the DALDA questionnaire across run test trials (Figure 5.2.3C; $p = 0.48$).

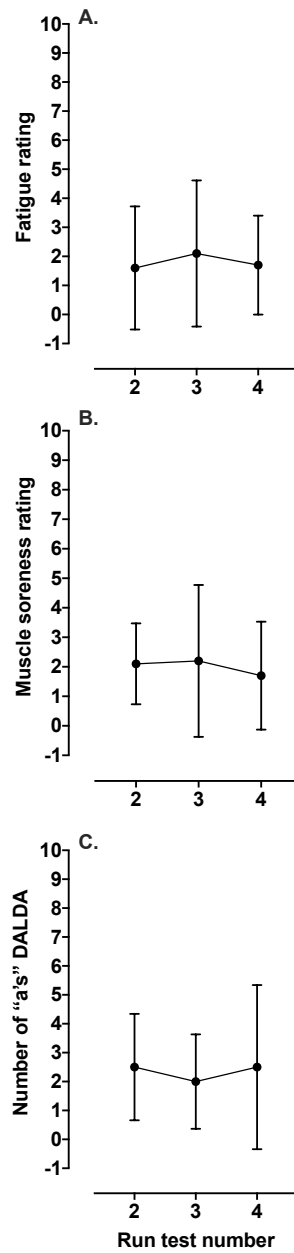


Figure 5.2.3A-C. Data are presented as mean \pm SD. $n = 10$. Perceived rating of: **A)** fatigue 0-10, **B)** muscle soreness 0-10, and **C)** number of "a" responses on the DALDA questionnaire (out of a possible 34).

Discussion

The main aim of the study was to quantify the reliability of the **FINISHER** test and more specifically the typical error of measurement and smallest worthwhile change in the HR measured during the test. It is important to quantify these data so validity of the test can be interpreted accurately (Imperizelli & Marcora, 2009).

The results of the study show the **FINISHER** test is reliable. The intraclass correlation coefficients were high ($r = 0.93, 0.96, 0.96$) suggesting good test-retest reliability. The typical error or 'noise' around the test for HR is three beats/min (90% CI three – five beats/min). The smallest worthwhile change (ES = 0.21) was three beats/min. This indicates that coaches and sports scientists would be able to detect moderate or large changes in HR measurements (\geq eight beats/min).

Previous reliability studies have reported only ICC values (Atkinson & Nevill, 1998). However, research has suggested TEM and CI should also be determined to ensure reliability (Hopkins, 2000). The ICC values suggest when the test is repeated, the results have high correlation to each other. It is important to consider that participants were instructed to keep training, diet, and sleep patterns similar for the testing period. They were also instructed to run each test on the same route. If these factors are not controlled for, we would expect lower ICC values.

The importance of the TEM is to understand the 'noise' around the measurement. If a change in the outcome variable falls within the TEM, the results must be interpreted with caution. In the context of our study, the 'noise' around the HR measurements was three beats/min. Thus, changes in HR would have to be larger than the SWC (three beats/min) to be considered significant.

We now know the **FINISHER** test is feasible and reliable. This sets up future studies to determine how test results may be related to training load and

performance. If athletes perform the **FINISHER** test weekly or bi-weekly, a change in HR of ≥ 8 beats/min may be considered meaningful.

Limitations

A limitation of the study is that participants performed the tests on their own. In this particular study, it was not feasible for the researchers to monitor all sessions. However, GPS files can confirm the time and place of the session. They also provide data points every one – three seconds with running speed and HR information. This limitation is also an advantage, because it makes the test more ecologically valid and feasible. Another limitation in a field study such as this is an uncontrolled outdoor environment. Wind and temperature can affect running speed and HR values. It is important to educate participants about factors that can affect speed and HR and encourage them to not perform a test in adverse weather conditions. However, a running test that can be performed in an outdoor environment increases its practicality. Despite participants completing the study on their own in an outdoor environment, the day-to-day variability in HR was smaller than a previous study (five - eight beats/min) (Lamberts et al., 2004). This indicates the outdoor setting was not a major limitation in this study.

Conclusion

In conclusion, the **FINISHER** running test is a reliable test that can be performed independently by an athlete in a field setting. Field studies in sports science studies can often answer questions that cannot be answered in laboratory studies and have the potential for greater practical applications. They also provide an opportunity for daily data collection over an extended period of time with large participant numbers. The test is able to detect a moderate or large change in HR (≥ 8 beats/min). The smallest worthwhile change and typical error of measurement associated with the test should be considered when using HR as a marker of training status in athletes. Future studies should determine relationships between **FINISHER** test results, training load, and performance.

Chapter 6: Interactions between training load, submaximal heart rate, and performance

Study 1: Description of training load, variation in load, and performance level in well-trained competitive recreational runners

Introduction

In Ch.3.2 we determined training load in a group of competitive recreational runners in the six weeks leading up to an ultramarathon running race. This provided useful information regarding the peak week(s) of training and taper phase in preparation for a race in this group. However, it is important to determine how well-trained competitive recreational runners train over a period of several months. This would provide information about training loads over a mesocycle; defined as a training period of 16 – 24 weeks (Pyne, 1996). It would also provide information about how training load varies over time. Compared to elite runners, recreational runners are more likely to train without the guidance of a coach or set training programme. How much this group varies their training is currently not known.

In Ch.3.2 higher training load was associated with better relative race performances. This was a heterogenous group of competitive recreational runners. Whether higher training load is associated with performance level in a group of well-trained competitive recreational runners is unknown. This information would help coaches and sports scientists provide appropriate advice regarding training. Better knowledge regarding training load would help maximise performance and reduce risk of overuse injury.

Many previous training research studies have used elite athletes as participants (Foster, 1983; Mujika et al., 1995, 2014; Seiler & Kjerland, 2006; Sparling, Wilson, & Pate, 1987; Tønnessen et al., 2015). There is currently a gap in the research regarding how well-trained competitive recreational runners train. With less time to train and more life demands such as full-time work and family commitments, we would expect different training loads compared to elite athletes.

Existing studies investigating recreational runners have used questionnaires to assess training (Gordon et al., 2017; Leyk et al., 2009; Schmid et al., 2012; Zillmann et al., 2013). Borresen and Lambert (2006) showed that 24% of their

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participants overestimated their training duration with self-reports of training, and 17% underestimated their training duration. In addition, the questionnaires assessed training on a weekly basis; i.e.- number of runs per week; kilometres run per week, etc.. This does not allow for calculating daily training load or the daily variation in load. With Global Positioning Systems (GPS) technology and the widespread use of GPS sport devices, daily, objective collection of training load is possible. This eliminates errors due to recall bias.

Coaches and sports scientists should also consider inter-individual variability. Inter-individual differences in stress response to the same relative exercise bout exist (Mann et al., 2014). Differences in stress responses to exercise affect recovery time. Individuals with lower stress responses and faster recovery time would be more tolerant to higher training loads. In addition, there are additional factors that can affect recovery time such as fitness level, sleep, and psychological stress (Mann et al., 2014). In a group of well-trained competitive recreational athletes, we would predict inter-individual variation in training load, but this has not been investigated to date.

The aims of the study were therefore to : 1) describe training load volume and intra-individual variation in training load over time in a group of well-trained competitive recreational runners over a 6-month duration; 2) describe the inter-individual variation in training load; 3) determine relationships between training load volume and intra-individual variation over time; and 4) determine relationships between training load volume and performance level.

Methods

Participants

Forty-one well-trained competitive recreational runners enrolled in the study. Out of the 41 participants, data sets from 26 participants (female n = 6; male n = 20) were used for data analysis. The reasons for the 15 excluded participants included: did not complete six months of training or did not participate in any races during the period of the study. The research study was approved by the

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University of Cape Town Human Research Ethics Committee (HREF REF: 017/2018), and all participants provided informed consent prior to study enrolment. The participant characteristics are shown in Table 6.1.1. Their ages ranged from 22 to 47 years old with an average age of 38 years. The study required that participants trained with a GPS sport watch and chest strap HR monitor. They had to be running a minimum of 40 km/week divided into at least three runs/week when enrolling in the study. They were also required to have a 10-km race time of ≤ 55 minutes in the 12-months prior to the study. The participants had to be registered to run a minimum of three races in the six-month study period. They had to be injury-free for the six months preceding study enrolment. Participants were not using any cardiovascular medications and were required to be non-smokers. Participants had the following GPS devices: Suunto Ambit[®] Series, n = 4; Polar[®] M600, n = 1; Garmin Fenix[®] Series, n = 6; Garmin Forerunner[®] Series, n = 7; Garmin Forerunner[®] XT Series, n = 8. Sixteen out of the 26 participants were training for a target marathon distance race ranging from study day #77 – 154 for each respective participant. Six out of the 26 participants were training for various distance races (10-km – ultramarathon distances) throughout the study duration with no specific target race. Four out of the 26 participants were training for a target half marathon distance race ranging from study day #14 – 168 for each respective participant.

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Table 6.1.1. Participant Characteristics.

Participant ID number	Age (yrs)	Height (cm)	Weight (kg)	Experience (yr)	Dist per/week (km)	10-km Time (mm:ss)
P1	37	167	72	1	60	49:13
P2	30	169	61	4	45	38:30
P3	47	168	56	27	80	44:22
P4	47	181	73	6	60	40:00
P5	43	161	67	5	45	48:39
P6	47	183	70	5	60	39:26
P7	29	169	68	2	40	54:59
P8	39	190	85	8	55	48:04
P9	31	178	77	4	45	44:55
P10	47	177	66	2	60	45:25
P11	43	185	82	7	64	39:41
P12	39	156	50	3	70	44:34
P13	34	184	77	3	55	41:00
P14	40	170	61	10	60	37:40
P15	42	170	58	3	46	53:12
P16	47	166	62	3	50	46:47
P17	45	190	81	20	60	42:08
P18	41	176	81	15	45	53:00
P19	22	174	62	2	80	36:20
P21	36	168	76	5	70	52:00
P22	32	175	78	2	70	42:50
P23	36	189	77	4	78	41:15
P24	29	157	56	1	40	46:36
P27	32	175	86	2	50	45:00
P28	44	172	67	15	45	53:56
P30	33	174	54	12	65	45:19
Mean ± SD	38±7	174±9	69±10	7±6	58±12	45:11±5:18

Experience = Number of years of running experience before the study enrolment.

Dist per/week = Average running distance per week for the six months before the study.

10-km Time = Best 10-km race time within the previous 12 months.

Data in bold text are expressed as mean ± SD.

Study Design and Calculations

Runners were enrolled in the study for a period of six months. Each participant received a Training Peaks™ athlete account which recorded their GPS data. This enabled the researchers to see the route completed and allowed the athlete to make comments about weather, sickness, or any other factors they felt were relevant. Runners were instructed to train *ad libitum* with the exception of performing the **FINISHER** test (explained in detail in Ch.5.1) once per week and a 5-km time trial bi-weekly.

GPS files were downloaded and used for the following calculations:

1) Training load was calculated using a running training stress score (rTSS) (McGregor et al., 2009). The formula for rTSS = duration (hours) * intensity factor (IF)² * 100. The intensity factor for running is the ratio of running speed in relation to running speed at lactate threshold. In this study, running speed for a best 10-km race in the previous 12 months was used as an estimate of speed at lactate threshold (Kumagi et al., 1982; Perez, I., Perez, D., Gonzalez, & Esteve-Lanao, 2012).

If participants did not have a best 10-km time from the previous 12 months (n = 6), a best time from a 5-km, 21-km, or 42-km race from the previous 12 months was taken and plugged into the Pete Riegel race time projection model (Riegel, 1981). The equation is $T_2 = T_1 * (D_2/D_1)^{1.06}$ where T_2 is the predicted time; T_1 = race time for known distance; D_2 = predicted distance; D_1 = distance for known race time.

2) To get an overall training value for each participant, area under the curve (AUC) rTSS for each runner was calculated for the six-month study duration. This was done using GraphPad Prism which computes AUC using the trapezoid rule (“How to: Area under the curve,” 2019).

3) Acute Training Load (ATL) was calculated as a seven-day rolling average of rTSS (Gabbett, 2016; Murray et al., 2017).

4) Chronic training load (CTL) was calculated as a 28-day rolling average of rTSS.

5) The acute: chronic workload ratio (ACWR) is defined as the ATL divided by the CTL (Banister et al., 1975; Banister & Calvert, 1980; Hulin et al., 2014).

6) The coefficient of variation (CV) was calculated as the standard deviation (SD) divided by the mean then multiplied by 100.

Statistical Analyses

Graphpad Prism (GraphPad Software, San Diego, California USA, www.graphpad.com) was used for statistical analysis. A Kruskal-Wallis test was used to determine differences in CV between training load variables. The Dunn's *post hoc* test was used for the multiple comparisons.

Linear regression analyses were used to determine relationships between total training load and: running duration; intensity factor; CV of training load variables; and performance level.

Results

The training load performed in the 6-month study duration varied greatly among participants (Figure 6.1.1A-D). The AUC for training load varied nearly 3.5-fold (Figure 6.1.1A). The AUC ranged from 3,207 – 11,013. The participants ran 4.4 ± 2.0 (median \pm Interquartile range (IQR)) hours/week with a range of 2.7 – 8.7 hours/week (Figure 6.1.1B). The average distance run per week ranged from 24 – 83 km/week with a median of 44 km/week (Figure 6.1.1C). In the two variables that determine rTSS: Running duration varied nearly four-fold (57 – 209 hours) (Figure 6.1.1B), and average IF varied 1.5-fold (0.61 – 0.92) (Figure 6.1.1D).

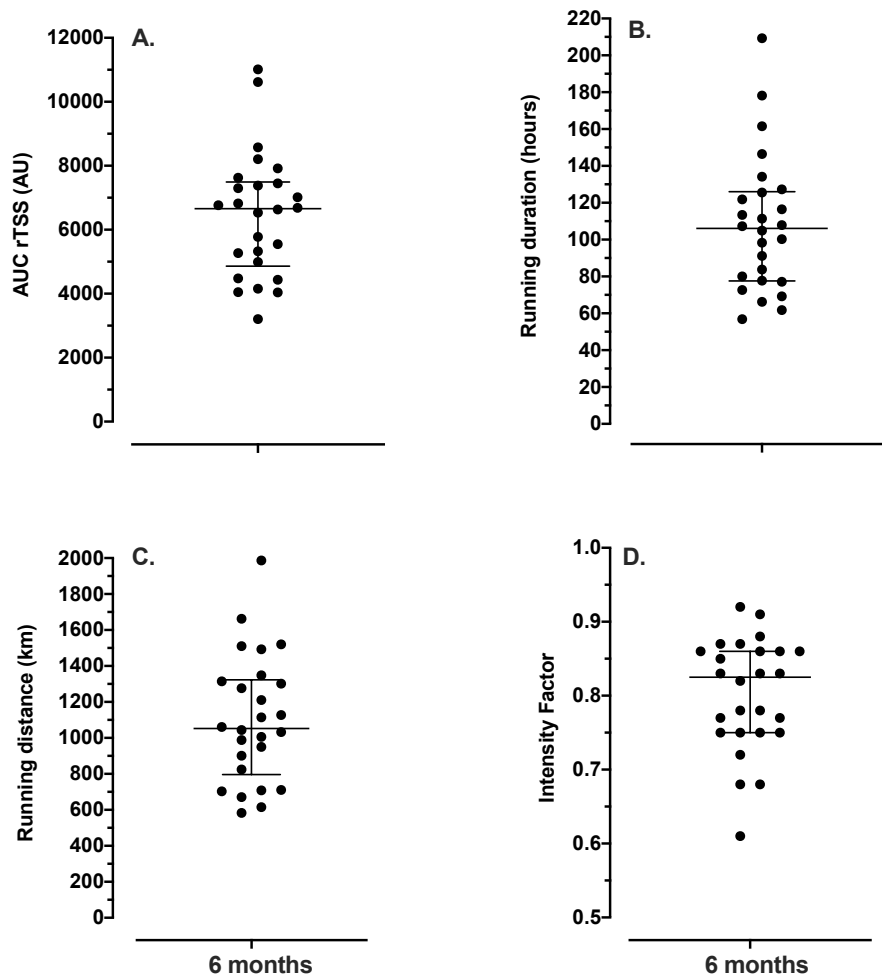


Figure 6.1.1A-D. Data are presented as median \pm IQR. $n = 26$. **A)** Area under the curve (AUC) running training stress score (rTSS) for six months. **B)** Total running duration for six months. **C)** Total running distance for six months. **D)** Average intensity factor for six months.

Daily training load (rTSS) varied approximately 2.5-fold (41 – 101%) with a median of 63% (Figure 6.1.2). The variation in daily training load was higher than the variation in ATL, CTL, and ACWR ($p < 0.01$). Weekly training load (ATL) varied approximately 10-fold (14 – 136%) with a median of 36%. Monthly training load (CTL) varied approximately eight-fold (7 – 56%) with a median of 14%. The variation in ATL was higher than CTL ($p < 0.01$). When training load is considered as a ratio between weekly and monthly training load (ACWR), it varied approximately seven-fold (12 – 82%) with a median of 32% (Figure 6.1.2). The variation in ACWR was higher than CTL ($p < 0.01$). Based on the ATL

and CTL data points, the runners with high variation in ACWR is due to a large variation in weekly training load (ATL).

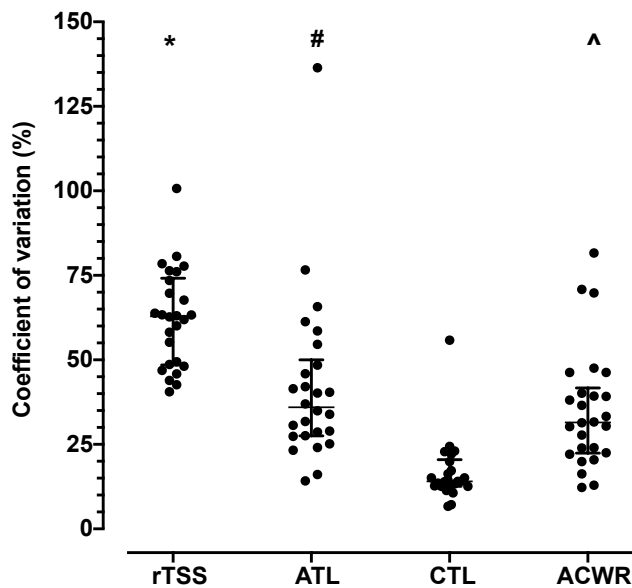


Figure 6.1.2. Data are presented as median \pm IQR. $n = 26$. Coefficient of variation over six months for running training stress score (rTSS), Acute training load (ATL), Chronic training load (CTL), & the acute: chronic workload ratio (ACWR).

* $p < 0.01$ vs. ATL, CTL, & ACWR. # $p < 0.01$ vs. CTL. ^ $p < 0.01$ vs. CTL.

Running duration had a positive linear correlation with total training load performed in the six months ($r^2 = 0.57$, $p < 0.001$) (Figure 6.1.3A). Runners who performed higher training load also performed more running hours. Intensity factor did not have a relationship with total training load in this group ($r^2 = 0.02$, $p = 0.51$) (Figure 6.1.3B). Runners who had low overall training load ran at similar relative speeds to runners who had high overall training load.

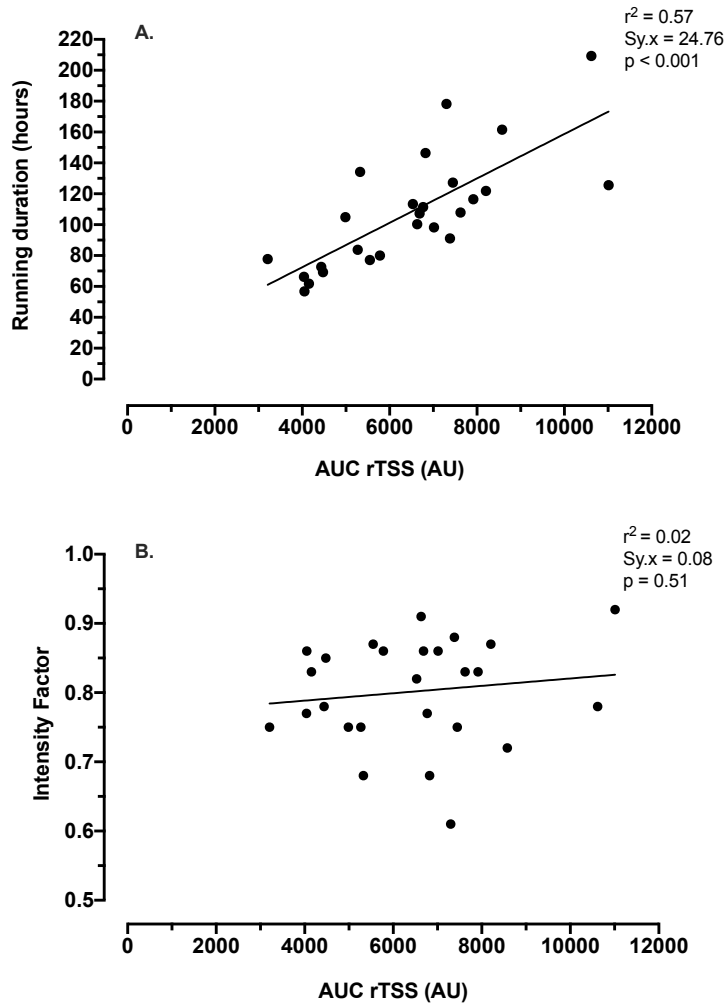


Figure 6.1.3A-B. Relationship between area under the curve (AUC) running training stress score (rTSS) & **A**) total running duration ($n = 26$), **B**) average intensity factor for six months ($n = 26$). $Sy.x$ = standard deviation of estimate.

There was no relationship between overall training load performed and variation in daily training load (rTSS) ($r^2 = 0.08$, $p = 0.17$) (Figure 6.1.4A). The runners who trained less had similar daily variation in load compared to runners who trained more. There was a negative linear relationship between overall training load performed and variation in weekly training load (ATL) ($r^2 = 0.24$, $p = 0.01$) (Figure 6.1.4B). The runners who trained more had smaller weekly variation in training load compared to runners who trained less. There was no relationship between overall training load performed and variation in monthly training load (CTL) ($r^2 = 0.11$, $p = 0.11$) (Figure 6.1.4C). The runners who trained less had similar monthly variation in load compared to runners who trained

more. There was a negative linear relationship between overall training load performed and variation in the ACWR ($r^2 = 0.34$, $p = 0.002$) (Figure 6.1.4D). The runners who trained more had smaller variation in the ratio between weekly and monthly training load.

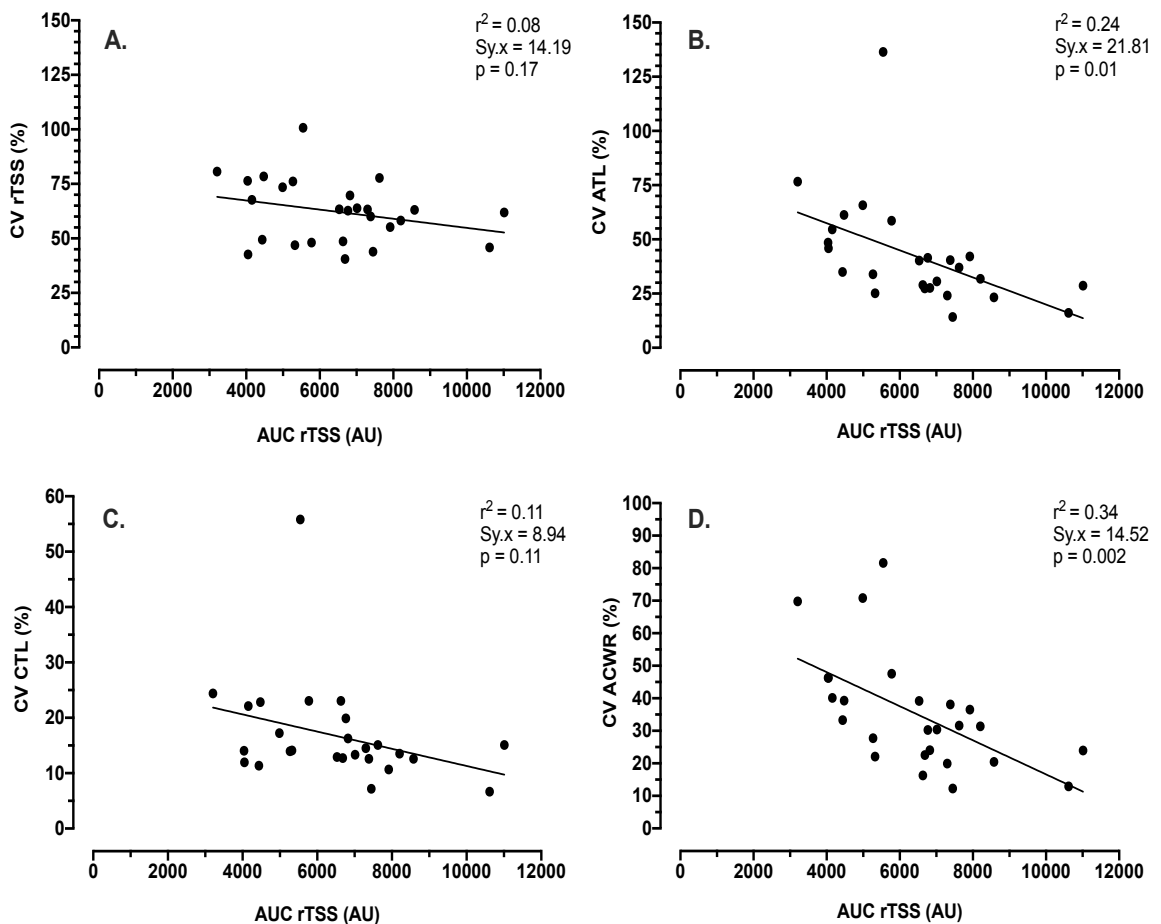


Figure 6.1.4A-D. Relationship between area under the curve (AUC) running training stress score (rTSS) & **A**) coefficient of variation (CV) rTSS, **B**) CV acute training load (ATL), **C**) CV chronic training load (CTL), **D**) CV acute: chronic workload ration (ACWR) for six months. Sy,x = standard deviation of estimate. $n = 26$ for A-D.

There was no relationship between overall training load performed and performance level ($r^2 = 0.02$, $p = 0.50$) (Figure 6.1.5). The amount of training the runners did in the 6-month time frame was not related to their performance level.

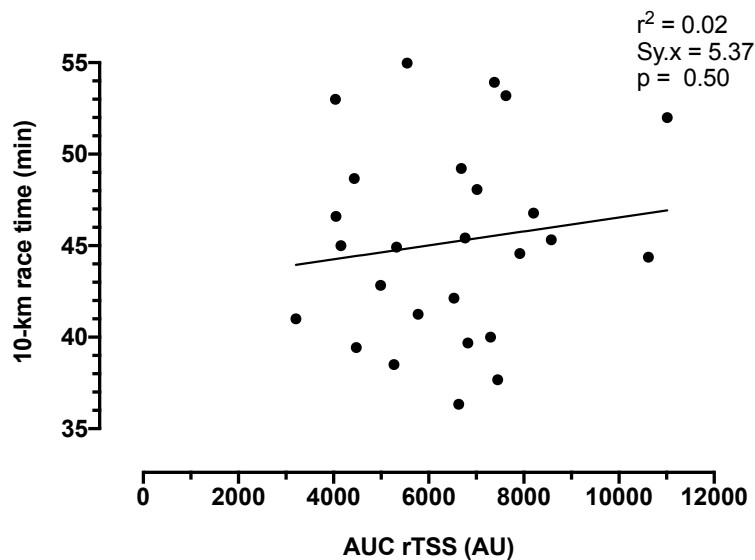


Figure 6.1.5. Relationship between area under the curve (AUC) running training stress score (rTSS) for six months and participants' best 10-km race time. $n = 26$. $S_{y.x}$ = standard deviation of estimate.

Discussion

Training Load Volume

This group of well-trained competitive recreational runners were training for 21-km ($n = 3$) or ≥ 42 -km distance ($n = 23$) races. The distance run per week (44 ± 22 km/week) is similar to our findings presented in the Ch.3.2 study where runners completed 51 ± 31 km/week (median \pm IQR) in preparation for a 56-km race and Leyk et al. (2009) who found marathon runners ran an average of 45 – 50 km/week. It is also similar to Zillmann et al. (2013) that reported 45 ± 25 km/week (mean \pm SD) in a group of recreational male marathoners. The volume of training in this cohort is substantially lower compared to sub-elite or elite runners. In a group of runners with an average marathon time of 3h 7min, the average training volume was 92 km/week (Foster, 1983). In a more recent study (Karp, 2007), elite marathon runners averaged 145 km/week in training. Why recreational runners only run 30 – 50% of the weekly volume compared to elite runners is not fully understood. It may be reasonable to suggest recreational runners do not have time available to train as many times per week as elite

runners. They also may not have sufficient time available to run as far within each session particularly during the week. Since recreational runners are slower, it would take more time to achieve the same running distance as an elite runner. It is also possible that recreational runners aren't physically capable of sustaining a very high training load. One of the attributes of an elite runner is that they can sustain a high training volume.

Training load in this group was related to running duration but not intensity. Previous research (Foster, 1983) found a higher correlation between running volume and marathon performance ($r^2 = 0.37$) compared to intensity and marathon performance ($r^2 = 0.04$). This would suggest that in preparing for endurance running events, running duration plays a larger role than intensity in overall training load.

Intra-individual training load variation

This group of runners altered their training load on a day-to-day basis ($63 \pm 26\%$; median \pm IQR). Some runners varied their weekly training load substantially (136%), while others varied their weekly load by only a small margin (14%). The participant with the lowest variation in ATL (14%) averaged 63 km/week of running. He completed seven races in the six-month study (four 10-km races; two 15-km races; & one 21-km race). The participant with the second lowest variation in ATL (16%) averaged 83 km/week of running. She completed five races in the six-month time frame (three 5 - 6-km races; one 10-km race; & one 42-km race). The participant with the highest variation in ATL (136%) averaged 30 km/week of running. She completed two races in the six-month time frame (one 90-km ultramarathon race; one 21-km race). The participant with the second highest variation in ATL (77%) averaged 29 km/week of running. He completed four races (one 35-km race; two 42-km races; & one 75-km ultramarathon race). A higher training load in the six months was associated with lower variation in ATL and ACWR over time. The athletes with lower variation in ATL may have an increased ability to tolerate consistently high training loads compared to the athletes with higher variation in ATL. Another

possible explanation may be well-trained competitive recreational runners who race ultramarathon races have lower overall training loads and higher variation in weekly load in a mesocycle due to the required recovery after races, particularly if the ultramarathon occurs at the beginning or middle of the mesocycle.

Inter-individual training load variation

The large IQR in training load in Ch.3.2 and the current study is important to note. Runners training for the same distance races complete different quantities of training. For example, two male participants in the study completed a marathon race with the same relative performance (101% of their best marathon time). One participant averaged 41 km/week of running at an average intensity factor of 0.86. The other participant averaged only 24 km/week of running at an average intensity factor of 0.77. When prescribing training to recreational runners, it is important to consider the large inter-individual variation in training load. A runner's training should be designed considering their individual training history, injury history, and life stressors rather than having him or her aim for a specific distance per week.

In this group of runners, there was a greater inter-individual variation in time spent running vs. their relative training speed (4-fold vs. 1.5-fold). This may be a characteristic of endurance runners training for races ≥ 21 -km. Fifty percent of the participants averaged a training speed of 75 – 87% of their best 10-km time. Another possible consideration is due to this being part of a larger study, all participants were performing similar speed work sessions: a fartlek run once per week and a 5-km time trial bi-weekly.

Relationship between training load and performance level

In Ch.3.2 we demonstrated a positive linear relationship between training load and relative race performance. However, that group was more heterogenous in training load and performance level compared to the cohort in this study. There was no relationship between training load and performance level in this group

of well-trained competitive recreational runners. Participants with a 10-km race time < 40 minutes completed the same volume of training load as participants with a 10-km race time > 50 minutes. This indicates that coaches and sports scientists should not design training programmes solely based on performance level (e.g.- sub-three hour marathon training programme). A runner with a high performance level but low tolerance for training load may risk injury or poor performance by completing an 'advanced' training programme. Programmes should be designed based on the volume of training an athlete has accomplished within the last year without experiencing adverse consequences in combination with their performance goals.

Conclusion

In conclusion, this group of well-trained competitive recreational runners performed 44 ± 22 km/week in a six-month time frame. This volume is similar to previous reports of recreational endurance runners (Leyk et al., 2009; Zillmann et al., 2013) and is only 30 – 50% of the volume performed by elite endurance runners. This group had a wide range of inter-individual differences in training load performed even when considering participants who had the same relative marathon performance. This may suggest that some recreational runners have lower training load tolerance and may not be able to sustain increases in load without experiencing adverse effects. There was no relationship between training load performed and best 10-km time in this cohort. This may be applicable to coaches and runners when prescribing training. Simply because a runner has a fast 10-km time, does not mean that he or she can tolerate an advanced programme with high training load. This study described training load performed in a six-month time period in well-trained competitive recreational runners. Future research should examine concepts such as the ACWR; relative weekly changes in load; and relationships between training load, performance, and internal training load variables.

Study 2: The acute: chronic workload ratio & 10% rule in endurance sport

Introduction

As discussed in greater detail in Chapter 2, the acute: chronic workload ratio (ACWR) provides information about the athlete's current workload vs. the workload he or she has been prepared for, and, in part, aims to predict performance and injury risk (Banister et al., 1975; Banister & Calvert, 1980; Gabbett, 2016; Hulin et al., 2014). Ideally, an athlete should participate in an important competition while exhibiting high chronic training load (CTL) values and relatively low acute training load (ATL) values. The calculation of the ACWR is simply the ATL divided by the CTL. "Fitness" or CTL is typically represented as a 28 – 50-day rolling average of training load. "Fatigue" or ATL is typically represented as a 7 – 14-day rolling average of training load (Banister & Calvert, 1980, Gabbett, 2016; Murray et al., 2017).

As originally proposed by Eric Banister in 1980, performance can be modelled on assessments of fitness and fatigue (Banister & Calvert, 1980), which suggests that 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 when an athlete encounters a training-induced stress over a prolonged period of time, thereby stimulating an adaptive response (Stone, Stone, & Sands, 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. An excessive amount of stress (physiological, emotional or environmental) encountered by an athlete in training, in the absence of adequate recovery, may also lead to an accumulation of fatigue, and as a result, performance may be negatively affected as a consequence of fatigue being greater than fitness.

The ACWR has been studied mainly in the context of team sports in relation to risk of injury (Gabbett, 2016; Hulin et al., 2014, 2016; Murray et al., 2017). Gabbett (2016) suggested the 'sweet spot' for the ACWR in training is 0.8-1.3, while ACWR values > 1.5 are associated with increased risk of injury. These

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conclusions were based on three studies involving cricket, rugby, and soccer (Hulin et al., 2014, 2016; Ehrmann et al., 2016). There is a lack of research regarding the ACWR in endurance sports. The ACWR values across an extended training period such as a mesocycle (Pyne, 1996) in endurance athletes will likely differ to team sports. Further it will vary depending on the specific endurance sport and demographics of the study cohort. Load tolerance for spikes in the ACWR values will be unique to sport and group. It is important to better understand the ACWR in relation to well-trained competitive recreational endurance runners.

The 10% rule in running literature advises athletes to not increase training load by more than 10% a week (Johnston, Taunton, Lloyd-Smith, & McKenzie, 2003; Ullyot, 1980). Many studies have found large weekly increases in training load increases the risk of injury in a range of team sports (Cross, Williams, Trewartha, Kemp, & Stokes, 2016; Piggott, 2008; Rogalski, Dawson, Heasman, & Gabbett, 2013). In a training load consensus statement (Soligard et al., 2016), the researchers suggested athletes respond better to relatively small increases or decreases in training load. They also suggested that, based on studies in Australian football, cricket, and rugby league, the weekly increase in training load should be limited to < 10% (Soligard et al., 2016).

It is important to note the first known person to write about the 10% rule in running (Ullyot, 1980) was a medical doctor and journalist. The rule was written as a guide for runners' training but was not backed by scientific evidence. Sports scientist Tim Gabbett advocates that the 10% rule "is, at best, a 'guideline' rather than a 'code' (Gabbett, 2018)." One study (Buist et al., 2008) compared the risk of injury in novice runners who increased their weekly distance by 24% over eight weeks vs. a group that increased their weekly distance by 10% over 12 weeks. They found no difference in the incidence of running-related injuries in the two groups. Another study (Nielsen et al., 2014) found novice runners who increased their weekly running distance by > 30% were at increased risk of injury vs. runners who increased their weekly load by < 10%. Important to note is the two running studies discussed used novice runners as their cohort.

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Running experience may affect how much of an increase in load a runner can tolerate. The training, performance, and injury relationship is complex and multifactorial (Gabbett, 2018). Besides training load, factors such as biomechanics (Vanrenterghem, Nedergaard, Robinson, & Drust, 2017), psychological stressors (Gabbett et al., 2017), and sleep (Milewski et al., 2014) can all affect performance and risk of injury. It is not known if well-trained competitive recreational runners who train *ad libitum* abide by the '10% rule'.

Running literature advises runners to avoid rapid increases in training load (James, Bates, & Osternig, 1978; Johnston et al., 2003). However, coaches regularly use intensified training blocks of one – two weeks with the goal of enhancing physiological adaptation to training (Fernandez-Fernandez, Sanz-Rivas, Sarabia, & Moya, 2015; Wahl, Güldner, & Mester, 2014; Zinner, Wahl, Achtzehn, Reed, & Mester, 2014). We do not know if well-trained competitive recreational runners have large spikes in training load and, if so, the magnitude of the spike and reason for the spike.

The aims of the study were therefore to determine: the intra-individual range of the ACWR values in a group of well-trained competitive recreational runners training *ad libitum* for a time period of 6 months; the magnitude of peaks in the ACWR; and the weekly relative change in training load.

Methods

Participants

Forty-one well-trained competitive recreational runners enrolled in the study. Out of the 41 participants, data sets from 26 participants (female $n = 6$; male $n = 20$) were used for data analysis. The reasons for the 15 excluded participants included: did not complete six months of training or did not participate in any races during the study period. The participant characteristics are described in Table 1. The participants were described in detail in Ch.6.1. The same cohort was used in this study.

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Table 6.2.1. Participant Characteristics

Participant ID Number	Age (yrs)	Height (cm)	Weight (kg)	Experience (yr)	Dist per/week (km)	10-km Time (mm:ss)
P1	37	167	72	1	60	49:13
P2	30	169	61	4	45	38:30
P3	47	168	56	27	80	44:22
P4	47	181	73	6	60	40:00
P5	43	161	67	5	45	48:39
P6	47	183	70	5	60	39:26
P7	29	169	68	2	40	54:59
P8	39	190	85	8	55	48:04
P9	31	178	77	4	45	44:55
P10	47	177	66	2	60	45:25
P11	43	185	82	7	64	39:41
P12	39	156	50	3	70	44:34
P13	34	184	77	3	55	41:00
P14	40	170	61	10	60	37:40
P15	42	170	58	3	46	53:12
P16	47	166	62	3	50	46:47
P17	45	190	81	20	60	42:08
P18	41	176	81	15	45	53:00
P19	22	174	62	2	80	36:20
P21	36	168	76	5	70	52:00
P22	32	175	78	2	70	42:50
P23	36	189	77	4	78	41:15
P24	29	157	56	1	40	46:36
P27	32	175	86	2	50	45:00
P28	44	172	67	15	45	53:56
P30	33	174	54	12	65	45:19
Mean ± SD	38±7	174±9	69±10	7±6	58±12	45:11±5:18

Data in bold text are presented as mean ± SD. Experience = Number of years of running experience previous to study enrolment. Dist per/week = Average running distance per week for the six months previous to study enrolment. 10-km Time = Best 10-km race time within the last 12 months.

Study Design & Calculations

The general design of this study is the same as the design discussed in Ch.6.1.

Global Positioning Systems (GPS) files were downloaded and used for the following calculations:

- 1)** Training load was calculated using a running training stress score (rTSS) (McGregor et al., 2009). The formula for $rTSS = \text{duration (hours)} * \text{intensity factor (IF)}^2 * 100$. This was previously described in Ch.3.2 & Ch.6.1.
- 2)** ATL was calculated as a seven-day rolling average of rTSS (Gabbett, 2016; Murray et al., 2017).
- 3)** CTL was calculated as a 28-day rolling average of rTSS.
- 4)** The ACWR calculation = ATL divided by the CTL (Banister et al., 1975; Banister & Calvert, 1980; Hulin et al., 2014).
- 5)** The weekly relative change in training load was calculated as; $((\text{previous week sum rTSS} - \text{current week sum rTSS}) / \text{previous week sum rTSS}) * -100$.
- 6)** The weekly relative change in training load vs. the preceding greatest training load week was calculated as; $((\text{greatest preceding week sum rTSS} - \text{current week sum rTSS}) / \text{greatest preceding week sum rTSS}) * -100$.

Statistical Analyses

Microsoft Excel 2016 (Redmond, WA, USA) was used to calculate relative weekly changes in training load. Graphpad Prism (GraphPad Software, San Diego, California USA, www.graphpad.com) was used for all remaining analyses: median \pm IQRs and minimum-maximum ranges for the ACWR; relative weekly changes in training load data; a Kruskal-Wallis test to determine differences in changes in training load and the number of consecutive weeks of increasing load.

Structure of results & discussion section

This research is presented as a descriptive study. Each participant was analysed as an individual case study. Certain participants required further explanation, so the reader can accurately interpret the data. To enhance readability and interpretation of the data, a brief discussion section follows each of the three

results sections: The ACWR; spikes in the ACWR; and weekly relative change in training load.

Results & Discussion

The ACWR: Results

The average median for the ACWR over the six-month time period in the 26 participants was 0.98 with a range of 0.75 – 1.04 (Figure 6.2.1). The average lower quartile was 0.81 with a range of 0.55 – 0.92. The average upper quartile was 1.14 with a range of 1.07 – 1.22 (Figure 6.2.1). When comparing to previously recommended ranges in team sports (Gabbett, 2016), no participants had upper quartile ACWR values exceeding 1.3. Six participants had lower quartile ACWR values below 0.8.

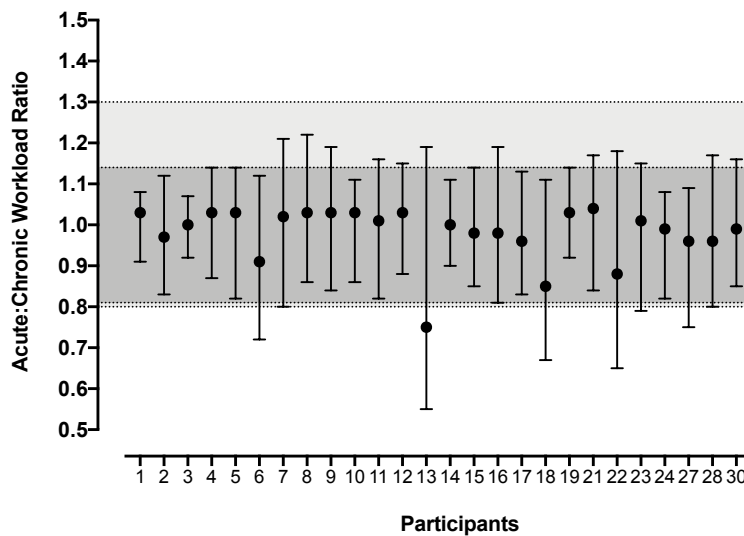


Figure 6.2.1. Data are presented as median \pm IQR for six months of training. Numbers on x-axis denote Participant ID number. The dark grey shaded region represents the group means for the lower to upper limits of the IQR. The light grey shaded region is in reference to Gabbett, 2016.

The ACWR: Discussion

When the participants are considered as a group, the IQR for ACWR values was 0.81 – 1.14. The participant with the largest IQR in ACWR values was P13 (0.55 – 1.19). The participant with the smallest IQR in ACWR values was P3 (0.92 – 1.07). Participant 13 had a relatively low training load compared to other participants for the study duration (AUC rTSS = 3,207; average distance per week = 29 km/week). Participant 13 completed four races throughout the study (three of which were ≥ 42 km) with relatively low training load between those races. Of particular note is that from study day 111-168, P13 only completed six training sessions. The participant reported being very busy at work during this time. This caused CTL values to decrease sharply from 87 to 23 and rolling ATL values were also low due to many days with no training.

In contrast, P3 had a relatively high training load compared to the other participants (AUC rTSS = 10,617; average distance per week = 83 km/week). The runner never took more than two consecutive days off from running (a total of 33 out of 168 days) which caused the participant's CTL values to remain steady. The runner also only participated in one race ≥ 42 km but raced on four occasions with distances ranging from 5 – 10-km. Participating in shorter races (≤ 10 -km) causes smaller spikes in ATL values compared to longer races (≥ 21 -km).

In Ch. 6.1, we demonstrated that there was a significant inverse linear relationship between AUC rTSS and the coefficient of variation (CV) in ACWR values (Figure 6.1.4D); Participant 13 and P3 reflect this relationship. Previous research has suggested training with high monotony (low variation in weekly training load) may negatively impact performance and increase risk of illness (Lehmann et al., 1991; Foster, 1998). It is important to not assume that a runner with high variation in ATL is training with superior methods vs. a runner with low variation in ATL. It may indicate, as in this case, that the runner with high variation has missed several training days which would negatively impact their fitness and tolerance for load. It may also indicate that the runner participates

in many marathon or ultramarathon distance races. This would cause large spikes in ACWR values particularly if preparedness was low before the race.

Spikes in the ACWR: Results

When the daily ACWR values were plotted over time for all participants (Figure 6.2.2), 19 out of 26 participants (73%) had ACWR peaks above 1.5. In these 19 participants, there were a total of 61 days out of a possible 3,192 days (2%) with ACWR peaks above 1.5. Participants had a range of one – six days in the six-month timeframe with ACWR peaks above 1.5. Forty-nine out of the 61 spikes in ACWR were due to participants completing a race (21-km race: four days; 25-km race: one day; 32-km race: five days; 42-km race: 23 days; & ultramarathon race: 15 days). Nine out of the 61 spikes in ACWR were due to a participant taking a break from training. Three out of the 61 spikes in ACWR were due to participants completing a training session with a relatively large TSS value.

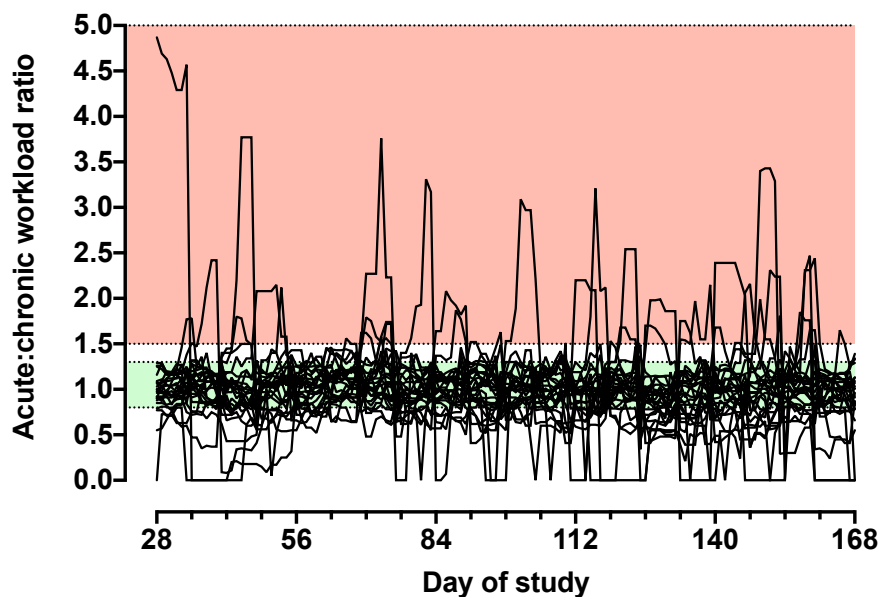


Figure 6.2.2. Daily ACWR values for each participant ($n = 26$). Highlighted sections (0.8 – 1.3 & > 1.5) are in reference to Gabbett, 2016.

Spikes in the ACWR: Discussion

In this group, 80% of the days with ACWR values above 1.5 were due to participants completing races. Only 5% of the days were due to training sessions with relatively large TSS values. In a group of well-trained competitive recreational runners training *ad libitum*, there are rarely spikes in ACWR values due to training. Coaches and athletes should be mindful of symptoms of fatigue and any impairments in performance in the one - two weeks after a race (≥ 21 -km in distance). They may require additional recovery after a longer race. Also considering performance, injury, and training are multifactorial, the athlete may need to visit a physiotherapist or massage therapist for tissue mobility work; pay extra attention to nutrition; and focus on adequate sleep (Herring et al., 2019).

Weekly relative change in training load: Results

All 26 participants had an IQR larger than $\pm 10\%$ for weekly relative change in volume of training load (Figure 6.2.3A). The group average for the IQR was -38% to +64% weekly change in load.

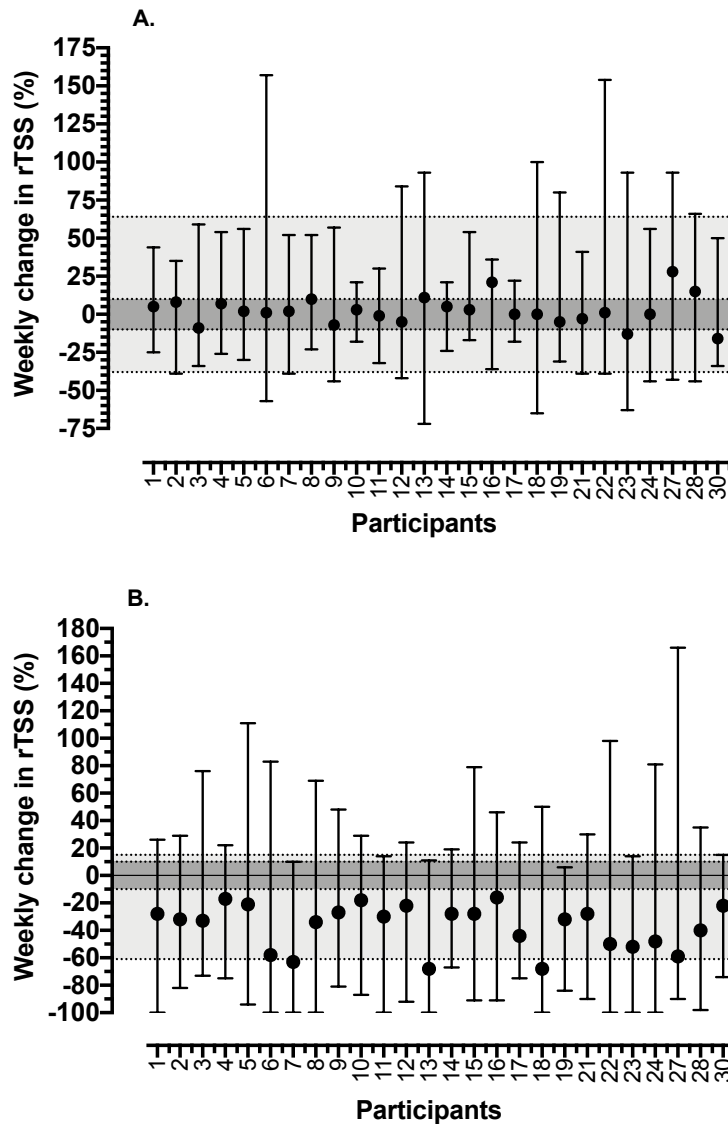


Figure 6.2.3A-B. The dark grey shaded region represents the 10% rule. The light grey shaded region represents the group means for the lower to upper limits of the IQR. Numbers on the x-axis denote Participant ID number.

A) Data are presented as median \pm IQR. The data were calculated as weekly relative change in running training stress score (rTSS). **B)** Data are presented as median \pm min-max. The data were calculated as weekly relative change in rTSS vs. preceding largest week.

When calculating percent change in weekly load relative to the preceding largest week completed, the group average for the IQR was -61% to +15% weekly change in load (Figure 6.2.3B). The group median for maximum relative increases in load was 30%. Two participants had maximum increases of

≤ 10%; Five had maximum increases of 11-20%; Seven had maximum increases of 21-30%; and 12 had maximum increases of > 30% with a range of 35 – 166%.

Eleven out of 26 participants (42%) had more than one week in a row with relative increases in load vs. the preceding largest week (Appendix, Ch.6.2 Figure 5 Addendum). The remaining participants all had a minimum of one week of decreased load between increasing weeks. Six out of the 11 participants had a maximum of two consecutive weeks of progressive increases. Three participants had a maximum of three consecutive weeks of increasing load. One participant had a maximum of four consecutive weeks of increasing load, and one participant had a maximum of five consecutive weeks of increasing load. The number of weeks and their associated relative increase in training load are displayed in Figure 6.2.4. There were no significant differences in the relative change in training load between the number of consecutive weeks ($p = 0.53$).

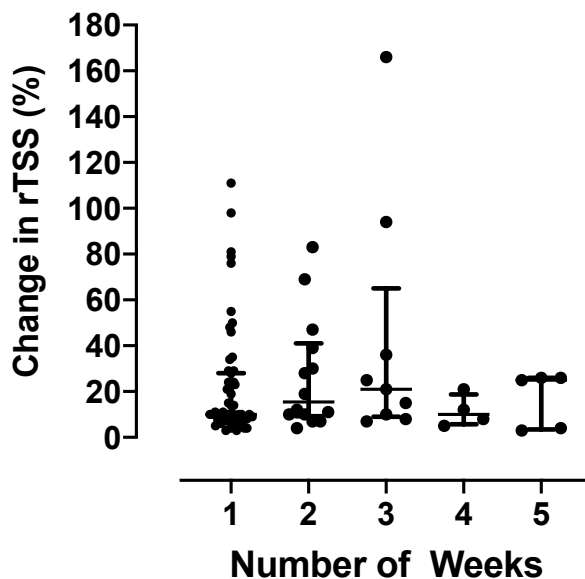


Figure 6.2.4. Data are presented as median \pm IQR. The number of consecutive weeks of relative increases in load is on the x-axis. The relative magnitude of the change in relative running training stress scores (rTSS) is on the y-axis.

When calculating percent change in weekly load (Figure 6.2.5A.), P4 had nine out of 23 weeks with a percent weekly change larger than +10%. When calculating percent change in weekly load relative to the preceding largest week completed

(Figure 6.2.5B), the same participant only had two out of 23 weeks with a percent weekly change larger than 10%.

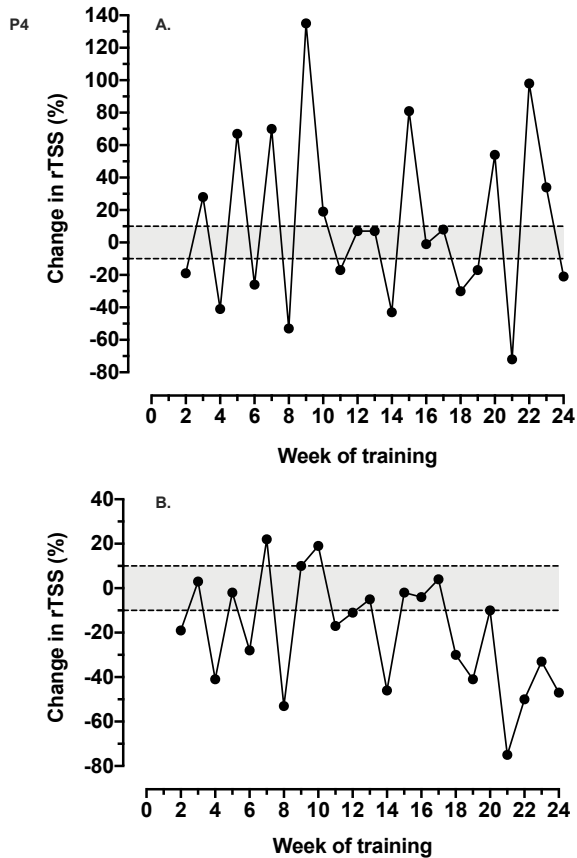


Figure 6.2.5A-B. Data for Participant #4. The grey shaded region represents the 10% rule. **A)** Relative weekly change in running training stress score (rTSS) values. **B)** Relative weekly change in rTSS vs. the preceding largest week of rTSS values.

Weekly relative change in training load: Discussion

This group of runners does not adhere to the 10% 'rule' according to their weekly relative change in training load. There is a large relative variation in their week-to-week training. As Gabbett suggests the 10% rule is at best a guide (Gabbett, 2018). Well-trained competitive recreational runners do not adhere to a 10% rule when calculating weekly relative change.

Well-trained competitive recreational runners are unlikely to have the guidance of a coach or a periodised training programme, in contrast to elite runners who are managed carefully. It is possible that this cohort may benefit from practical advice about increasing their training load in a systematic way. The relative weekly change compared to the preceding largest week of training may help provide more useful and practical advice. It is particularly interesting to look at the maximum values in figure 6.2.3B. The median maximum increase was 30% with only two participants having maximum increases of $\leq 10\%$. In fact, 73% of the participants had maximum increases of $> 20\%$. It is important to note however, that 58% of participants all had a minimum of one week of decreased load between increasing weeks. The increases in load are predominantly short term (one - two weeks). It is possible that the 10% guideline is too conservative for well-trained competitive recreational runners. It may be a more practical guide for novice runners who are not well-trained.

In Figure 6.2.5 we compared the two methods of calculating relative weekly change in load within the same participant and drastically different conclusions would be drawn from Fig 6.2.5A and Fig 6.2.5B. In figure 6.2.5A, the reader may conclude the runner was training randomly with huge fluctuations in weekly load. In Figure 6.2.5B, we can quickly interpret that the runner was progressively increasing load (albeit not each week) until week 17. This participant was following a set training programme that culminated in a marathon in week 20. We can also interpret from Figure 4B that the runner tapered in weeks 18 and 19.

Calculating weekly change in training load compared to the preceding largest week of training may be a superior way of calculating changes in training load. It enables the reader to more accurately interpret the data. It can also provide runners and coaches with more practical guidelines. In this group of well-trained competitive recreational runners the general suggestion would be to keep increases in load to $\leq 25\%$ compared to the preceding largest week in any given mesocycle. This is similar to the Nielsen et al. (2014) study which concluded that novice runners may be able to tolerate weekly increases in load of 20 – 25% for

short periods. There was however large variation around this number in our study cohort. It is also important to differentiate 'shock' microcycles in training (one - two weeks) vs. continually progressive increases which may need to be of smaller magnitude. There were only five out of 26 participants who had \geq three consecutive weeks of progressive increases in load, and thus not enough information to speculate about long term progressive increases in training load.

Conclusion

In conclusion, this group of well-trained competitive recreational runners maintain most of their training over a six-month period within the 0.81 – 1.14 ACWR range. When the ACWR values reached > 1.5 , this was mainly due to participation in endurance running races (≥ 21 -km). Practical advice arising from this study is that symptoms of fatigue and impaired performances for the one - two weeks after endurance running races should be monitored and the training load – recovery balance should adjusted as needed.

Well-trained competitive recreational runners may be able to tolerate weekly increases in training load of approximately 25%. However, this increase may only be maintained for a short period (one – two weeks). Future research should determine the threshold for weekly change in training load for a longer period (\geq three weeks).

Chapter 6.1 & 6.2 described *ad libitum* training load performed by well-trained competitive recreational runners. Chapters 6.3 and 6.4 will determine relationships between training load, performance, and submaximal HR in this cohort.

**Study 3: Relationships between training load and performance in a
marathon distance race**

Introduction

In Ch.6.1, we explored the variation in training load over a duration of six months. There was wide inter and intra-individual variation in training load across time. However, the study was descriptive in nature. How the training load may be associated with race performance in those participants is unknown. In Ch.3.2, we demonstrated that runners who completed higher training loads elicited better relative performances in an ultramarathon race (56-km). The group was heterogenous from the perspective of training completed and performance level. Whether the relationship between training load and performance applies in a more homogenous group of recreational runners is unknown.

There may be differences in the association between training load and performance depending on natural ability level and training history. A previous study found that increased training time at a low intensity was related to improved performances at 4-km and 10-km races in a group of sub-elite runners (Esteve-Lanao, San Juan, Earnest, Foster, & Lucia, 2005). In contrast to these findings, another research group found no significant relationships between distance ran or time spent in training zones and changes in performance in a group of elite middle- and long-distance runners (Balsalobre-Fernández, Tejero-González, & del Campo-Vecino, 2014). This suggests that the training load may be different in runners with a similar level of performance. However, the extent to which this may occur has not been established, because there is a gap in research regarding relationships between training load and performance in well-trained competitive recreational runners.

It is important for coaches to understand possible differences in the relationship between training load and performance level in different groups of runners. Failing to customise training load may expose the athlete to a risk of overuse injury or poor race performances. Therefore, the main aim of this study was to determine possible relationships between training load and marathon race performance in a group of well-trained competitive recreational runners.

Methods

Participants

The study consisted of 19 well-trained competitive recreational runners (female n = 3; male n = 16). The participant characteristics are demonstrated in Table 6.3.1. Inclusion and exclusion criteria have been described previously in Ch. 6.1 and were the same for this study. Participants used the following GPS devices: Suunto Ambit® Series, n = 4; Polar M600®, n = 1; Garmin Fenix® Series, n = 3; Garmin Forerunner® Series, n = 5; Garmin Forerunner® XT Series, n = 4; TomTom Runner® series, n = 2.

Table 6.3.1. Participant Characteristics.

Participant ID number	Age (yr)	Height (cm)	Weight (kg)	Years Exp	Dist/week (km)	10-km Time (mm:ss)
MP1	36	189	77	4	78	41:15
MP2	32	175	78	2	70	42:50
MP3	42	170	58	3	46	53:12
MP4	34	184	77	3	55	41:00
MP5	47	177	66	2	60	45:25
MP6	33	174	54	12	65	45:19
MP7	32	175	86	2	50	45:00
MP8	36	168	76	5	70	52:00
MP9	41	176	81	15	45	53:00
MP10	39	156	50	3	70	44:34
MP11	43	185	82	7	64	39:41
MP12	39	190	85	8	55	48:04
MP13	47	181	73	6	60	40:00
MP14	47	168	56	27	80	44:22
MP15	30	169	61	4	45	38:30
MP16	46	182	71	40	105	37:12
MP17	47	186	69	3	106	40:00
MP18	40	176	82	3	80	47:00
MP19	35	160	61	3	102	33:30
Mean ± SD	39 ± 6	176±9	71±11	8±10	69±19	43:47±5:21

Data in bold text are presented as mean ± SD. MP = marathon participant. Years Exp = Number of years of running experience before enrolling for the study.

Dist per/week = Average running distance per week for the six months before enrolling for the study. 10-km Time = Best 10-km race time within the previous 12 months.

Study Design & Calculations

Data for the 11 weeks leading up to a marathon distance race were analysed. Global Positioning Systems (GPS) files from each run were downloaded from Training Peaks™. Runners were instructed to train *ad libitum* with the exception of performing the **FINISHER** test (explained in detail in Ch.5.1) once per week and a 5-km time trial bi-weekly.

The following calculations were done:

1) Relative performance was calculated by taking the race time in minutes divided by the Pete Riegel predicted marathon time in minutes using the participant's best 10-km race time from the previous 12 months (Riegel, 1981). The formula used to calculate a predicted best marathon time was:

$$\text{Time}_{\text{marathon}} = \text{Time}_{10\text{-km}} * (\text{Distance}_{\text{marathon}}/\text{Distance}_{10\text{-km}})^{1.06}.$$

The marathon race time was adjusted for elevation gain using the following formula:

$$\text{Adjusted Time} = [(\text{distance of race (km)}) + (4.4 * \text{race elevation gain (km)})/\text{race speed (km/min)}] \text{ (Norman, 2004)}.$$

2) Training load was calculated using a running training stress score (rTSS) (McGregor et al., 2009). The formula for rTSS = duration (hours) * intensity factor (IF)² * 100. This was previously described in detail in Ch.3.2 and Ch.6.1.

3) A weekly area under the curve (AUC) rTSS value for each participant was calculated. This was done using GraphPad Prism which computes AUC using the trapezoid rule ("How to: Area under the curve," 2019).

4) Acute Training Load (ATL) was calculated as a 7-day rolling average of rTSS (Gabbett, 2016; Murray et al., 2017).

5) Chronic training load (CTL) was calculated as a 28-day rolling average of rTSS.

6) The Acute: Chronic Workload Ratio (ACWR) is defined as the ATL divided by the CTL (Banister et al., 1975; Banister & Calvert, 1980; Hulin et al., 2014).

7) The coefficient of variation (CV) was calculated as the standard deviation (SD) divided by the mean then multiplied by 100.

8) A total running duration was calculated by the sum of the 11-weeks for each participant.

9) The data for weekly AUC rTSS, running duration, and IF were normalised using Z-scores to standardise values for the participants. The Z-score was

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calculated by taking the daily measure subtracted from the mean for that week and divided by the SD of that week's mean value. Z-scores of ≥ 1 or ≤ -1 were considered to be a significant change in training load (Crowcroft, McCleave, Slattery, & Coutts, 2017).

Statistical Analyses

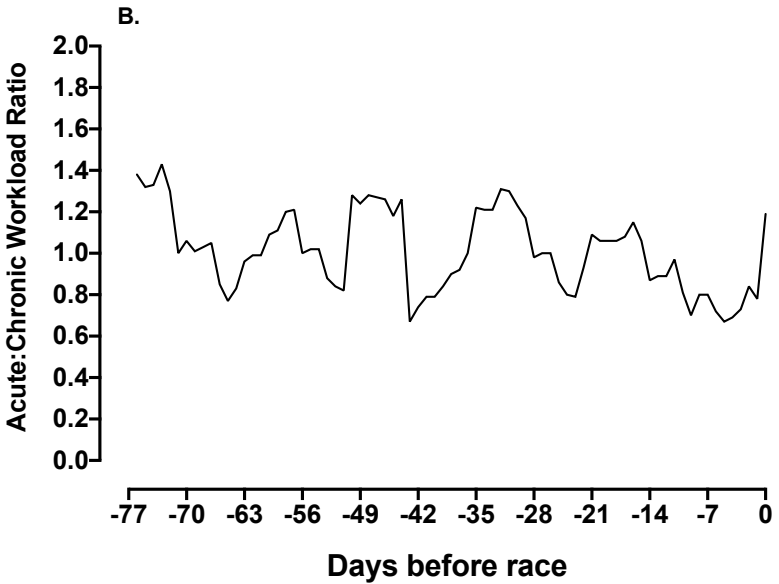
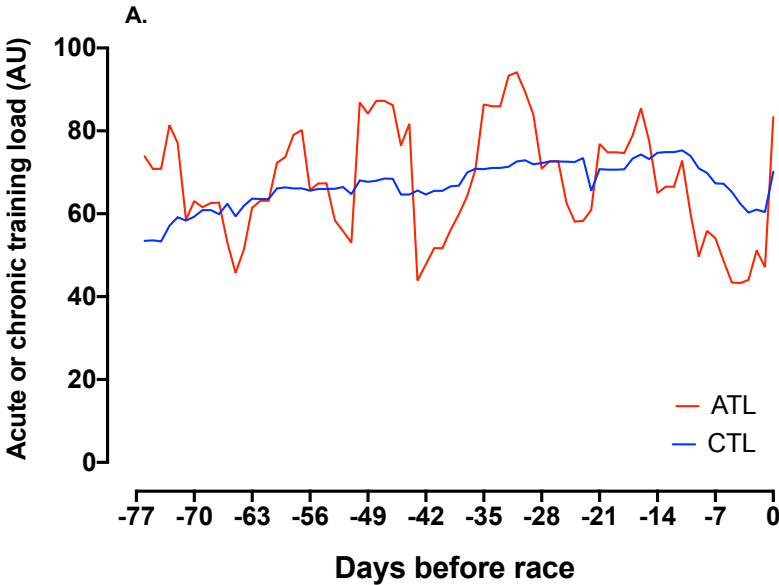
Graphpad Prism (GraphPad Software, San Diego, California USA, www.graphpad.com) was used for statistical analysis. Linear regression analyses were used to determine relationships between relative race performance and: sum running duration for the 11-weeks; average IF for the 11-weeks; CV AUC; CV running duration; CV IF (all CV were for the 11-weeks); and best 10-km race time.

Multiple variable analyses using correlation matrices were used to determine correlation coefficients between relative performance and: AUC rTSS, running duration, and IF each week leading up to the marathon.

Results

Case Studies

The data of each of the 19 participants were analysed and reported as individual case studies. The following graphs were drawn for all participants: Daily ATL & CTL; daily ACWR; weekly AUC rTSS; weekly running duration; weekly average IF; weekly Z-scores for AUC rTSS; running duration; & IF. A sample case study is shown in Figure 6.3.1A-G. The individual graphs of the remaining 18 participants are shown in the Appendix 6.3 Figure 1 addendum.



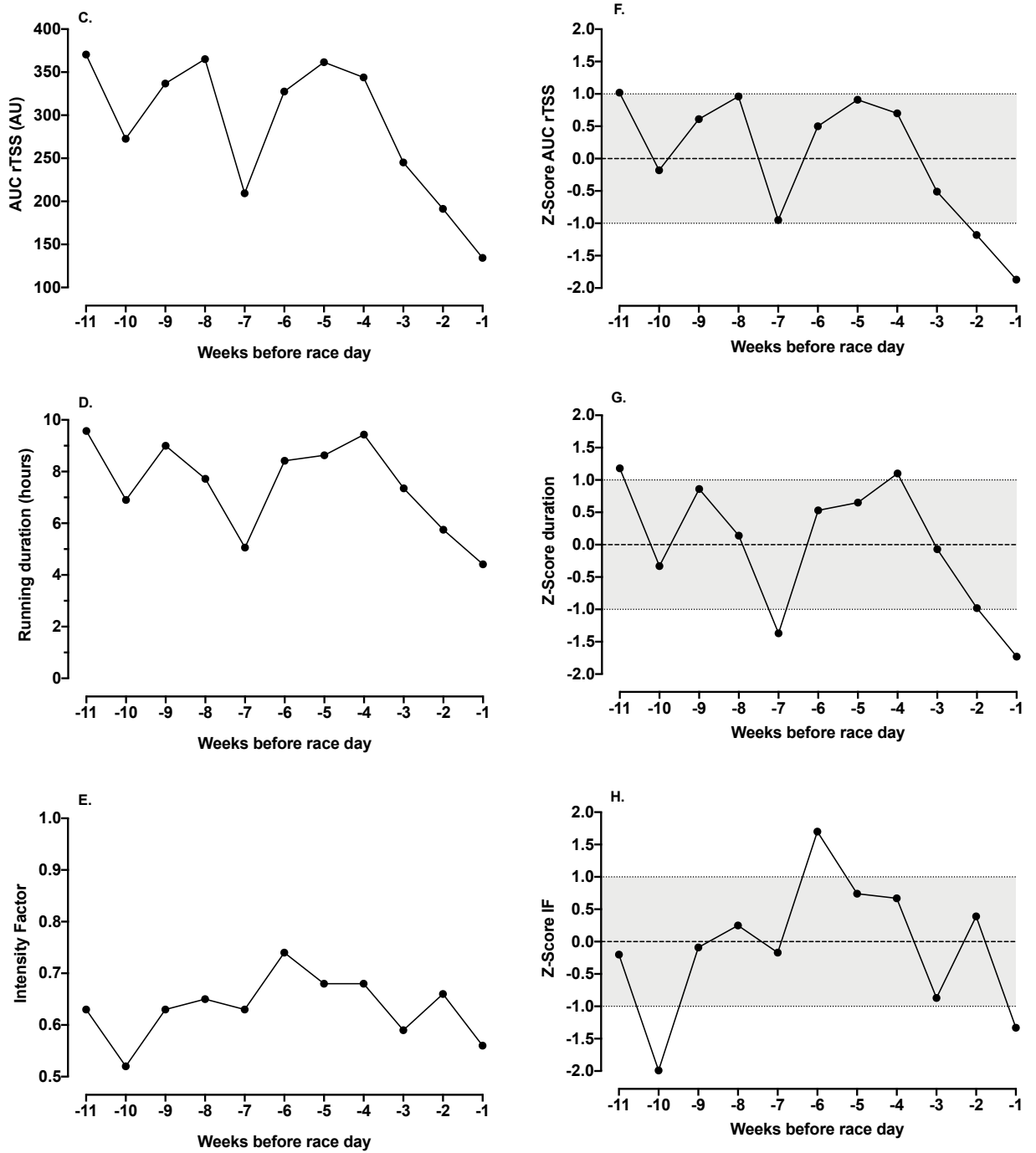


Figure 6.3.1A-H. Case study figures for Participant #1. **A)** Daily ATL & CTL; **B)** Daily ACWR; **C)** Weekly area under the curve (AUC) running training stress score (rTSS); **D)** Weekly running duration; **E)** Weekly average intensity factor; **F)** Weekly normalised AUC rTSS; **G)** Weekly normalised running duration; **H)** Weekly normalised intensity factor. The shaded region in F - H represent the region of no significant change. Data points outside the shaded region are considered a significant change.

Correlations

The correlations between relative race performance and measurements of training load are shown in Figure 6.3.2A-F. Relative performance was calculated as the race time in minutes divided by the predicted best marathon race time in minutes (Riegel, 1981). There was no significant relationship between total 11-week running duration and relative performance (Figure 6.3.2A). The participant who performed the best (84% relative performance) had a running duration of 50 hours while a participant with a performance 15% slower than their predicted best time ran a total of 85 hours. There was no significant relationship between relative performance and average intensity factor (Figure 6.3.2B). In the 100 – 105% relative performance range the average intensity factors ranged from 0.66 – 0.86. There was no significant relationship between relative performance and the CV of any of the training load variables (running duration, IF, AUC rTSS) (Figures 6.3.2C, D, & E respectively). Finally, there was no significant relationship between relative performance and best 10-km race time (Figure 6.3.2F).

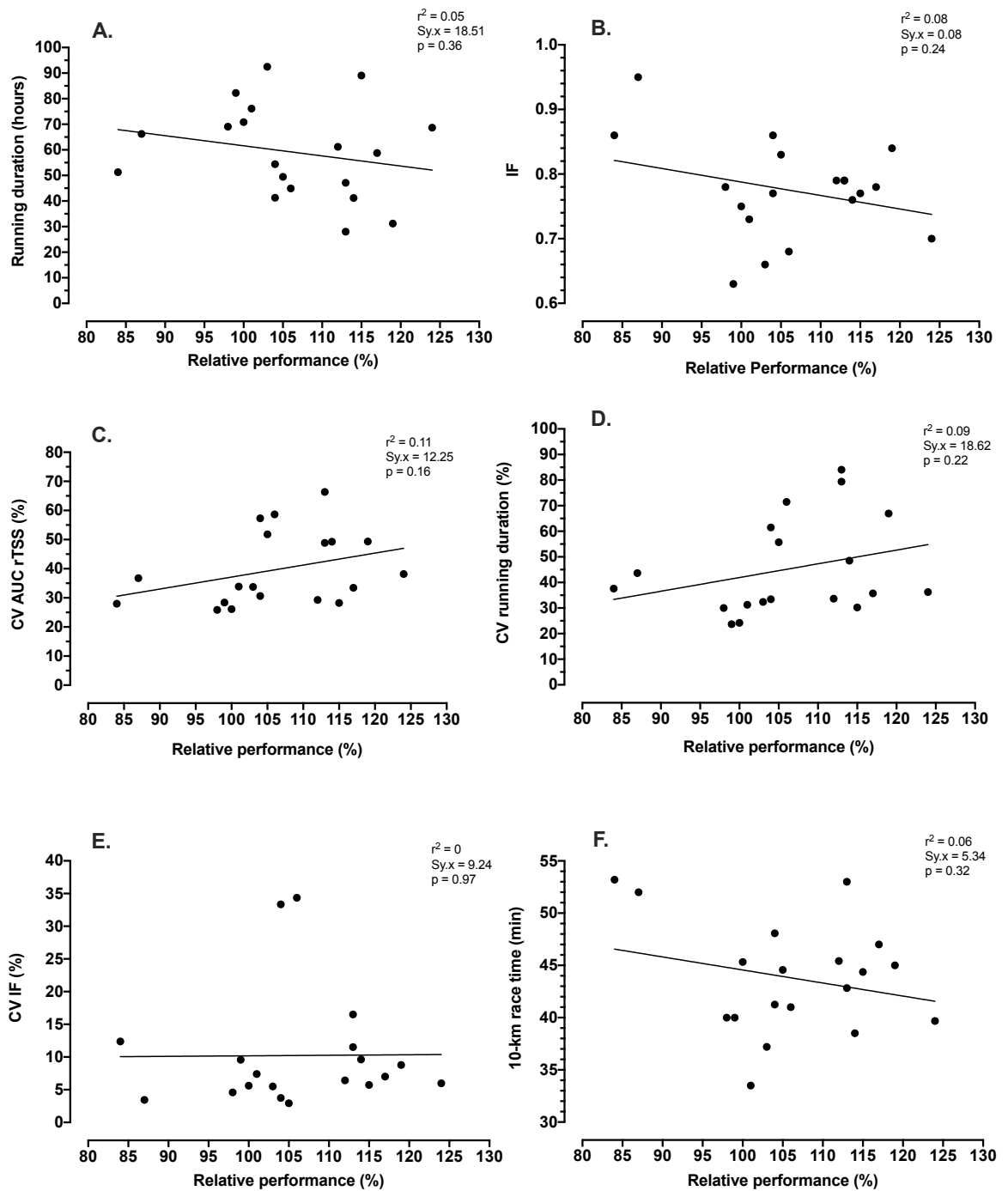


Figure 6.3.2A-F. Relationships between relative performance and: **A)** total 11-week running duration; **B)** 11-week average intensity factor; **C)** 11-week coefficient of variation (CV) for area under the curve running training stress score (AUC rTSS); **D)** 11-week CV running duration; **E)** 11-week CV intensity factor; & **F)** best 10-km race time. $Sy.x$ = standard deviation of estimate. $n = 19$ for A-F.

Normalised Data

When data were normalised and represented as Z-scores there was no group change in AUC rTSS until one week before the marathon race when AUC rTSS decreased (Figure 6.3.3A). When data were graphed with each participant's change over time (Figure 6.3.3B):

- 32% of participants had an increase in AUC rTSS in the seventh week before the marathon.
- 26% of participants had an increase in AUC rTSS in the sixth and fourth week before the race.
- 21% of participants had an increase in AUC rTSS in the fifth week before the race.
- 79% of participants had a decrease in AUC rTSS in the one week before the race.
- 21% had a decrease in AUC rTSS in the fifth week before the race.
- 16% of participants had a decrease in AUC rTSS in the second week before the race.

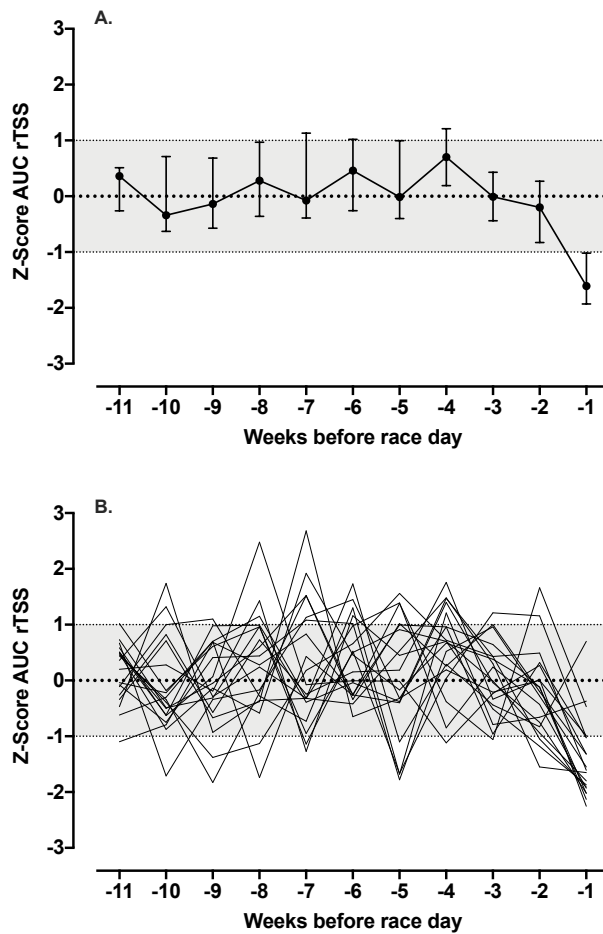


Figure 6.3.3A-B. **A)** Data are presented as median \pm IQR. $n = 19$. Normalised group data for weekly area under the curve (AUC) running training stress score (rTSS). The shaded region represents the area of no change. **B)** Normalised individual data for weekly AUC rTSS. $n = 19$. Each line represents one participant. The shaded region represents the area of no change.

There was no group change in running duration until one week before the marathon race when running duration decreased (Figure 6.3.4A). When data were graphed with each participant's change over time (Figure 6.3.4B),

- 26% of the participants had an increase in running duration in the seventh, fifth, and fourth week before the marathon.
- In the last week before the race, 79% of participants had a decrease in running duration.
- In the seventh and fifth week before the marathon, 16% had a decrease in running duration.

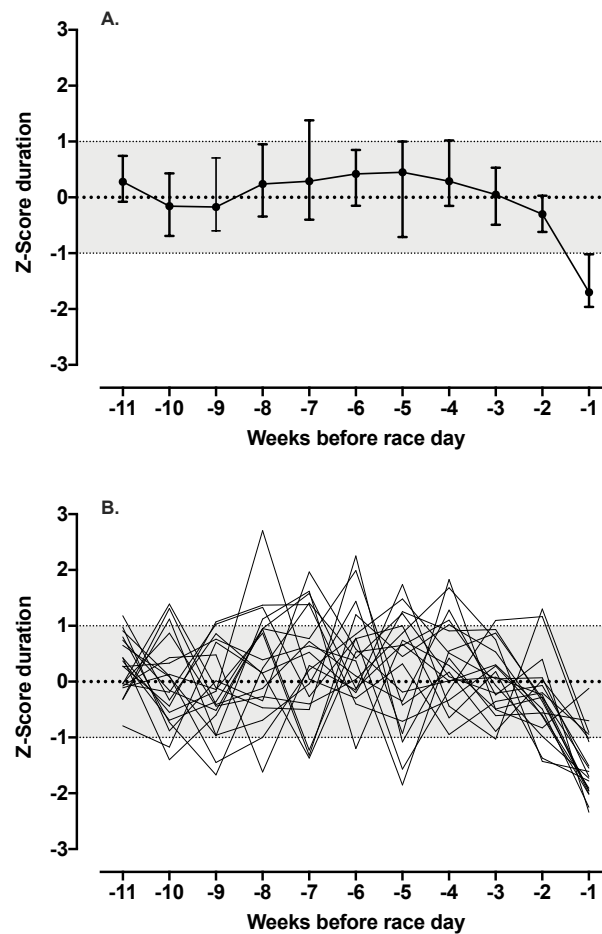


Figure 6.3.4A-B. **A)** Data are presented as median \pm IQR. $n = 19$. Normalised group data for weekly running duration. The shaded region represents the area of no change. **B)** Normalised individual data for weekly running duration. $n = 19$. Each line represents one participant. The shaded region represents the area of no change.

There was no group change in intensity factor in any of the 11 weeks (Figure 6.3.5A). When data were graphed with each participant's change over time (Figure 6.3.5B),

- 26% of the participants had an increase in average running intensity in the last week before the marathon.
- In the sixth and second week before the race, 21% of participants had an increase in running intensity.
- In the tenth and seventh week before the race, 32% of participants had a decrease in running intensity.

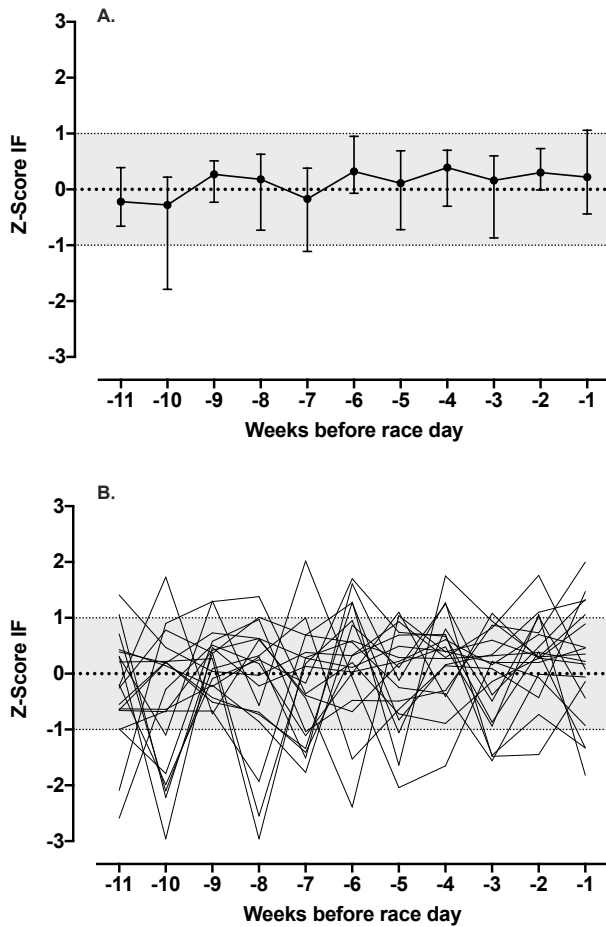


Figure 6.3.5A-B. **A)** Data are presented as median \pm IQR. Normalised group data for weekly average intensity factor (IF). The shaded region represents the area of no change. **B)** Normalised individual data for weekly average intensity factor. Each line represents one participant. The shaded region represents the area of no change.

Figure 6.3.6A-C show the Z-score for each participant's AUC rTSS, duration, and intensity respectively. It also shows each participant's relative performance. Each vertical line of data points represents one participant's 11 weeks of data. The participant with the best relative performance (84%), had an increase in AUC rTSS in the fourth week before the race, and a decrease in the second and last week before the race. The participant with the second best performance (87%), had an increase in AUC rTSS in the seventh and fifth week before the race and a decrease in the ninth and last week before the race. The participant with the worst relative performance (124%) had an increase in AUC rTSS in the seventh and sixth week before the race and a decrease in the fifth and last week before the race. The most consistent pattern across relative performances was

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a decrease in AUC rTSS and running duration in the last week before the marathon.

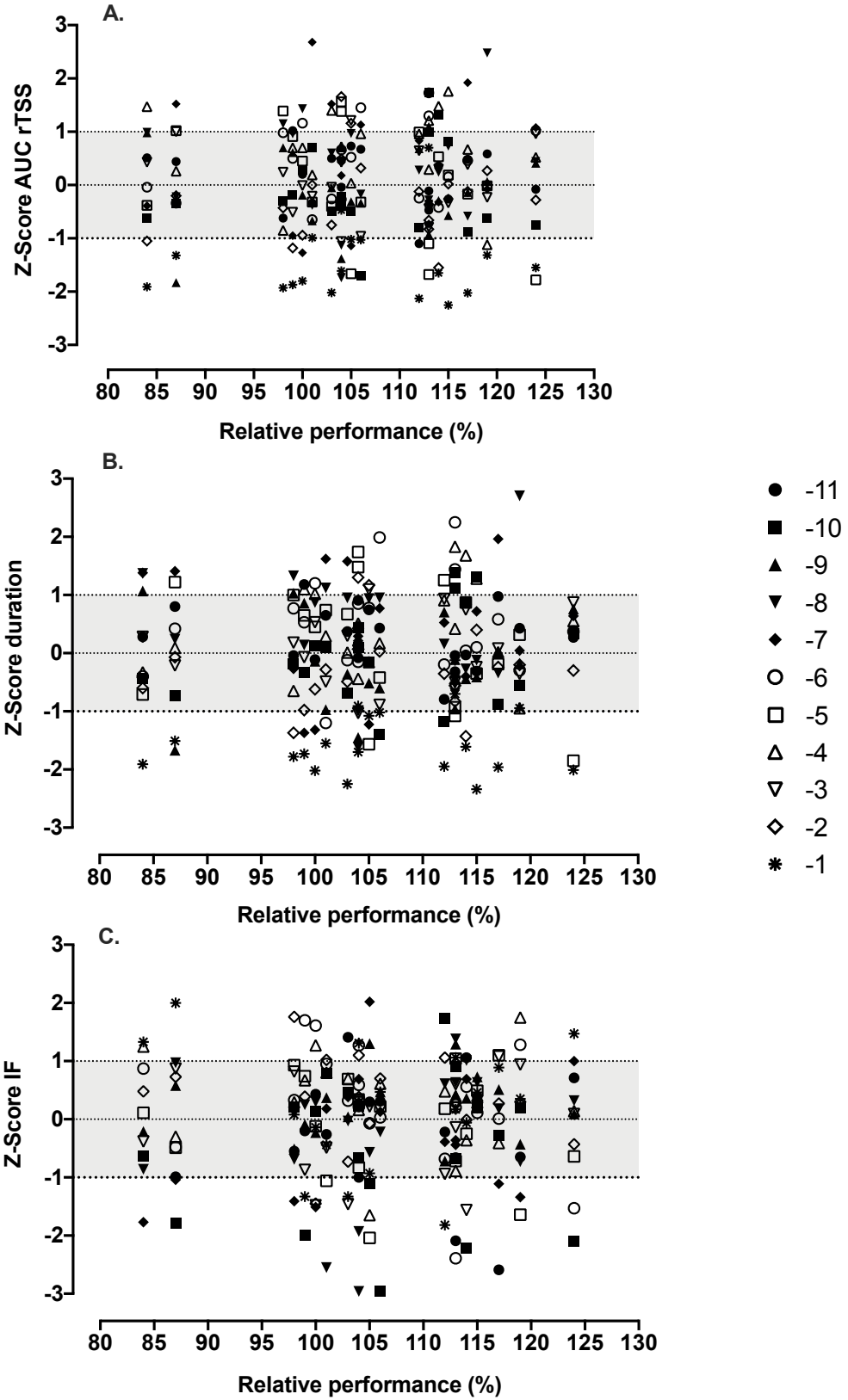


Figure 6.3.6A-C. Normalised weekly data for each relative performance. Each vertical line of data points represents one participant's 11 weeks of data. The shaded region represents the area of no change. **A)** Normalised weekly area under the curve (AUC) running training stress score (rTSS); **B)** Normalised weekly running duration; **C)** Normalised weekly average intensity factor (IF).

Correlation matrix: normalised data

In Figure 6.3.7A-C, correlation coefficients were plotted for each week between relative performance and AUC rTSS, running duration, and IF respectively. The mean \pm 95% confidence intervals (CI) cross zero for all weeks and variables. There were no significant correlations between relative performance and the variables of interest for any week leading up to the marathon.

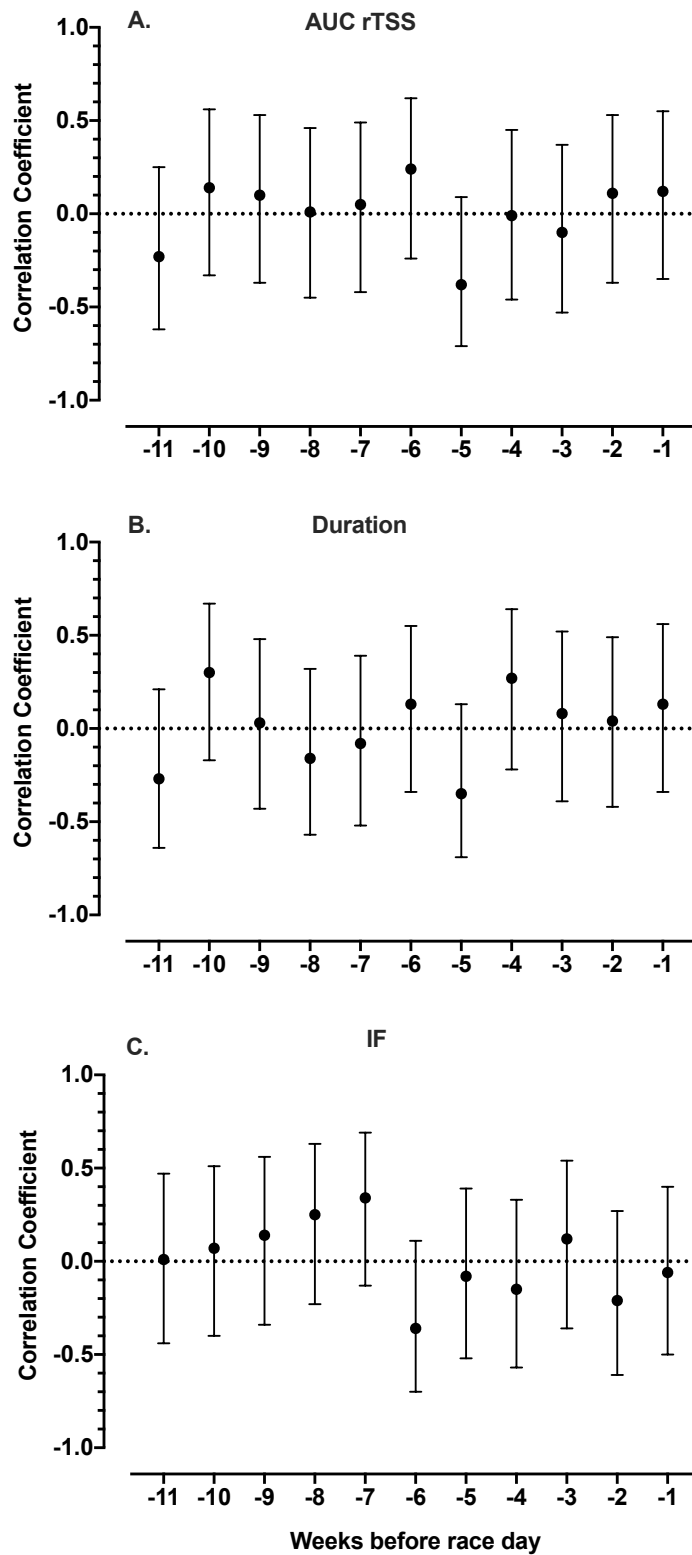


Figure 6.3.7A-C. Data are presented as mean \pm 95% confidence interval. Group correlation coefficients between relative performance and **A)** normalised weekly area under the curve (AUC) running training stress score (rTSS); **B)** normalised weekly running duration; & **C)** normalised weekly average intensity factor (IF). $n = 19$ for A-C.

Discussion

The data from this study suggest there is no relationship between training load and relative performance in this group of well-trained competitive recreational runners. Previous research has also found a lack of relationship between training load and performance (Balsalobre-Fernández et al., 2014; Foster, Daines, Hector, Snyder, & Welsh, 1996; Knechtle, Wirth, Knechtle, Zimmermann, & Kohler, 2009). In contrast, the training load data in Ch.3.2 showed a significant relationship between performance and overall training load in the six weeks leading up to a 56-km race. Runners who trained more had better relative performances. It is reasonable to suggest the lack of relationships in the current dataset is because the participant group is more homogenous than in Ch.3.2. These runners were required to train a minimum of 40 km/week upon enrolment in the study and had a best 10-km race time of ≤ 55 minutes. The participant group in Ch. 3.2 was heterogenous in training load time and performance level. There were no requirements to enrol in the study besides running the 56-km race.

It is important to note the wide inter-individual variation in training load in this participant group. The participant who performed the best ran only 59% of the total hours that the worst performer did. In addition, there was a 20% range in average running intensity in just the 100 – 105% relative performance range. We can only speculate about the reasons for the variation. However, a couple plausible reasons may be: 1) training relative to what they have successfully completed in the past, and 2) other possible life stressors such as work and family. For example, the best performer ran 50 hours vs. the worst performer's 85 hours. It is important to consider the best performer averaged 46 km/week in the six months prior to the study while the worst performer averaged 64 km/week during the same time. So, it is likely the best performer had lower running duration during the 11 weeks before the race, because he was not accustomed to training as much as other participants. Stress does impact training and performance (Bali, 2015), therefore runners with demanding jobs and/or families to care for may be unable to train with as high a volume as an

athlete who works less or has no family commitments. Factors such as genetics, age, nutrition, and psychological state should also be considered (Mann et al., 2014).

When data were normalised and represented as Z-scores there was no group change in AUC rTSS or running duration until one week before the marathon race. This indicates that a majority of the participants (79%) decrease their running time in the week before the marathon. In Ch.3.2 we also found a decrease in training load in the week before a 56-km race. This reduction represents the taper period. Research has shown planned systematic reductions in training volume can lead to improvements in aerobic capacity and performance (Hickson et al., 1982, 1985; Mujika et al., 1996). As discussed in Ch.3.2, previous research on tapering suggests that a 12 – 14 day reduction in training load is optimal (Banister et al., 1999; Morton, 1997). This is now the second dataset with a different study population that did not decrease load until the last week before the race. It seems reasonable to suggest that recreational runners may not require as long of a taper as elite level athletes, because their overall training loads are significantly lower. With less overall stress, there may be a shortened recovery time needed for supercompensation to occur (Cunanan et al., 2018).

An interesting finding is the wide variation when the largest training load was completed before the race. About 30% of participants completed their largest week of training seven weeks before the marathon race. And about 25% of participants completed their largest week of training six and four weeks before the race respectively. Finally, about 20% of participants completed the largest week of training five weeks before the marathon. Therefore, nearly 80% of participants completed their largest week of training anywhere from four weeks to seven weeks before the race. A study of three elite marathoners, showed they completed their highest volume of running six, eight, and nine weeks before the marathon race (Stellingwerff, 2012). Coaching literature suggests peak week of training should occur approximately four weeks before a marathon (“Marathon Training: The Long Run”). This could be an explanation for the relatively poor performances in this study. Only 21% of participants had a relative performance

faster than their predicted best marathon time. With recreational runners completing far lower training volumes compared to elite runners, they may need to time their peak week of training closer to the race day.

Intensity factor remained constant throughout the 11 weeks leading up to race day. Previous research suggests exercise intensity should be maintained during a taper (Hickson et al., 1982, 1985; Wittig et al., 1989, 1992). This suggests this group follows recommended tapering techniques regarding intensity. This also indicates that running duration contributes more to changes in training load than intensity in this group. Over 66% of the participants had increases in running intensity in either the sixth, second, or one week before the race. This indicates that when runners had their largest week of training (seven – four weeks before race day) it was mainly due to running more volume. It is interesting that 25% of the participants had an increase in running intensity in the last week before the race when the volume tapered off. The participants who had an increase in running intensity in the last week before the race had performances that ranged from 84% (the best relative performance) to 124% (the worst relative performance). There was no relationship between change in running intensity in the week before the race and relative performance.

The correlation coefficients between relative performance and the training load variables indicate the lack of any significant relationships and wide variability. There are other factors besides training load that should be considered in the effects on relative performance. These may include stress (Bali, 2015), sleep (Reilly & Piercy, 1994; Soussi et al., 2008), weather on race day (Tatterson, Hahn, Martini, & Febbraio, 2000), nutrition on race day (Burke, Millet, & Tarnopolsky, 2007), and/or pacing on race day (March et al., 2011; Renfree & Gibson, 2013).

Limitations

One limitation in the current study is that not all participants competed in the same marathon race. Ten out of 19 participants competed in the Cape Town marathon. Four out of 19 participants competed in the Soweto Marathon. Two

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out of 19 participants competed in the Bluff marathon. The remaining three participants competed in the Berlin marathon, Abingdon marathon, and Onward Shay marathon respectively. We controlled for this limitation by adjusting race times for elevation gain (Norman, 2004) so that all times would match the elevation gain at the Cape Town marathon – the race 53% of participants competed in.

Another limitation to consider is the possible effect of weather conditions on race performance. The range in temperature at the various races was six degrees Celsius (13 – 19 degrees C). The range in wind speed was 23 km/h (6 – 29 km/h) with the Cape Town marathon displaying the windiest conditions and Soweto marathon a close second (27 km/h). However, the two participants with the best relative performances participated in the Cape Town marathon and the Soweto marathon.

There are other factors that may have affected performance such as nutrition, sleep deprivation, or stress. In addition, there is likely variation among participants in terms of their motivation to run the marathon at a maximal effort. There is also the possibility that a participant's best 10-km time in the previous 12 months was not an accurate representation of their fitness level on the day of the marathon. These limitations are expected in field research, and are minor in comparison to the benefit of the ecological validity of the study results.

Conclusion

In conclusion, there is no relationship between different measures of training load and relative performance in this group of well-trained competitive recreational runners. Running duration decreased in the one week before the marathon race. Factors such as stress, sleep, weather, race day nutrition and/or pacing may be related to performance and should be considered in future research. Future research should also determine relationships between training load, performance, and internal training load variables.

Study 4: Relationships between training load, submaximal heart rate, and performance using the FINISHER running test

Introduction

The training principle of overload states that an athlete must progressively increase their training load with the goal of improved performances (Zaryski & Smith, 2005). The progressively increased training load needs to be balanced with adequate recovery between training sessions. As athletes gain more experience and reach higher performance levels, achieving the balance between training load and recovery becomes more challenging. If an optimal balance is not achieved, there is an increased risk of overuse injury and/or poor performances (Budgett, 1998; Halson & Jeukendrup, 2004; Urhausen & Kindermann, 2002). To further complicate the issue, there is individual variability in response to the same training load (Bouchard & Rankinen, 2001; Hautala et al., 2006; Mann et al., 2014; McPhee, Williams, Degens, & Jones, 2010; Scharhag-Rosenberger, Walitzek, Kindermann, & Meyer, 2012). Each athlete has a unique balance between training load and recovery. Therefore it is not possible to have a template for training that is standardised. Rather, training loads need to be adjusted based on how the athlete is adapting.

To assist with markers of training adaptation it would be helpful for sports scientists and coaches to have a field test that athletes can perform to indicate whether they may need adjustments to their training plan. In accordance with this Vesterinen et al. (2016) tested the ability of a submaximal field test to determine endurance training adaptation. The 16-minute test was performed weekly and included six minutes at 70% heart rate (HR) max, six minutes at 80% HR max, and three minutes at 90% HR max. The authors found significant correlations between running speed during the test and endurance performance variables such as VO₂ max and peak running speed. The authors showed that a submaximal field test performed without supervision can be used to monitor training adaptation. However, the study was not designed to determine any possible rationale for poor performances during the tests. In addition, running at a target HR as required in this test, is practically challenging compared to running at a target speed or rating of perceived exertion (RPE) level. As discussed in Chapter 5, the ideal test should be submaximal, be incorporated as

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a workout that can be repeated on a regular basis, and require minimal equipment. Using these parameters, we designed the fartlek run using speed and HR (**FINISHER**) test and determined its reliability as described in Chapter 5.

Heart rate is an objective measurement that provides feedback about the state of the autonomic nervous system. An increase in HR during exercise at the same running speed reflects an increase in sympathetic nervous system activity, while a decrease in HR reflects a withdrawal of sympathetic nervous system activity and an increase in parasympathetic activity (Robinson et al., 1966). Considering the accuracy and simplicity of measuring submaximal HR data in the field, the technique is underused by sports scientists. Much research emphasis is placed on HR recovery and HR variability. However, the application of these techniques by runners and coaches as an aid to training is low. Submaximal HR can be measured during training and does not require any additional time from the athlete before or after the training session. In addition, a well-designed workout repeated on a weekly basis can easily be included as part of the athlete's training programme.

There is a lack of research regarding relationships between HR, performance, and training load in well-trained competitive recreational runners. There is agreement in the literature that when an untrained individual becomes trained, submaximal HR at the same running speed decreases (Hedelin et al., 2000; Skinner et al., 2003; Uusitalo, 2001; Wilmore et al., 2001). There also is some agreement that a large increase in training load in well-trained athletes, either through a race or an overload training period of one - two weeks, is associated with decreases in submaximal HR (Bellenger et al., 2017; Hedelin et al., 2000; Siegl et al., 2017). However, the increases in training load in those studies is often not ecologically valid. Acute fatigue may be associated with a decrease in HR, but how it is associated with smaller, more ecologically valid increases in training load is unknown.

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The main aim of this study was to determine the relationships between training load, submaximal HR, and performance using the **FINISHER** test in a group of well-trained competitive recreational runners.

Methods

Participants

Forty-one well-trained competitive recreational runners enrolled in the study. Out of the 41 participants, data sets from 29 participants (female n = 6; male n = 23) were used for data analysis. The reasons for the 12 excluded participants included: did not complete an adequate number of **FINISHER** tests; did not perform the **FINISHER** tests correctly; did the **FINISHER** tests on varying terrain; did not have adequate or accurate HR readings; or did not participate in any races during the period of the study. All participants provided written informed consent and the research study was approved by the University of Cape Town Human Research Ethics Committee (HREC REF: 017/2018). The demographics are in Table 6.4.1. Inclusion and exclusion criteria for the participant group were described in Ch. 6.1, and were the same for this study. Participants used the following Global Positioning Systems (GPS) devices: Suunto Ambit[®] Series, n = 4; Polar M600[®], n = 1; Garmin Fenix[®] Series, n = 7; Garmin Forerunner[®] Series, n = 7; Garmin Forerunner[®] XT Series, n = 10.

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Table 6.4.1. Participant Characteristics.

Participant ID Number	Age (yrs)	Height (cm)	Weight (kg)	Experience (yr)	Dist per/week (km)	10-km Time (mm:ss)
P1	37	167	72	1	60	49:13
P2	30	169	61	4	45	38:30
P3	47	168	56	27	80	44:22
P4	47	181	73	6	60	40:00
P5	43	161	67	5	45	48:39
P6	47	183	70	5	60	39:26
P7	29	169	68	2	40	54:59
P8	39	190	85	8	55	48:04
P9	31	178	77	4	45	44:55
P10	47	177	66	2	60	45:25
P11	43	185	82	7	64	39:41
P12	39	156	50	3	70	44:34
P13	34	184	77	3	55	41:00
P14	40	170	61	10	60	37:40
P15	42	170	58	3	46	53:12
P16	47	166	62	3	50	46:47
P17	45	190	81	20	60	42:08
P18	41	176	81	15	45	53:00
P19	22	174	62	2	80	36:20
P20	26	183	83	2	25	45:00
P21	36	168	76	5	70	52:00
P22	32	175	78	2	70	42:50
P23	36	189	77	4	78	41:15
P24	29	157	56	1	40	46:36
P26	47	168	64	27	85	37:42
P27	32	175	86	2	50	45:00
P28	44	172	67	15	45	53:56
P29	32	180	80	7	54	36:46
P30	33	174	54	12	65	45:19
Mean ± SD	38±7	174±9	70±10	7±7	57±14	44:38±5:25

Data are presented as mean ± SD. n = 29. Years Exp = Number of years of running experience previous to study enrolment. Dist per/week = Average running distance per week for the six months previous to study enrolment. 10-km Time = Best 10-km race time within the last 12 months.

Study protocol

Runners were enrolled in the study for six months. Each participant received a Training Peaks™ athlete account whereby all GPS data were collected. This enabled the study personnel to see the route completed and the athlete to make comments about weather, illness, etc. The time of day of each run was recorded from the GPS file. The ambient temperature and wind speed for the **FINISHER** runs was recorded using the website: <https://www.timeanddate.com/>. Runners were instructed to perform the **FINISHER** test once per week and a 5-km time trial bi-weekly. The 5-km time trials were excluded from statistical analyses due to: lack of compliance; participants completing the time trials on differing routes; and/or uncertainty whether the time trial was completed at a maximal effort. Twenty-six out of the 29 participants were unable to complete all **FINISHER** tests due to circumstances such as illness, scheduling conflicts, or adverse weather conditions. On average, the 29 participants completed 17 **FINISHER** tests out of 24 (71% compliance). The participants were encouraged to complete the **FINISHER** test on the same day, time, and place each week. They were sent a newsletter educating them about factors that can affect HR such as diurnal changes (Reilly, 1984), hydration (Gonzalez-Alonso, Mora-Rodriguez, Below, & Coyle, 1997) caffeine, sleep, and stress (Cho, 2004; Sloan et al., 1994). They were also educated in the newsletter about best practices for using a chest strap HR monitor and signs indicating the battery in the transmitter/monitor needs to be replaced.

The **FINISHER** test is a fartlek run with seven intervals of three minutes each in duration with two minutes of easy jogging between intervals. It has previously been discussed in detail in Ch.5.1. In brief, the rating of perceived exertion (RPE) intensities of the intervals are the following (in order that they are completed):

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- RPE 1 (very easy)
- RPE 3 (moderate)
- RPE 4 (sort of hard)
- RPE 5 (hard)
- RPE 6 (hard)
- RPE 8 (really hard)
- RPE 9 (really, really hard)

Training Load Calculations

Training load was calculated using a running training stress score (rTSS) (McGregor et al., 2009). The formula for $rTSS = \text{duration (hours)} * \text{intensity factor (IF)}^2 * 100$. This was previously described in Ch. 3.2 and Ch.6.1. Acute Training Load (ATL) was calculated as a 7-day rolling average of rTSS (Gabbett, 2016; Murray et al., 2017). Chronic Training Load (CTL) was calculated as a 28-day rolling average of rTSS. The Acute: Chronic Workload Ratio (ACWR) calculation = ATL divided by the CTL (Banister, 1975; Banister & Calvert, 1980; Hulin et al., 2014). Participants were requested to log session RPE values after each run. However, only 34% of participants complied with this request so these data were excluded from training load calculations. The session RPE values leading up to positive or negative performances for the 10 participants who complied are in Appendix 6.4.sRPE.

Data Analysis

Participant characteristics are presented as mean \pm standard deviation (SD). Minutes one – three (the final two minutes) of each interval of the **FINISHER** test were analysed for average speed and HR. The first minute of each interval was excluded from analysis to allow HR and running speed to reach steady state. A line of best fit (HR vs. running speed) and correlation coefficient were calculated from the seven intervals. The equation for the best fit line was used to calculate a predicted HR at four speeds (either 10, 12, 14, and 16 km/h or 8, 10, 12, and 14 km/h). The four speeds were chosen to represent a diverse range of speeds for the specific participant. Microsoft Excel 2016 was used for the above analyses.

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To determine positive and negative performance days, the average speed for each of the seven intervals was calculated. The mean speed \pm 95% confidence interval (CI) was calculated for each interval taking all the fartlek runs completed into account. A positive performance was defined as a speed faster than the mean plus 95% CI at RPE 9. A negative performance was defined as a speed slower than the mean minus 95% CI at RPE 9.

Graphpad Prism (GraphPad Software, San Diego, California USA, www.graphpad.com) was used for all remaining analyses. Due to the presence of non-normal distributions and unequal variances, non-parametric statistical analyses were performed. To determine training load leading up to positive and negative performance days, the ATL, CTL, and ACWR on positive and negative performance days were compared using Mann-Whitney tests. The average ACWR in the seven days and 28 days preceding the positive or negative performance was calculated and compared using Mann-Whitney tests. The predicted HR for the four speeds on positive and negative performance days was compared using Mann-Whitney tests.

The relative performance was calculated by using the speed at RPE 9 on each **FINISHER** test divided by the fastest speed at RPE 9 out of all the tests performed. The relative HR was calculated by taking the predicted HR at speed 14 or 16 km/h (speed four) on each **FINISHER** test divided by the highest predicted HR at speed four out of all the tests performed.

The magnitude of the relationships between 1) Relative HR and relative performance; 2) ACWR and relative performance; and 3) ACWR and relative HR were determined using linear regression analyses.

The Mann-Whitney test statistics for relative and absolute HR comparisons on positive vs. negative performance days were transformed into effect sizes (Cohen, 2008; Fritz, Morris, & Richler, 2012). The thresholds for determining magnitudes of the transformed effect sizes were: *trivial* ($d < 0.2$), *small* ($d = 0.21$), *moderate* ($d = 0.6$), and *large* ($d = 1.2$) (Hopkins et al., 2009).

Results

The data are presented as grouped data followed by selected individual cases.

Group Results

The training load was not different leading up to positive or negative performances (Figure 6.4.1A-C). The ATL (POS- 63 ± 25 , $n = 110$ data points, NEG- 64 ± 26 , $n = 97$ data points (med \pm IQR), $p = 0.31$,)) (Figure 6.4.1A), CTL (POS- 66 ± 21 , $n = 96$ data points, NEG- 67 ± 16 , $p = 0.80$, $n = 82$ data points) (Figure 6.4.1B), and ACWR (POS- 0.99 ± 0.22 , $n = 94$ data points, NEG- 1.04 ± 0.29 , $n = 81$ data points, $p = 0.12$) (Figure 6.4.1C) were the same on positive and negative performances.

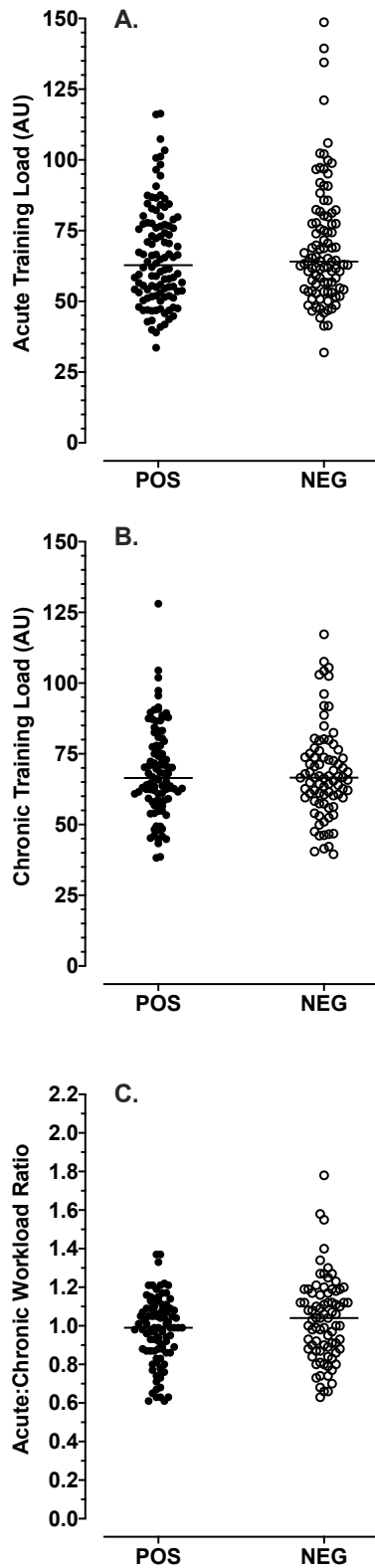


Figure 6.4.1A-C. Data are presented as individual data points with group median represented with horizontal lines. POS = Positive performance. NEG = Negative performance. The **A)** ATL, **B)** CTL, and **C)** ACWR on positive and negative performance days for each participant (n = 28)*.

*One participant was excluded from this analysis due to predominantly participating in cycle training between fartlek runs.

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As a group, the relative HR was higher on negative performance days vs. positive performance days for speed two (POS- 78 ± 5 %, NEG- 80 ± 7 %, $p = 0.049$), speed three (POS- 86 ± 4 %, NEG- 88 ± 5 %, $p < 0.0001$), and speed four (POS- 93 ± 5 %, NEG- 96 ± 6 %, $p < 0.0001$) (Figure 6.4.2A-C). The effect size was considered *moderate* for speed four ($d = 0.71$), *moderate* for speed three ($d = 0.65$), *small* for speed two ($d = 0.27$), and *trivial* for speed one ($d = 0.19$). The HR was the same for positive and negative performances for speed one (POS- 71 ± 9 %, NEG- 73 ± 9 %, $p = 0.17$) (Figure 6.4.2D). There was only one instance of a 100% relative HR at speed four on a positive performance day (0.84% of all data points). In contrast, there were 17 instances of 100% relative HR at speed four on a negative performance day (17% of all data points). For 99% relative HR, there were two instances on a positive performance day (2% of all data points) and seven instances on a negative performance day (7% of all data points). For 98% relative HR, there were seven instances on a positive performance day (6% of all data points) and 12 instances on a negative performance day (12% of all data points).

The absolute HR values for speeds one – four reveal similar results to the relative HR. The absolute HR was higher on negative days vs. positive days for speeds two (POS- 144 ± 18 , NEG- 148 ± 19 , $p = 0.025$), three (POS- 159 ± 17 , NEG- 162 ± 17 , $p = 0.007$), and four (POS- 173 ± 14 , NEG- 177 ± 17 , $p = 0.002$). The effect size for speed four was *small* ($d = 0.43$), for speed three it was *small* ($d = 0.37$), speed two it was *small* ($d = 0.30$), and speed one it was *trivial* ($d = 0.20$). The HR was the same for speed one (POS: 131 ± 22 , NEG- 133 ± 21 , $p = 0.14$).

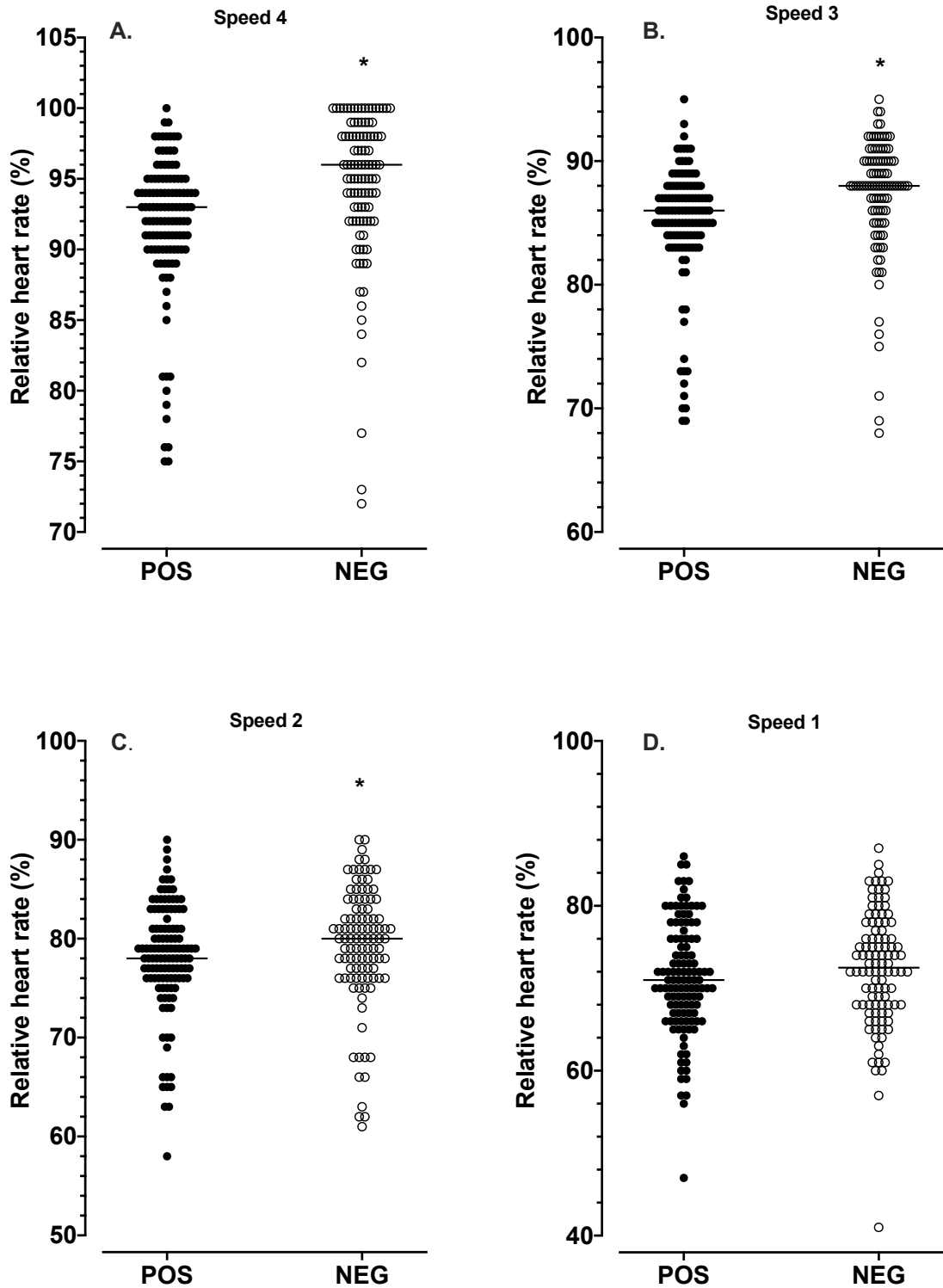


Figure 6.4.2A-D. Data are presented as individual data points with group median represented with horizontal line. POS = Positive performance. NEG = Negative performance. The predicted HR values for speeds four, three, two, and one respectively on positive and negative performance days for each participant (n = 28)*.

* p < 0.05 vs. POS.

* One participant was excluded from this analysis due to faulty HR readings.

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All data were pooled to determine possible relationships between training load, performance, and HR (Figures 6.4.3A-C). There was no significant relationship between the ACWR and relative performance (Figure 6.4.3A) ($r^2 = 0.01$, $S_{y.x}$ (standard deviation of estimate) = 6.5 $p = 0.12$). There was a significant negative linear relationship between relative HR at speed four and relative performance (Figure 6.4.3B) ($r^2 = 0.04$, $S_{y.x} = 6.5$, $p = 0.005$). There was no significant relationship between ACWR and relative HR at speed 4 (Figure 6.4.3C) ($r^2 = 0$, $S_{y.x} = 5.3$, $p = 0.92$).

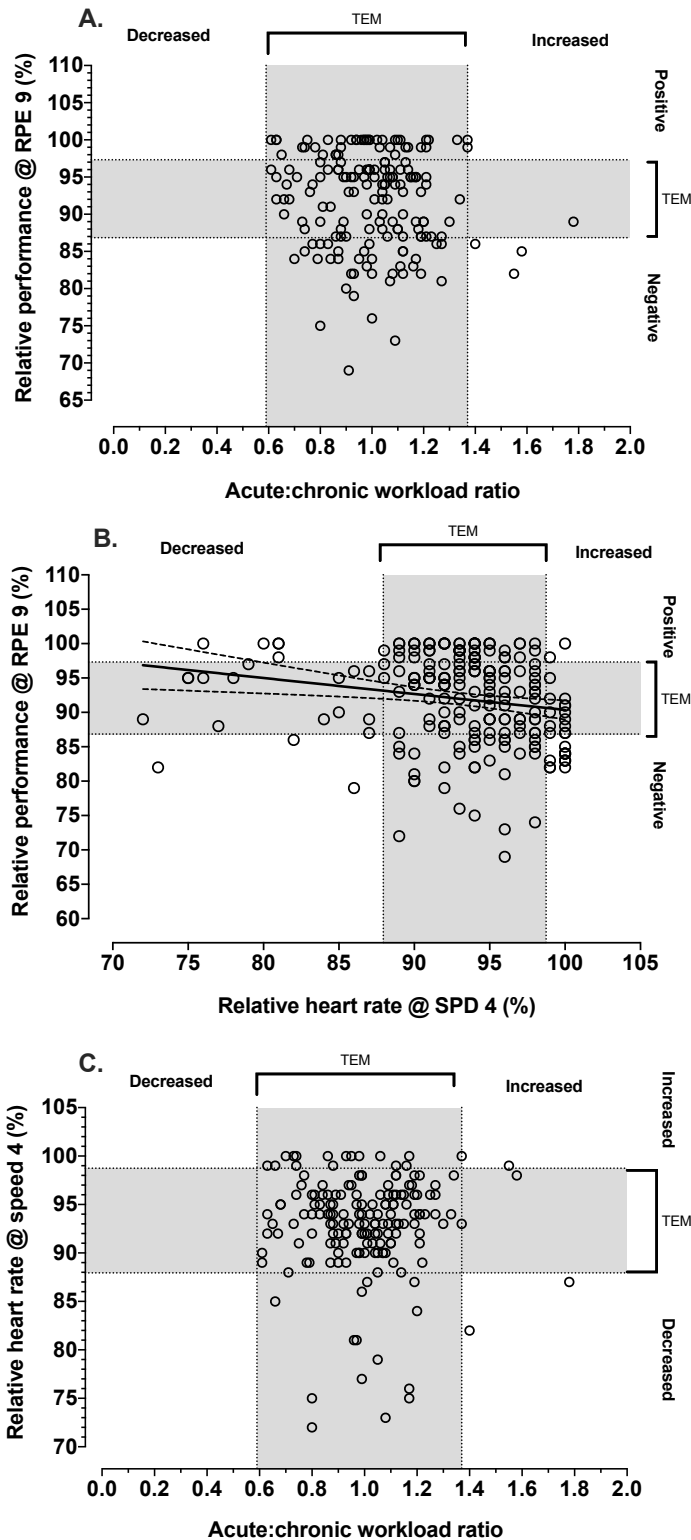


Figure 6.4.3A-C. Individual relationships between, **A)** The ACWR and relative performance (n = 26)*, **B)** Relative HR and relative performance (n= 28)^ and **C)** ACWR and relative HR (n = 26)*. Each data point represents a **FINISHER** test. The grey shaded regions represent the mean \pm typical error of measurement (TEM). In Figure **B)** the solid line represents the line of best fit. The dotted lines represent the 90% confidence interval (CI) around the line of best fit.

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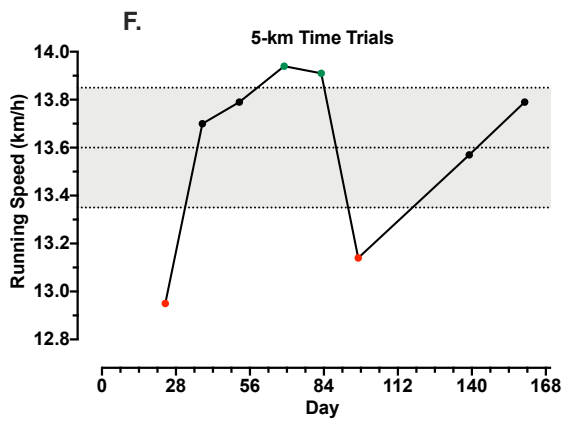
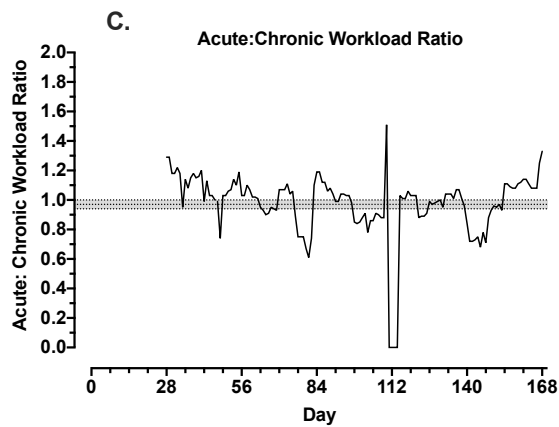
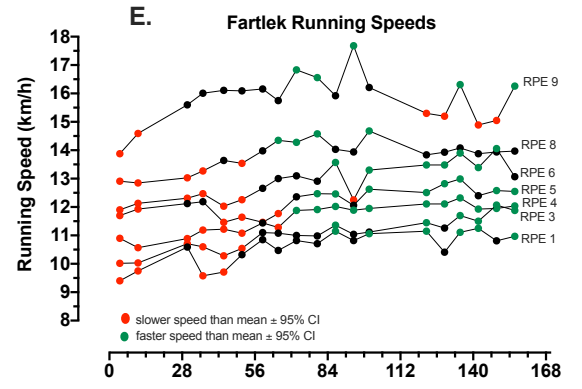
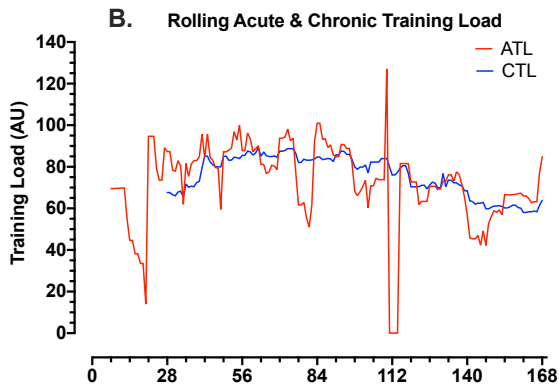
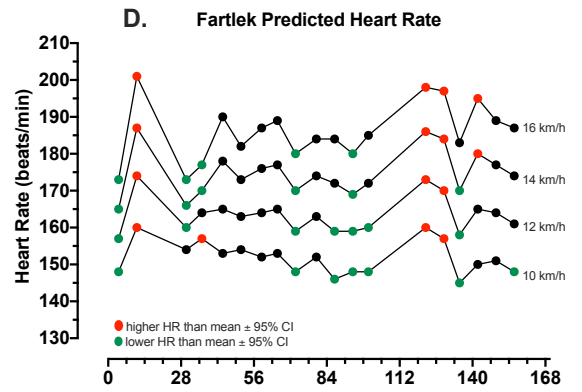
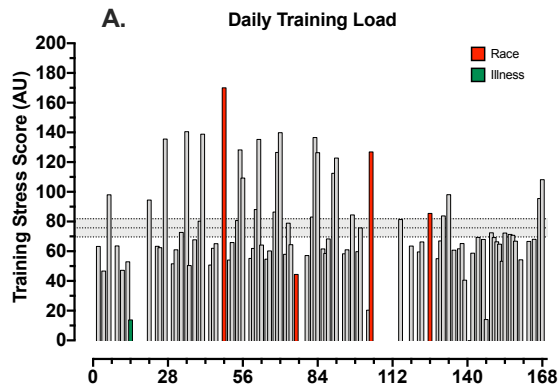
**One participant was excluded from this analysis due to predominantly participating in cycle training between fartlek runs. Two participants were excluded due to a lack of data points to determine a relationship.*

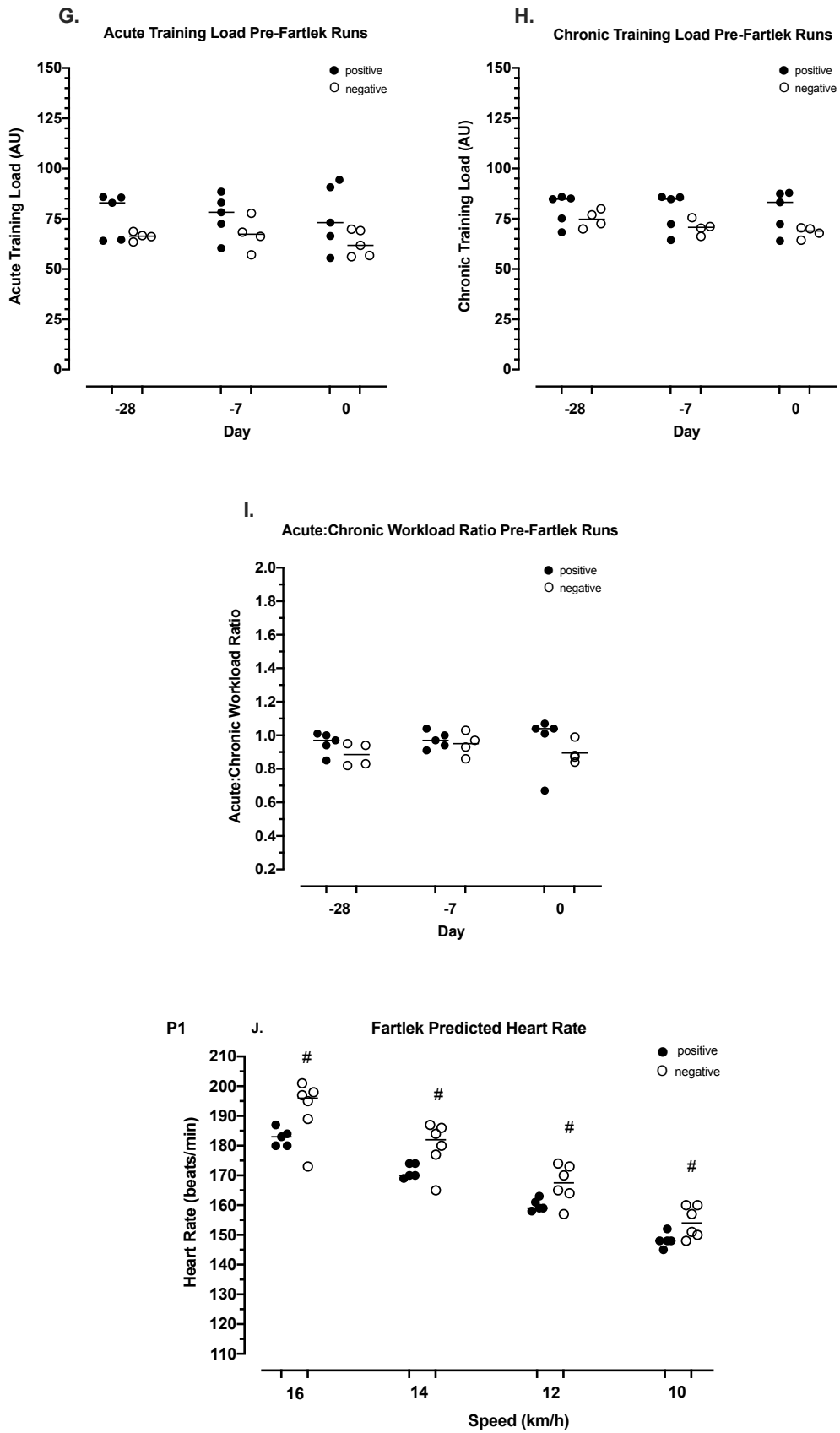
^ One participant was excluded from this analysis due to faulty HR readings.

Individual Results

Each of the 29 participants had the following data graphed: **A)** daily rTSS bar graph; **B)** Rolling average ATL and CTL line graph; **C)** daily ACWR line graph; **D)** Predicted HR at four speeds for each fartlek run line graph; **E)** average speed at each RPE level for each fartlek run completed line graph; **F)** average speed for 5-km time trials completed line graph; **G, H, and I)** ATL, CTL, and ACWR on positive and negative performance days and average in the seven and 28 days preceding the days respectively; **J)** predicted HR at four speeds. The case study with all 10 graphs for participant #1 is presented below. All 29 case studies can be seen in the Appendix Ch.6.4 Figure 4 addendum.

Participant #1





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Figure 6.4.4A-J. Case study for participant #1. **A)** daily running training stress score. Shaded region represents mean \pm 95% CI. The red bars indicate days when the participant did a race. The green bars indicate days when the participant reported being sick. **B)** Rolling daily acute (red line) and chronic (blue line) training load. **C)** Rolling daily acute: chronic workload ratios. **D)** Predicted heart rate at four speeds. Red dots indicate a value higher than mean + 95% CI. Green dots indicate a value lower than mean - 95% CI. **E)** Average running speed at each RPE level for the fartlek runs. Red dots indicate a value lower than mean - 95% CI. Green dots indicate a value higher than mean + 95% CI. **F)** Average speed during the 5-km time trials. Red dots indicate a value lower than mean - 95% CI. Green dots indicate a value higher than mean + 95% CI. **G - I)** The average acute training load, chronic training load, or acute: chronic workload ratio respectively for the 28 days and 7 days before positive and negative performances. The values above the 0 represent the acute training load, chronic training load, or acute: chronic workload ratio respectively on the day of the positive and negative performances. The horizontal line represents the median value. **J)** Predicted heart rate at speed 4 for positive and negative performances. The horizontal line represents the median value. # $p < 0.10$ vs. positive values.

Two participants showed significant differences in training load leading up to positive or negative performance days. Participant #4 had a significantly higher CTL value on the negative days vs. the positive days (Figure 6.4.5A) (POS- 53 ± 11 , NEG- 67 ± 9 , $p = 0.03$). Participant #4 showed a trend for higher average CTL values in the seven days leading up to a negative performance day (Figure 6.4.5A) (POS- 52 ± 11 , NEG- 64 ± 12 , $p = 0.07$). Participant #10 had a significantly higher average CTL in the seven days preceding a positive performance vs. poor performance (POS- 76 ± 11 , NEG- 59 ± 22 , $p = 0.03$) (Figure 6.4.5B). Participant #10 showed a trend for higher average CTL values on the day (POS- 73 ± 12 , NEG- 59 ± 20 , $p = 0.05$) and in the 28 days (POS- 75 ± 7 , NEG- 63 ± 17 , $p = 0.06$) preceding a positive performance vs. poor performance (Figure 6.4.5B). Participant #10 had a significantly higher average ATL in the 28 days preceding a positive performance vs. poor performance (POS- 77 ± 15 , NEG- 59 ± 21 , $p = 0.03$) (Figure 6.4.5C).

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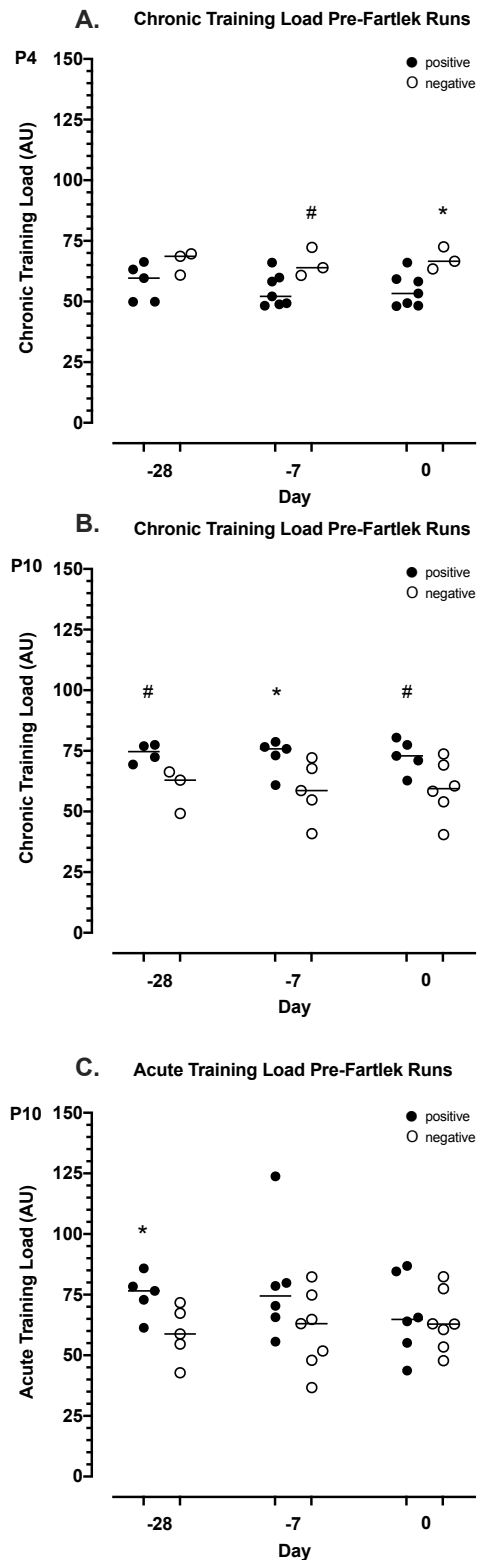


Figure 6.4.5A-C. Each data point represents a **FINISHER** test. The median is represented with a horizontal line. -28; -7; 0 = average CTL or ATL in the 28, 7, or 0 days preceding the run respectively. **A)** The CTL values on positive and negative performances for participant #4. **B)** The CTL values on positive and negative performances for participant #10. **C)** The ATL values on positive and negative performances for participant #10. * $p < 0.05$ vs. positive or negative performance. # $p < 0.10$ vs. positive or negative performance.

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Two participants had higher predicted HR on negative performance days vs. positive days (Figure 6.4.6A-B). Participant #9 had higher HR at 16 km/h (POS- 178 ± 4 , NEG- 183 ± 12 , $p = 0.002$) and 14 km/h (POS- 166 ± 6 , NEG- 173 ± 8 , $p = 0.01$) (Figure 6.4.6A). There was a trend for higher HR at 12 km/h (POS- 156 ± 9 , NEG- 161 ± 11 , $p = 0.06$) (Figure 6.4.6A). Participant #11 had higher HR at 16 km/h (POS- 165 ± 8 , NEG- 172 ± 7 , $p = 0.005$), 14 km/h (POS- 149 ± 6 , NEG- 159 ± 7 , $p = 0.01$), 12 km/h (POS- 135 ± 7 , NEG- 144 ± 6 , $p = 0.01$), and 10 km/h (POS- 121 ± 7 , NEG- 129 ± 7 , $p = 0.03$) (Figure 6.4.6B).

Three participants had a trend for higher predicted HR on negative performance days (Figure 6.4.6C-E). Participant #1 had a trend for higher HR at 16 km/h (POS- 183 ± 6 , NEG- 196 ± 14 , $p = 0.08$), 14 km/h (POS- 170 ± 5 , NEG- 182 ± 12 , $p = 0.07$), 12 km/h (POS- 159 ± 4 , NEG- 168 ± 11 , $p = 0.07$), and 10 km/h (POS- 148 ± 4 , NEG- 154 ± 11 , $p = 0.06$) (Figure 6.4.6C). Participant #4 had a trend for higher HR at 16 km/h (POS- 167 ± 5 , NEG- 171 ± 6 , $p = 0.06$) (Figure 6D). Participant #19 had a trend for higher HR at 16 km/h (POS- 178 ± 3 , NEG- 190 ± 9 , $p = 0.06$) and 14 km/h (POS- 167 ± 6 , NEG- 178 ± 5 , $p = 0.06$) (Figure 6.4.6E).

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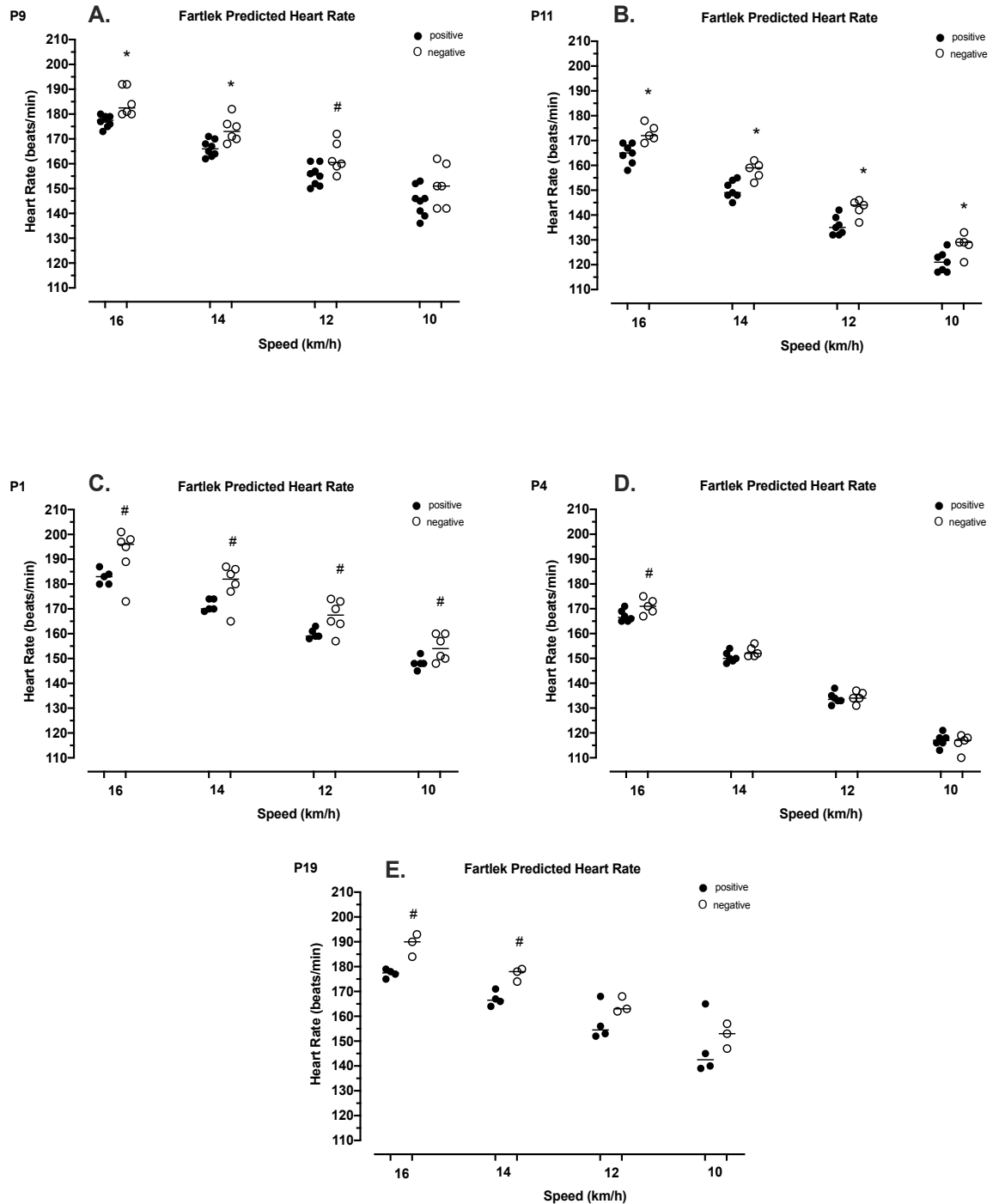


Figure 6.4.6A-E. Each data point represents a **FINISHER** test. The median is represented with a horizontal line. The predicted HR at four speeds (16, 14, 12, and 10 km/h for participant #9, 11, 1, 4, and 19 respectively).

* p < 0.05 vs. positive. # p < 0.10 vs. positive.

Six participants had a significant negative linear correlation between relative HR at speed four and relative performance at RPE 9 (Figure 6.4.7A-F).

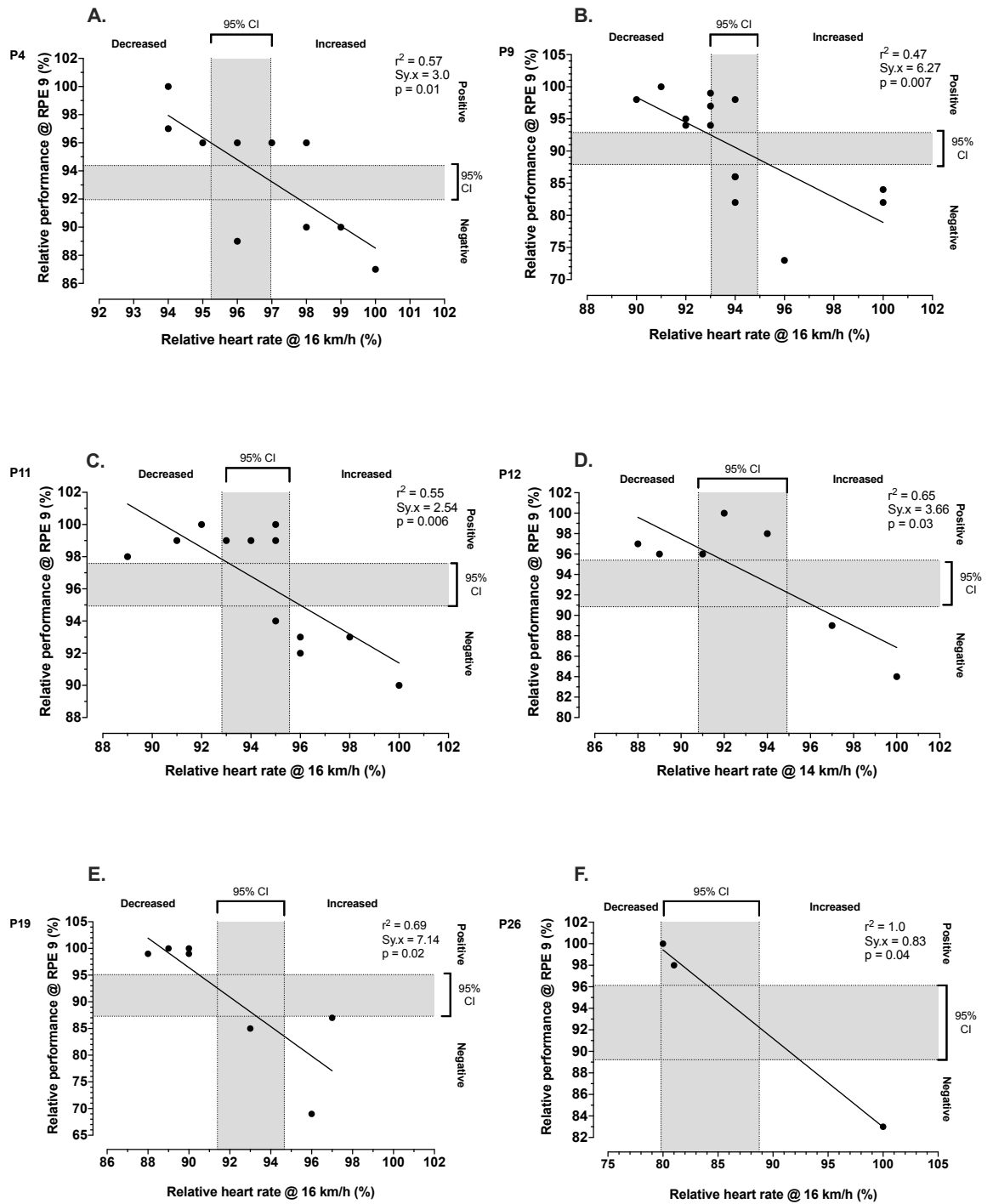


Figure 6.4.7A-F. The relationship between relative HR at speed four (16 or 14 km/h) and relative performance at RPE 9 for participant #4, 9, 11, 12, 19, and 26 respectively. Each data point represents a **FINISHER** test. The grey shaded regions represent the mean \pm 95% CI. The solid line represents the line of best fit. Sy.x = standard deviation of estimate.

One participant had a significant positive linear correlation between the ACWR on the day of the **FINISHER** test and relative HR at speed four (Figure 6.4.8A), and one participant had a significant negative linear correlation between the ACWR and relative HR at speed four (Figure 6.4.8B).

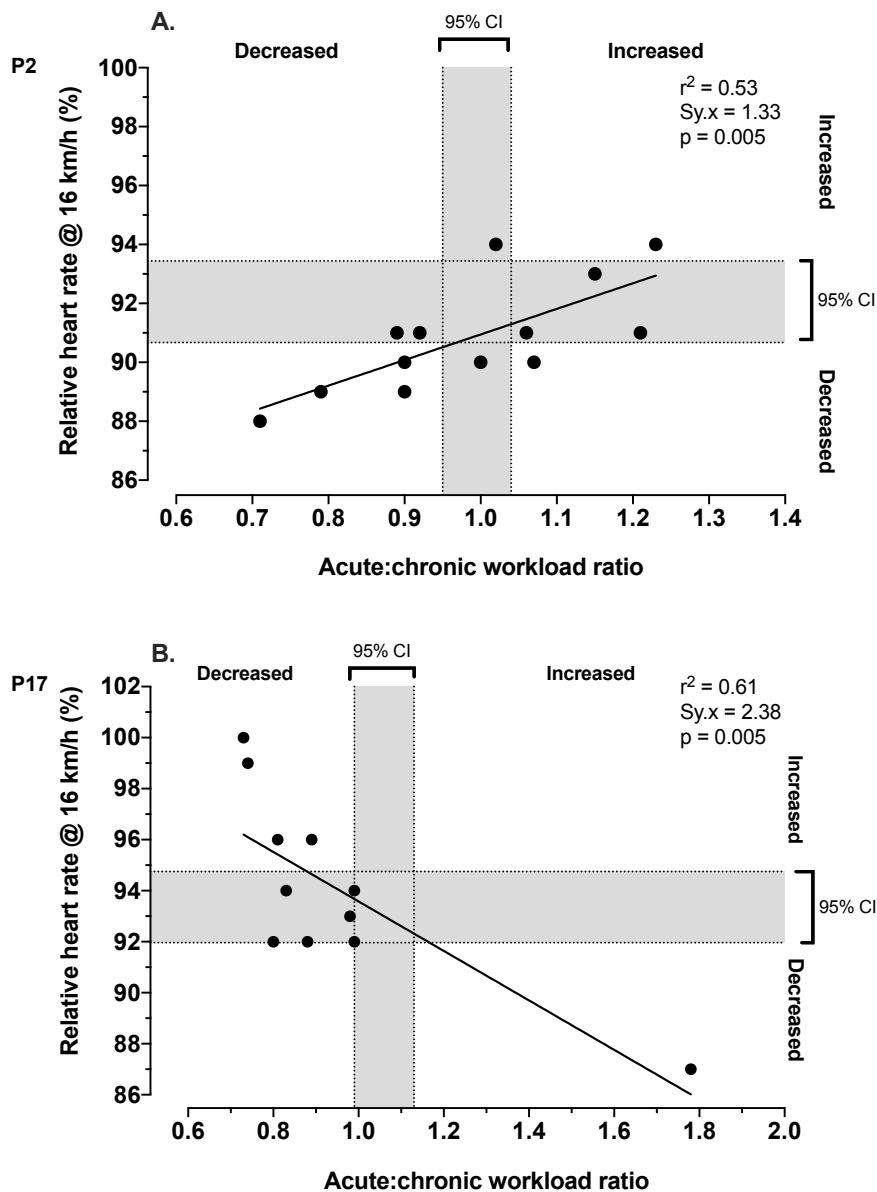


Figure 6.4.8A-B. The relationship between ACWR and relative HR at 16 km/h for participant #2 and #17 respectively. The grey shaded regions represent the mean \pm 95% CI. The solid line represents the line of best fit. $Sy.x$ = standard deviation of estimate.

One participant had a significant negative linear relationship between the ACWR on the day of the fartlek run and relative performance (Figure 6.4.9).

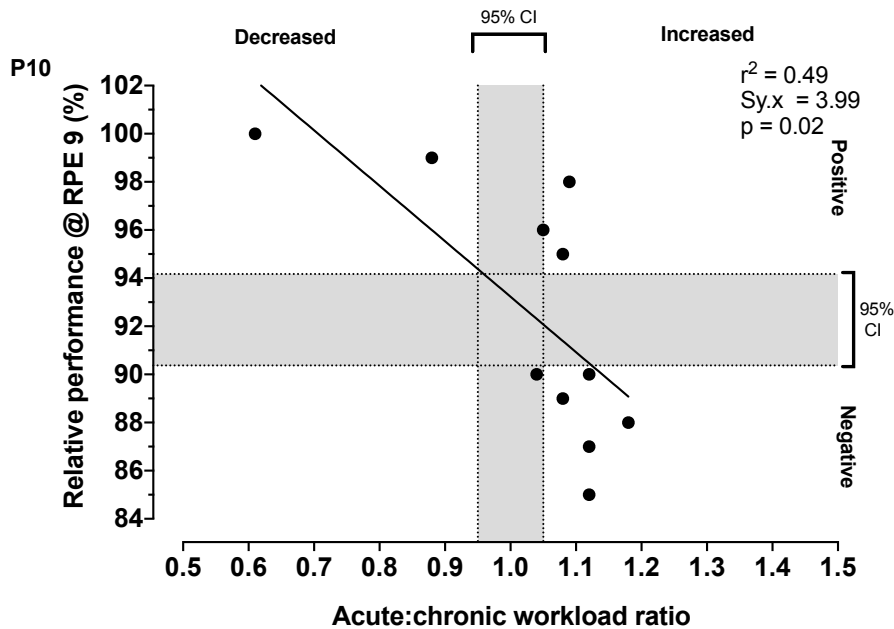


Figure 6.4.9. The relationship between ACWR and relative performance at RPE 9 for participant #10. The grey shaded regions represent the mean \pm 95% CI. The solid line represents the line of best fit. $Sy.x$ = standard deviation of estimate.

Discussion

Group Results

When the group data were analysed the training load was not different leading up to a positive or negative performance. However, there were four data points for ATL on negative days (Figure 6.4.1A) that were higher than any value on a positive day. Upon further examination, all four of these values aligned with participants competing in marathon or ultramarathon distance races in the two – five days preceding the negative performance. For example, on day 45 of the study P17 had a negative performance on the **FINISHER** test. The ATL on that

day was 139 (Figure 6.4.1A). On day 41, P17 raced a 50-km road race. On day 42, the participant raced a 21-km distance road race. It may be reasonable to speculate that these races and the associated high ATL value may have negatively impacted P17's performance on the **FINISHER** test. Therefore, while the group data is not sufficiently strong to be significant, a case-by-case analysis may reveal contrasting information.

Previous research has shown little or no correlation between training load and performance (Foster et al., 1996; Hellard et al., 2005; Vermeire et al., 2019). For example, Foster et al. (1996) found no correlations between improvements in time trial performance, training duration, duration spent training at high intensity, or session load. Hellard et al. (2005) found training variables only explained 30% of the variation in performance in a group of Olympic swimmers. The authors of these studies speculated that inter and intra-individual responses to training as well as other factors may contribute to the lack of, or small relationship, between training and performance. Alternatively, studies have found decreased performances with rapid increases in training load such as a race or training camp (Bellenger et al., 2017; Hedelin et al., 2000; Siegl et al., 2017). These cases have less ecological validity in a group of recreational athletes who may not undergo such large increases in load.

When the group data were analysed, HR was higher on negative performance days vs. positive performance days for speeds two, three, and four. The effect size was the largest for speed four for relative HR values ($d = 0.71$). Despite a significant p value and *moderate* effect size, the absolute difference in HR values was three – four beats/min. In Ch.5.2, we determined the smallest worthwhile change in HR for the **FINISHER** test to be three beats/min. Thus, we cannot be confident that the group change in HR on negative performance days is a real change rather than a reflection of normal physiological variation. However, when only considering relative HR values of 98 – 100%, there were 10 instances on positive performance days (8% of all data points) and 36 instances on negative performance days (35% of all data points). As training load was no

different leading up to positive or negative performances, other factors that may affect HR should be considered.

For example, dehydration causes an increase in submaximal HR. One study (Gonzalez-Alonso et al., 1997) found a 5% increase in exercising HR with a 4% dehydrated state. The increase in HR was due to a 7% decrease in stroke volume. The same research group found up to a 7% increase in HR with a 4% dehydrated state in a separate study (Gonzalez-Alonso, Mora-Rodríguez, & Coyle, 2000). In addition, several research studies have supported an increased exercising HR in the heat (Gonzalez-Alonso et al., 1999; Rowell, Brengelmann, & Freund, 1987). While we cannot exclude heat as a contributing factor in our study, in one case study (Participant #9) there were no significant differences in temperature ($p = 0.10$), wind speed ($p = 0.92$), or time of day ($p = 0.51$) between positive and negative performances, even though Participant #9 did show increased HR on negative performance days. Furthermore, sleep deprivation and increased mental stress can cause predominance of the sympathetic nervous system (Cho, 2004; Sloan et al., 1994), which may have contributed to increased HR on negative performance days.

There was only one significant group correlation; this was a significant negative linear relationship between relative HR at speed four and relative performance at RPE 9 (Figure 6.4.3B). However, the relationship only explained 4% of the variance ($r^2 = 0.04$), therefore the statistical significance should be interpreted with caution. We certainly cannot conclude from the data that a higher relative HR is associated with lower performances in all participants. There is little value in grouping data for correlations, as individual data provide more insight.

Individual Results

Two participants demonstrated differences in training load leading up to positive or negative performance days. Participant #4 had higher CTL on negative performance days, while P10 had higher ATL and CTL values on positive performance days. It is important to note there is inter-individual variability in response to the same training load. Participant #4 had a negative

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performance with a CTL of 67 AU while P10 had a positive performance with a CTL of 76 AU. This highlights that two runners completing similar training loads can show different responses to the load.

Two participants had significantly higher HR on negative performance days vs. positive performance days. For example, P9 had a greater HR of five beats/min on negative days, and P11 had a greater HR of seven – ten beats/min on negative days. When considering the smallest worthwhile change of three beats/min from Ch.5.2, we can be confident that the higher HR was not due to random variation. Both P9 and P11 had no differences in outside temperature ($p = 0.10$, $p = 0.10$), wind speed ($p = 0.92$, $p = 0.22$), or time of day ($p = 0.51$, $p = 0.55$) on positive vs. negative performance days. However, hydration status, stress, or lack of sleep could have played a role in increased HR on negative days (Gonzalez-Alonso et al., 2000; Sloan et al., 1994). Siegl et al. (2017) found 21% of their participants had increased HR at 85% of peak treadmill speed two days after a 56-km running race. Sixty-four percent of the participants showed decreased HR at that same intensity, which supports individual variability. Our research supports these findings, suggesting each athlete must be monitored individually.

Six participants had a significant negative linear relationship between relative HR at speed four and relative performance at RPE 9. Negative performances were associated with a higher HR while positive performances were associated with lower HR. In these individuals, when HR was low, and performances were good they may have been experiencing positive adaptations to training (Borresen & Lambert, 2008; Hedelin et al., 2000; Skinner et al., 2003; Uusitalo, 2001; Wilmore et al., 2001). When HR was high, and performances were poor they may have been experiencing dehydration, stress, and/or disturbed sleep. All these factors negatively impact performance and increase sympathetic tone (Dattilo et al., 2011; McEwen, 2006; Samuels, 2008; Spiegel, Leproult, & Van Cauter, 1999; Stults-Kolehmainen & Bartholomew, 2012). Although training load was no different on positive vs. negative performance days, there may be intra-individual differences week-to-week in response to the same training load.

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Two participants had a significant linear relationship between ACWR and relative HR at speed four; one was positive (P2) and one was negative (P17). It is important to note P17's negative linear relationship is largely driven by the data point in the lower right quadrant. This **FINISHER** test happened four days after a 50-km race and three days after a 21-km race. It makes sense from a physiological perspective that submaximal HR would be lower in the days after racing 71-km. After an endurance event such as an ultramarathon or endurance cycling race, plasma volume temporarily increases which causes increased stroke volume and decreased HR (Neumayr et al., 2005; Overgaard, Lindstrøm, Ingemann-Hansen, & Clausen, 2002).

Finally, P10 had a significant negative linear relationship between the ACWR and relative performance at RPE 9. This relationship was largely attributed to the two data points in the upper left quadrant. It may be reasonable to speculate this participant had his best performances when he was rested and training load was relatively low. On day 80 (ACWR = 0.88, relative performance = 99%) there was a 26% decrease in load the previous week compared to the preceding largest week of training. On day 122 (ACWR = 0.61, relative performance = 100%) there was an 80% decrease in load the previous week compared to the preceding largest week of training. It is possible this participant underwent supercompensation after a period of relative recovery (Zaryski & Smith, 2005).

Limitations

One limitation of the study is the lack of subjective data such as questionnaires to assess stress and sleep patterns. As discussed in the literature review, these questionnaires are time-consuming for the athlete to complete. This study required a long commitment (six months) from participants as well as compliance with performing the **FINISHER** running test each week. We did not want to overburden the participants for fear of them withdrawing from the study because the data collection was too onerous. However, we do acknowledge this would have added value to the study and recommend its use for future research.

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As discussed in Ch.6.3, environmental conditions in a field study is a limitation. We minimised this limitation by instructing the participants not to complete the **FINISHER** tests on days with adverse weather such as strong winds, extreme heat, or rain. We also analysed three participants and compared temperature and wind speed on positive vs. negative performance days and found no differences.

Study personnel did not monitor the training sessions, **FINISHER** run tests, or 5-km time trials. We ultimately decided to exclude the 5-km time trials from analyses due to the lack of control. We cannot be certain participants exerted a maximal effort for the 5-km distance. This is a limitation, but also gives the study more ecological validity.

Conclusion

Submaximal HR at a given running speed has a negative linear relationship with performance in 21% of the study participants. Training load was only related to changes in performance in one participant. We can largely conclude that changes in training load were not linked to changes in performance in this study cohort. When the participants had a poor performance on the **FINISHER** test it may have been due to factors such as lack of motivation, fatigue, mental stress, dehydration, and/or lack of sleep.

Coaches and sports scientists should monitor athletes individually. If they applied conclusions derived from one athlete to a larger group, interpretations would be flawed in many of the athletes. This could lead to incorrect changes in athletes' training programmes.

The conclusions of this study may differ in an elite population where changes in training load are much greater throughout a season. Future studies should consider testing the relationships between training load, HR, and performance in an elite running population using the **FINISHER** test.

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Future studies could also attempt to determine what factors are responsible for a higher HR on negative performance days in 21% of the participants. Methods may include testing for hydration status and filling out questionnaires to assess sleep and mental stress.

If a well-trained competitive recreational runner has a negative performance on a **FINISHER** test they should take note of any changes in training. Particularly, if they have raced ≥ 21 km in the last seven days. However, it may be more important for the athlete to note their motivation level, sleep, stress, and diet in the days preceding the poor performance. Practical advice to recreational athletes when they have a poor training session would be to take a holistic view of the training – recovery balance. It may be unnecessary to decrease training load, and the emphasis may need to be on increasing recovery practices such as proper diet, hydration, sleep, and work-life balance.

Chapter 7: Conclusions and Practical Applications

Introduction

A main objective of this thesis was to better understand the training habits of well-trained competitive recreational runners and how these relate to performance. As discussed in the literature review in Chapter 2, the popularity of endurance running events has increased in the last 30-40 years. Contemporary well-trained competitive recreational runners are older, slower, and train less than the runners 40-50 years ago. With the changing demographics of well-trained competitive recreational runners, it is important to better understand how this population can maximise performance and decrease the risk of injury.

It is also important to be able to study runners without any intervention to get accurate data on their *ad libitum* training. For this purpose we developed a reliable submaximal running test that runners could include as part of their training. The variables of interest from the submaximal running test were heart rate (HR) and running speed. These data were related to training load and running performance.

There were five specific questions, discussed in Chapters 3 - 6, that the studies in this thesis attempted to answer. These questions are listed below with succinct answers, practical applications, and suggestions for future research associated with each question.

Question #1

What are the relationships between race performance, pacing, and training load in competitive recreational runners and well-trained competitive recreational runners?

Answer #1

- In Chapter 3.1, the participants represented a heterogeneous group of competitive recreational runners. The fastest two quartiles of finishers slow down less in the second half of a 56-km race compared to the slowest quartile. When examined in each of the four available race segments, this difference is attributable to the fastest two quartiles of competitors running relatively faster from the 28 – 42-km mark which includes the first of two major climbs in the race.

- In Chapter 3.2, the participants represented a heterogeneous group of competitive recreational runners. Runners with better relative race performances:
 - displayed more even pacing in a 56-km race.
 - completed higher training loads in the six weeks leading up to a 56-km race.
 - performed a one-week taper characterised by reduced running volume and maintained running speed.

- In Chapter 6.3, the participants represented a homogenous group of well-trained competitive recreational runners. The main findings included:
 - There were no relationships between different measures of training load and relative race performance at the marathon distance.
 - Running duration decreased in the one week before the marathon race while running speed was maintained.
 - There was no relationship between performance in the 10-km distance and race performance at the marathon distance.

Practical Applications

- Coaches and sports scientists should encourage runners to maintain their own pace at the beginning of endurance races, and not be influenced by other competitors' pace. Being too competitive in the first half of the race, may lead to sub-optimal pacing in the second half.
- Although recreational runners with better relative performances completed higher training loads, there is wide variability in the relationship between training load and performance. Coaches and sports scientists should prescribe training loads on an individual basis to ensure optimal performance and decrease the risk of injury.
- When dealing with well-trained competitive recreational runners, training load may have no relationship to race performance. Factors such as stress, sleep, weather, race day nutrition and/or pacing may be related to performance.

Future Research

- The relationships between pacing and performance would be better understood if runners were interviewed before the race about their expected race time. This would give researchers more insight about pacing strategy.
- Research on relationships between training load and race performance would be strengthened with an intervention study. If runners with low training load and poor relative performances increased their training load, would their performances improve (and *vice versa*)?

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- Factors such as stress, sleep, weather, race day nutrition and/or pacing may be related to performance and should be considered in future research.

Question #2

Are GPS sport watches an accurate tool to calculate external training load?

Answer #2

In Chapter 4, we found GPS sport watches accurately measure running distance within an 0.6 – 1.9% margin of error. The error appears to be greater in areas with more changes in elevation and turns compared to flatter and straighter areas. The Garmin Forerunner XT series, Garmin Forerunner series, Suunto devices, TomTom devices, and Polar devices had lower overall errors compared to cell phones and Garmin Fenix devices.

Practical Applications

- Coaches, runners, and sports scientists can use GPS sport watches as a valid and feasible tool to accurately measure performance and track training load.
- The small error associated with each brand needs to be considered when data are interpreted. Sports scientists, coaches, and runners should also consider that error may be influenced by changes in elevation, non-linear movement, tree cover, and cloud cover.

Future Research

- Future research should consider testing the accuracy of specific brands and models of GPS sport watches in more controlled settings. This would provide more information on how error may differ with changes in elevation, non-linear movement, or tree cover.

- Our understanding of GPS watches would be improved by testing the reliability of GPS sport watches.
- The GLONASS technology is now included in some devices, and its accuracy compared to GPS devices should be tested.

Question #3

What is the 'noise' around HR measurements during the **FINISHER** running test?

Answer #3

In Chapter 5, we found the noise around the test to be three – five beats/min. This means any change in HR that is < eight beats/min could be considered 'random' or due to day-to-day biological variability. The **FINISHER** test would be able to detect moderate or large changes in HR (\geq eight beats/min).

Practical Applications

- Runners can complete the **FINISHER** test on their own in the field. The test can easily be incorporated into runners' training programmes with minimal disruption to their routine.
- When coaches, sports scientists, or runners compare HR measurements between **FINISHER** tests, a change in HR \geq 8 beats/min would indicate a meaningful change.
- Although the smallest worthwhile change is 3 beats/min, this falls within the typical error of measurement. A change in HR < 8 beats/min may be due to day-to-day biological variability.

Future Research

- Future research should consider investigating how specific variables such as a change in sleep, stress, hydration, or weather affects day-to-day variability of HR responses to the **FINISHER** test.

Question #4

What are the *ad libitum* training habits of well-trained competitive recreational runners? What is the variation in training load; do they have spikes in training load and, if so, what is the reason for the spikes? Do they adhere to small progressions ($\leq 10\%$) in training load.

Answer #4

In Chapter 6.1, we showed a group of well-trained competitive recreational runners performed 44 ± 22 km/week (median \pm IQR) in a six-month time frame. This volume is similar to previous reports of recreational endurance runners (Leyk et al., 2009; Zillmann et al., 2013) and is only 30 – 50% of the volume performed by elite endurance runners. This group had a wide range of inter-individual differences in training load performed even when considering participants who had the same relative marathon performance.

In Chapter 6.2, we showed the same group of well-trained competitive recreational runners maintained most of their training over a six-month period in the 0.81 – 1.14 ACWR range. When ACWR values reached > 1.5 , it was mainly due to participation in endurance running races (≥ 21 -km).

Well-trained competitive recreational runners may be able to tolerate weekly increases in training load of approximately 25%. However, this increase may only be maintained for a short period (one – two weeks).

Practical Applications

- The wide variability in training load suggests some well-trained competitive recreational runners have lower training load tolerance and may not be able to handle increases in load without adverse effects.
- The lack of relationship between training load performed and best 10-km time suggests a runner with fast 10-km race time may not be able to handle a high training load in preparation for races ≥ 21 km in distance.
- Coaches, sports scientists, and runners should be aware that ACWR spikes > 1.5 in well-trained competitive recreational runners are mainly due to participation in endurance races. Symptoms of fatigue and impaired performances for the one-two weeks after endurance running races should be monitored and the training load – recovery balance adjusted as needed.

Future Research

- A research study with an intervention and a control group would provide more insight to the research. If participants who have low training load increased their load, would their performances improve as a result?
- Qualitative research investigating why certain runners train with less volume would provide more insight to the research. Is it due to lack of time, lack of knowledge, or possibly another factor?
- Future research should determine the threshold for weekly changes in training load in well-trained competitive recreational runners for a longer period (\geq three weeks) of time.

Question #5

What is the relationship between training load, submaximal HR, and performance using the **FINISHER** test?

Answer #5

In Chapter 6.4, we demonstrated that HR has a negative linear relationship with performance in 21% of the study participants. Training load was only related to changes in performance in one participant. We can conclude that changes in training load were not linked to changes in performance in this study cohort. Although we can only speculate, when the participants had a poor performance on the **FINISHER** test it may have been due to factors such as lack of motivation, fatigue, mental stress, dehydration, and/or lack of sleep.

Practical Applications

- Coaches and sports scientists should monitor athletes individually. If they apply conclusions derived from one athlete to a larger group of athletes, interpretations could be flawed in many of the athletes. This could lead to inappropriate modifications to the athletes' training programmes.
- Well-trained competitive recreational runners should take note of any changes in training following a negative performance during a **FINISHER** test. This applies, particularly, if they have raced ≥ 21 -km in the last seven days. However, it may be more important for the athletes to note their motivation level, sleep, stress, and diet in the days preceding the poor performance. Practical advice to recreational athletes when they have a bad training session would be to take a holistic view of the training – recovery balance. It may be unnecessary to decrease training load, and

the emphasis may need to be on increasing recovery practices such as proper diet, hydration, sleep, and work-life balance.

Future Research

- The conclusions of this study may differ in an elite running population where changes in training load are much greater throughout a season. Future studies should consider testing the relationships between training load, HR, and performance in an elite running population using the **FINISHER** test.
- Future studies could also attempt to determine the factors that are associated with a higher HR on negative performance days in 21% of the participants. Methods may include testing for hydration status and monitoring runners' sleep quality and quantity and mental stress.

Closing Statement

This thesis confirms that no single variable can provide the necessary information on how to balance training load and recovery. Athletes, coaches, and sports scientists need to have a holistic view of stress exposure and how this affects the body. Stress can be derived from running training, but can also come from a career, caring for a family, lack of sleep, or a change in diet. If stress from a factor not associated with running increases, running training may need to be decreased to avoid accumulating too much stress. Or, if training needs to be maintained – recovery practices would need to be emphasised. Individual variability in response to changes in the training load – recovery balance should also be considered. For example, with increased mental stress from a job some athletes will be able to maintain their same training load if they emphasise adequate sleep. Other athletes may need to decrease their training load in addition to focusing on adequate sleep.

It is important for runners, coaches, and sports scientists to approach the training load – recovery balance as being unique for each athlete. Even in a

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homogenous group of well-trained competitive recreational runners, their *ad libitum* training load is widely varied and not associated with performance or ability level. The balance should be adjusted over time based on the athlete's symptoms. A proposed way to do this can be seen below in Figure 1.

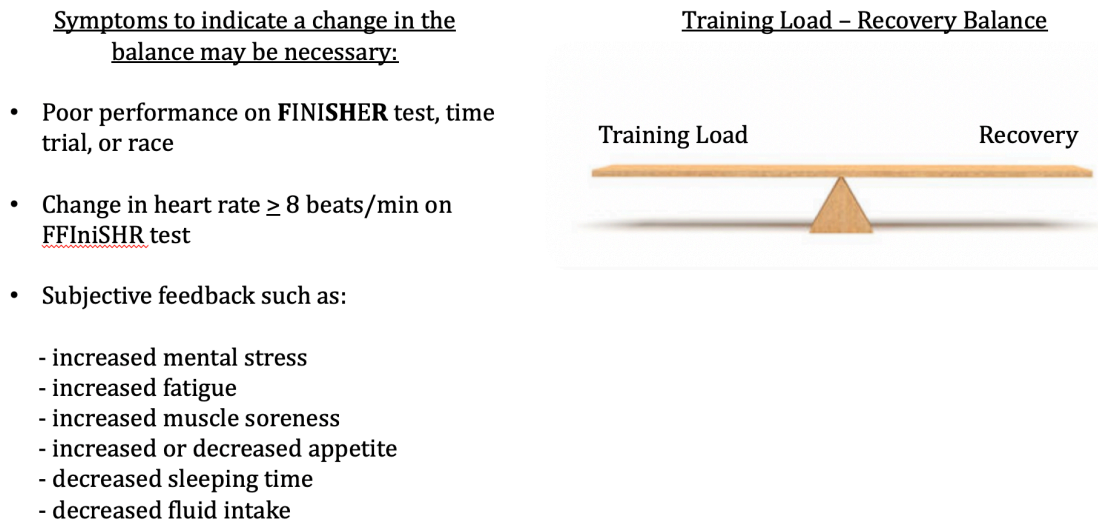


Figure 7.1. Proposed symptom-based adjustments to training load – recovery balance.

This thesis provides novel information regarding how well-trained competitive recreational runners train as well as relationships between training, performance, and submaximal heart rate. The information presented will help athletes, coaches, and sports scientists make more informed decisions regarding training. The **FINISHER** test is a reliable and feasible workout that can be included in runners' training programmes. Runners and coaches can use the methods presented to determine positive or negative performances on the test as well as interpret what a significant change in heart rate would be. We would encourage runners, coaches, and sports scientists to not only track training load but also assess subjective feedback such as questionnaires to assess stress, sleep, and diet. Although time-consuming, this combination may ultimately be the best way to assess whether a change in the training load – recovery balance is needed and to maximise performance.

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Chapter 9: Appendices

Ch.3.1

Research Ethics Approval Letter



UNIVERSITY OF CAPE TOWN
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Human Research Ethics Committee



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03 May 2016

REF NO: R009/2016

Prof M Lambert
Human Biology
Sports Science Institute

Dear Prof Lambert

PROJECT TITLE: TWO OCEANS MARATHON REGISTRY

Thank you submitting your registry to the Faculty of Health Sciences Human Research Ethics Committee for review.

The HREC has **approved** the registration of your database.

Please Note: All research, including that undertaken for a master's or doctoral degree, using registered databases, registries and repositories, requires submission as a new study. It requires an application form ([FHS013](#)) and a protocol which has undergone departmental review. The study will receive its own HREC REF number which will be linked to the main database or repository.

The registration of this database is valid until **30 May 2019**.

Please quote the HREC reference number in all your correspondence.

Yours sincerely

Signature removed to avoid exposure online

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE

Ch.3.2

Research Ethics Approval Letter



UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee



Room E53-46 Old Main Building
Grooteschoor Hospital
Observatory 7925
Telephone [021] 406 6492
Email: Sumayah.ariefdien@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

31 October 2016

HREC/REF: R037/2016

Prof M Lambert
Division of Exercise Science & Sports Medicine
Newlands

Dear Prof Lambert

Project Title: SMART BEAT APPLICATION

Thank you for your submission to the Faculty of Health Sciences Human Research Ethics Committee (HREC).

The HREC has **approved** the registration of your registry.

The registration of this registry is valid until 30 OCTOBER 2019.

Please provide the HREC with an update if the registry continues beyond this period. Please Note: All research, including that undertaken for a master's or doctoral degree, using registered databases, registries and repositories, requires submission as a new study. It requires an application form (FHS013) and a protocol which has undergone departmental review. The study will receive its own HREC REF number which will be linked to the main database or repository.

Please provide the HREC with an update if the registry continues beyond this period.

Please quote the HREC REF in all your correspondence.

Yours sincerely

Signature removed to avoid exposure online

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE

Hrec/ref:R037/2016

Ch.5.2

Research Ethics Approval Letter



UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee



Room E53-46 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6492
Email: sumayah.ariefdien@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

06 March 2017

HREC REF: 093/2017

Prof M Lambert
Sports Science Institute
Human Biology
Newlands

Dear Prof Lambert

PROJECT TITLE: TESTING THE RELIABILITY OF A SUBMAXIMAL RUNNING TEST (PHD CANDIDATE - MS R JOHANSSON)

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee (HREC) for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30 March 2018.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.

(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

We acknowledge that the student, R Johansson will also be involved in this study.

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate Institutional approval before the research may occur.

Yours sincerely

Signature removed to avoid exposure online

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE

Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

HREC 093/2017

Consent Form

Participant Information
This is a summary only.

Dear Study Participant,

Thank you for your interest in this research study. The goal of the study is to determine how much heart rate changes on a day-to-day basis while running at 7 different effort levels. This will contribute to our long term goal which is to create a running test that produces repeatable results. Moderate to well – trained runners who train at least twice per week are invited to participate. You will perform four submaximal 40 minute running tests within 5 consecutive days. Each 40 minute running test includes: a 5 minute warm-up, 7 x 3 minute intervals at the following effort level (on a scale of 0-10)- 1,3,4,5,6,8,9. You will jog very easy for 2 minutes between each 3 minute interval. We will record your heart rate and running speed from each 3 minute interval.

Risks

When you run, there is always a small risk of injury to your muscles, bones, tendons, and ligaments. There is also a small risk of a cardiac emergency happening such as a heart attack. We have made efforts to make the risk as small as possible. We have asked about your medical and injury history, and only people who are healthy and free from injury are eligible to participate in the study. When you run at a high effort, you will have some discomfort. This includes breathing faster and your heart beating harder and faster.

Benefits

You will get information about your heart rate and running speeds at 7 different effort levels. You will also get information on how much your heart rate during running changes on a day-to-day basis. You will be able to use this information to guide your training.

If you do not want to take part in this research, you may withdraw from the study at any point. You will not be penalised in any way for withdrawing from

Appendices

the study. Your study information will be used to write a scientific paper. All your information will be confidential, and your name will not be used in any reporting of results.

Appendix V

DEPARTMENT OF HUMAN BIOLOGY DIVISION OF EXERCISE SCIENCE AND SPORTS MEDICINE INFORMED CONSENT

- *Why is this study being done?*

The goal of the study is to determine how much heart rate changes on a day-to-day basis while running at 7 different effort levels. This will contribute to our long term goal which is to create a running test that produces repeatable results.

- *Why are you being asked to take part?*

You are asked to take part in the study because you are a moderate to well-trained runner. You run at least 2x/week, are between 18-50 years old, and are healthy and free of injury.

- *How many people will take part in the study?*

Forty people will take part in the study. Twenty people will do the study on an indoor track under supervision, and 20 people will do the study on the road with their own equipment.

- *How long will the study last?*

You will be asked to do the 40 minute running test a total of 4 times within 5 days. Each study visit will take ~60 minutes, and the total time required is ~4 hours.

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- *What do we do to decide if you are eligible to be take part?*

We will send you a physical activity readiness questionnaire to decide if you are healthy enough to be part of the study. We will also ask how far and often you are running right now, your age and gender, and if you currently train with a global positioning system (GPS) device and a heart rate (HR) monitor (chest strap).

- *What will happen if you decide to take part in the study?*

You will complete a total of four ~60 minute study visits within 5 days. The study visits will include the following:

- 1) Informed consent.
- 2) Fill in questionnaire with training and race history information (day 1 only).
- 3) Fill in evaluation of fatigue and muscle soreness questionnaire.
- 4) Record weight.
- 5) Put on heart rate monitor (both groupss) and GPS device (outdoor run group only).
- 6) Perform 40-minute running test including: a 5 minute warm-up, 7 x 3 minute intervals at the following effort level (on a scale of 0-10)- 1,3,4,5,6,8,9. You will jog very easy for 2 minutes between each 3 minute interval. We will record your heart rate and running speed from each 3 minute interval. During each test you will run about 6km. Depending on what study group you are a part of (indoor track group or outdoor running group), you will do the run test either on an indoor track or on a relatively flat road course.

- *What are the risks and discomforts of this study?*

When you run, there is always a small risk of injury to your muscles, bones, tendons, and ligaments. There is also a small risk of a cardiac emergency happening such as a heart attack. These risks are similar to the risks you will encounter during a moderate to high intensity 6 km training run. We have made efforts to make the risk as small as possible. We have asked about

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your medical and injury history, and only people who are healthy and free from injury are eligible to participate. When you run at a high effort, you will have some discomfort. This includes breathing faster and your heart beating harder and faster.

- *Are there any benefits to you for being in the study?*

You will get information about your heart rate and running speeds at 7 different effort levels. You will also get information on how much your heart rate during running changes on a day-to-day basis. You will be able to use this information to guide your training.

You will get information about your heart rate and running speeds at 7 different effort levels. You will also get information on how much your heart rate during running changes on a day-to-day basis. This may be useful information to guide your training.

- *What other choices do you have?*

If you do not want to take part in this research, you may withdraw from the study at any point. You will not be penalised in any way for withdrawing from the study. Your study information will be used to write a scientific paper. All your information will be confidential, and your name will not be used in any reporting of results

You are allowed to withdraw from the study at any time.

- *What will happen when the study is over?*

Your study information will be used to write a scientific paper. All of your information will be confidential. Your name will not be used in any reporting of results.

- *Will your test results be shared with you?*

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Yes. You will get information about your running speed and heart rate at each running intensity.

- *Will the results of the research be shared with you?*

We will send you a summary of the results when the scientific paper has been accepted for publication.

- *Will any of your blood, tissue or other samples be stored and used for research in the future?*

We will not take any blood, tissue or other samples from you in this study.

- *Will you receive any reward (money or food vouchers) for taking part in this study?*

You are a volunteer in the study, and will not receive any reward (money or food vouchers).

- *Who will see the information which is collected about you during the study?*

Only approved researchers will see information collected about you during the study. Your information will be confidential and will be stored in a secure place.

- *Who do I speak to (or contact) if I have any questions about the study?*

Should you have any ethical concerns or questions about your rights or welfare as a participant on this research study you can contact The UCT's Faculty of Health Sciences Human Research Ethics Committee (contact details provided below).

Chairperson: Professor Marc Blockman

Tel: 021 406 6338

Appendices

Should you have any additional questions or concerns related to the research study you may contact the Principal Investigator of the study or co-investigator (contact details provided).

Principal Investigator: Professor Mike Lambert , Division of Exercise Science and Sports Medicine, Department of Human Biology, PO Box 155, Newlands 7725, email: mike.lambert@uct.ac.za Tel : 021 650 4558

Co-investigator: Rebecca Johansson, E-mail: rejohansson@gmail.com, Tel: 079 596 6680

What happens if I get hurt taking part in this study?

This research study is covered by an insurance policy taken out by the University of Cape Town in the event of you suffering a bodily injury because you are taking part in the study.

The insurer will pay for all reasonable medical costs required to treat your bodily injury, according to the SA Good Clinical Practice Guidelines 2006 (*or latest version*), which are based on the Association of the British Pharmaceutical Industry Guidelines. The insurer will pay without you having to prove that the research was responsible for your bodily injury. You may ask the study doctor for a copy of these guidelines.

The insurer will *not* pay for harm if, during the study, you:

- Use medicines or other substances that are not allowed
- Do not follow the study doctor's instructions
- Do not take reasonable care of yourself

If you are harmed and the insurer pays for the necessary medical costs, usually you will 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 you give up your right to make a separate claim for other losses based on negligence, in a South African court.

It is important to follow the study doctor's instructions and to report straightaway if you have a side effect from the study.

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I confirm that the exact procedures of the tests have been fully explained to me. I understand that I may ask questions at any stage during the testing procedure, and that I am able to withdraw from the testing procedure at any given time, without prior warning. I have been informed that the personal information I have put forward will be kept confidential, and that the information obtained from the testing procedures will be used anonymously in statistical analysis.

I therefore understand the nature and protocol of the testing procedures. I agree to participate in this study and I give permission to the Division of Exercise Science and Sports Medicine of UCT Department of Human Biology to use my results anonymously for any publications that may be published as a result of this study.

Name (in full) of participant

Signature of participant:

Name (in full) of witness:

Signature of witness:

Date:

Ethical Considerations: Privacy, Confidentiality, and Liability

The study will be performed in accordance with the principles of **the Declaration of Helsinki (2013)**, Good Clinical Practice and the laws of South Africa. **Good Clinical Practice is an international ethical and scientific quality standard for research, and guidelines for human research in South Africa has been published (Department of Health 2006)**. No participant will be included unless the consent form has been signed, after the investigator has provided a full oral and written (see above) explanation of the study, including risk factors. You have the right to withdraw from the study at

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any time without stating a reason, and conversely, may be withdrawn from the study at any time by the investigator. The data generated will be stored in a computer database in a secure facility, and confidentiality will be assured. Anonymity will also be ensured when the findings are published. It is envisaged that the University of Cape Town will not cover any public liability.

Contact Info:

Should you have any ethical concerns, or questions about rights of welfare as a study participant please contact:

UCT's Faculty of Health Sciences Human Research Ethics Committee:

Chairperson: Professor Marc Blockman

Tel: 021 406 6338

Should you have any questions related to the research study please contact:

Principal Investigator: Professor Mike Lambert , Division of Exercise Science and Sports Medicine, Department of Human Biology, PO Box 155, Newlands 7725, email: mike.lambert@uct.ac.za Tel : 021 650 4558

Co-investigator: Rebecca Johansson, E-mail: rejhansson@gmail.com, Tel: 079 596 6680

DALDA Questionnaire

i. DALDA Questionnaire

Date: _____

Monitors state of well-being and mood state

(a = worse than normal, b = normal, c = better than normal)

Part A				
1.	a	b	c	Diet
2.	a	b	c	Home Life
3.	a	b	c	School/college/work
4.	a	b	c	Friends
5.	a	b	c	Sports Training
6.	a	b	c	Climate
7.	a	b	c	Sleep
8.	a	b	c	Recreation
9.	a	b	c	Health

Part B									
1.	a	b	c	Muscle Pains	14.	a	b	c	Enough sleep
2.	a	b	c	Techniques	15.	a	b	c	Between-session recovery
3.	a	b	c	Tiredness	16.	a	b	c	General weakness
4.	a	b	c	Need for Rest	17.	a	b	c	Interest
5.	a	b	c	Supplementary Work	18.	a	b	c	Arguments
6.	a	b	c	Boredom	19.	a	b	c	Skin rashes
7.	a	b	c	Recovery Time	20.	a	b	c	Congestion
8.	a	b	c	Irritability	21.	a	b	c	Training effort
9.	a	b	c	Weight	22.	a	b	c	Temper
10.	a	b	c	Throat	23.	a	b	c	Swelling
11.	a	b	c	Internal	24.	a	b	c	Likability
12.	a	b	c	Unexplained aches	25.	a	b	c	Running nose
13.	a	b	c	Technique Strength					

Number of "a" Scores: _____

Increase in "a" scores suggest overreaching or overtraining.

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Table 1: Sources of Life Stress for the DALDA including their definitions (Rushall, 1990).

Variable	Definition
Diet	Consider whether you are eating regularly and in adequate amounts. Are you missing meals? Do you like your meals?
Home-life	Have you had any arguments with your parents, brothers or sisters? Are you being asked to do too much around the house? How is your relationship with your wife/husband? Have there been any unusual happenings at home concerning your family? How are you getting on with your roommates?
School/college/ work	Consider the amount of work that you are doing there. Are you required to do more or less at home or in your own time? How are your grades or evaluations? Think of how you are interacting with administrators, teachers or bosses.
Friends	Have you lost or gained any friends? Have there been any arguments or problems with your friends? Are they complimenting you more or less? Do you spend more or less time with them?
Training and Exercise	How much and how often are you training? Are the levels of effort that are required easy or hard? Are you able to recover adequately between efforts? Are you enjoying your sport?
Climate	Is it too hot, cold, wet or dry?
Sleep	Are you getting enough sleep? Are you getting too much? Can you sleep when you want to?
Recreation	Consider the activities that you do outside of your sport for enjoyable relaxation. Are they taking too much time? Do they compete with your application to your sport?
Health	Do you have any infections, a cold, or other temporary health problems?

Table 2: Symptoms of Stress for the DALDA including their definitions (Rushall, 1990).

Variable	Definition
Muscle Soreness	Do you have any sore joints and/or pains in your muscles?
Techniques	How do your techniques seem/feel to you? Have your technical skills changed?
Tiredness	What is your general state of tiredness?
Need for Rest	Do you feel that you need a rest between training sessions?
Supplementary Work	How strong do you feel when you do supplementary training (e.g., weights, resistance work, stretching)?
Boredom	How boring is your training?
Recovery Time	Do the recovery times between each training effort need to be longer?
Irritability	Are you irritable? Do things get on your nerves?
Weight	How is your weight?
Throat	Have you noticed your throat being sore or irritated?
Internal	How do you feel internally? Have you had constipation, upset stomachs, etc.?
Unexplained Aches	Do you have any unexplained aches or pain?
Technique Power	How do you rate the level of power you develop in your techniques?
Enough Sleep	Are you getting enough sleep?
Recovery Between- sessions	Are you tired before you start your second training session of the day?
General Weakness	Do you feel weak all over?
Interest	Do you feel that you are maintaining your interest in your sport?
Arguments	Are you having squabbles and arguments with people?
Skin Rashes	Do you have any unexplained skin rashes or irritations?
Congestion	Are you experiencing congestion in the nose and/or sinuses?
Training Effort	Do you feel that you can give your best effort at training?

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Temper	Do you lose your temper?
Swellings	Do you have any lymph gland swellings under your arms, below your ears, in your groin, etc?
Likeability	Do people seem to like you?
Running Nose	Do you have a running nose?

Evaluation of fatigue and muscle soreness Questionnaire

Date: _____

In the last 24 hours, have you experienced any fatigue during normal daily activities?

Yes _____ No _____

If yes, please rank your fatigue on a scale of 0-10. 0 being “nothing at all”, and 10 being “maximal pain”.

0 1 2 3 4 5 6 7 8 9 10

In the last 24 hours, have you experienced any muscle soreness at rest in your lower extremities?

Yes _____ No _____

If yes, please rank your fatigue on a scale of 0-10. 0 being “nothing at all”, and 10 being “maximal pain”.

0 1 2 3 4 5 6 7 8 9 10

Ch.6.1

Research Ethics Approval Letter



UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee



Room E52-24 Old Main Building
Groota Schuur Hospital
Observatory 7925
Telephone [021] 404 7682
Email: nosi.tsama@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

12 March 2018

HREC REF: 017/2018

Prof M Lambert
Human Biology
Sports Science Institute

Dear Prof Lambert

PROJECT TITLE: INTERACTIONS BETWEEN TRAINING LOAD, SUBMAXIMAL HEART RATE AND PERFORMANCE IN ENDURANCE RUNNERS (PHD CANDIDATE - MS R JOHANSSON)

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30 March 2019.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.

(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

We acknowledge that the student Ms Rebecca Johansson will be involved in this study.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval before the research may occur.

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Yours sincerely

Signature removed to avoid exposure online

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical

Consent Form

Participant Information Sheet

Dear Study Participant,

Thank you for your interest in this research study. The goals of the study are to determine how much you train in lead up to races, how your heart rate changes with training while running at 7 different effort levels, and how your running performances change over a 6 month period. This will contribute to our long term goal of advising runners when to train hard or easy. You have been invited to participate because you are a well-trained runner who trains at least three to four times per week. You will perform 6 months of your own run training, a submaximal 40 minute running test once a week, and a 5-km time trial twice per month. Each 40 minute running test includes: a 5 minute warm-up, 7 x 3 minute intervals at the following effort level (on a scale of 0-10)- 1,3,4,5,6,8,9. You will jog very easy for 2 minutes between each 3 minute interval. You will record your heart rate and running speed from each 3 minute interval.

Risks

When you run, there is always a small risk of injury to your muscles, bones, tendons, and ligaments. There is also a small risk of a cardiac emergency happening such as a heart attack. We have made efforts to make the risk as small as possible. We have asked about your medical and injury history, and only people who were deemed healthy and free from injury were eligible to participate. We have also ensured that you are a well-trained runner who runs a minimum of 40 km/week. When you run at a high effort, you will have some discomfort. This includes breathing faster and your heart beating harder and faster.

Benefits

You will get free access to Training Peaks software for the duration of the study. You will get information about how your training changes over time, your heart rate and running speeds at 7 different effort levels, and how your

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running performance changes over time. You will be able to use this information to guide your training.

If you do not want to take part in this research, you may withdraw from the study at any point. You will not be penalised in any way for withdrawing from the study. Your study information will be used to write a scientific paper. All your information will be confidential, and your name will not be used in any reporting of results.

Appendix IV

DEPARTMENT OF HUMAN BIOLOGY, DIVISION OF EXERCISE SCIENCE AND SPORTS MEDICINE INFORMED CONSENT

- *Why is this study being done?*

The goal of the study is to determine how training changes over 6-months, how much heart rate changes on a weekly basis while running at 7 different effort levels, and how running performance changes over 6 months. This will contribute to our long term goal of advising runners on how to train to maximise performance and decrease risk of injury.

- *Why are you being asked to take part?*

You are asked to take part in the study because you are a well-trained runner. You run at least 3-4x/week, are between 18-50 years old, and are healthy and free of injury.

- *How many people will take part in the study?*

Fifty people will take part in the study.

- *How long will the study last?*

The study will last a period of 6 months.

- ***What did we do to decide if you were eligible to take part?***

We sent you a physical activity readiness questionnaire to decide if you were healthy enough to be part of the study. We also asked how far and often you are running right now, what races you plan to do, your age and gender, and if you currently train with a global positioning system (GPS) device and a heart rate (HR) monitor (chest strap).

- *What will happen in the study?*

You will be given a Training Peaks athlete account where 6 months of your training data will be uploaded. You will wear your personal GPS device and chest strap HR monitor for all runs. You will perform a fartlek run 1x/week. You will perform a 5-km time trial twice per month. You will compete in a minimum of 3 races in 6 months of your choosing.

7) Informed consent.

8) Fill in questionnaire with training and race history information.

9) Receive Training Peaks athlete account.

10) Wear GPS device and chest strap HR monitor for all runs. Upload all runs to Training Peaks athlete account.

11) Perform 40-minute running test 1x/week including: a 5 minute warm-up, 7 x 3 minute intervals at the following effort level (on a scale of 0-10)- 1,3,4,5,6,8,9. You will jog very easy for 2 minutes between each 3 minute interval. We will record your heart rate and running speed from each 3 minute interval. During each test you will run about 6km. You will do the run test either on an outdoor track or on a relatively flat road course.

12) Perform a 5-km time trial 2x/month.

13) Compete in a minimum of 3 races in 6 months.

- *What are the risks and discomforts of this study?*

When you run, there is always a risk of injury to your muscles, bones, tendons, and ligaments. There is also a small risk of a cardiac emergency happening

such as a heart attack. These risks are similar to the risks you will encounter during a moderate to high intensity 5-6 km training run. We have made efforts to make the risk as small as possible. We have asked about your medical and injury history, and only people who were deemed healthy and free from injury were eligible to participate. We have also ensured that you are a well-trained runner who runs a minimum of 40 km/week. When you run at a high effort, you will have some discomfort. This includes breathing faster and your heart beating harder and faster.

- *Are there any benefits to you for being in the study?*

You will get free access to Training Peaks software for the 6-month duration of the study. You will get information about your run training, heart rate and running speeds at 7 different effort levels, and run performances. You will be able to use this information to guide your training.

You will get information about your heart rate and running speeds at 7 different effort levels. You will also get information on how much your heart rate during running changes on a weekly basis. This may be useful information to guide your training.

- *What other choices do you have?*

If you do not want to take part in this research, you may withdraw from the study at any point. You will not be penalised in any way for withdrawing from the study. Your study information will be used to write a scientific paper. All your information will be confidential, and your name will not be used in any reporting of results. You are allowed to withdraw from the study at any time.

- *What will happen when the study is over?*

Your study information will be used to write a scientific paper. All of your information will be confidential. Your name will not be used in any reporting of results.

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- *Will your test results be shared with you?*

Yes. You will get information about your training, running speed and heart rate at each running intensity, and running performances.

- *Will the results of the research be shared with you?*

We will send you a summary of the results when the scientific paper has been accepted for publication.

- *Will any of your blood, tissue or other samples be stored and used for research in the future?*

We will not take any blood, tissue or other samples from you in this study.

- *Will you receive any reward (money or food vouchers) for taking part in this study?*

You are a volunteer in the study, and will not receive any reward (money or food vouchers).

- *Who will see the information which is collected about you during the study?*

Only approved researchers will see information collected about you during the study. Your information will be confidential and will be stored in a secure place.

- *Who do I speak to (or contact) if I have any questions about the study?*

Should you have any ethical concerns or questions about your rights or welfare as a participant on this research study you can contact The UCT's Faculty of Health Sciences Human Research Ethics Committee (contact details provided below).

Chairperson: Professor Marc Blockman

Tel: 021 406 6338

Should you have any additional questions or concerns related to the research study you may contact the Principal Investigator of the study or co-investigator (contact details provided).

Principal Investigator: Professor Mike Lambert , Division of Exercise Science and Sports Medicine, Department of Human Biology, PO Box 155, Newlands 7725, email: mike.lambert@uct.ac.za Tel : 021 650 4558

Co-investigator: Rebecca Johansson, E-mail: rejohansson@gmail.com, Tel: 079 596 6680

What happens if I get hurt taking part in this study?

This research study is covered by an insurance policy taken out by the University of Cape Town in the event of you suffering a bodily injury because you are taking part in the study.

The insurer will pay for all reasonable medical costs required to treat your bodily injury, according to the SA Good Clinical Practice Guidelines 2006 (*or latest version*), which are based on the Association of the British Pharmaceutical Industry Guidelines. The insurer will pay without you having to prove that the research was responsible for your bodily injury. You may ask the study doctor for a copy of these guidelines.

The insurer will *not* pay for harm if, during the study, you:

- Use medicines or other substances that are not allowed
- Do not follow the study doctor's instructions
- Do not take reasonable care of yourself

If you are harmed and the insurer pays for the necessary medical costs, usually you will 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 you give up your right to make a separate claim for other losses based on negligence, in a South African court.

It is important to follow the study doctor's instructions and to report straightaway if you have a side effect from the study.

Appendices

I confirm that the exact procedures of the tests have been fully explained to me. I understand that I may ask questions at any stage during the testing procedure, and that I am able to withdraw from the testing procedure at any given time, without prior warning. I have been informed that the personal information I have put forward will be kept confidential, and that the information obtained from the testing procedures will be used anonymously in statistical analysis.

I therefore understand the nature and protocol of the testing procedures. I agree to participate in this study and I give permission to the Division of Exercise Science and Sports Medicine of UCT Department of Human Biology to use my results anonymously for any publications that may be published as a result of this study.

Name (in full) of participant

Signature of participant:

Name (in full) of witness:

Signature of witness:

Date:

Ethical Considerations: Privacy, Confidentiality, and Liability

The study will be performed in accordance with the principles of **the Declaration of Helsinki (2013)**, Good Clinical Practice and the laws of South Africa. **Good Clinical Practice is an international ethical and scientific quality standard for research, and guidelines for human research in South Africa has been published (Department of Health 2006)**. No participant will be included unless the consent form has been signed, after the

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investigator has provided a full oral and written (see above) explanation of the study, including risk factors. You have the right to withdraw from the study at any time without stating a reason, and conversely, may be withdrawn from the study at any time by the investigator. The data generated will be stored in a computer database in a secure facility, and confidentiality will be assured. Anonymity will also be ensured when the findings are published. It is envisaged that the University of Cape Town will not cover any public liability.

Contact Info:

Should you have any ethical concerns, or questions about rights of welfare as a study participant please contact:

UCT's Faculty of Health Sciences Human Research Ethics Committee:

Chairperson: Professor Marc Blockman

Tel: 021 406 6338

Should you have any questions related to the research study please contact:

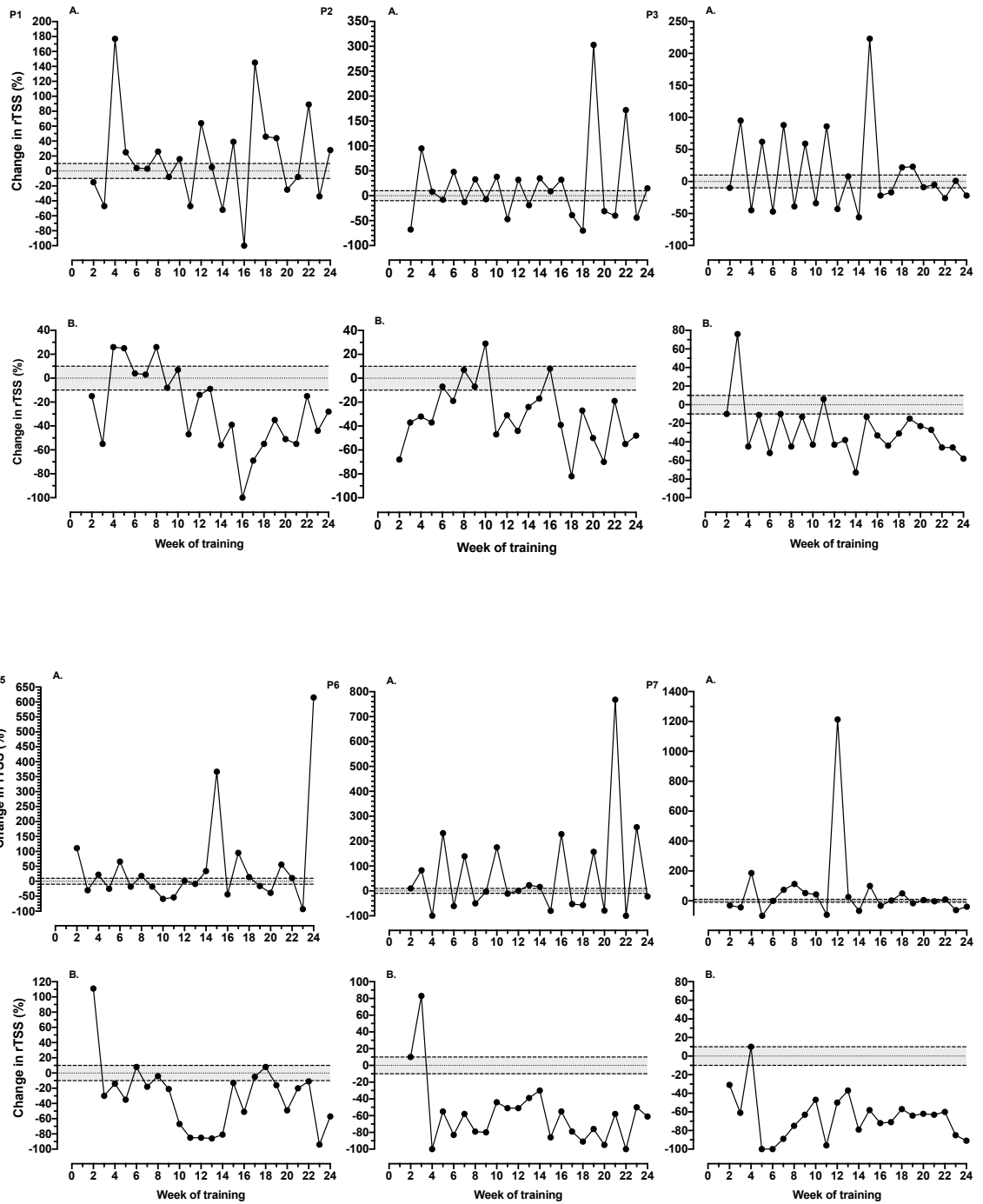
Principal Investigator: Professor Mike Lambert , Division of Exercise Science and Sports Medicine, Department of Human Biology, PO Box 155, Newlands 7725, email: mike.lambert@uct.ac.za Tel : 021 650 4558

Co-investigator: Rebecca Johansson, E-mail: rejohansson@gmail.com, Tel: 079 596 6680

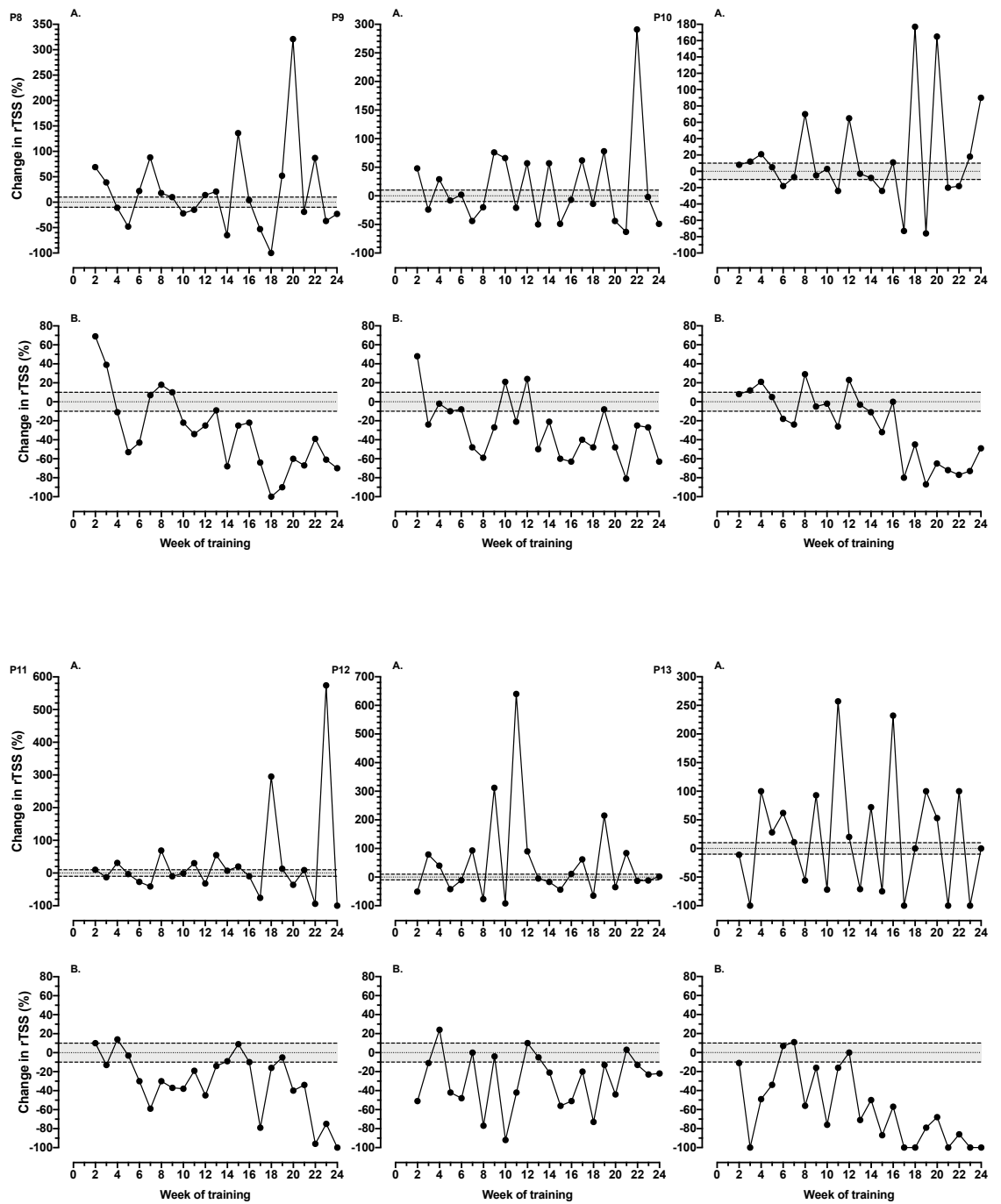
Ch.6.2

Figure 5 Addendum

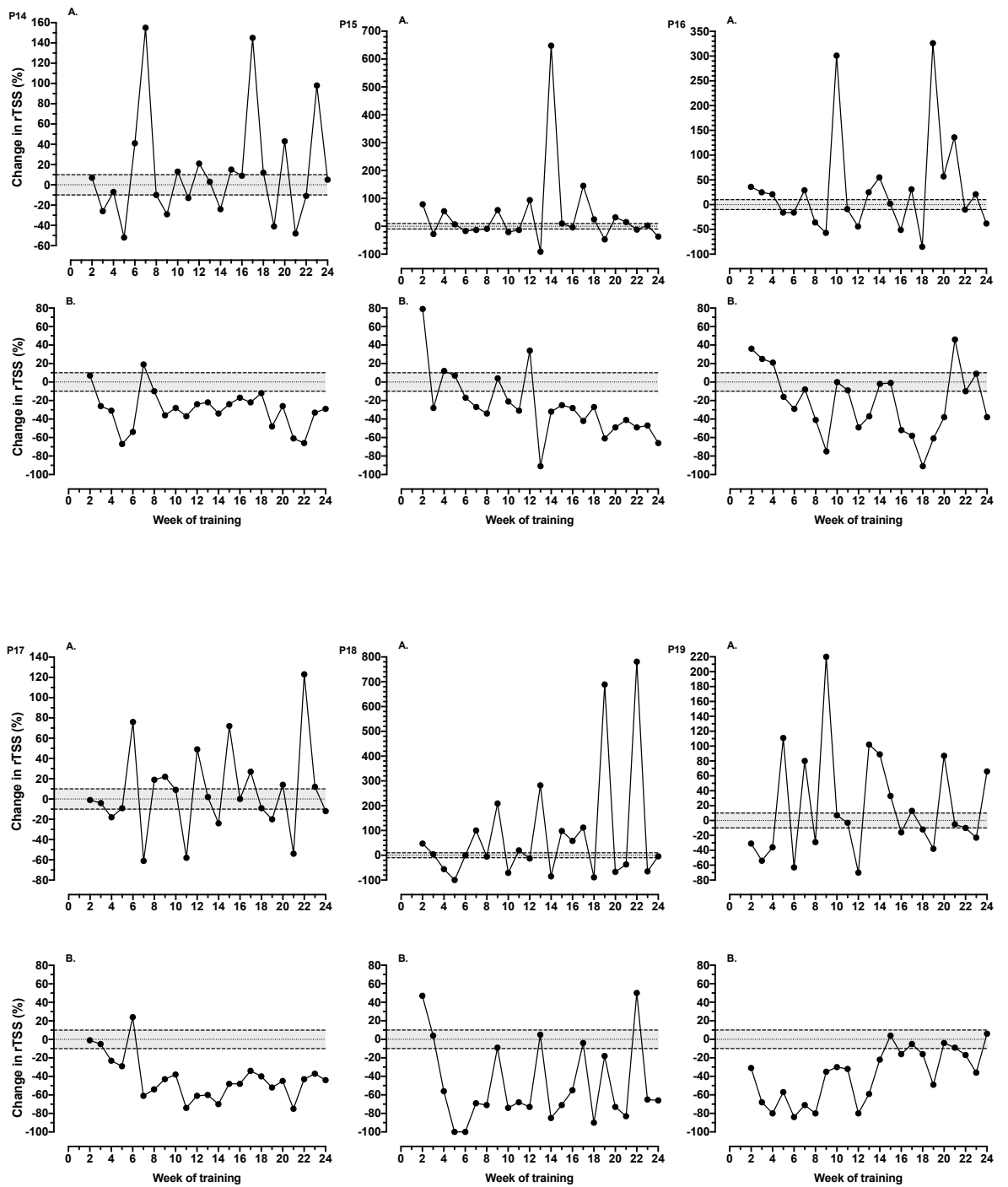
Data for Participants #1-3; 5-19; 21-24; 27-28; & 30. The participant number is labelled in the top left corner of each pair of figures. **A)** Relative weekly change in running training stress score (rTSS) values. **B)** Relative weekly change in rTSS vs. the preceding largest week of rTSS values.



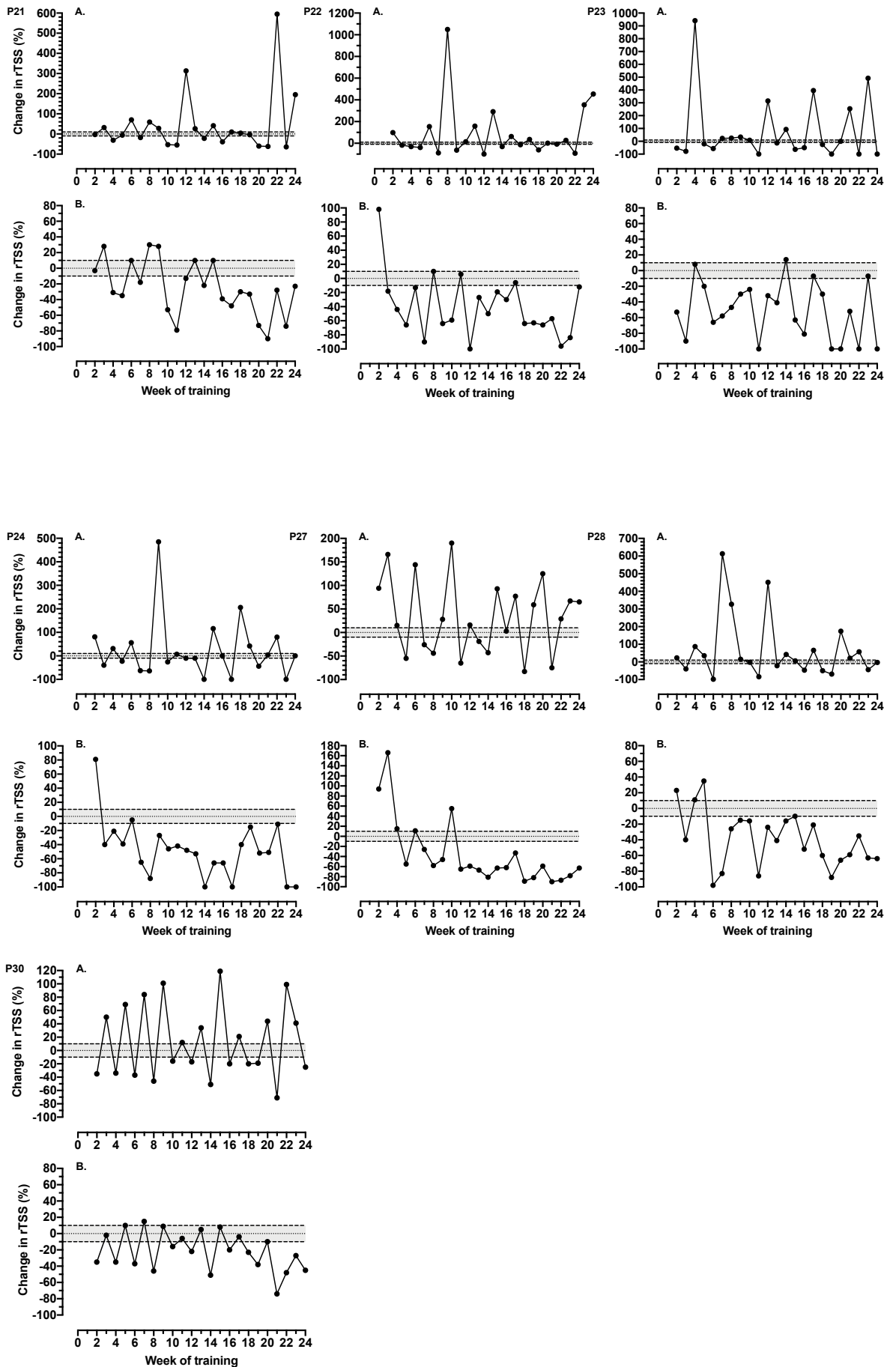
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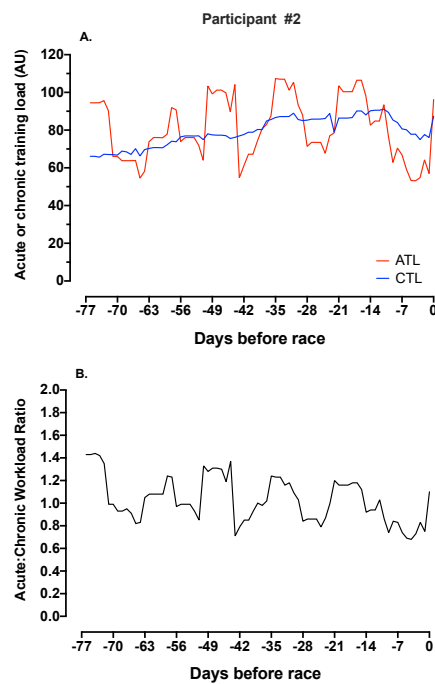
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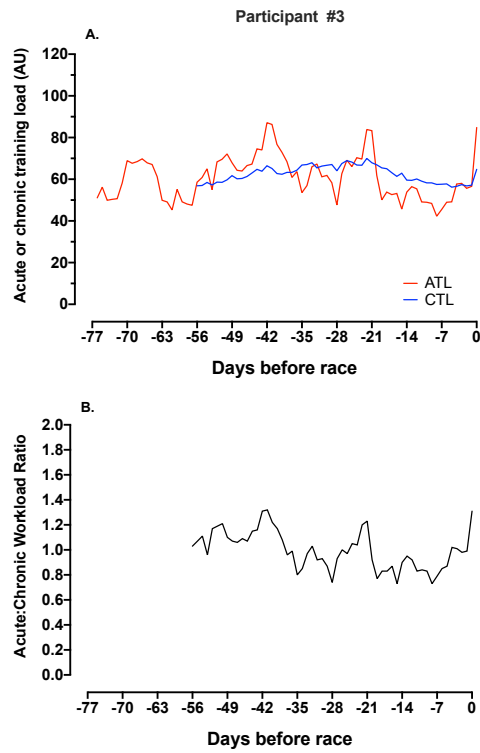
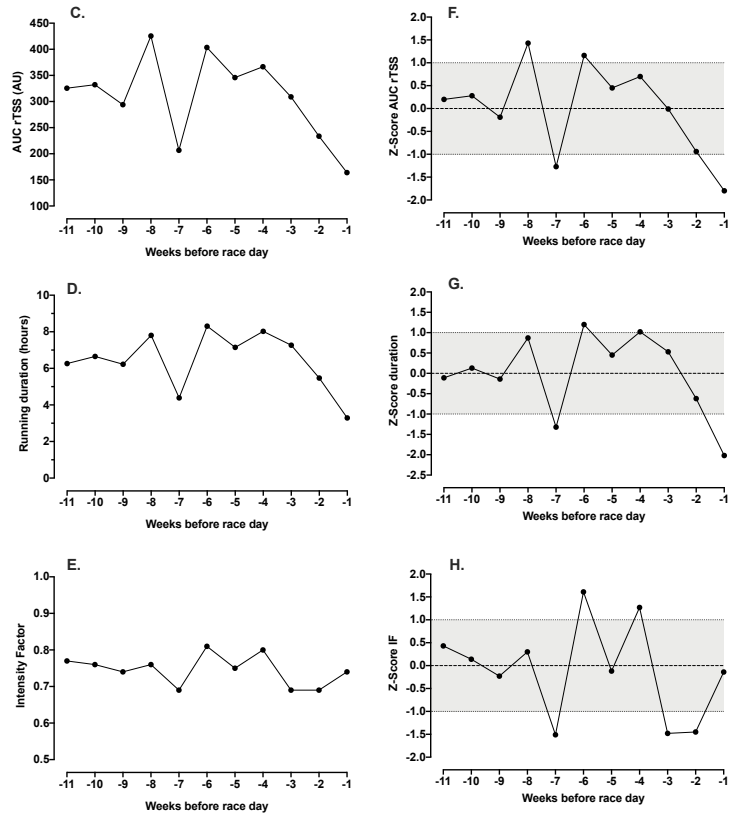
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Figure 1 Addendum

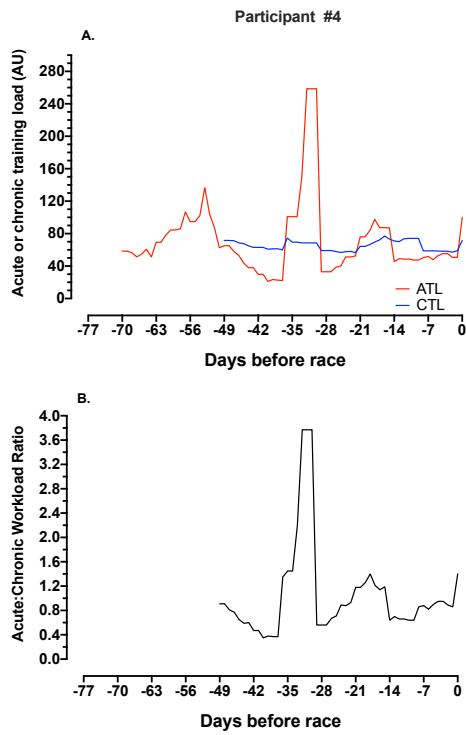
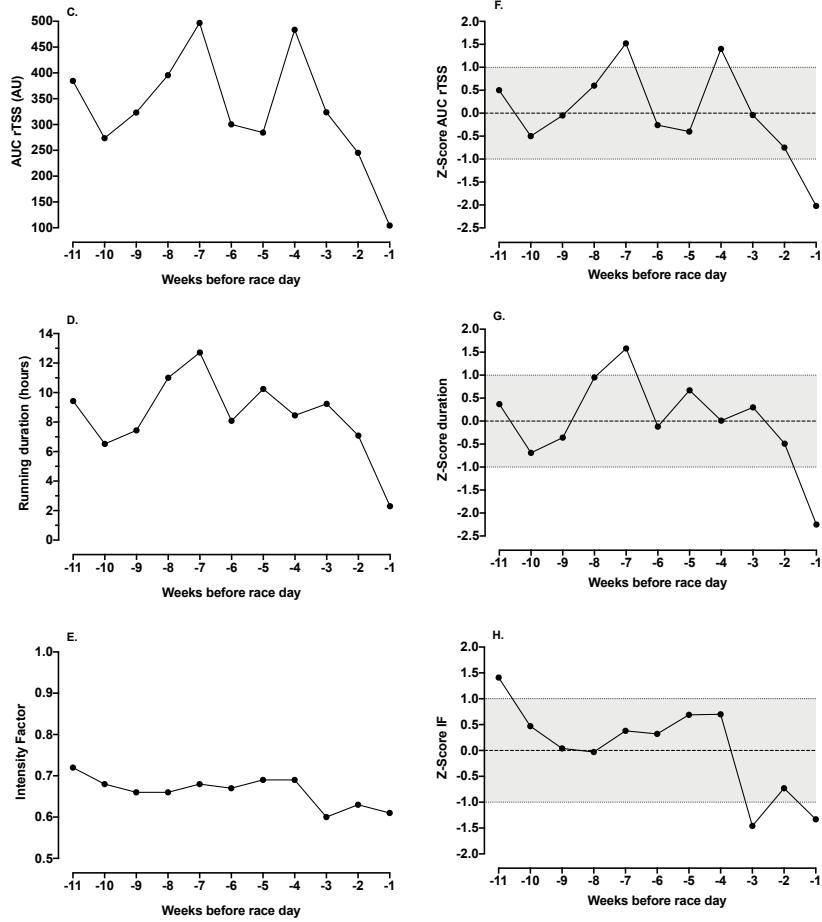
Case study figures for Participants #2-19. The participant number is labelled at the top center of each A. figure. **A)** Daily ATL & CTL; **B)** Daily ACWR; **C)** Weekly area under the curve (AUC) running training stress score (rTSS); **D)** Weekly running duration; **E)** Weekly average intensity factor; **F)** Weekly normalised AUC rTSS; **G)** Weekly normalised running duration; **H)** Weekly normalised intensity factor. The shaded region in F. – H. represent the region of no significant change. Data points outside the shaded region are considered a significant change.



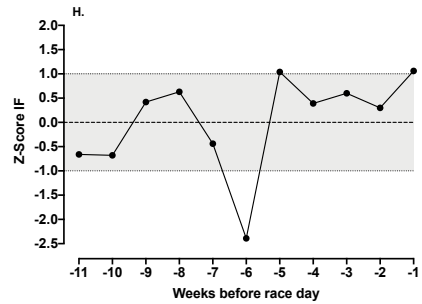
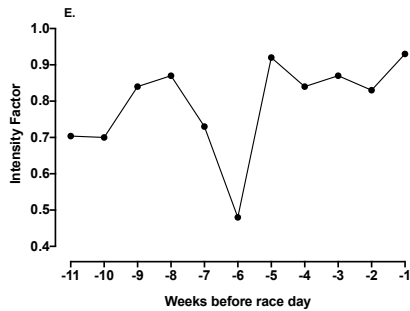
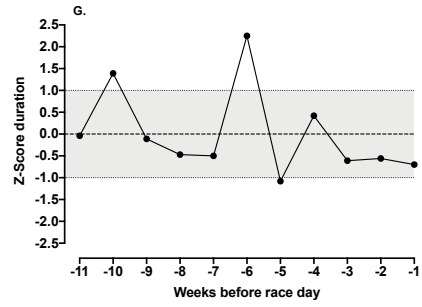
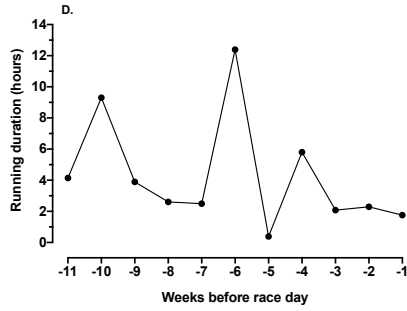
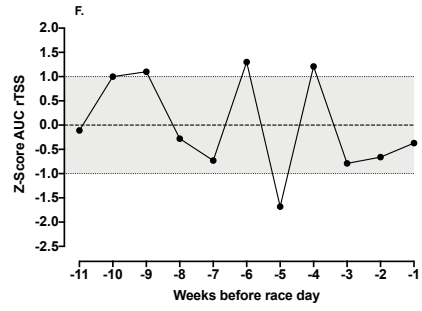
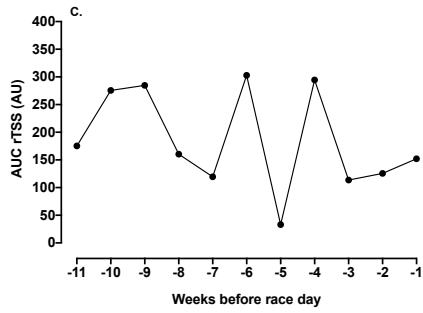
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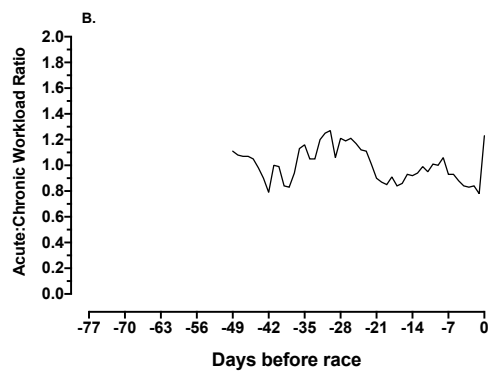
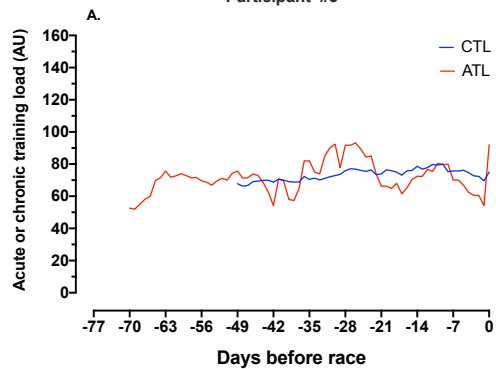
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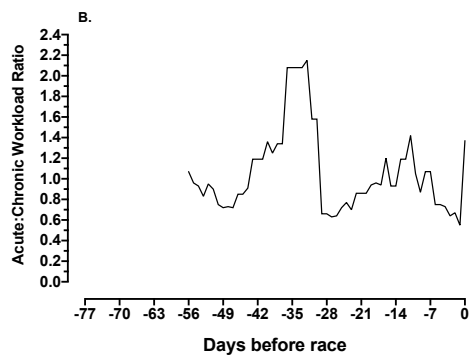
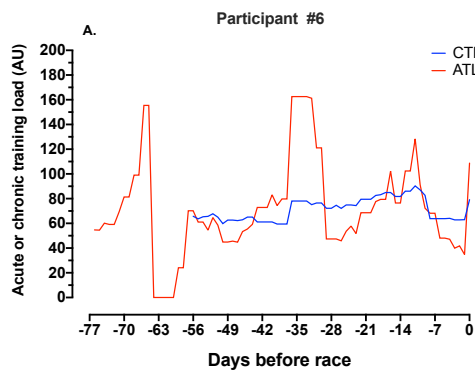
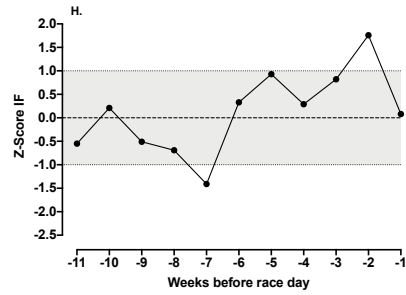
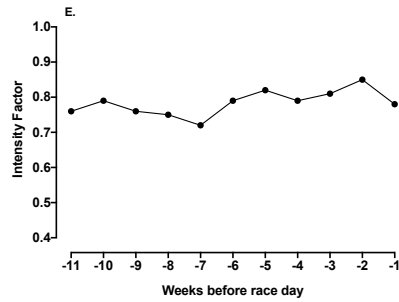
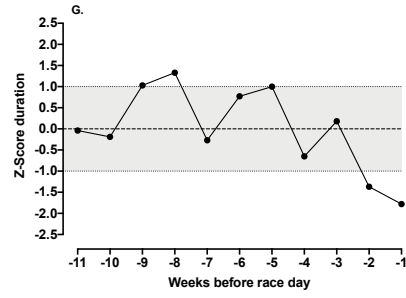
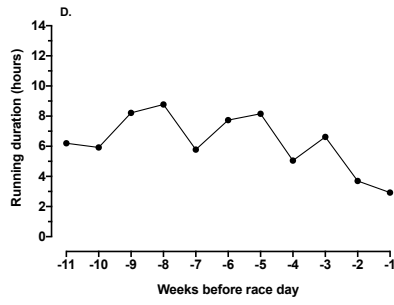
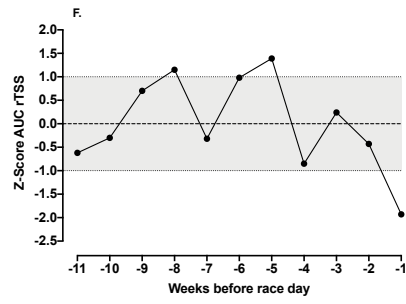
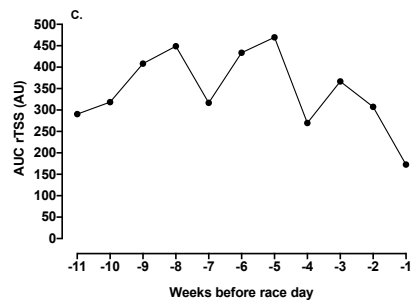
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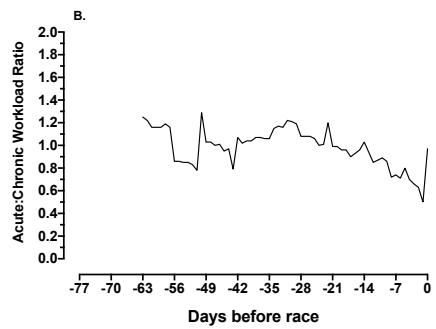
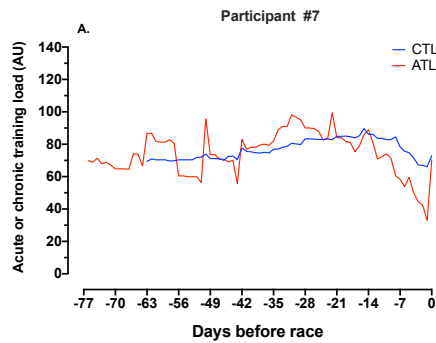
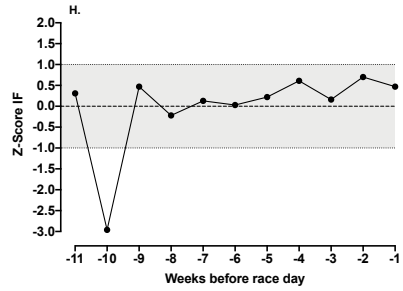
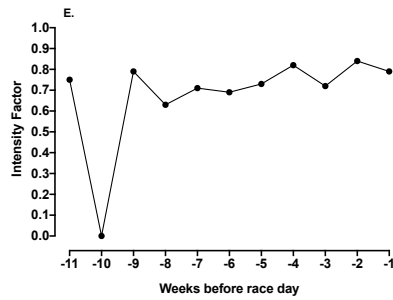
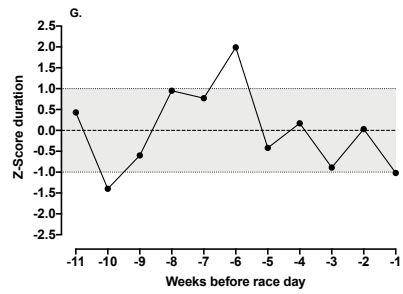
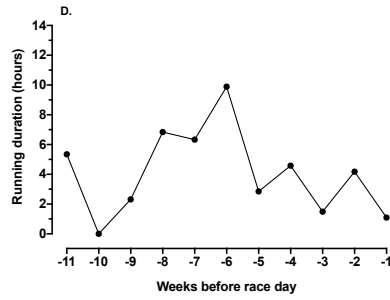
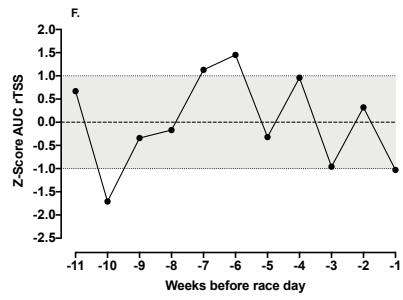
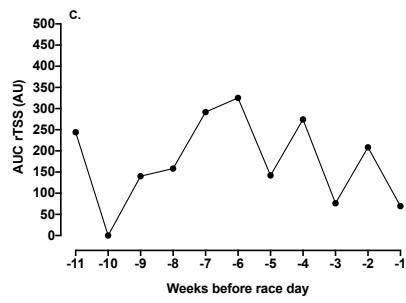
Participant #5



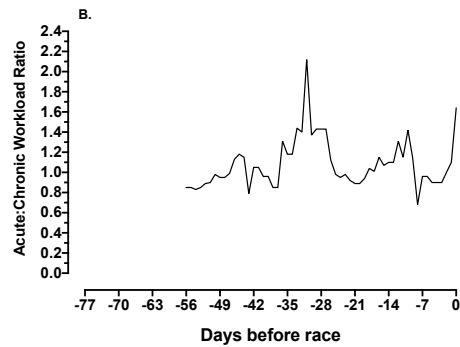
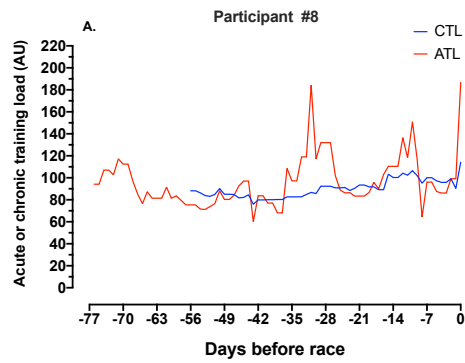
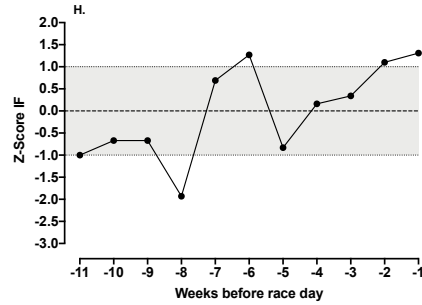
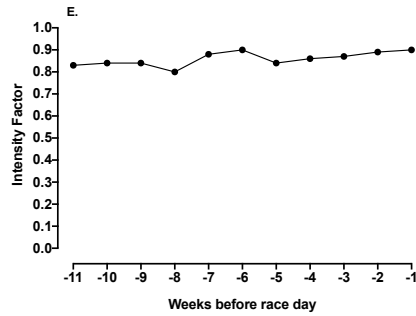
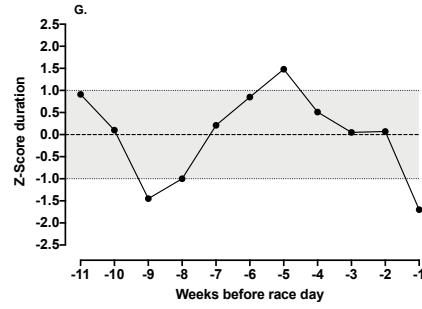
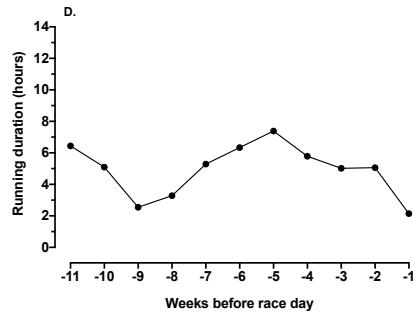
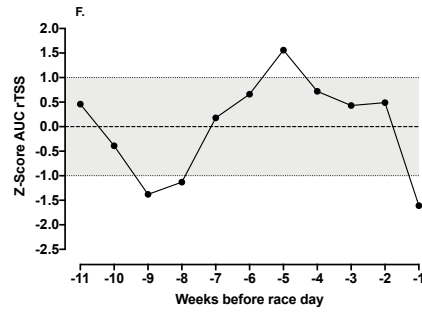
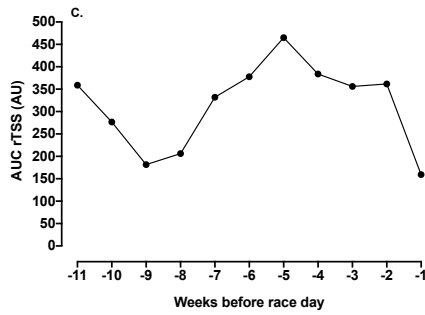
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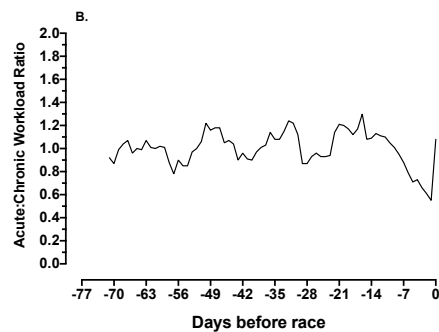
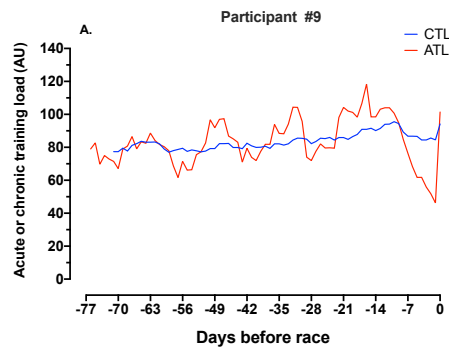
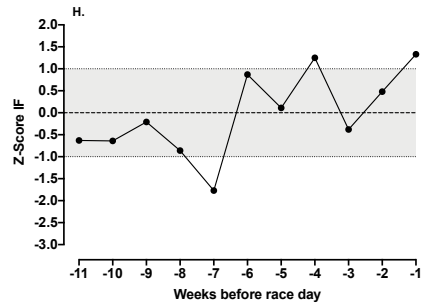
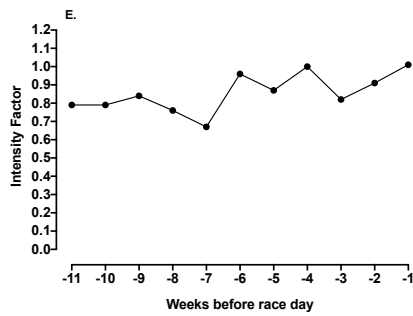
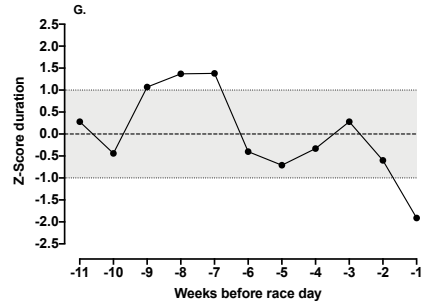
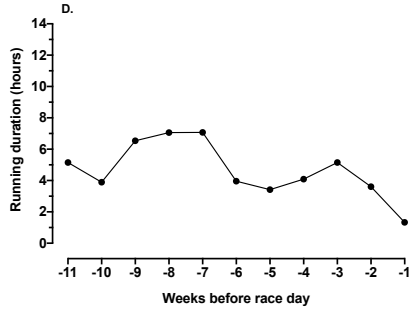
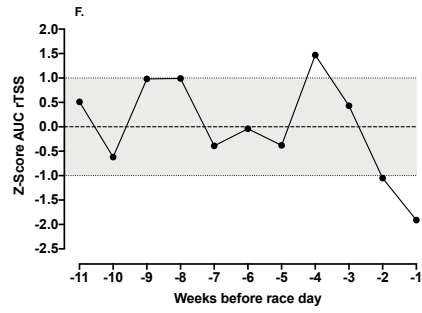
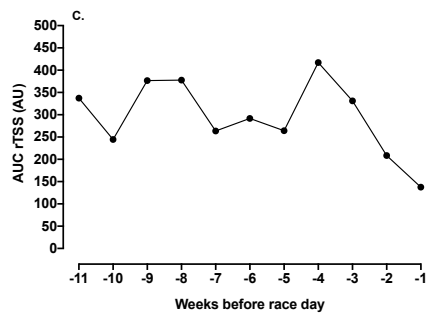
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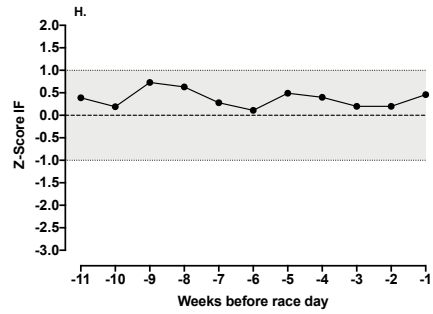
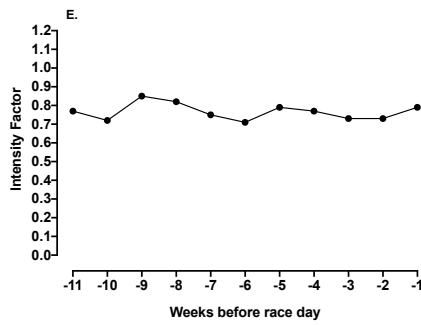
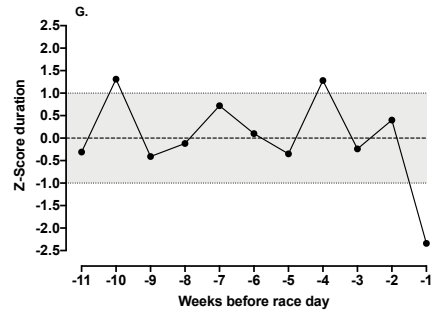
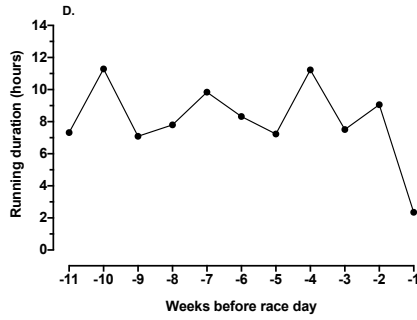
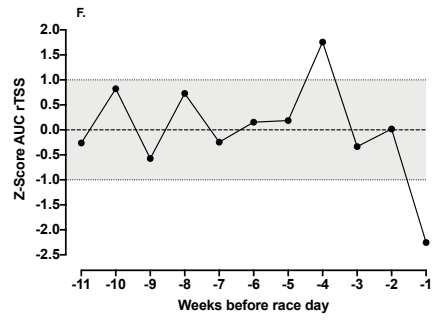
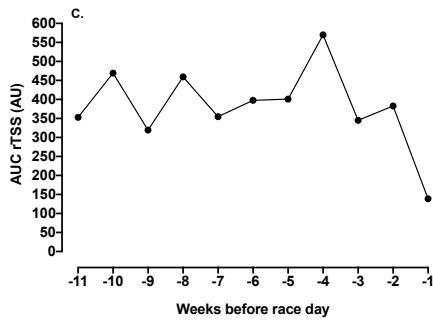
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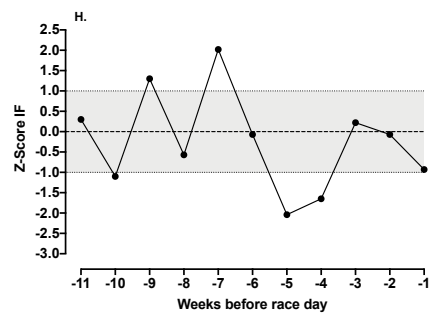
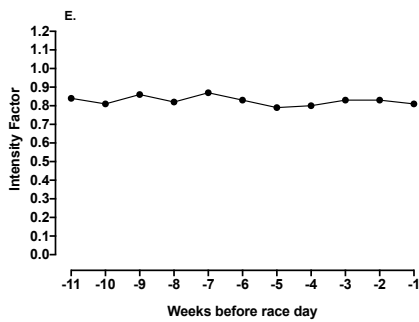
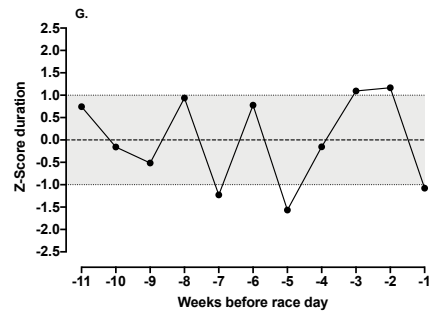
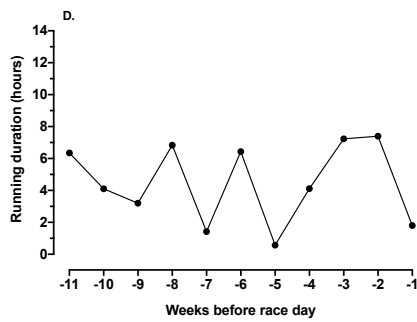
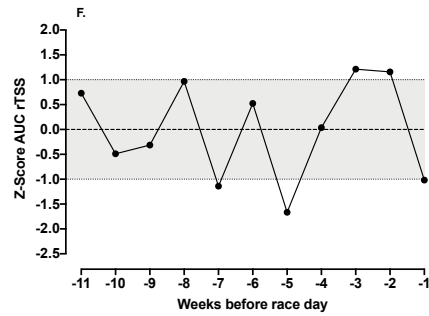
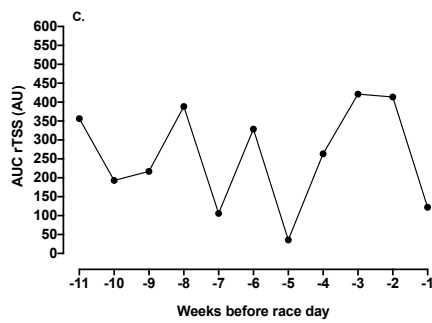
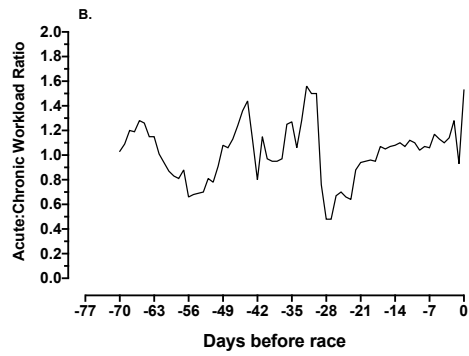
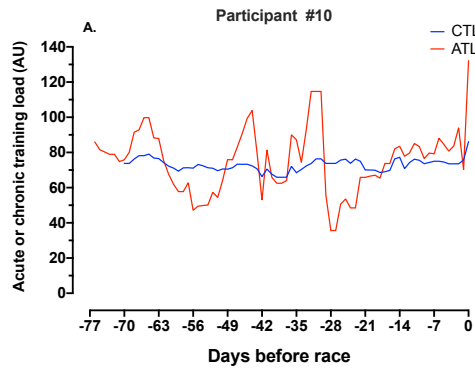
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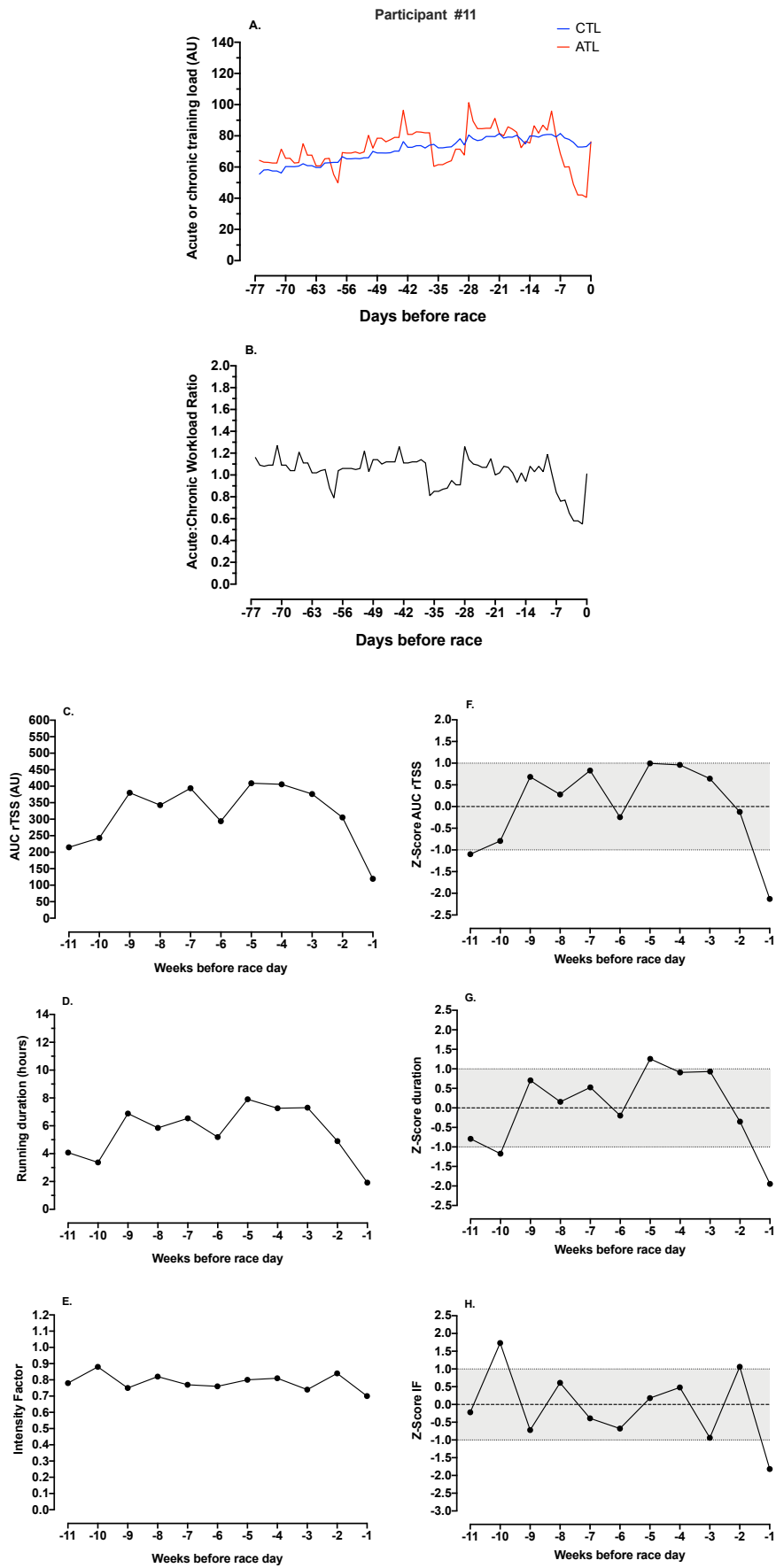
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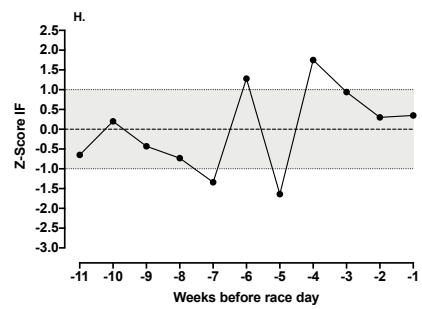
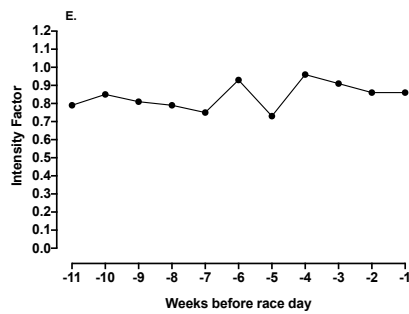
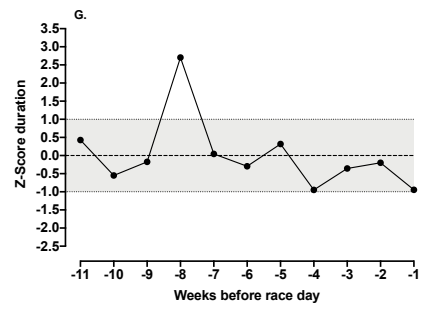
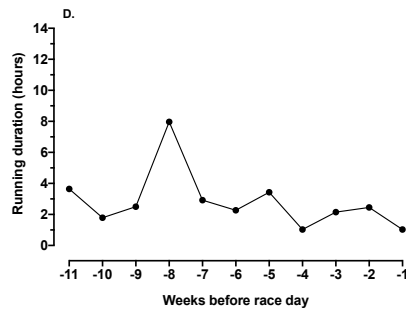
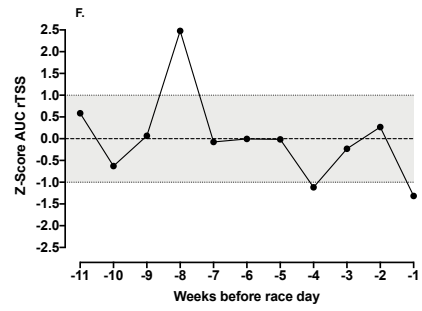
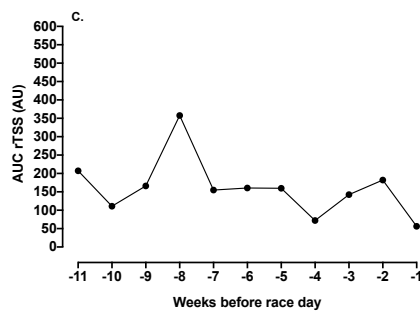
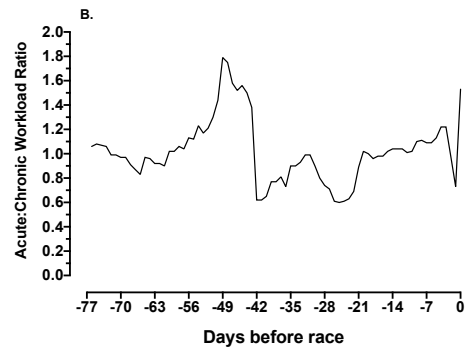
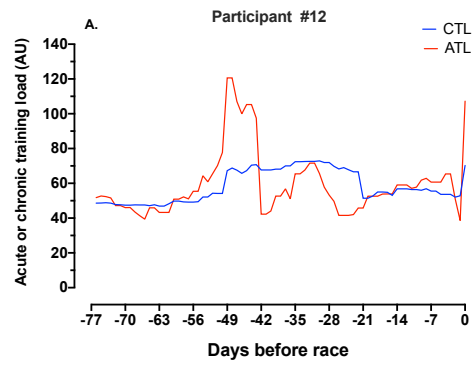
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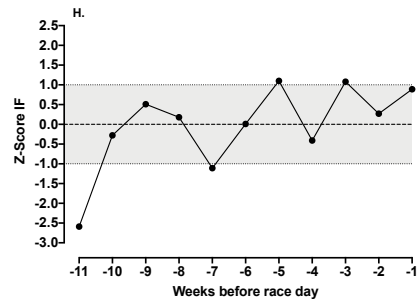
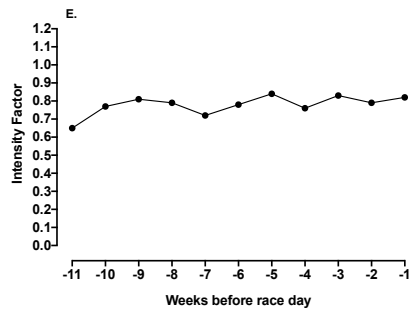
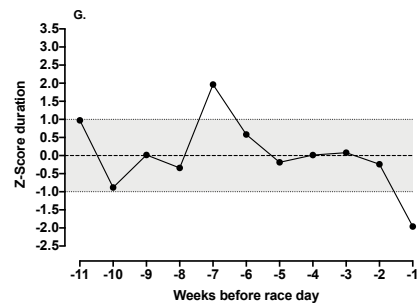
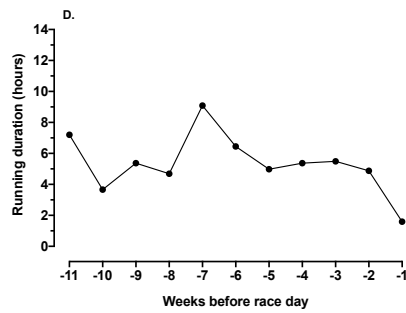
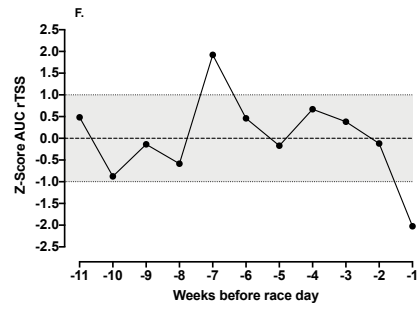
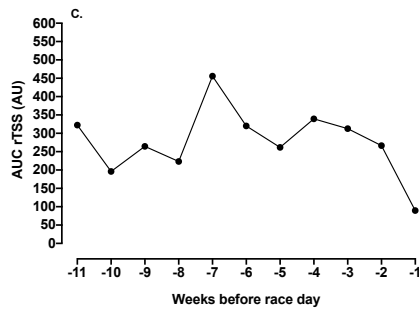
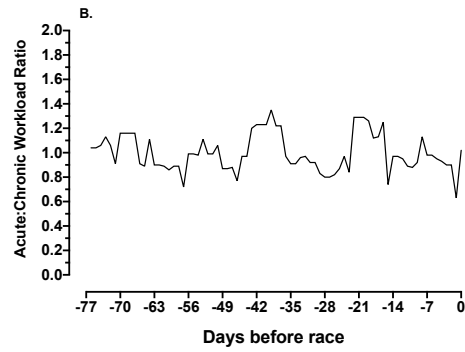
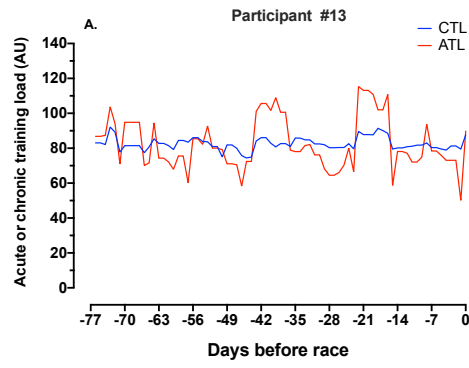
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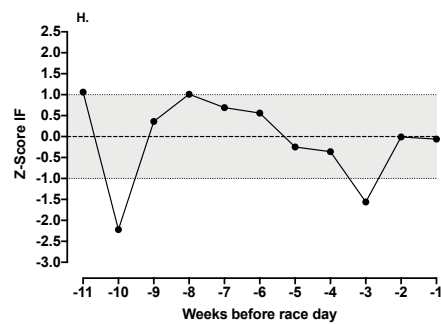
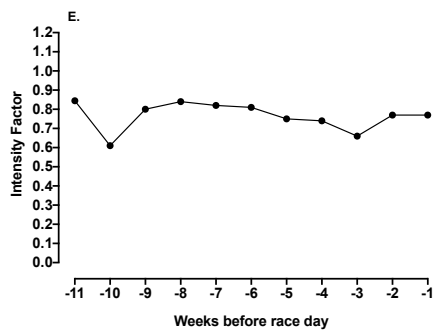
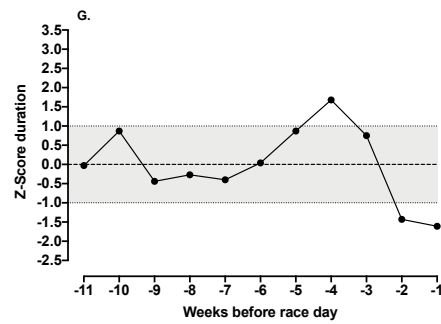
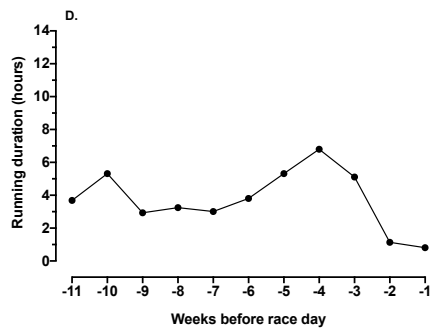
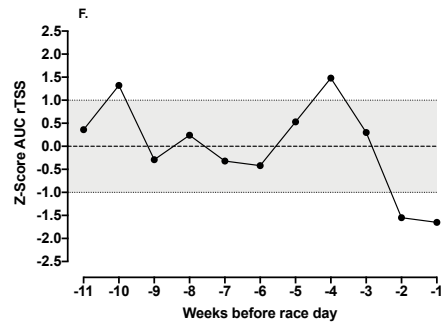
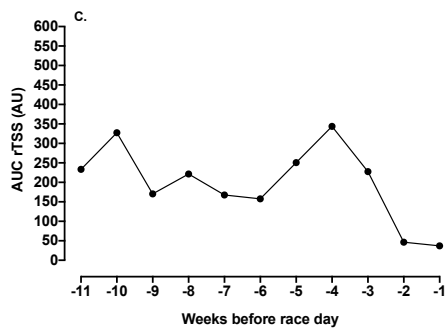
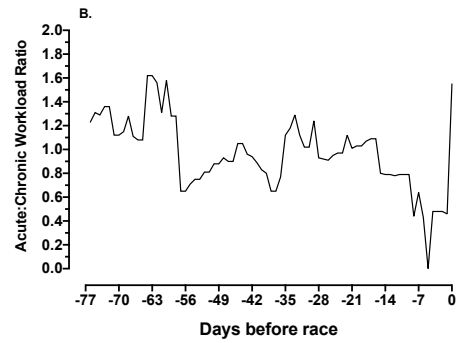
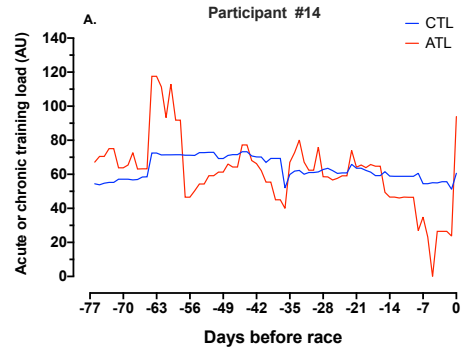
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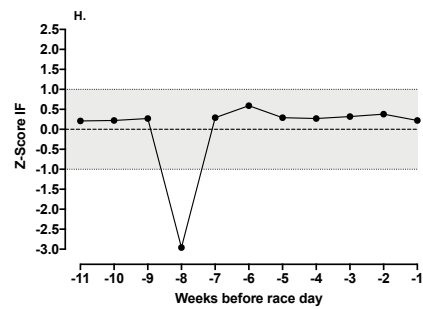
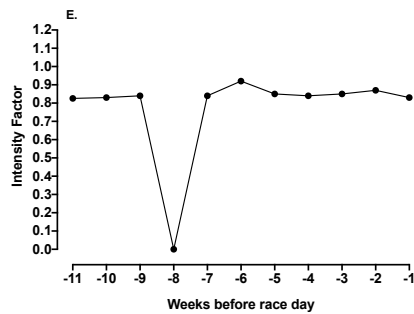
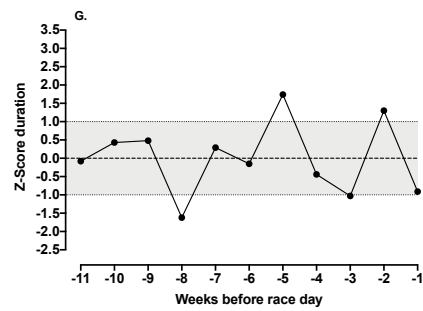
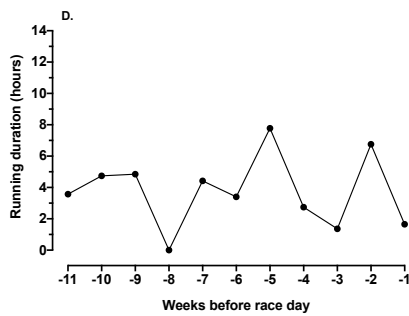
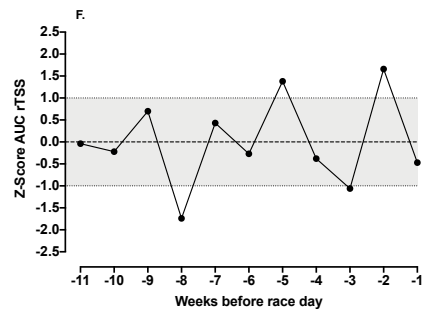
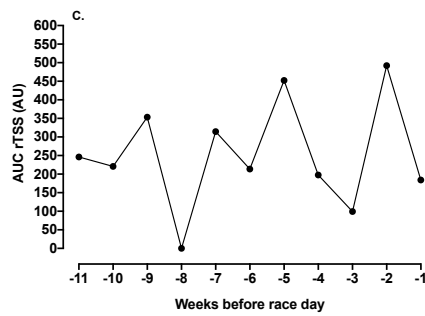
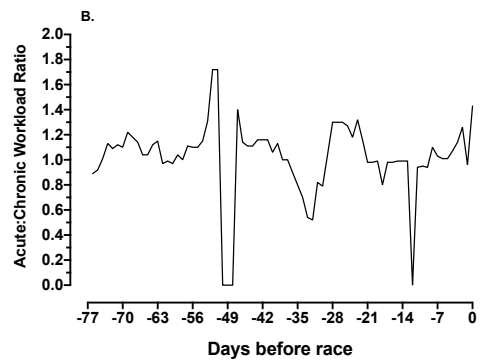
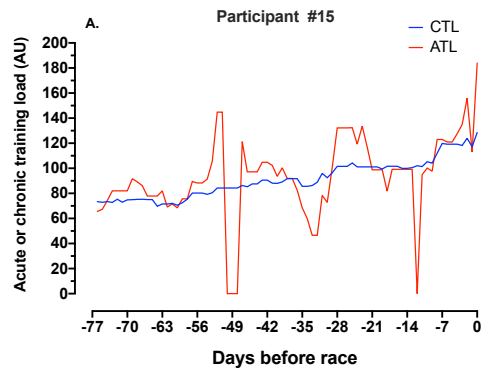
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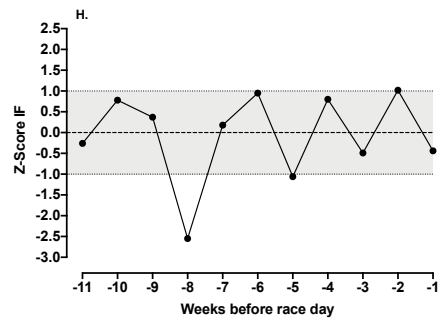
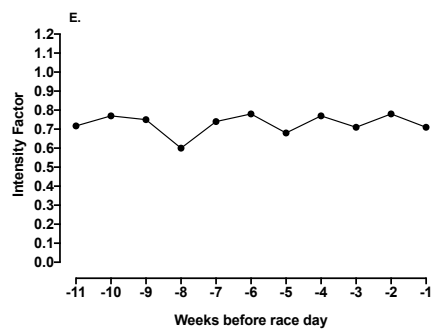
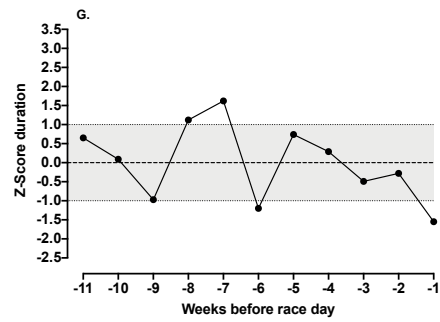
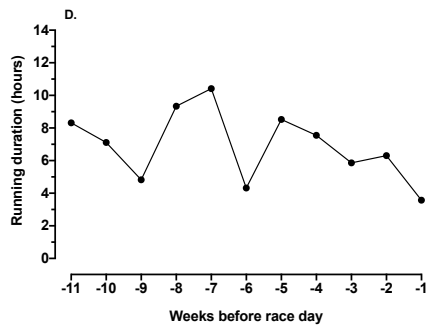
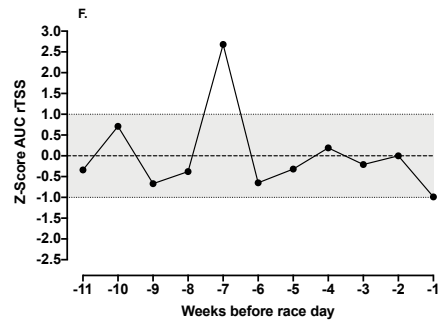
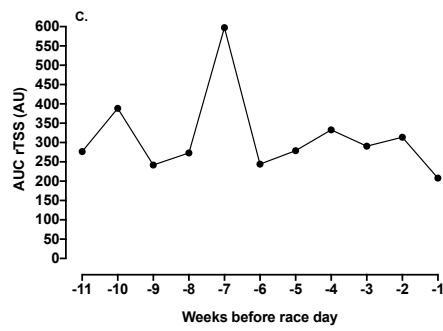
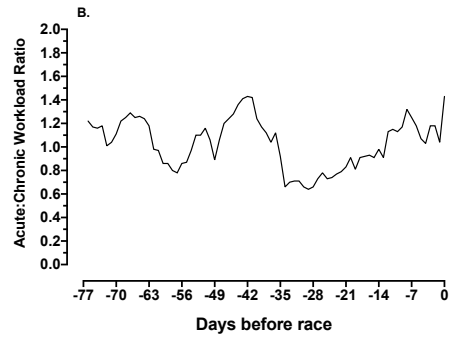
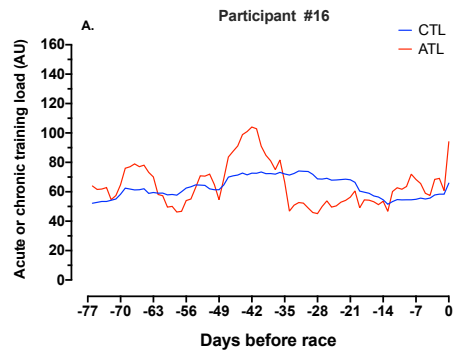
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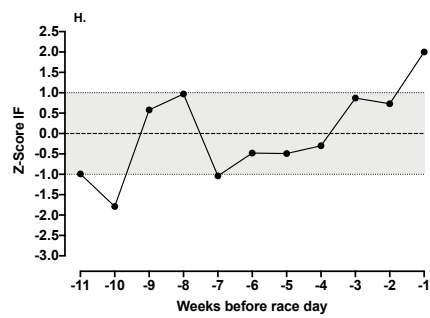
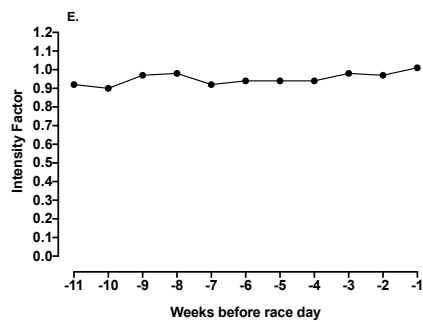
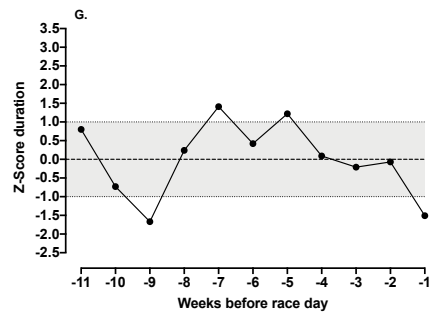
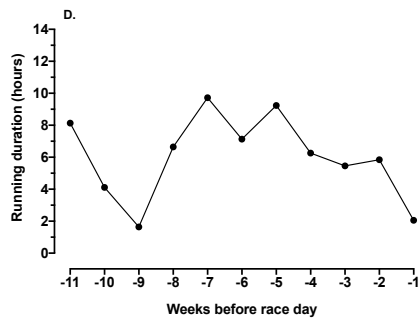
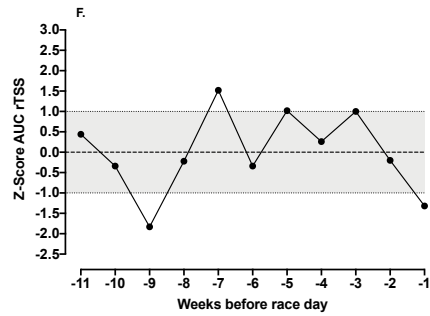
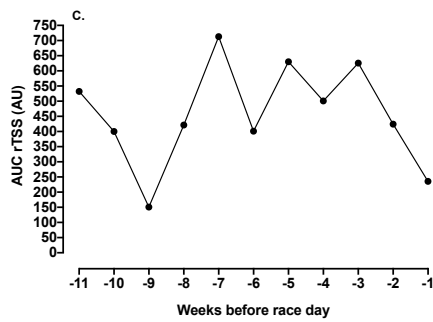
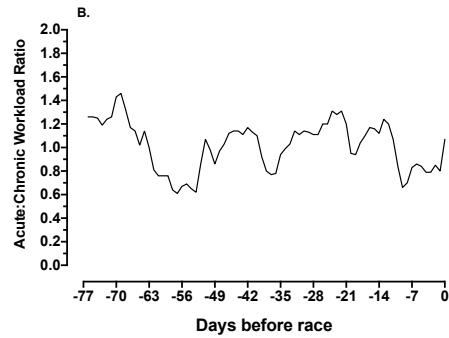
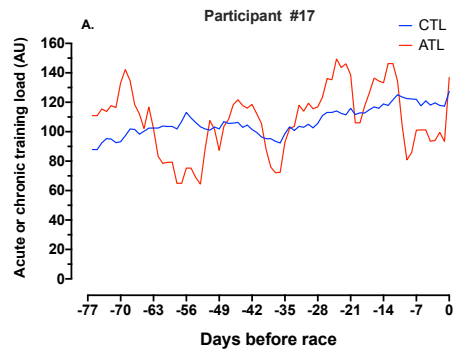
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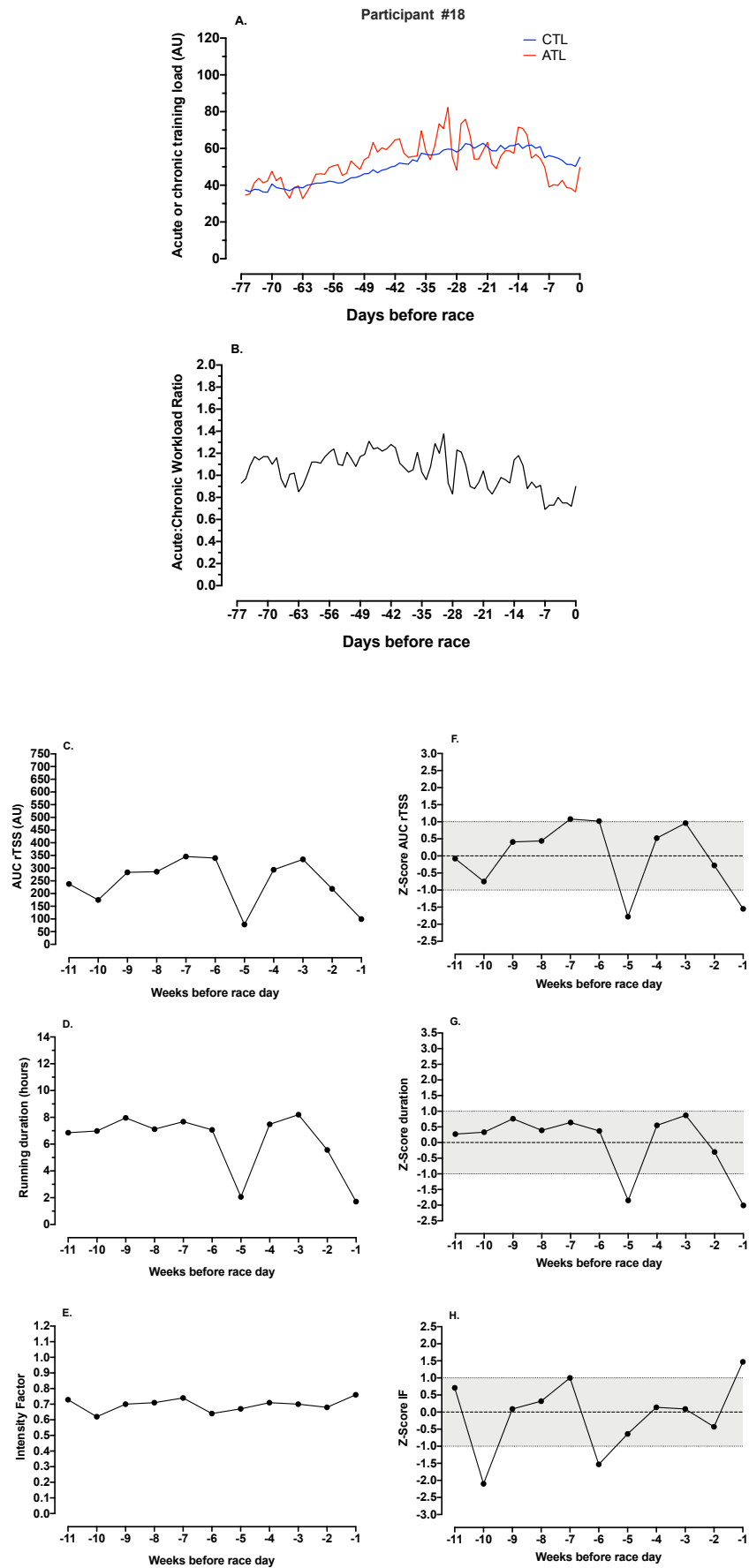
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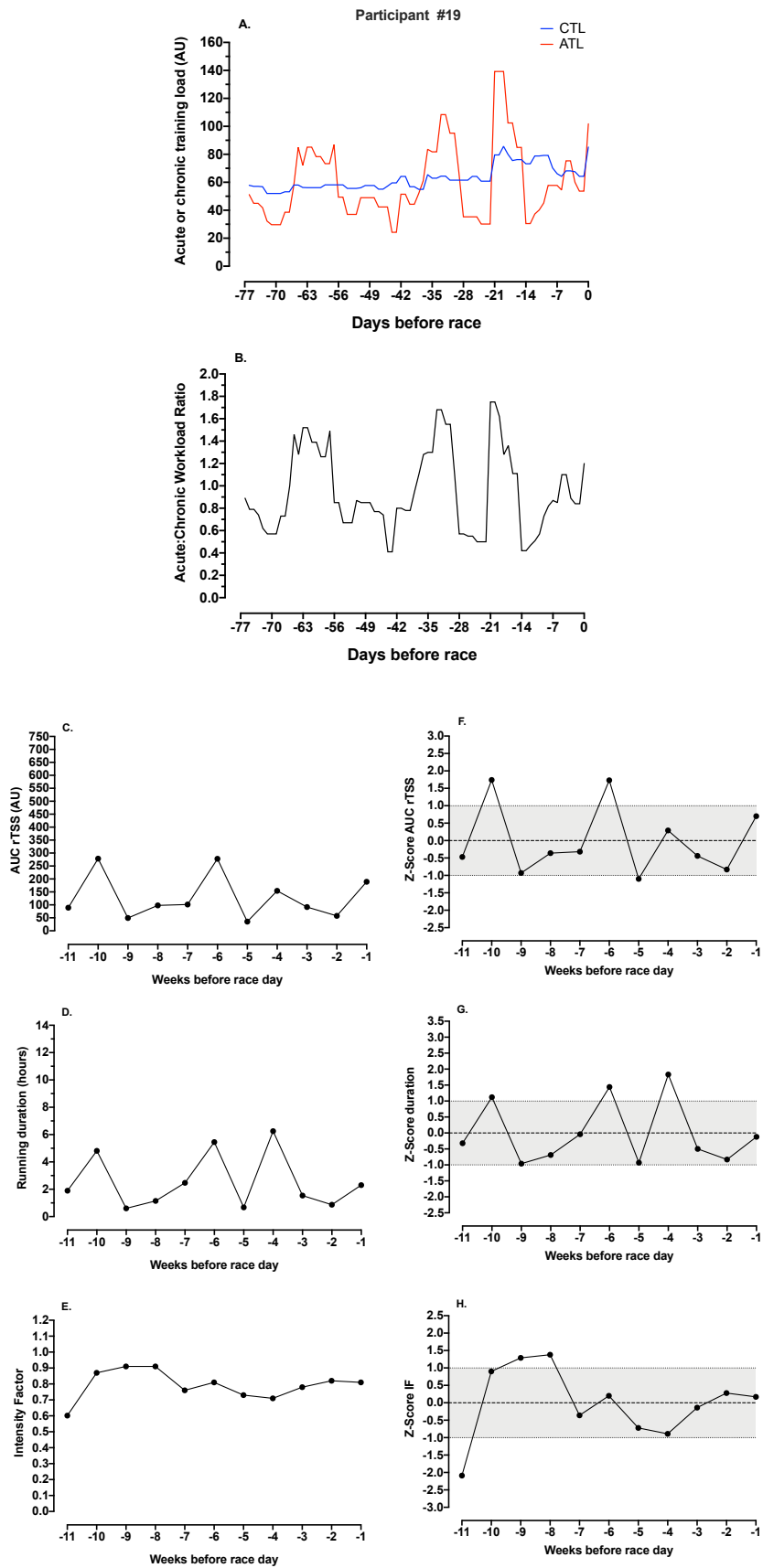
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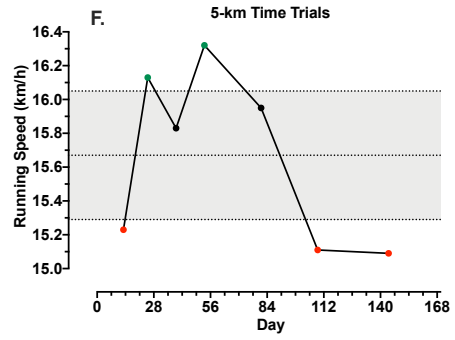
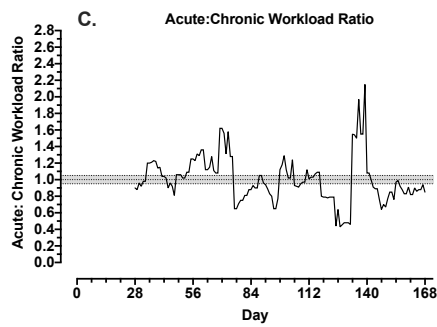
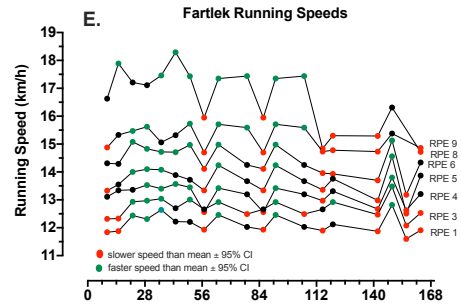
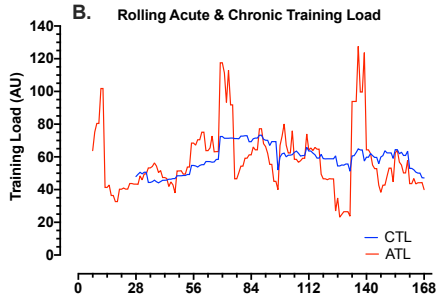
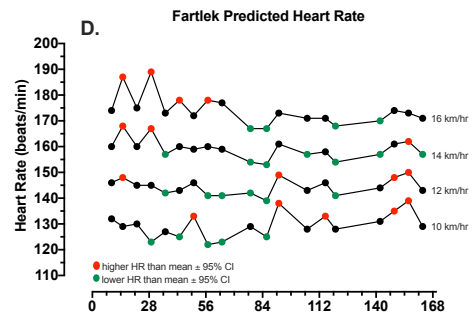
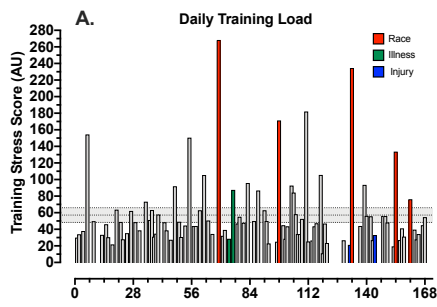


Ch.6.4

Figure 4 Addendum

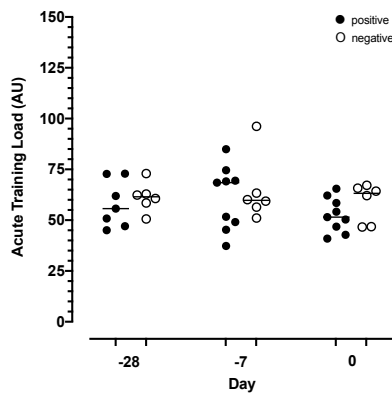
Case studies for participants #2-24, & #26-30 **A)** daily running training stress score. Shaded region represents mean \pm 95% CI. The red bars indicate days when the participant did a race. The green bars indicate days when the participant reported being sick. **B)** Rolling daily acute (red line) and chronic (blue line) training load. **C)** Rolling daily acute:chronic workload ratios. **D)** Predicted heart rate at four speeds. Red dots indicate a value higher than mean + 95% CI. Green dots indicate a value lower than mean - 95% CI. **E)** Average running speed at each RPE level for the fartlek runs. Red dots indicate a value lower than mean - 95% CI. Green dots indicate a value higher than mean + 95% CI. **F)** Average speed during the 5-km time trials. Red dots indicate a value lower than mean - 95% CI. Green dots indicate a value higher than mean + 95% CI. **G - I)** The average acute training load, chronic training load, or acute: chronic workload ratio respectively for the 28 days and 7 days before positive and negative performances. The values above the 0 represent the acute training load, chronic training load, or acute: chronic workload ratio respectively on the day of the positive and negative performances. The horizontal line represents the median value. **J)** Predicted heart rate at speed 4 for positive and negative performances. The horizontal line represents the median value. # p < 0.10 vs. positive values. The data points filled in blue represent a **FINISHER** test completed 1-5 days after an endurance running event.

Participant #2

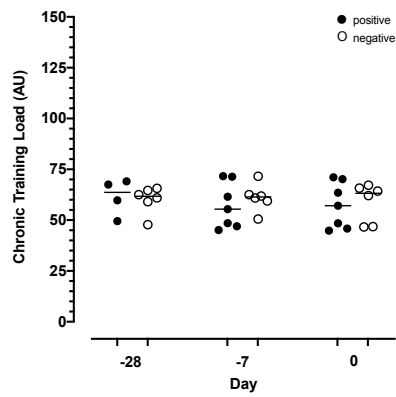


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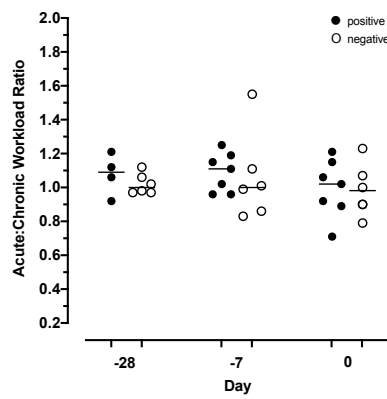
G. Acute Training Load Pre-Fartlek Runs



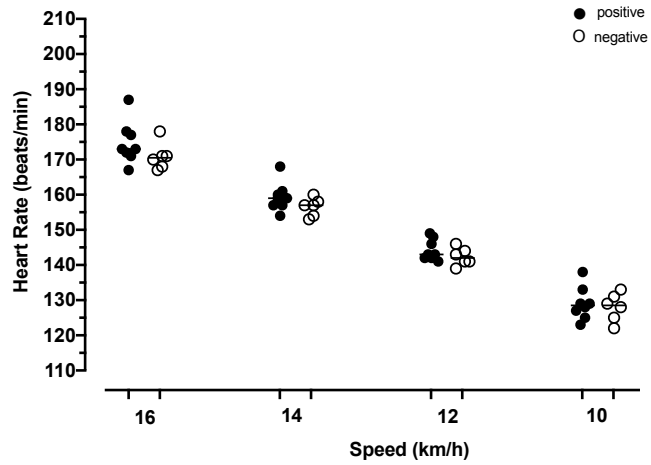
H. Chronic Training Load Pre-Fartlek Runs



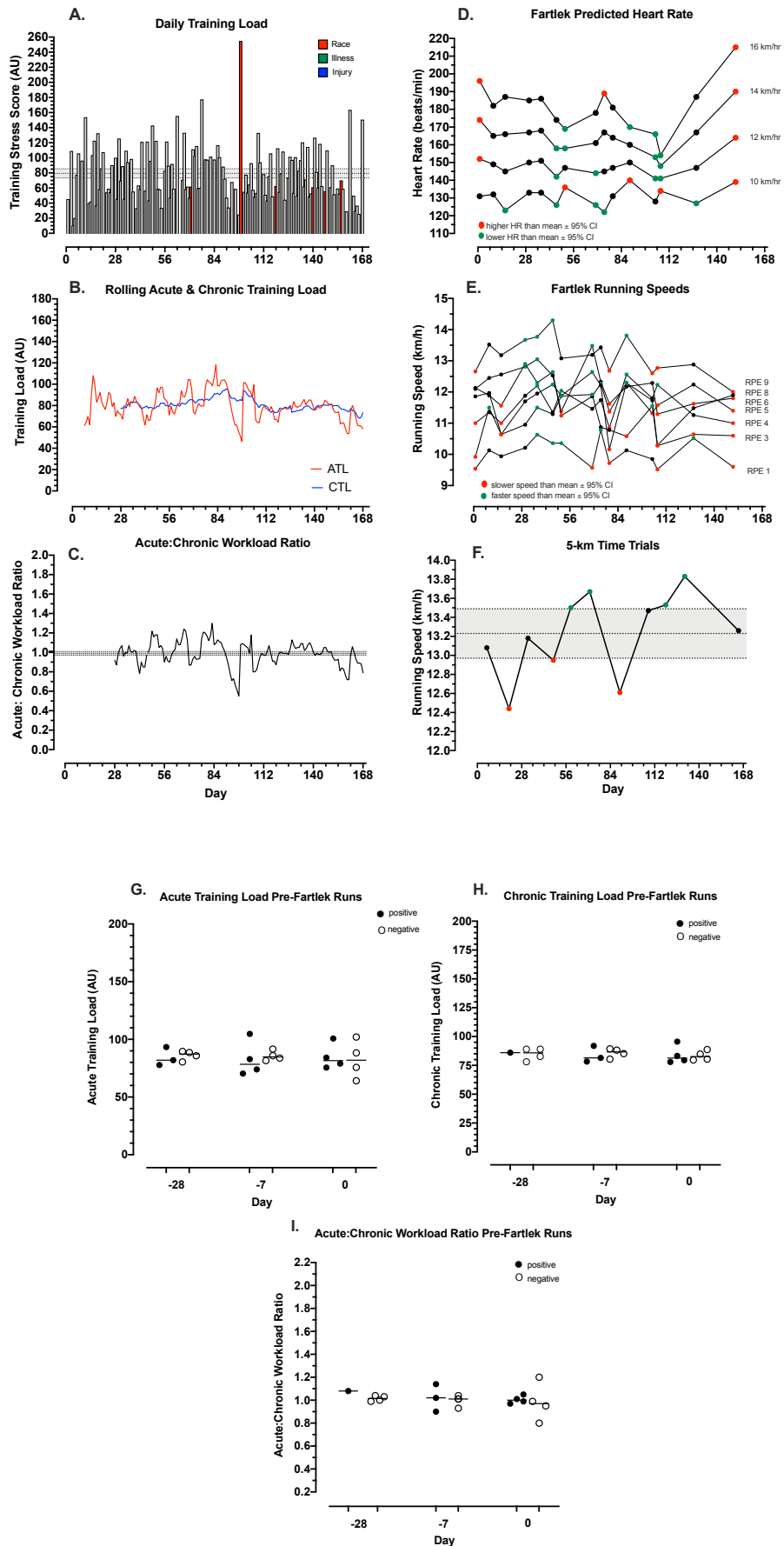
I. Acute:Chronic Workload Ratio Pre-Fartlek Runs

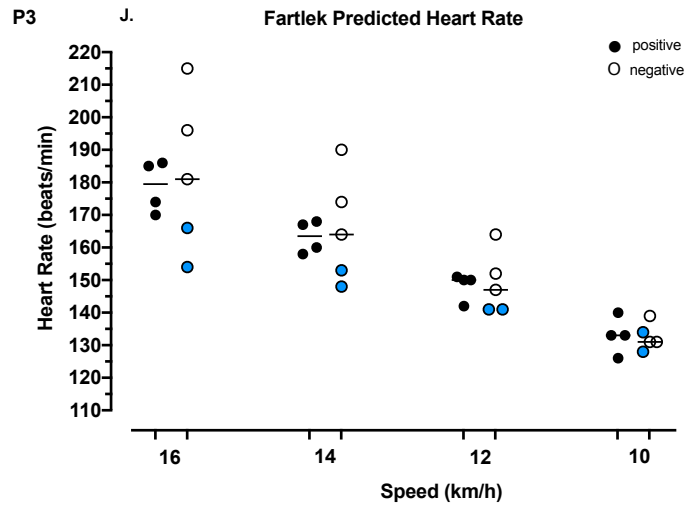


J. P2. Fartlek Predicted Heart Rate

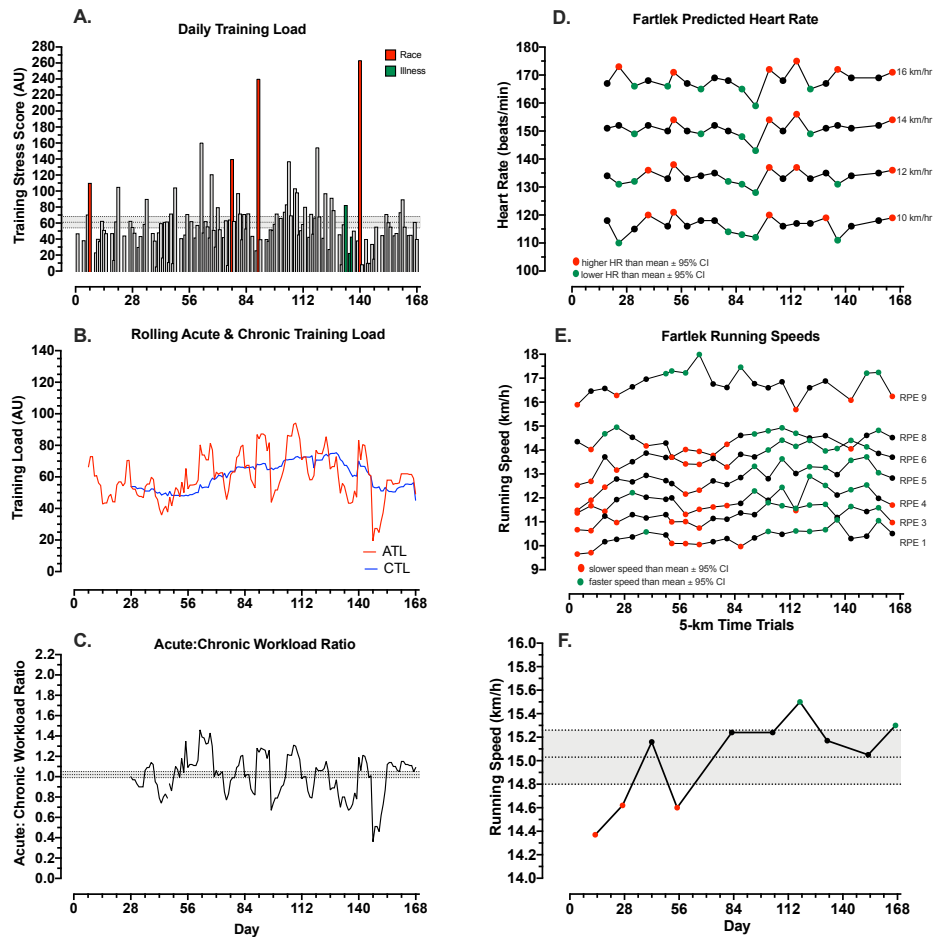


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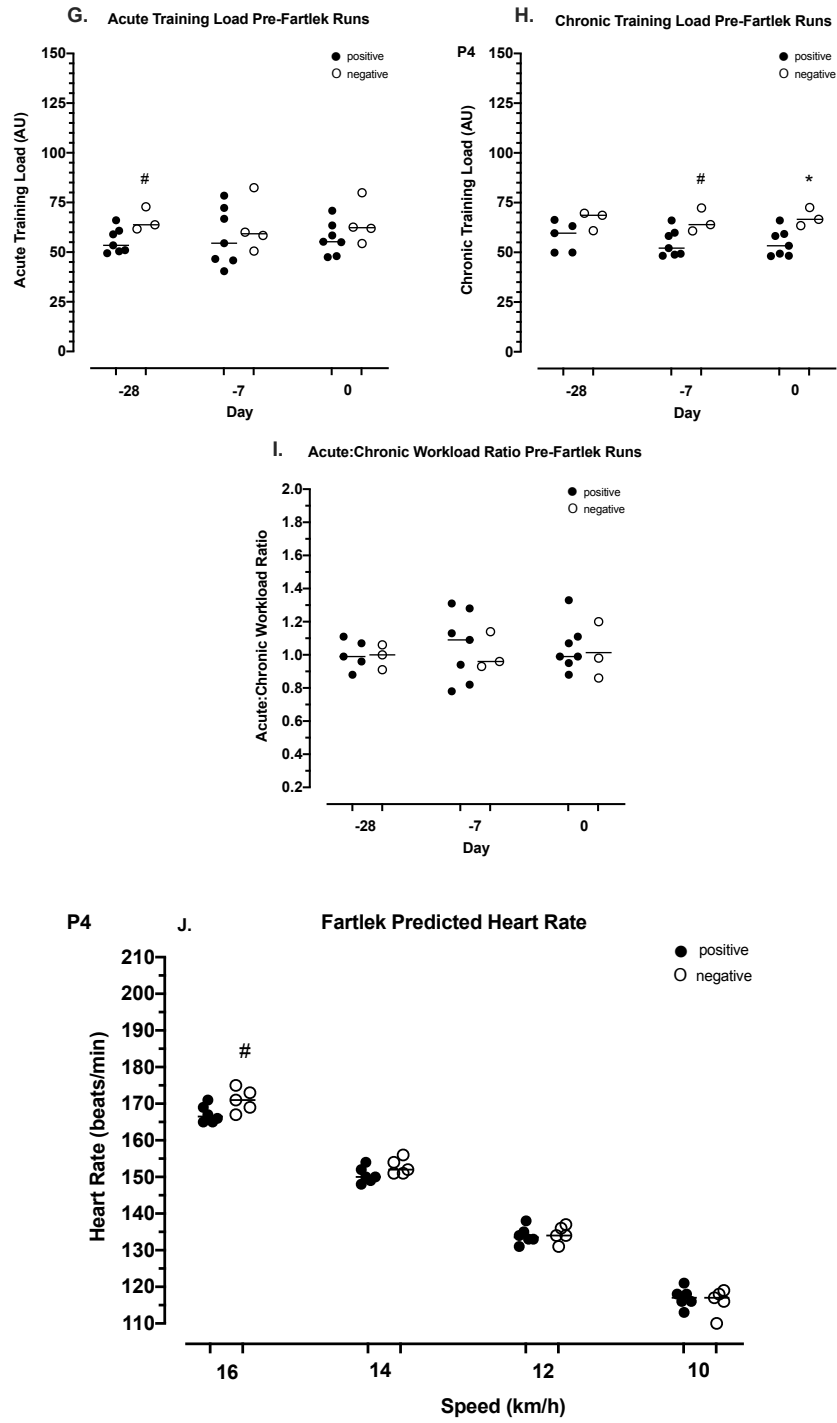




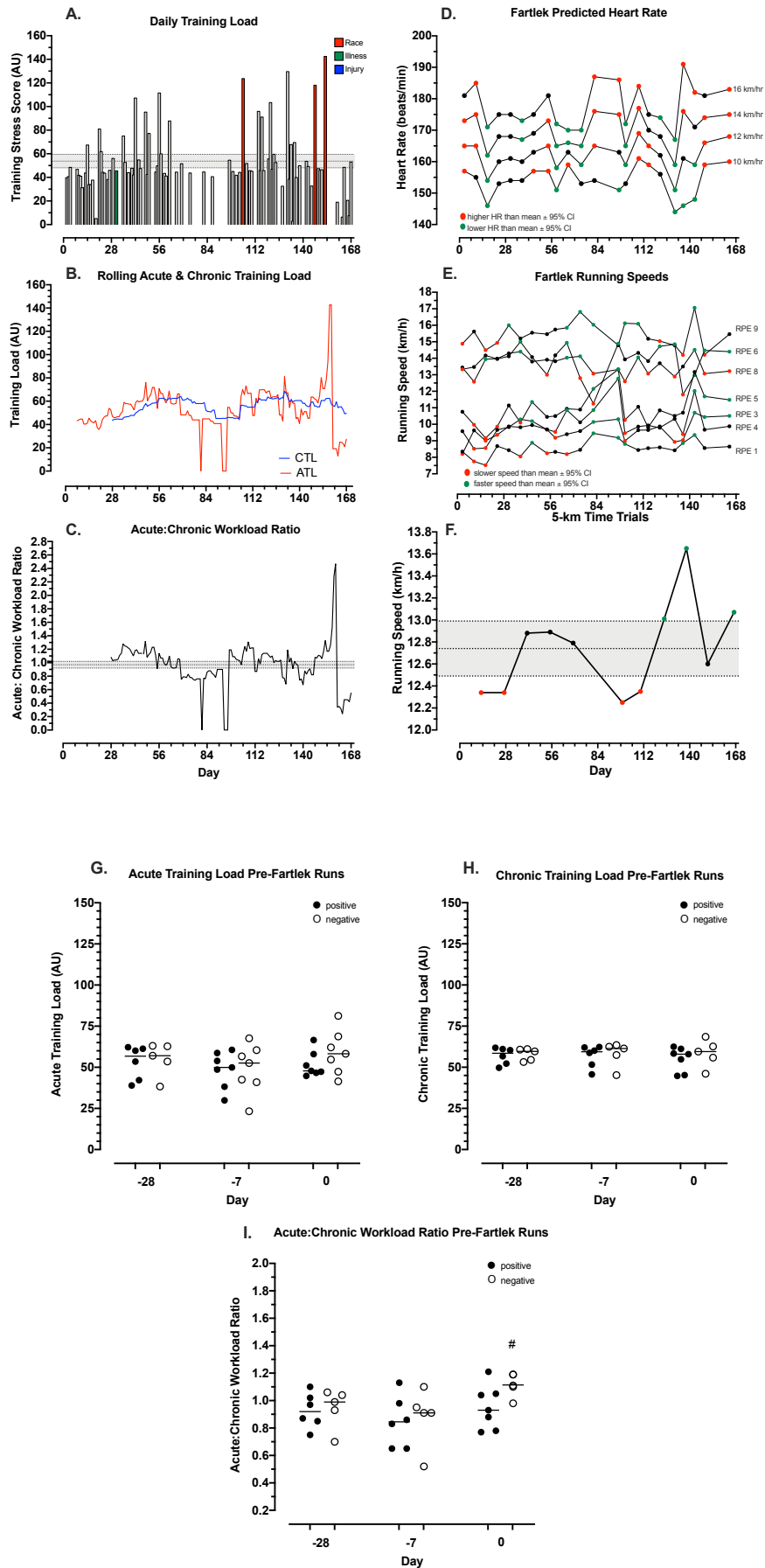
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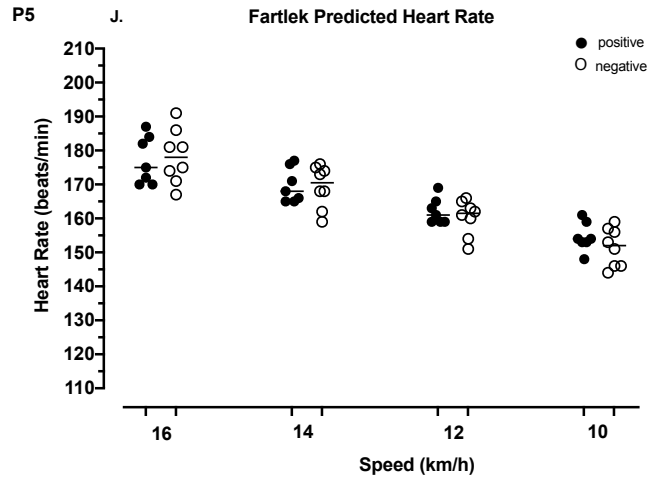


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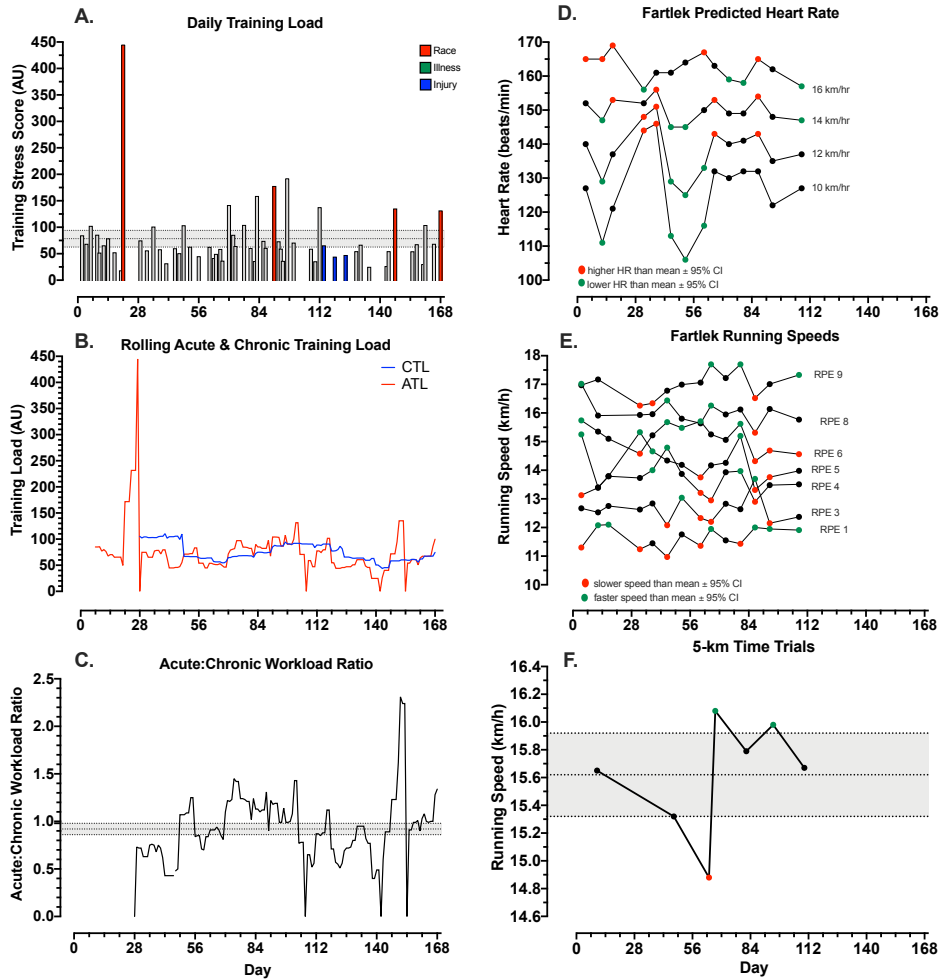


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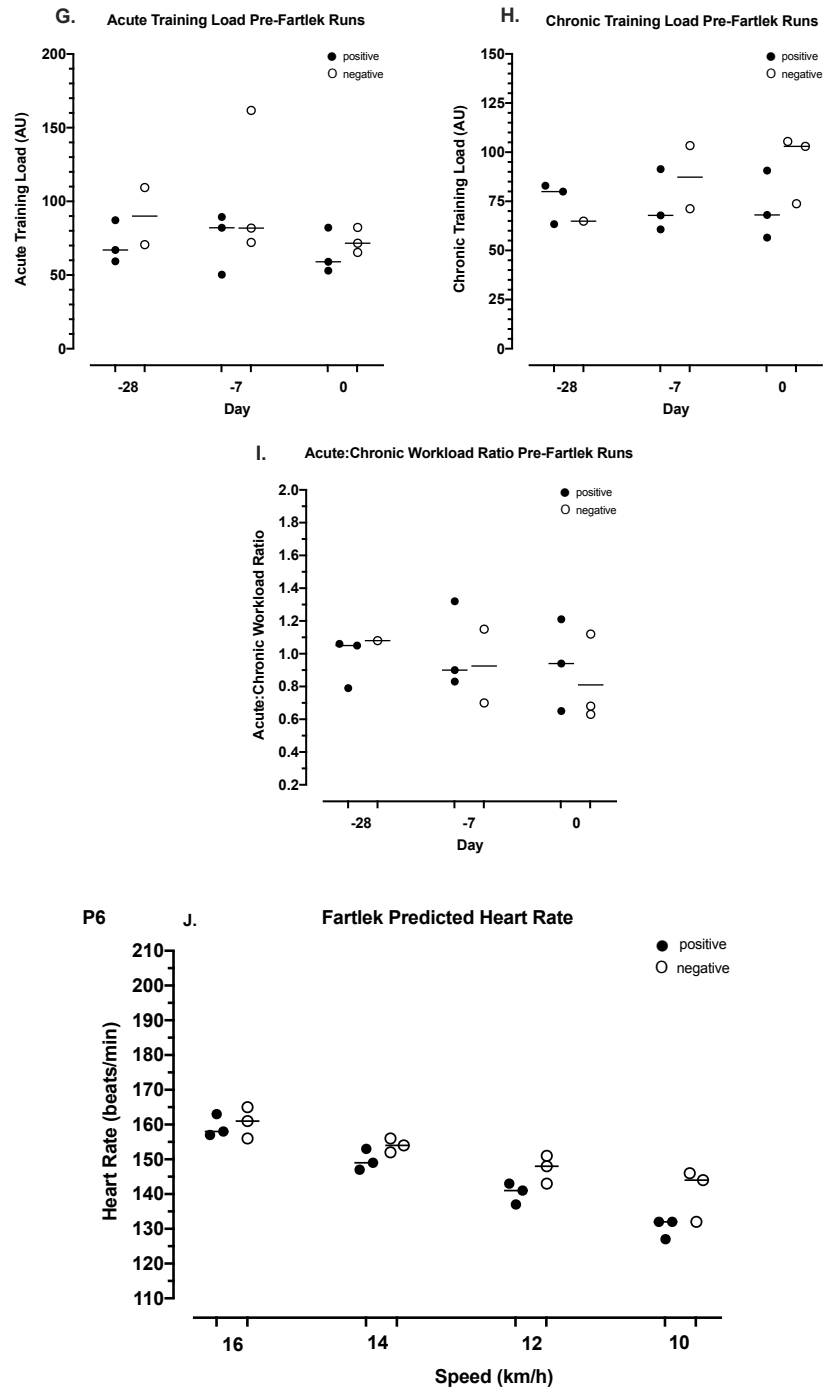




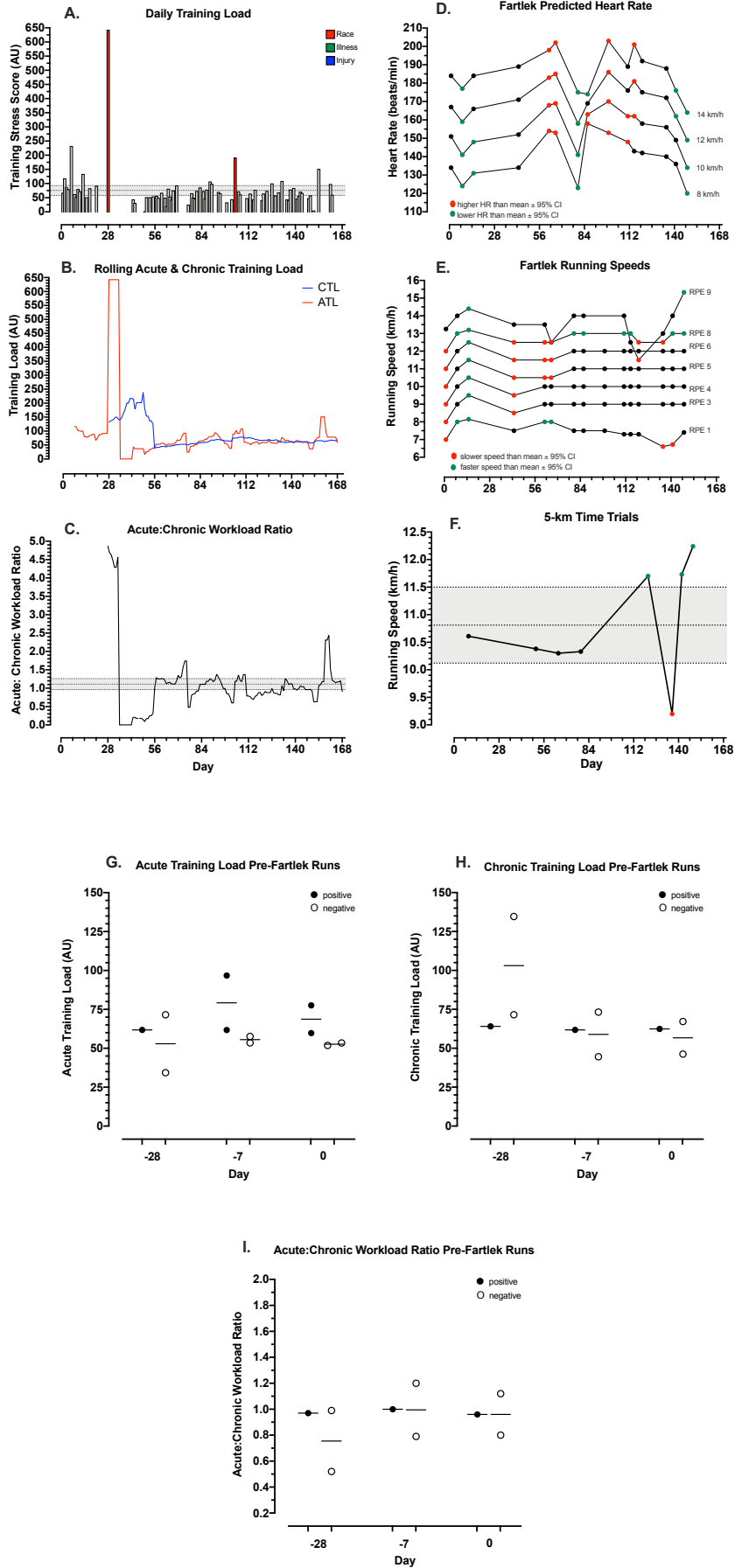
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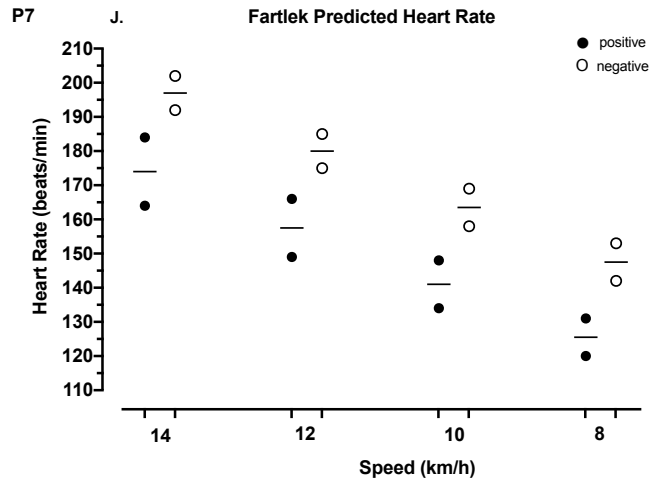


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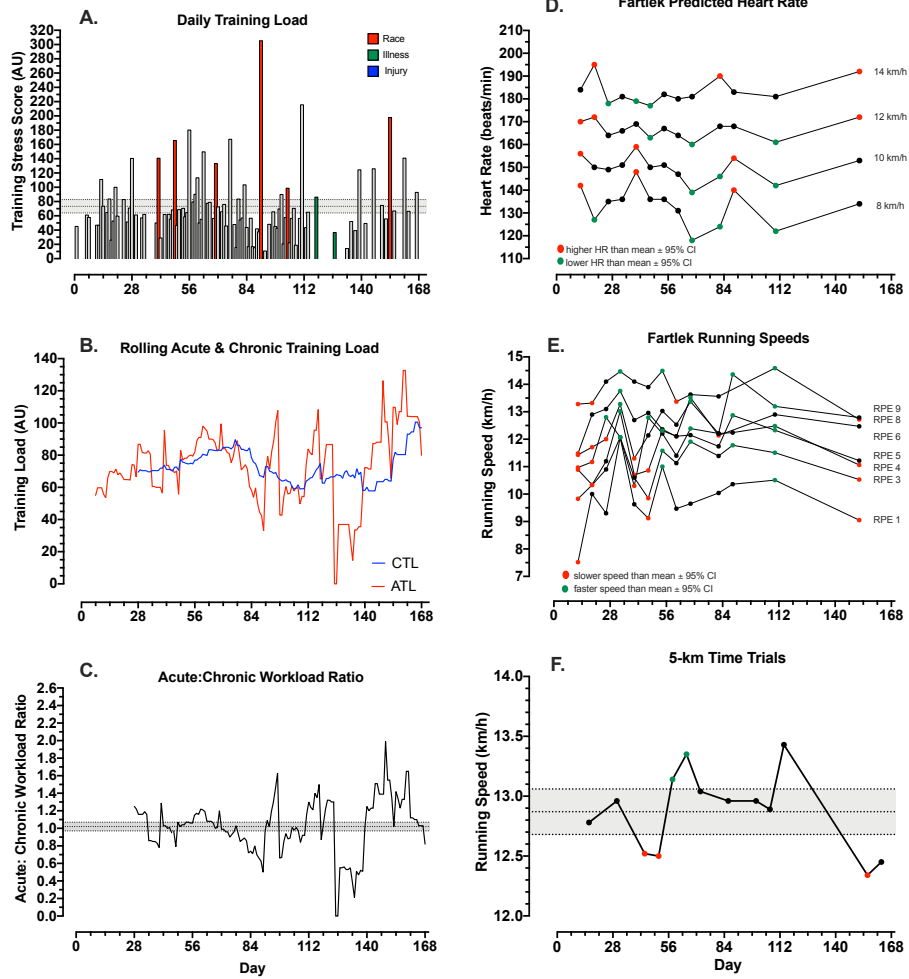


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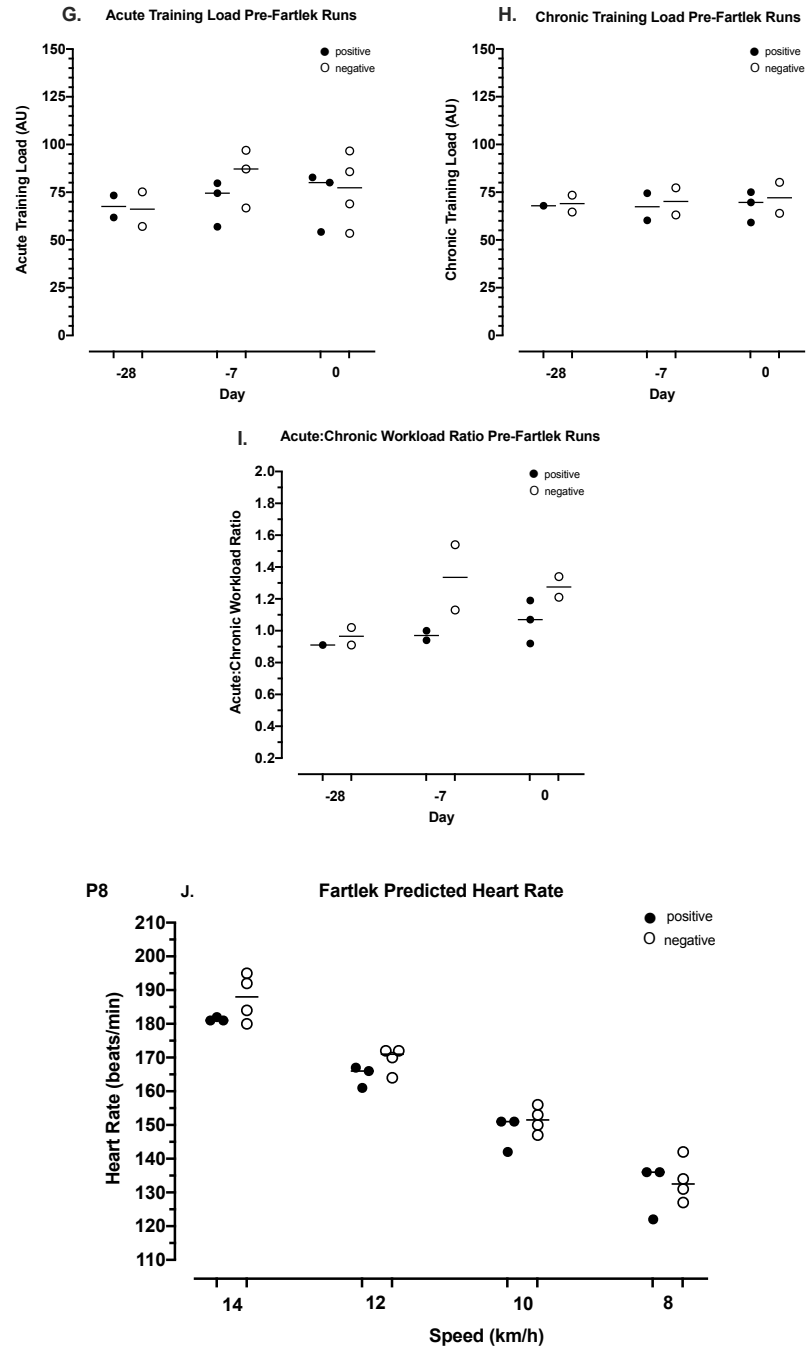




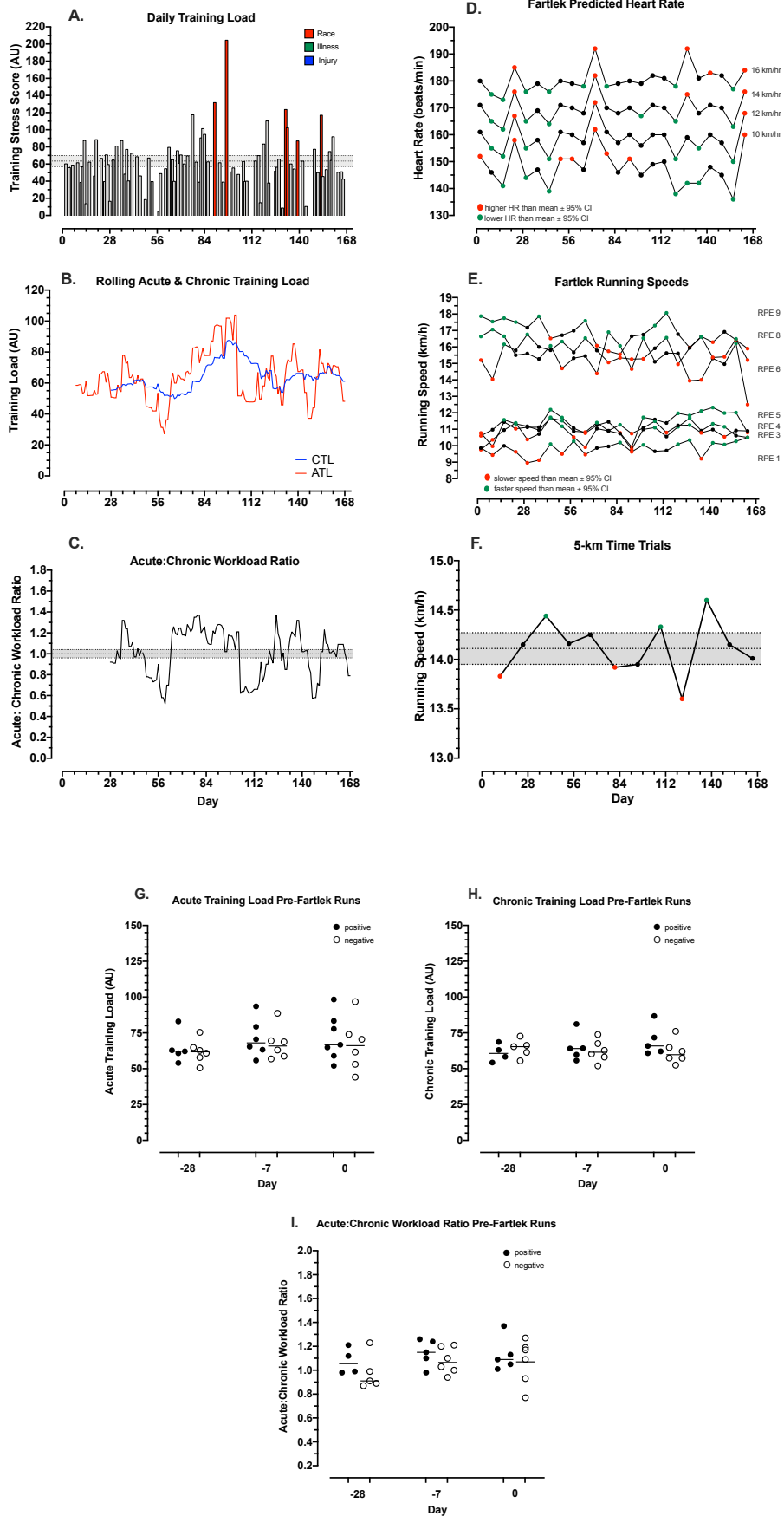
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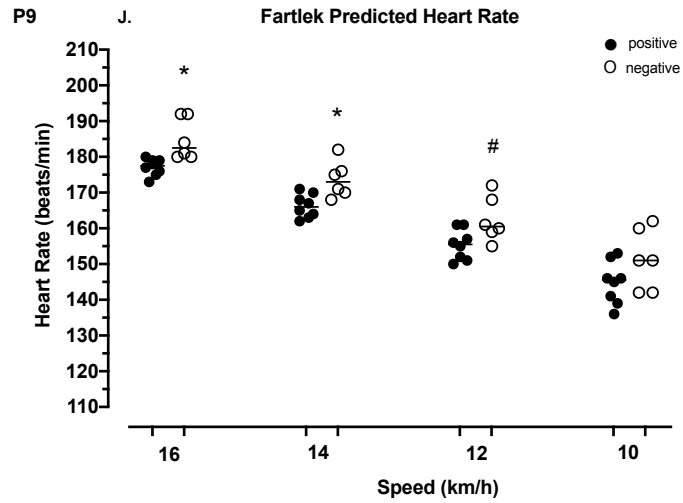


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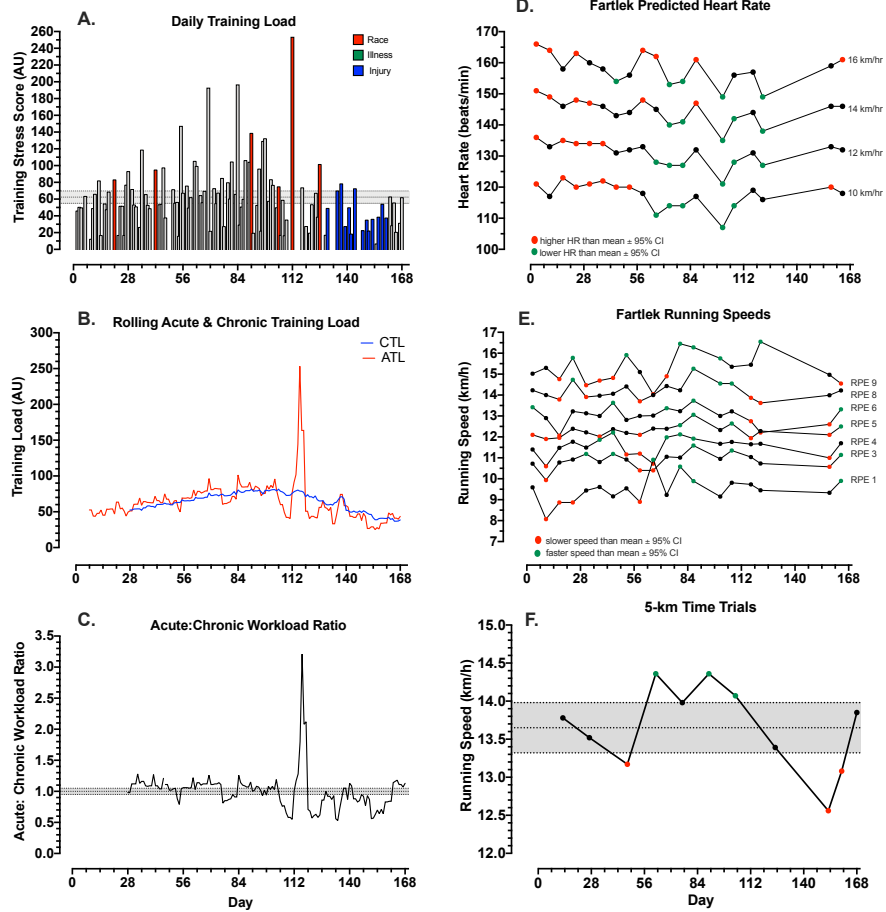


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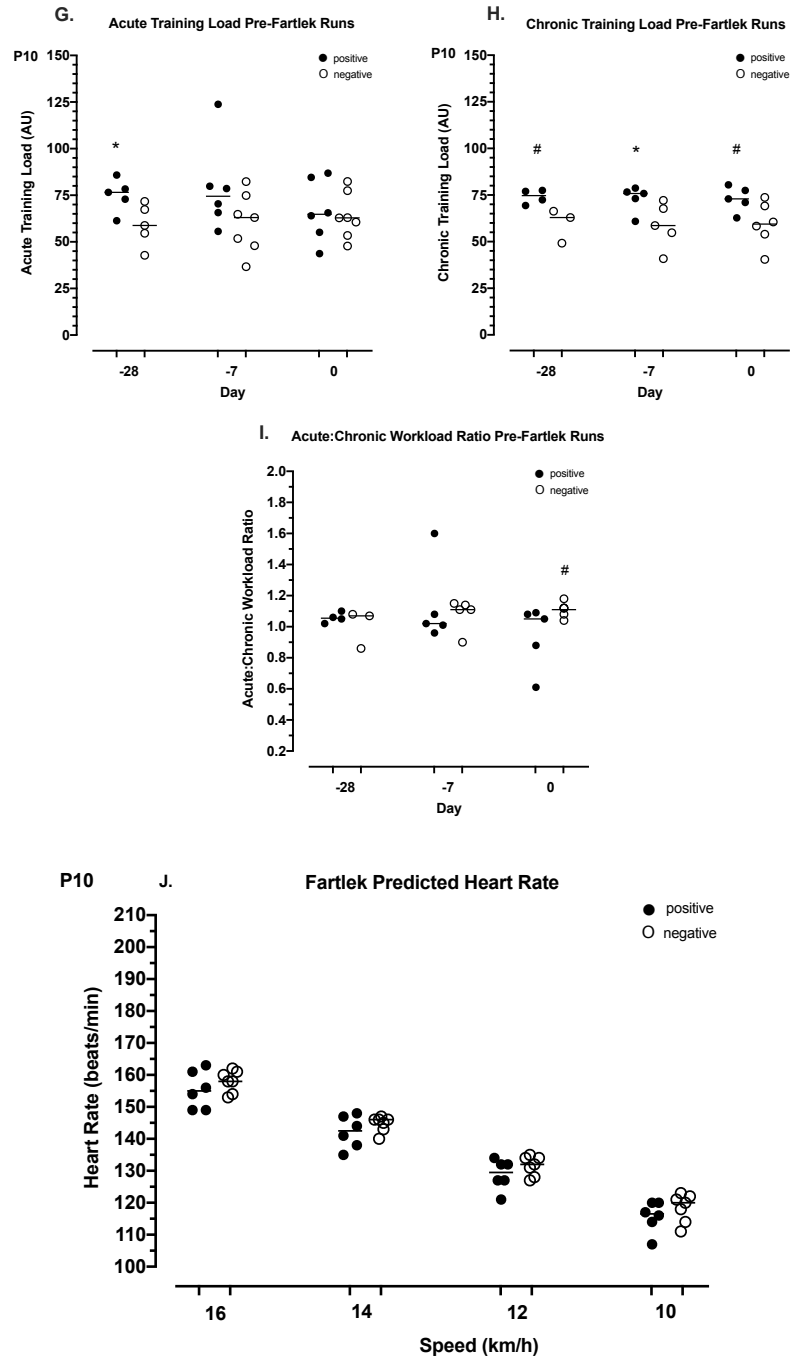




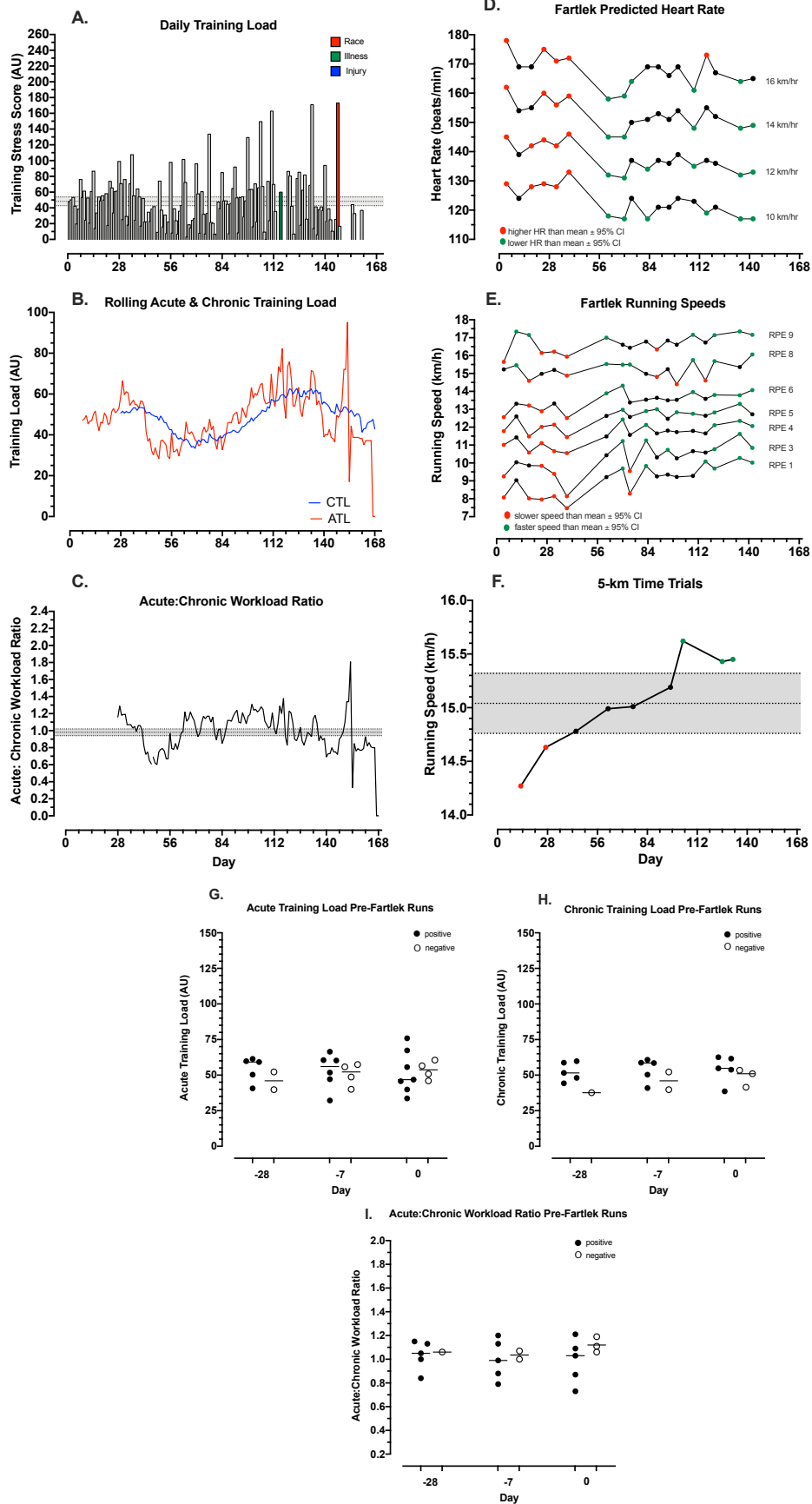
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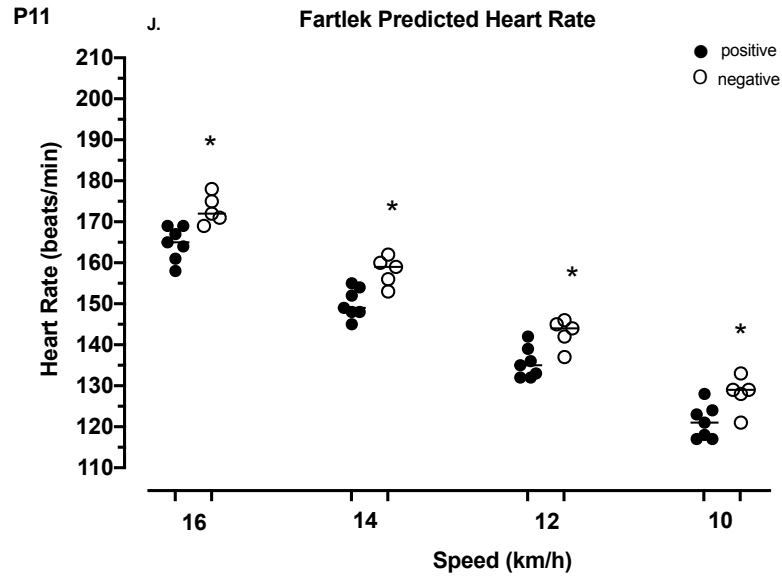


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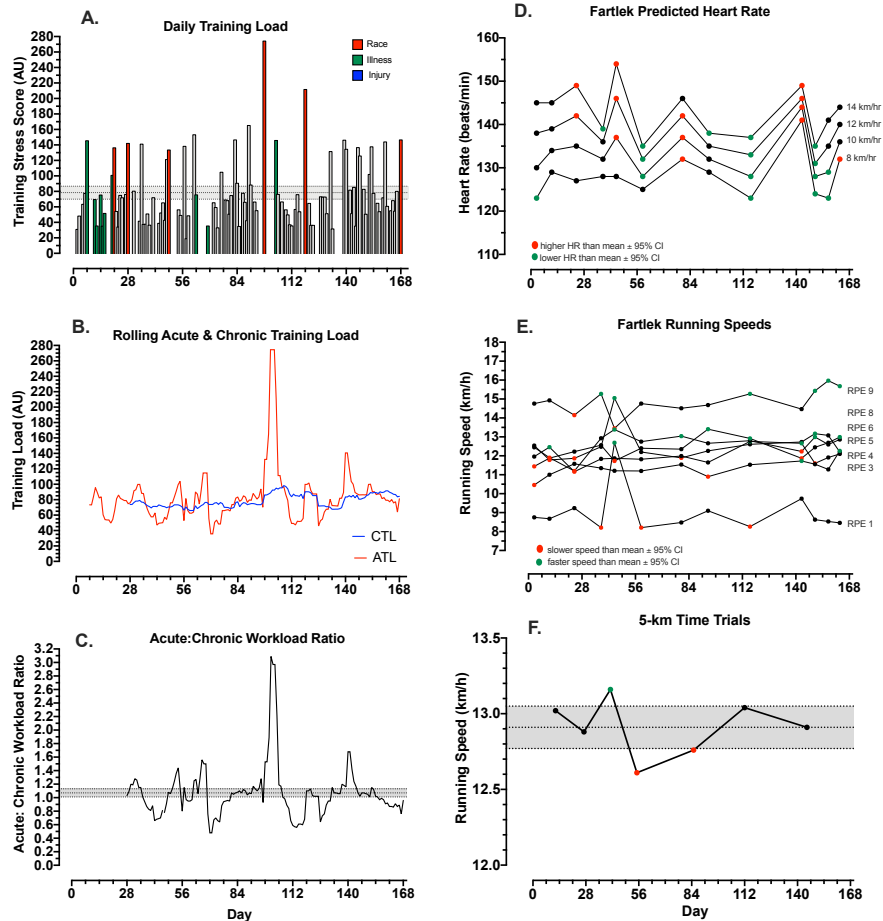


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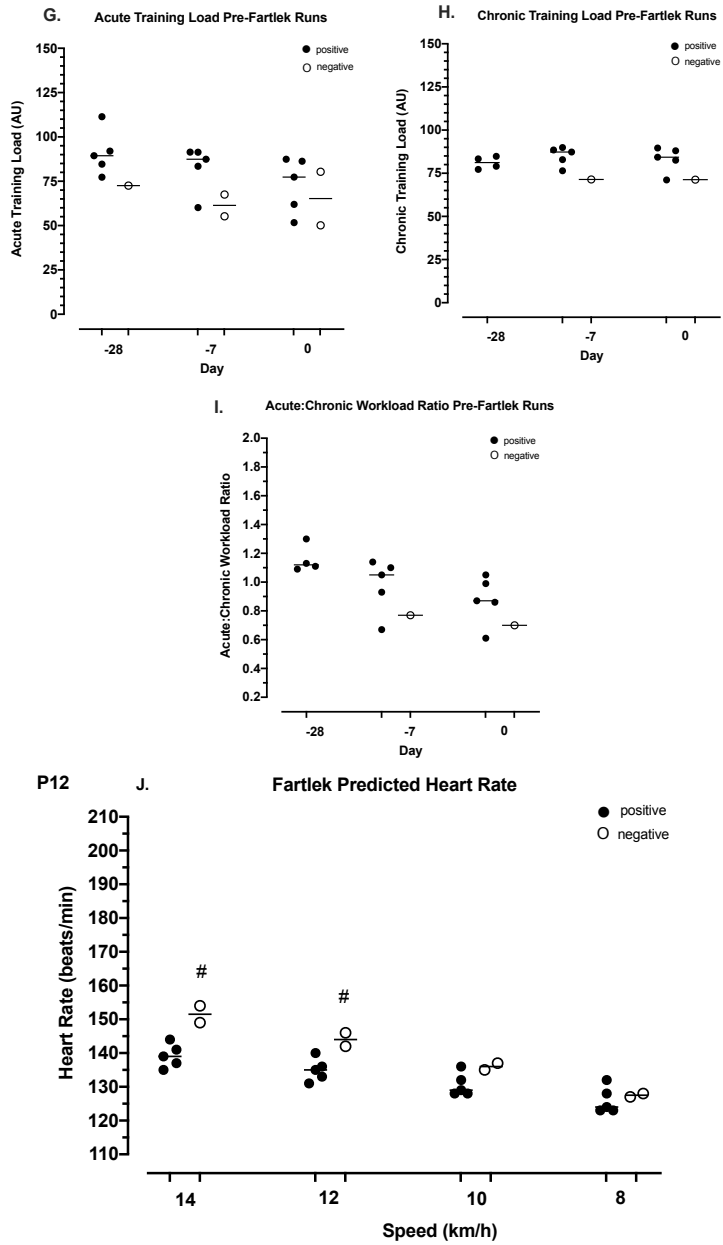




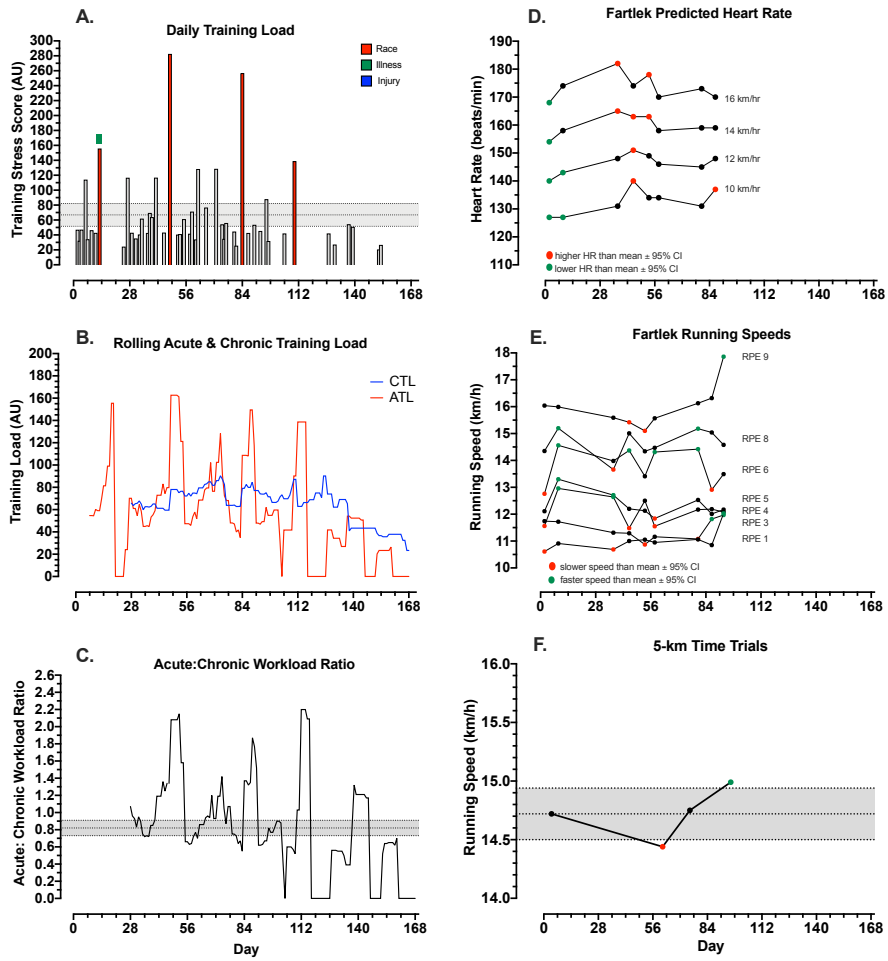
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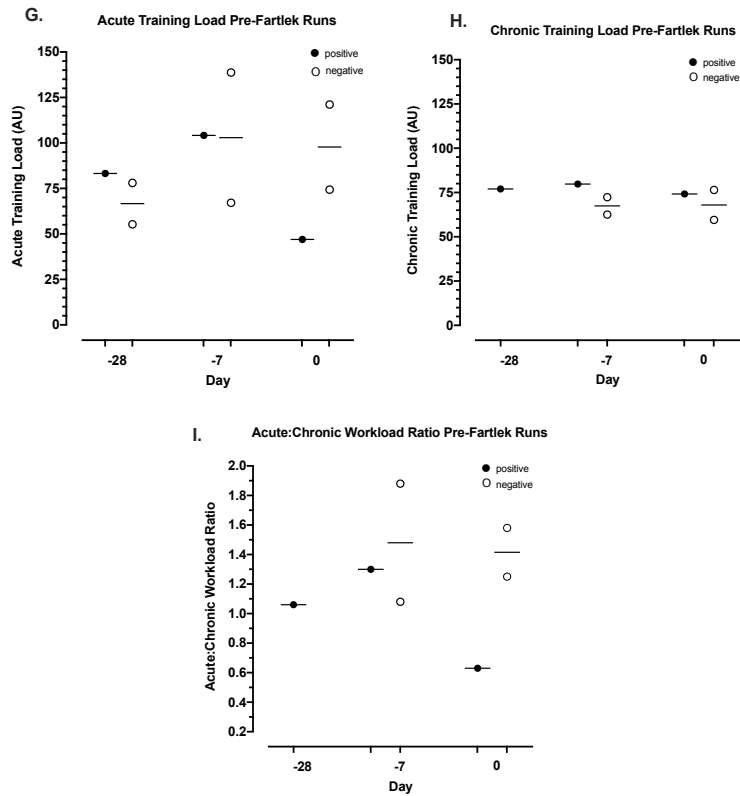
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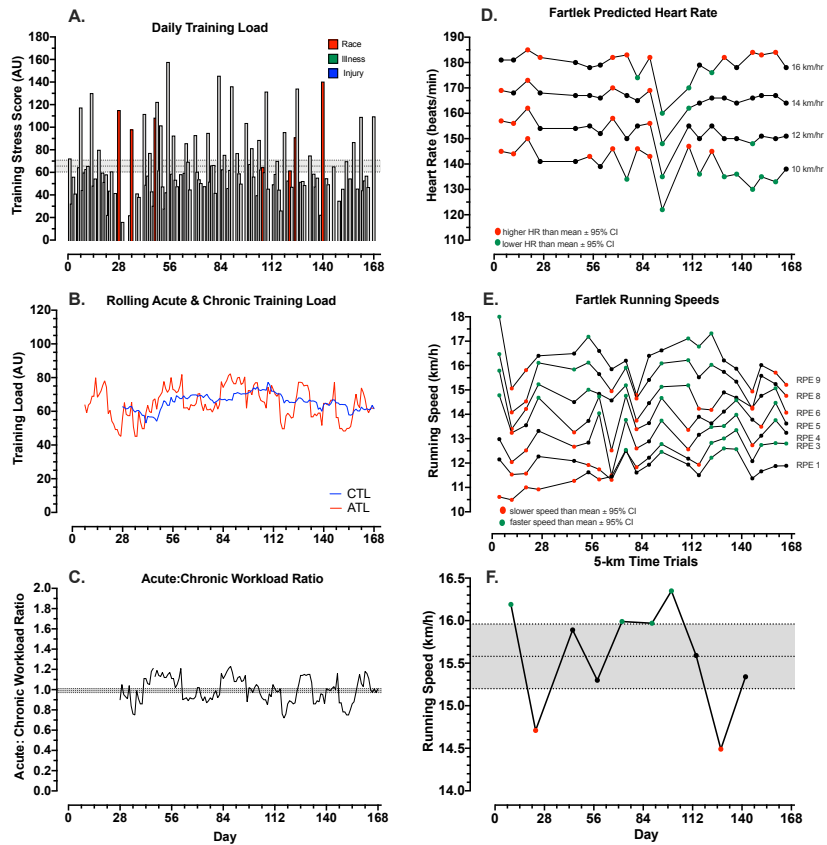
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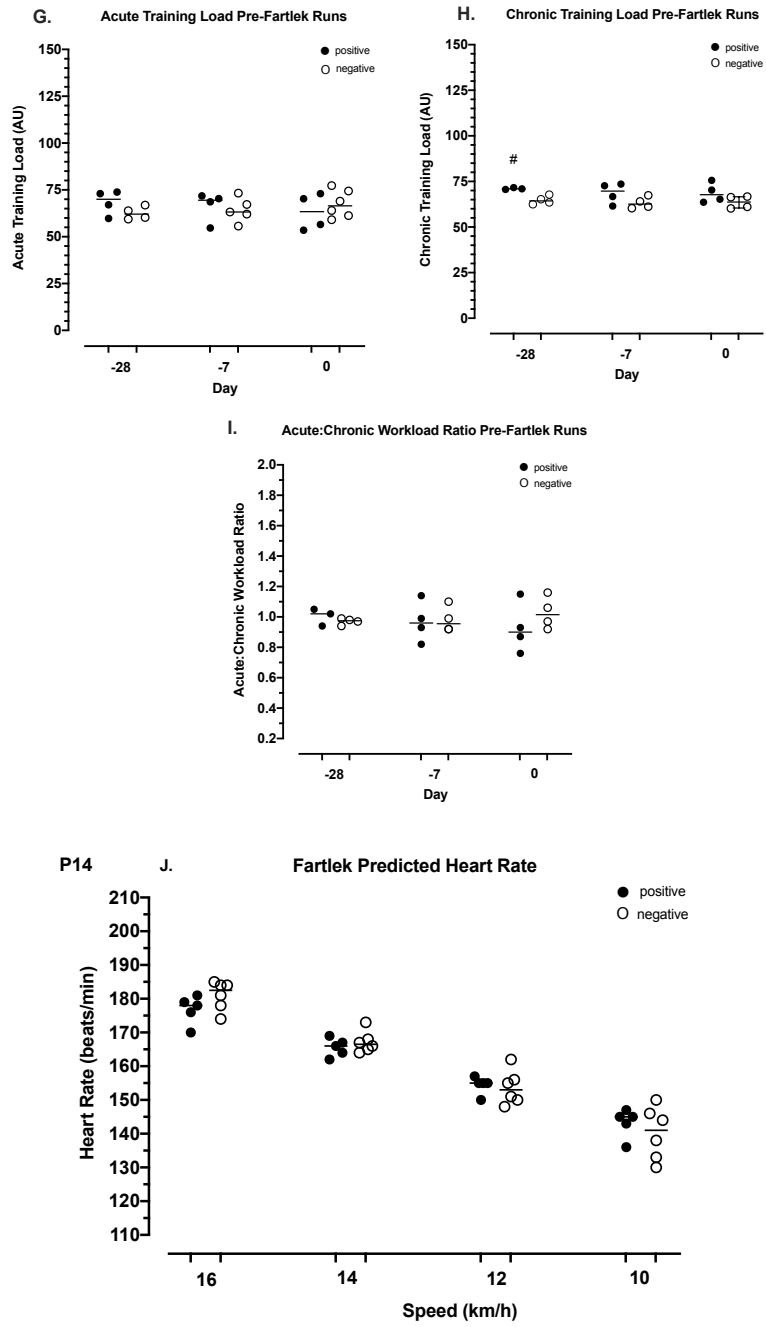
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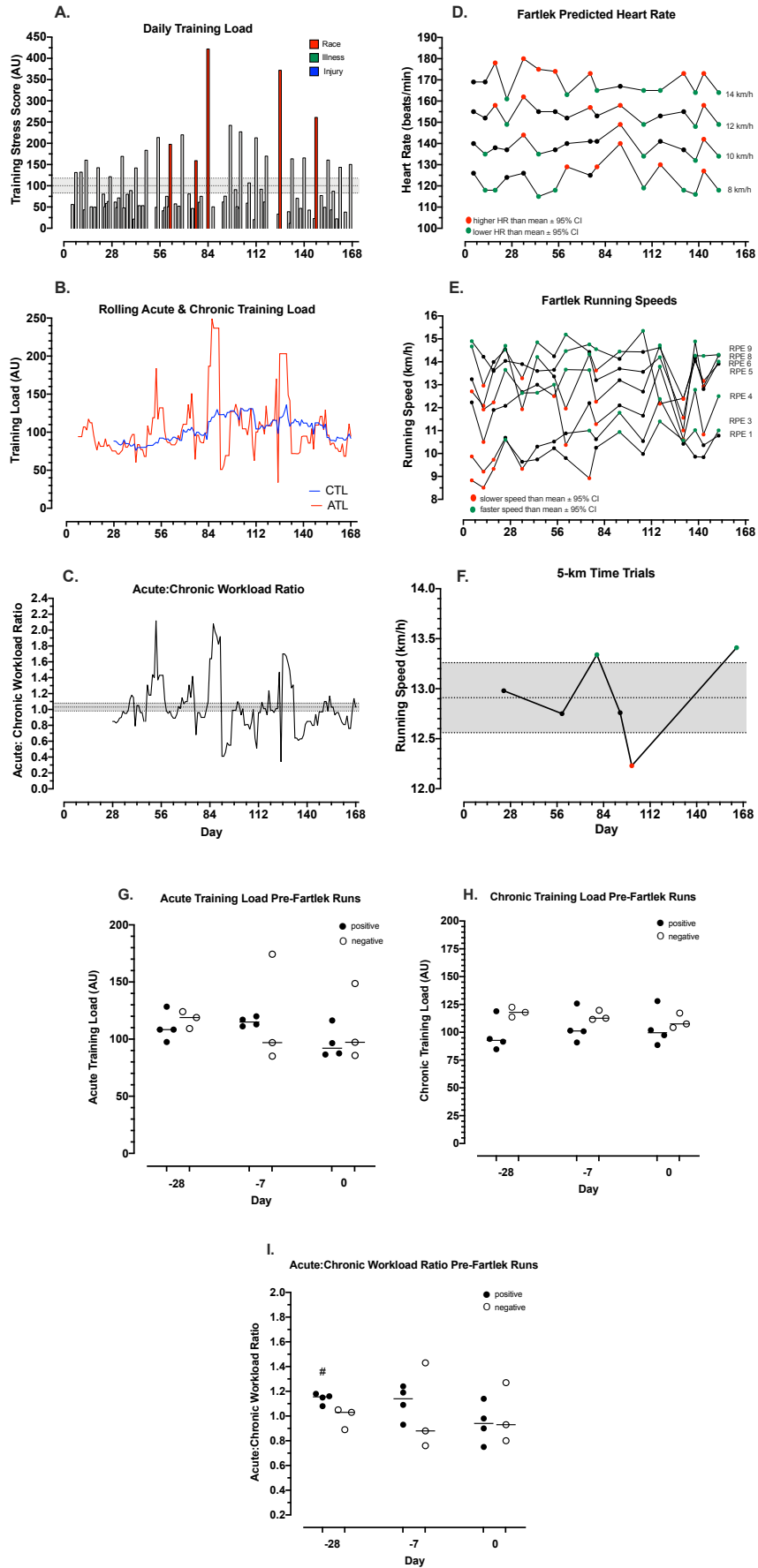
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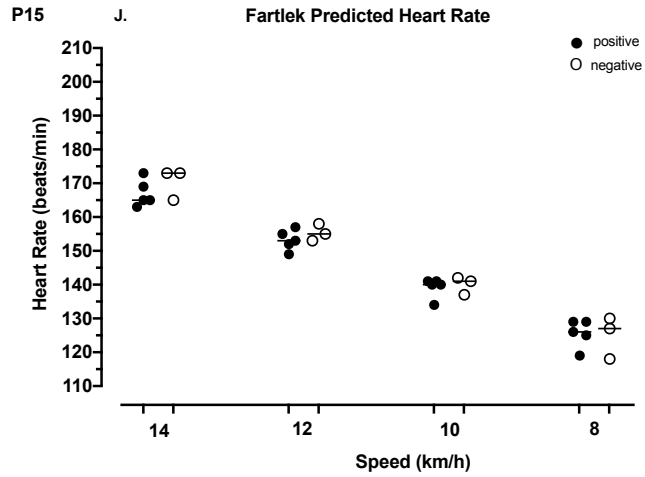
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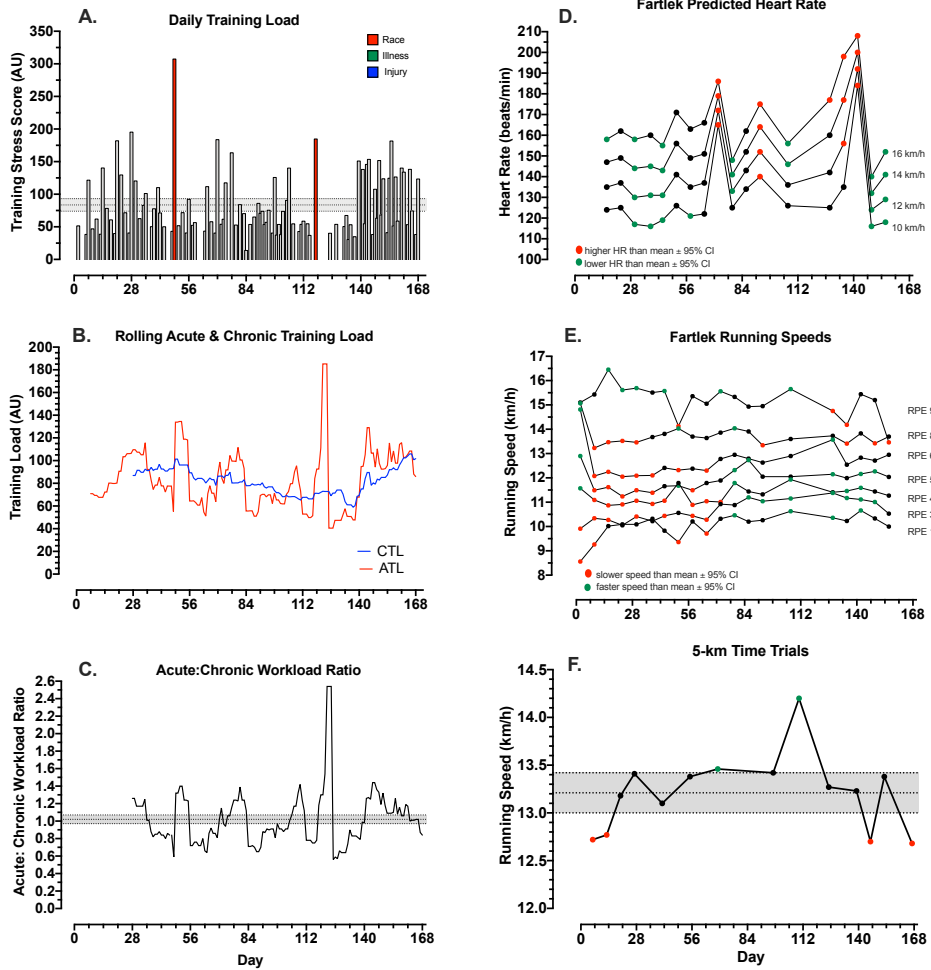
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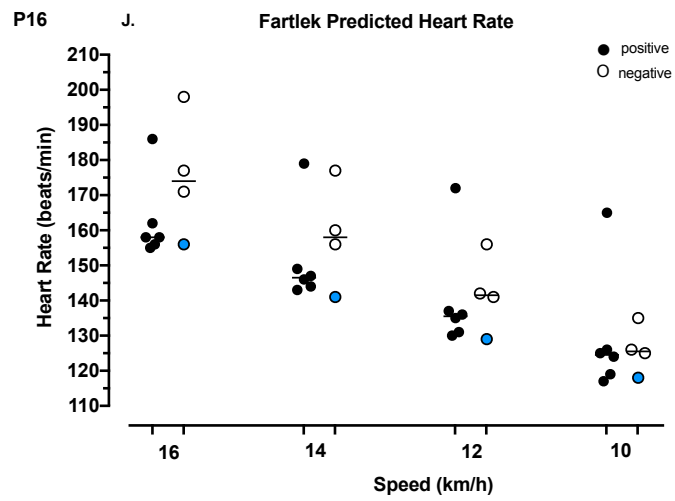
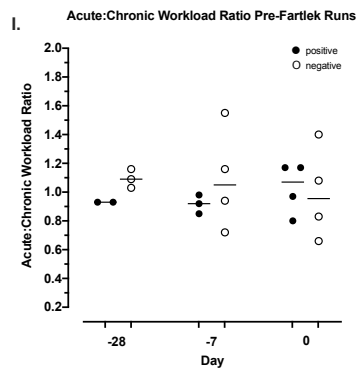
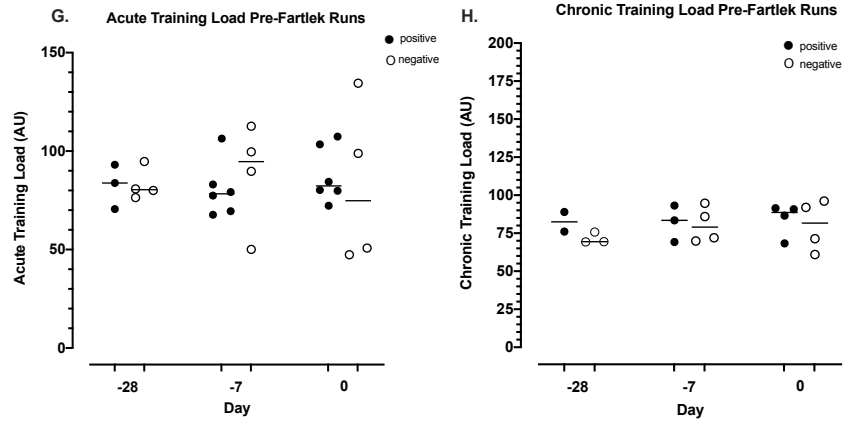
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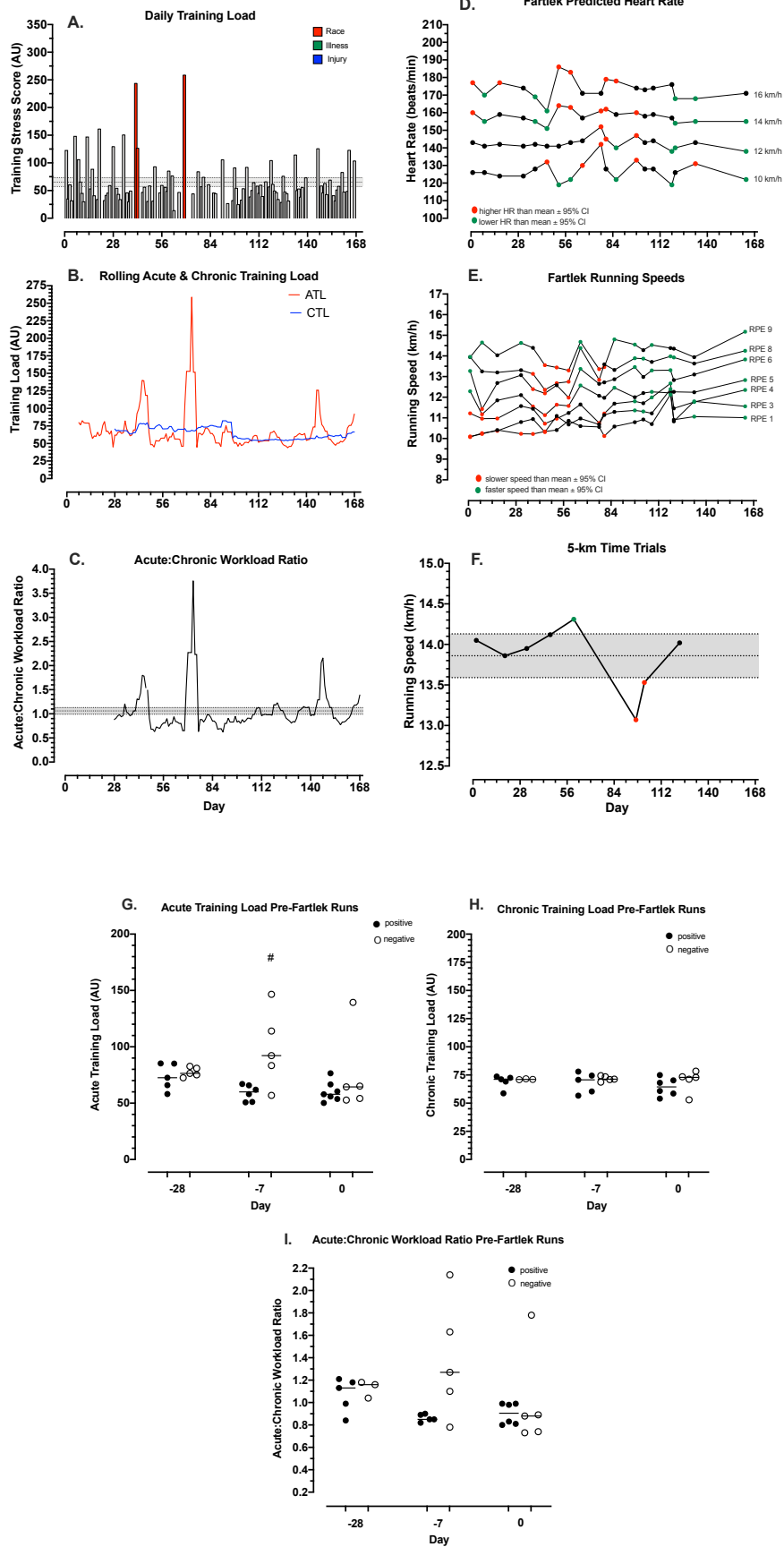
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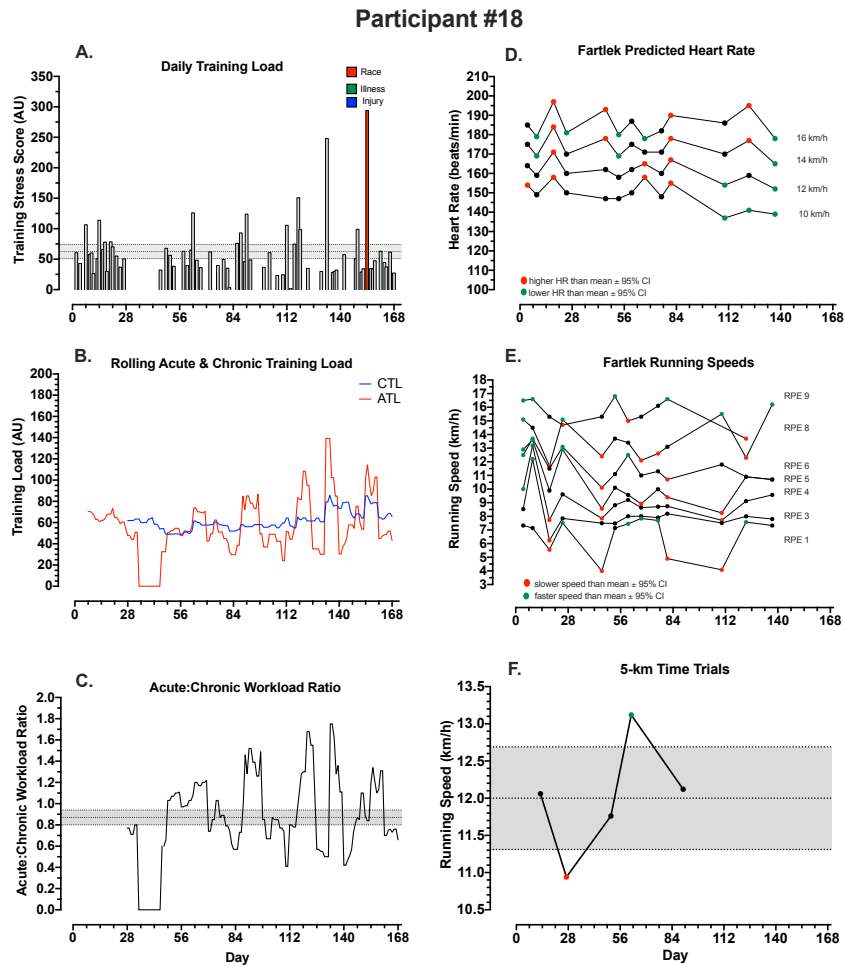
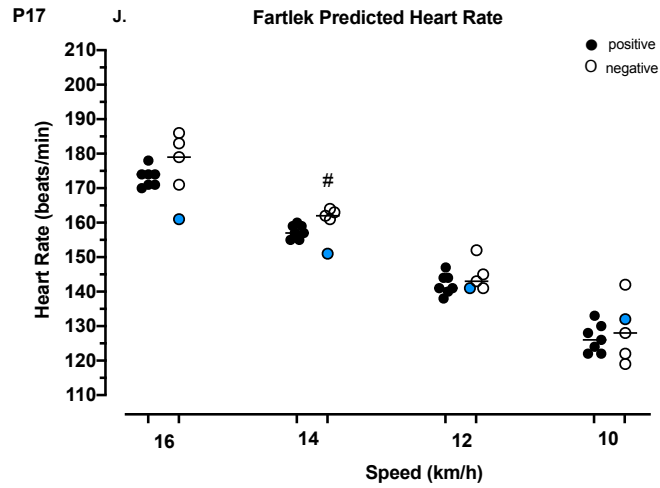


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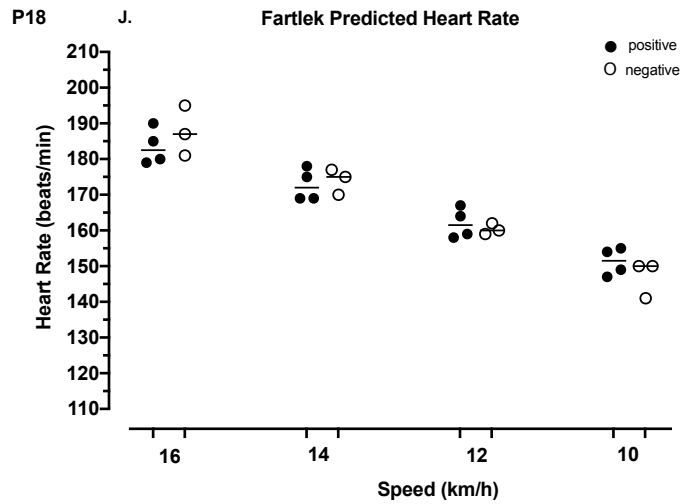
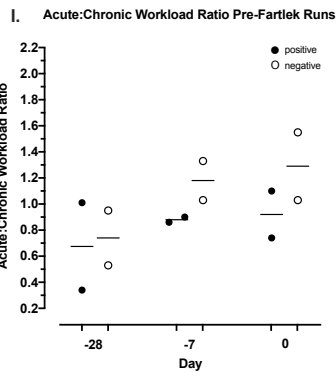
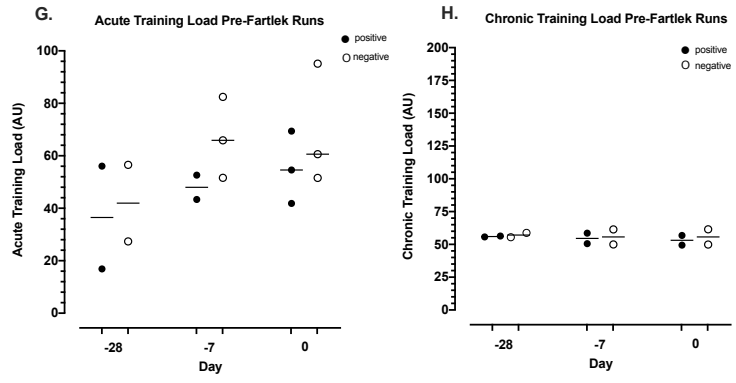


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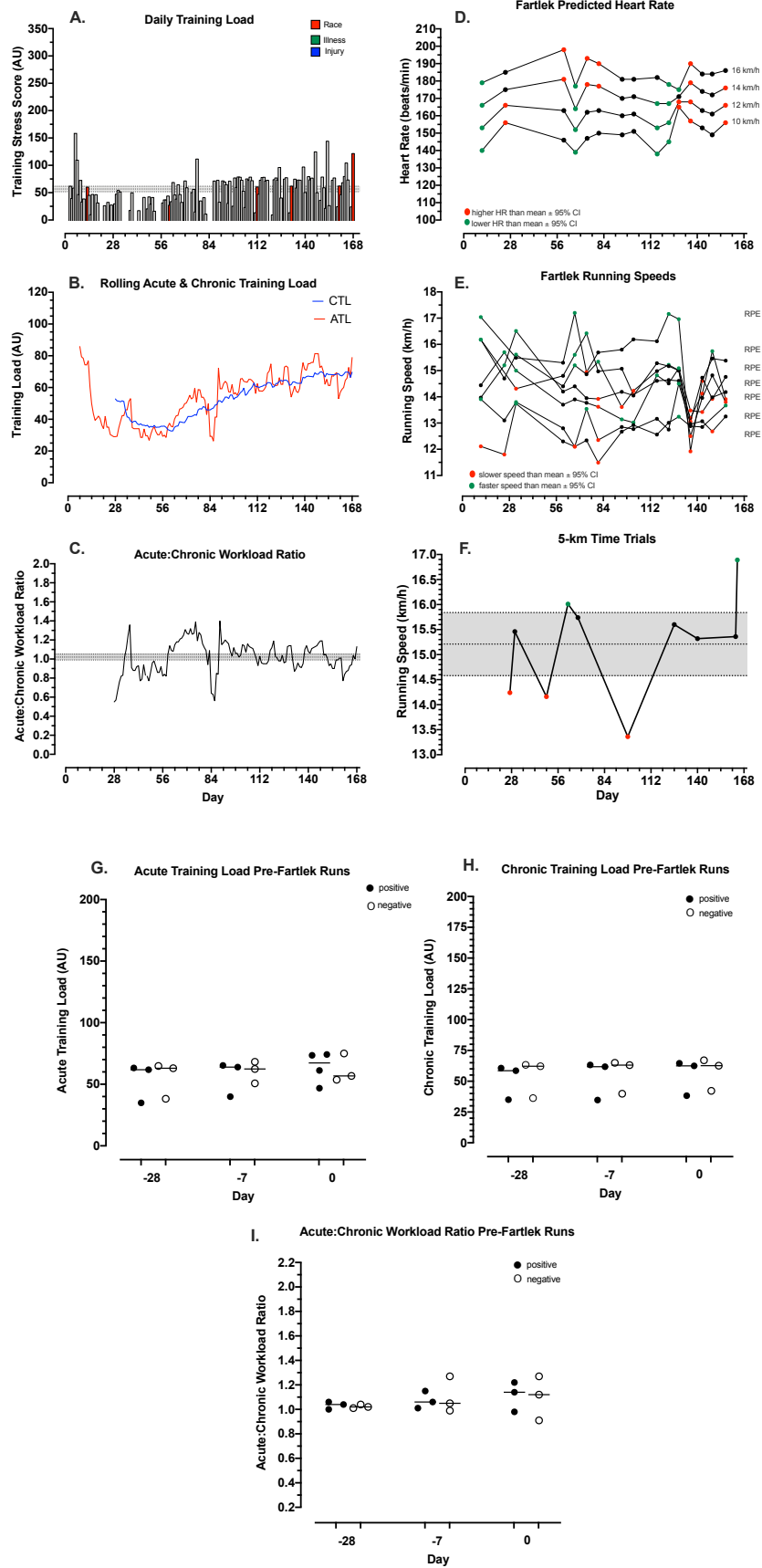


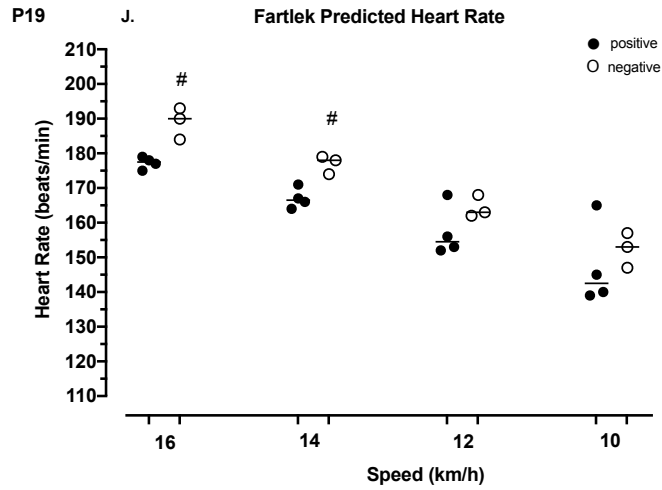


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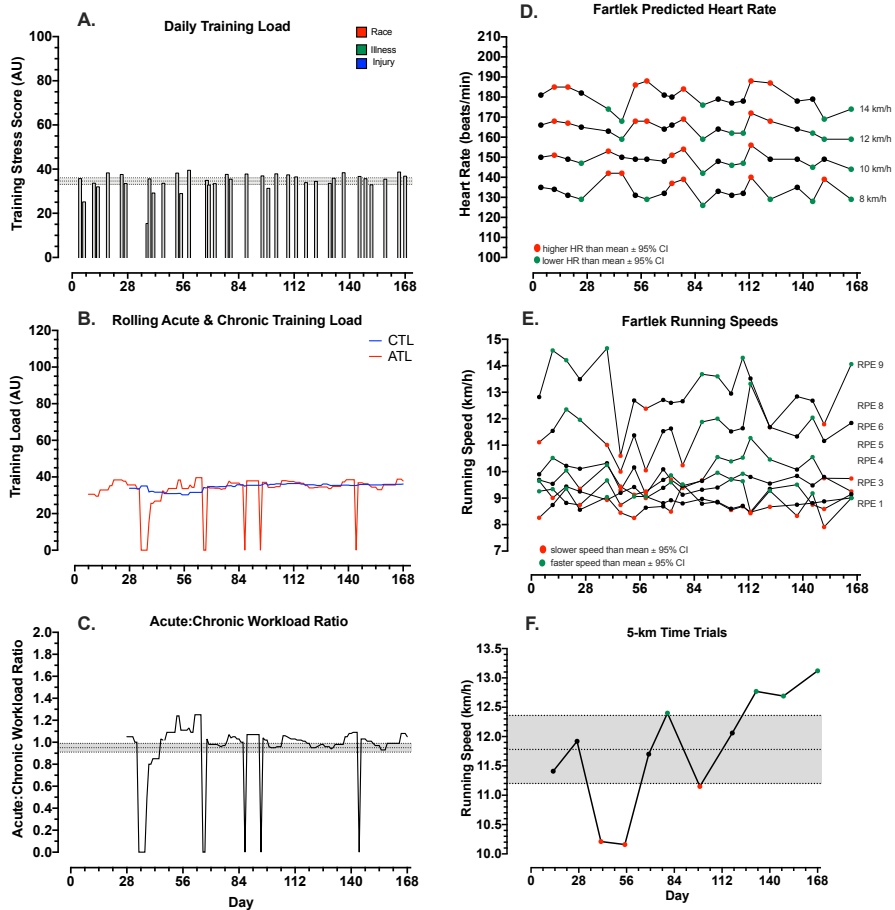


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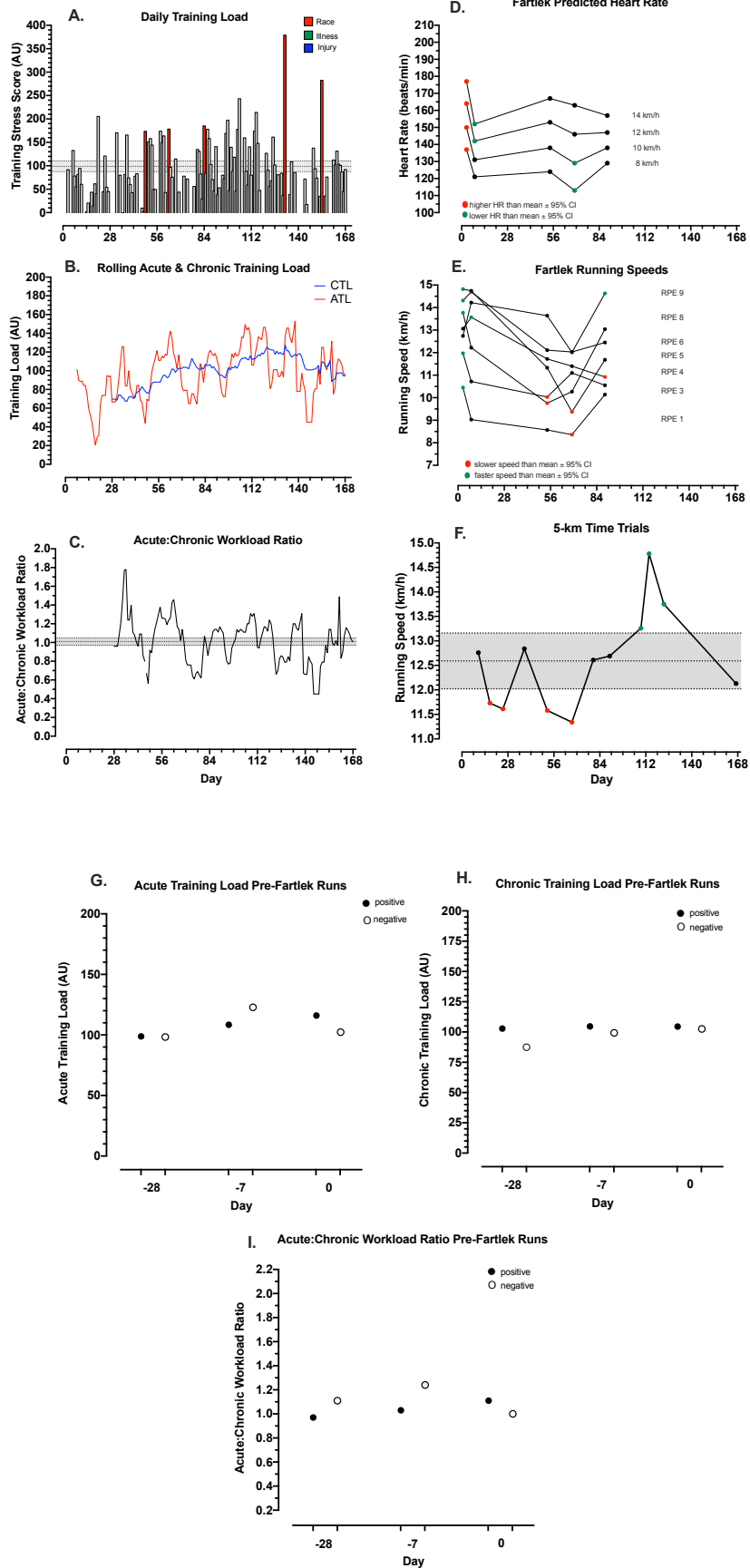


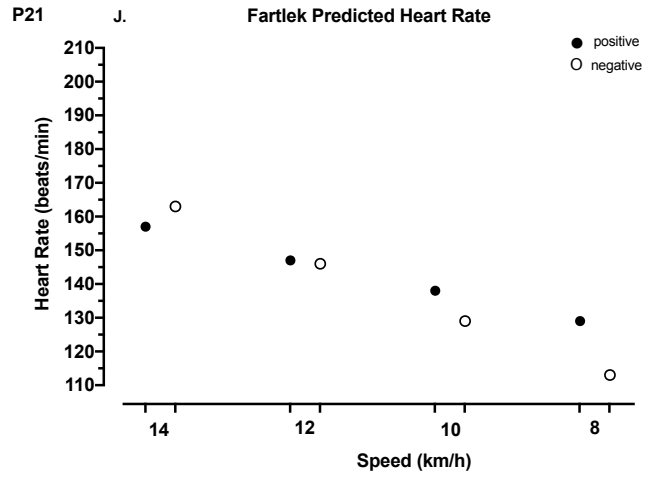


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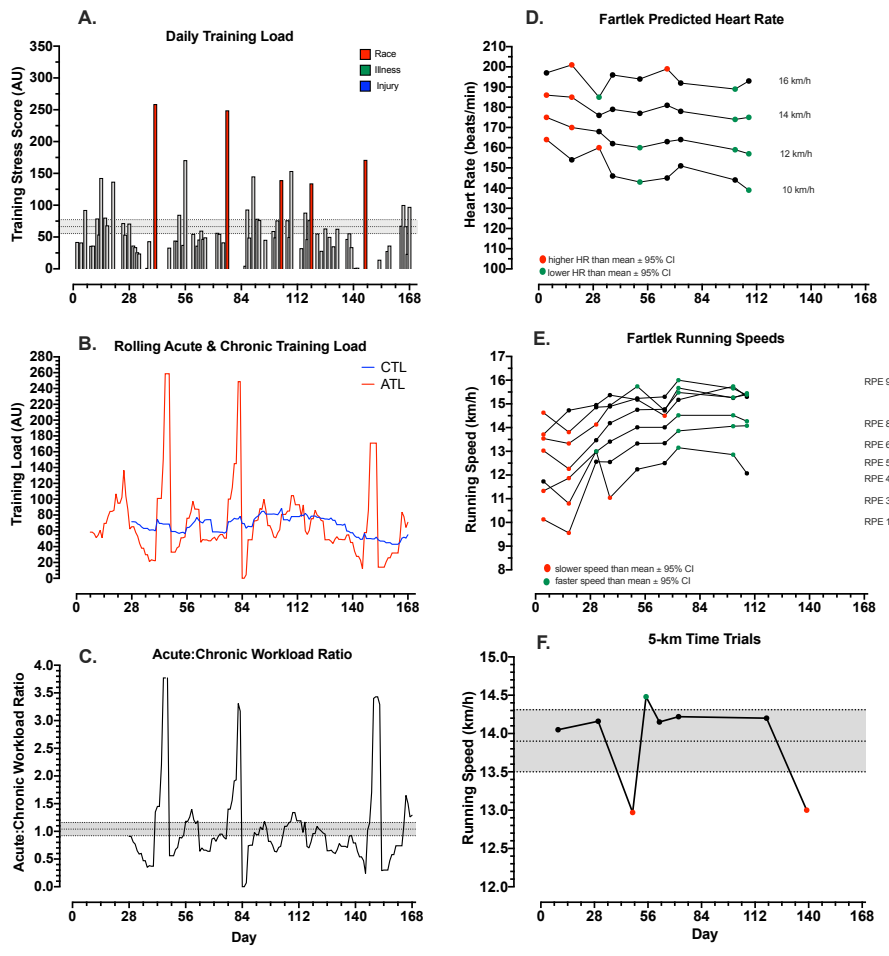


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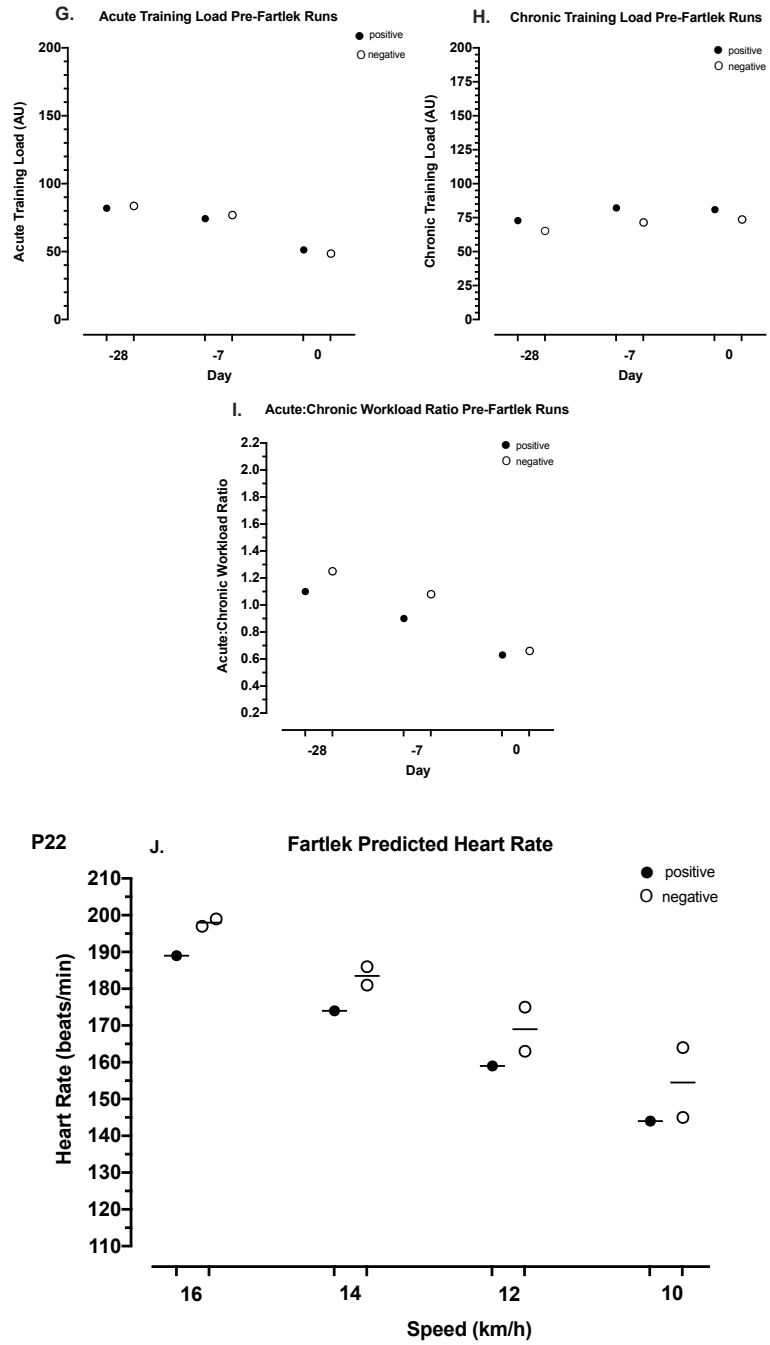




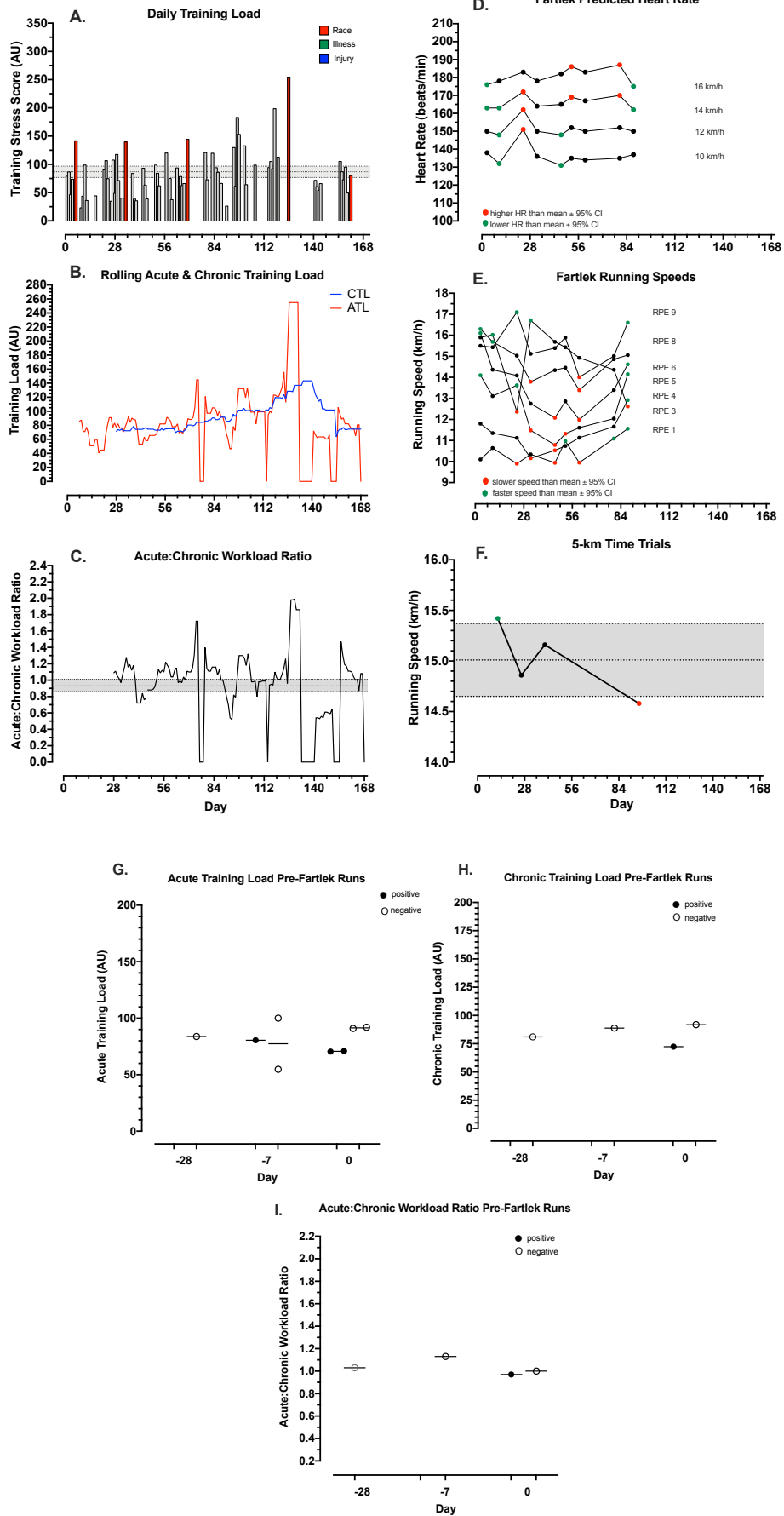
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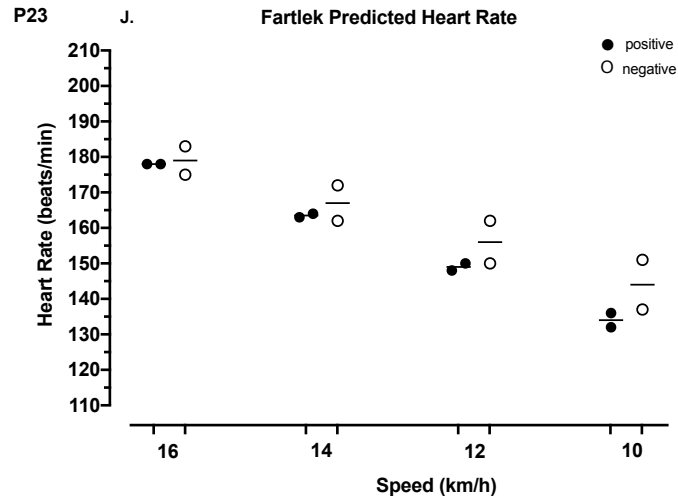


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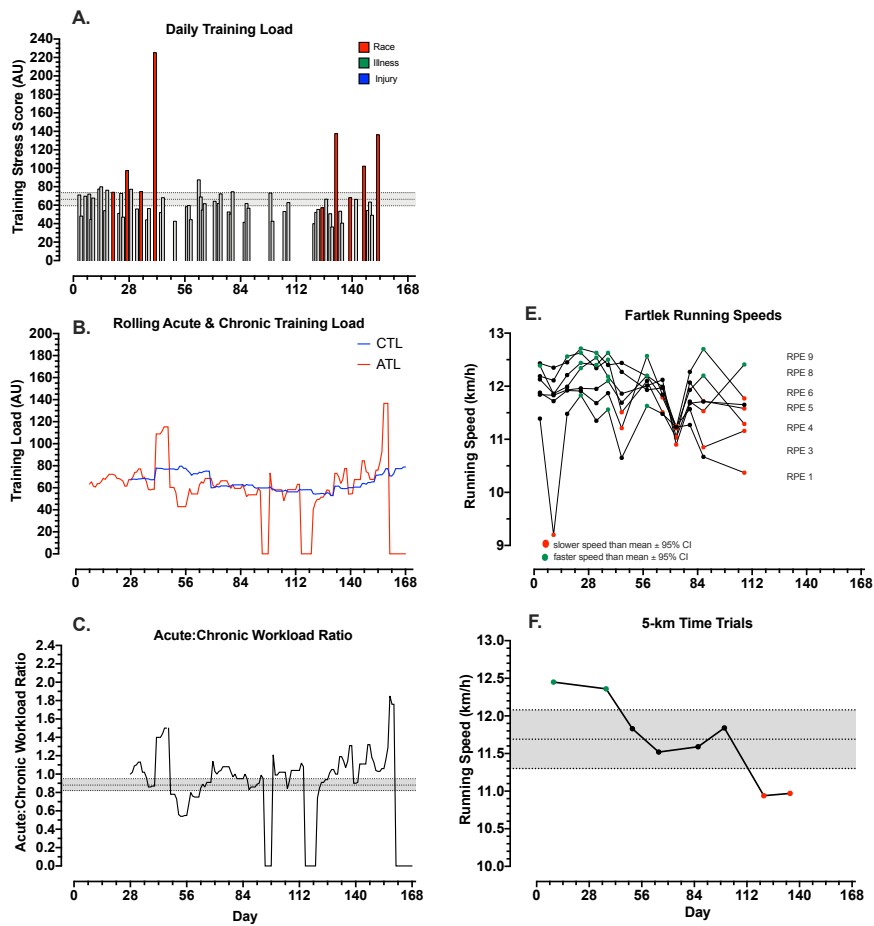


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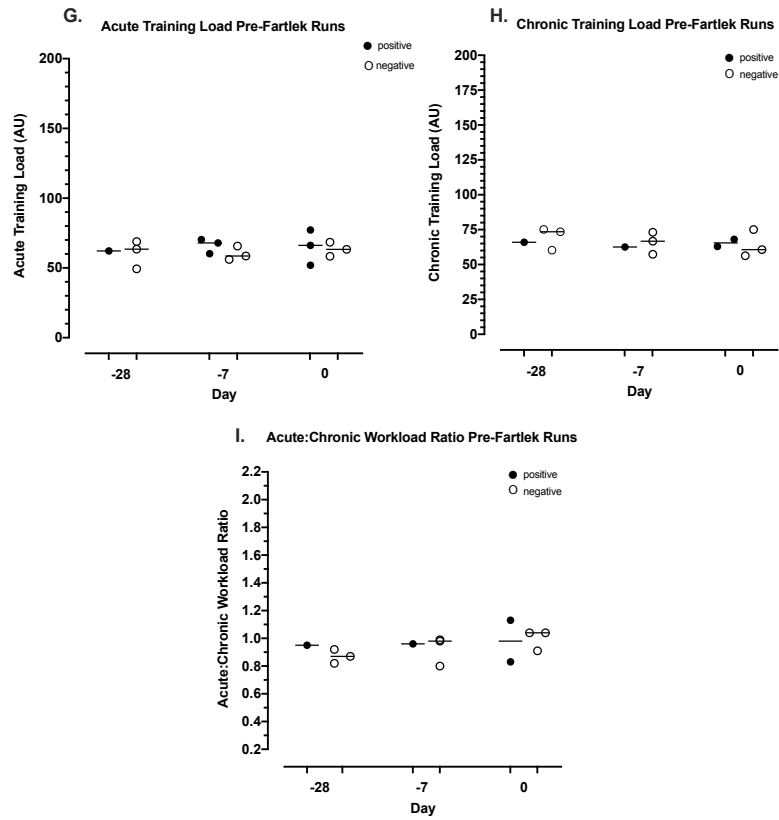




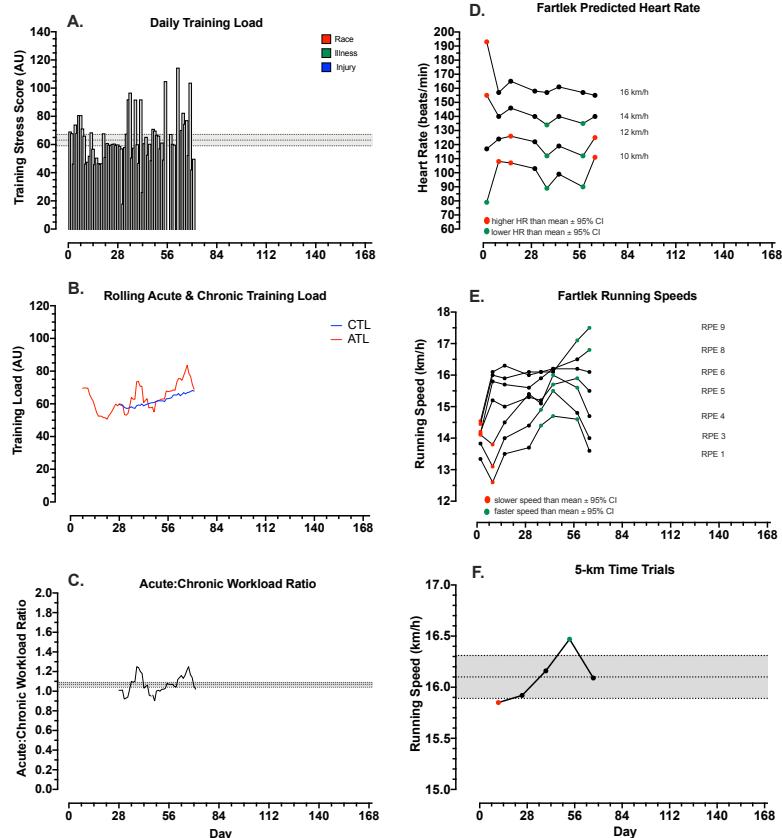
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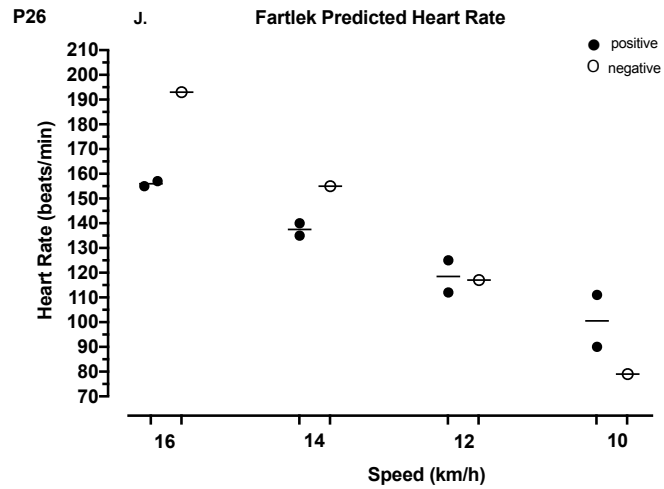
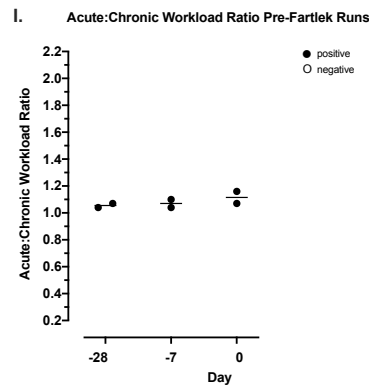
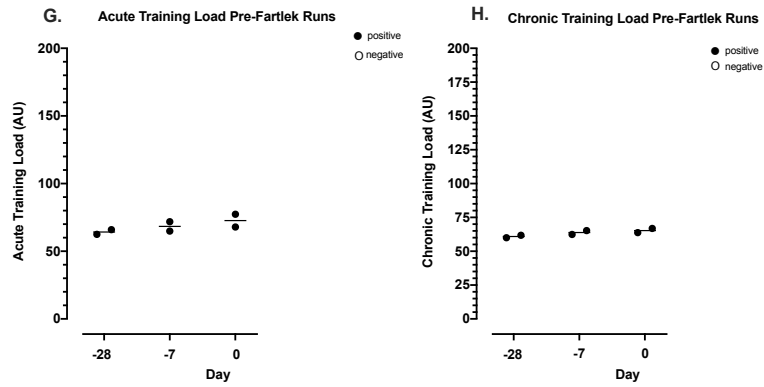
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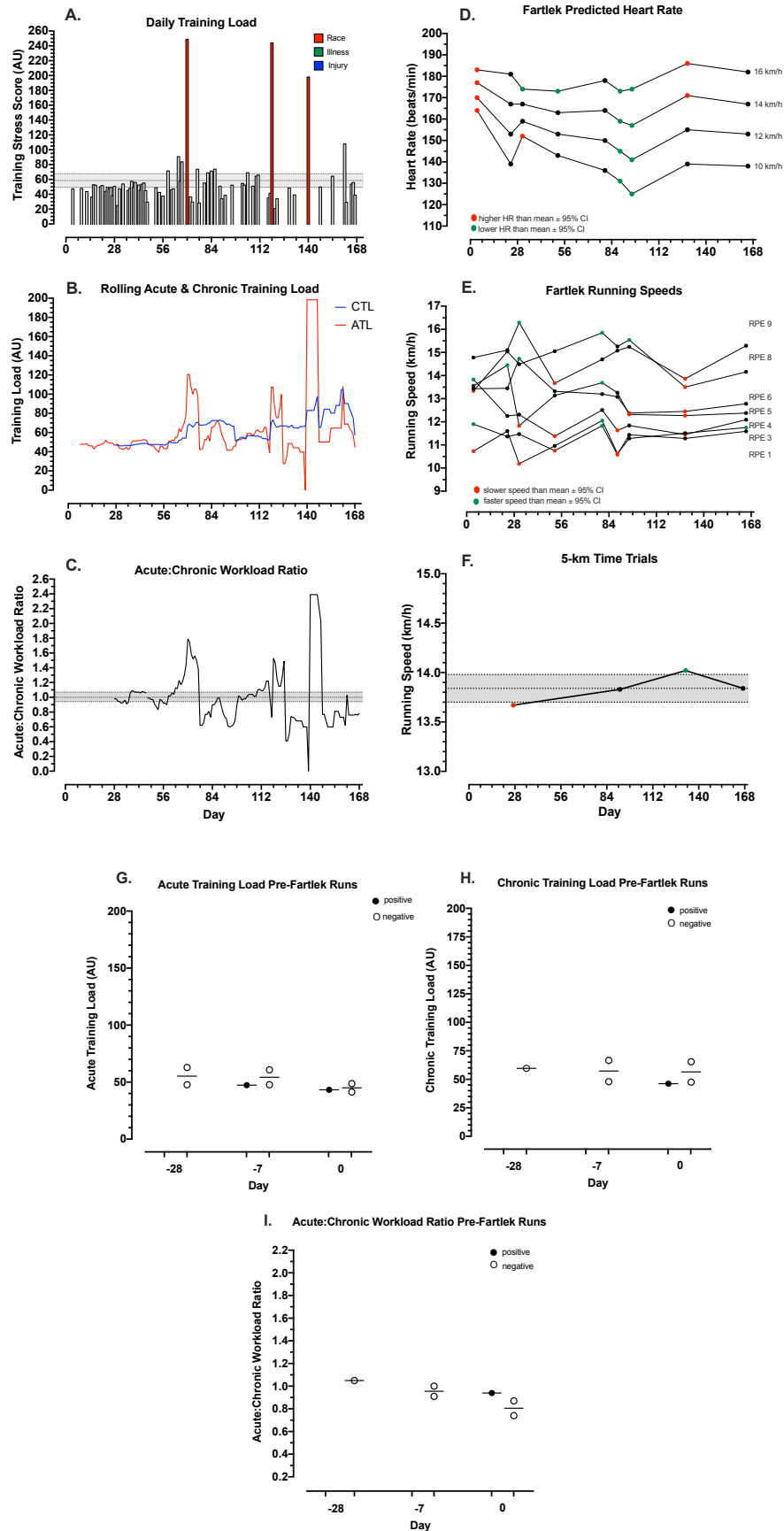
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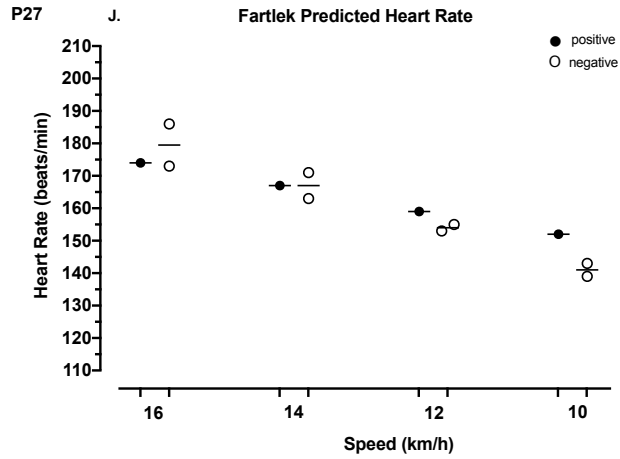
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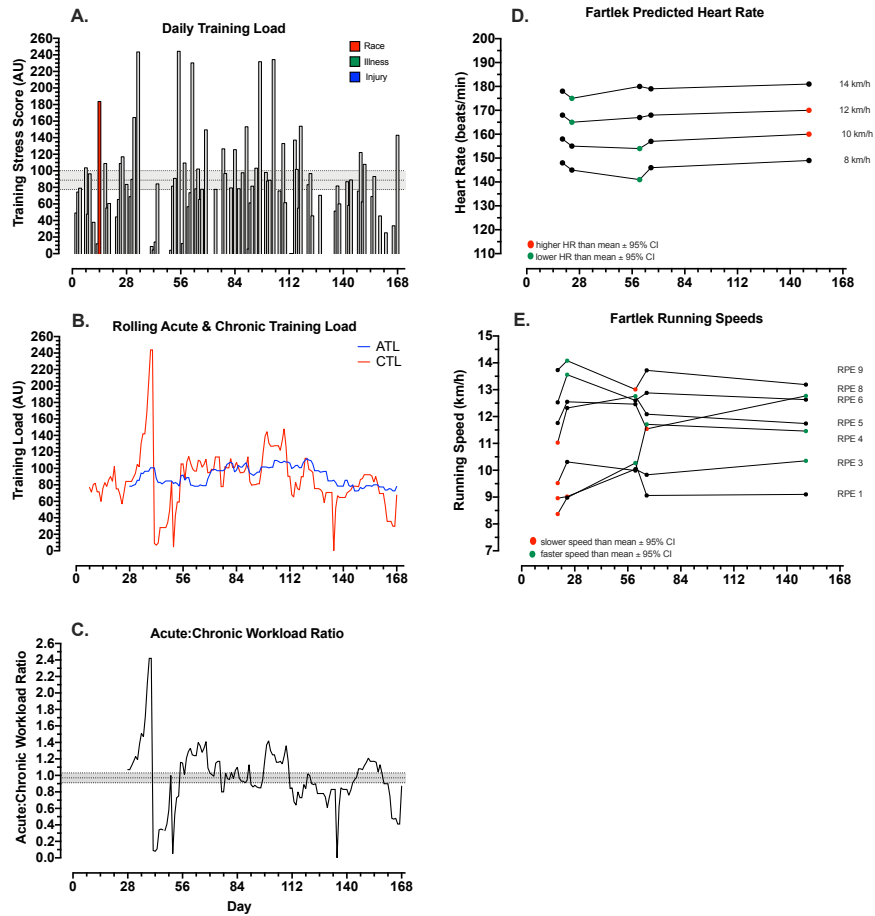
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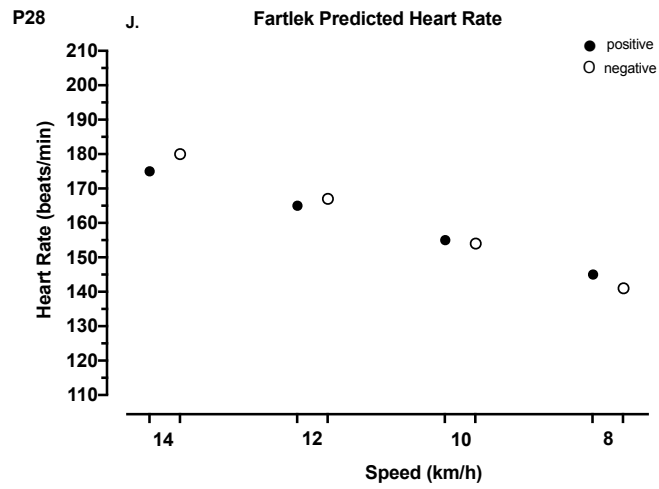
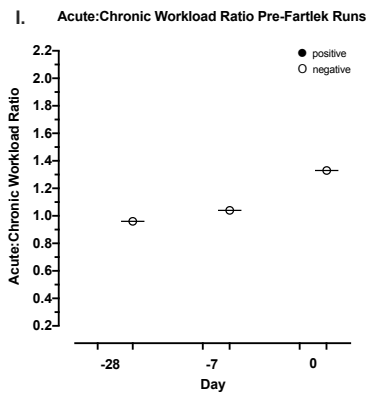
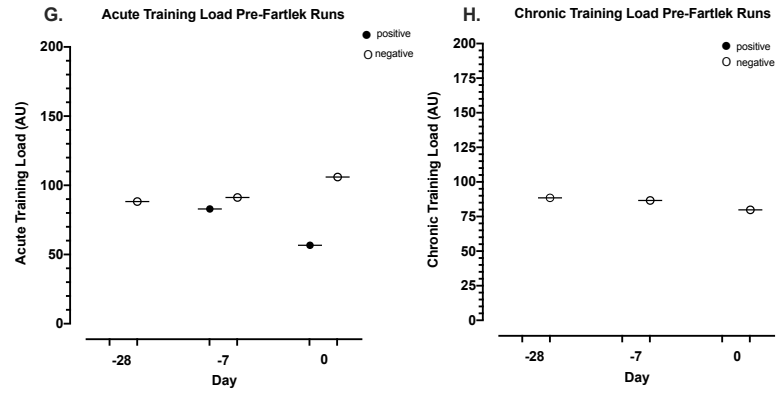
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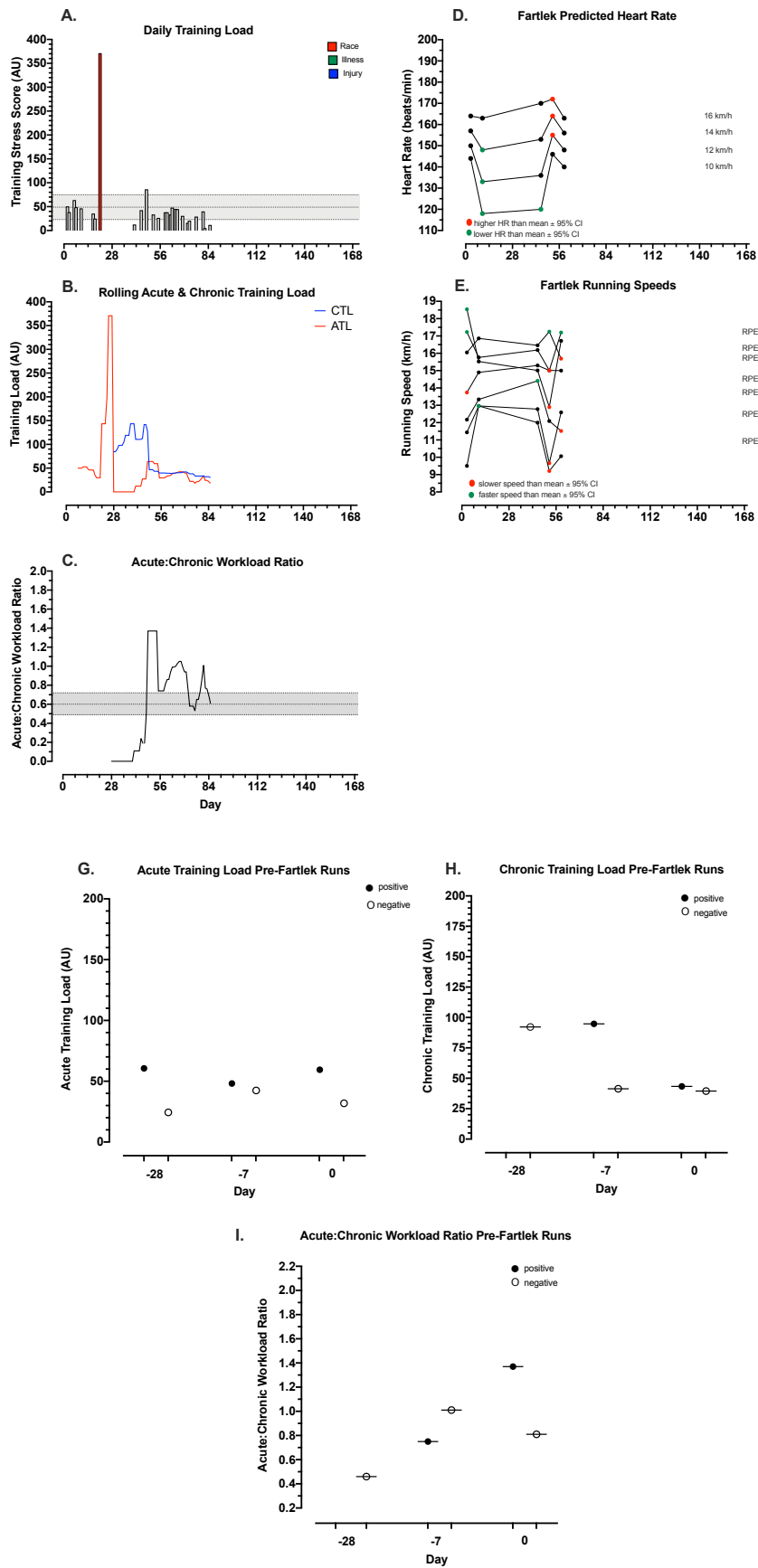
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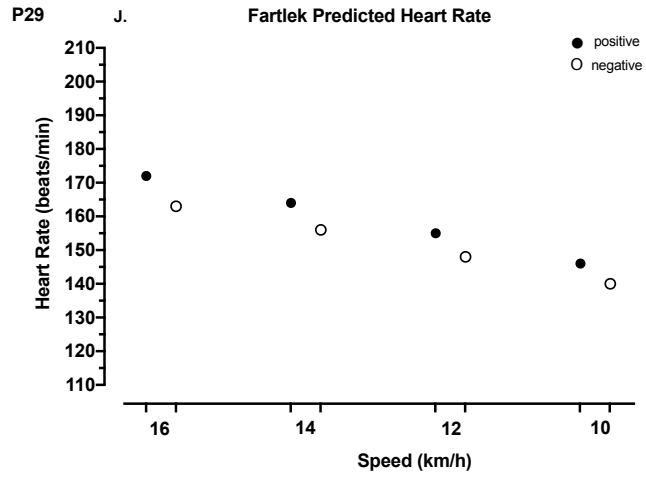


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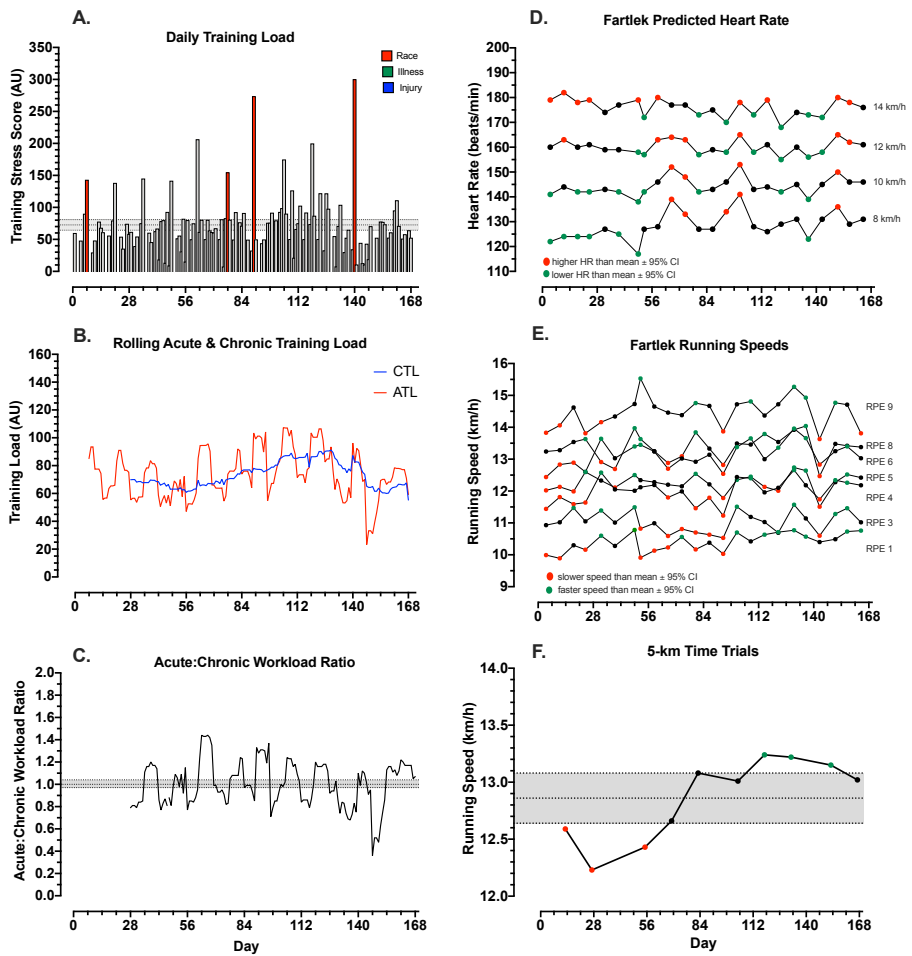


Participant #29





Participant #30



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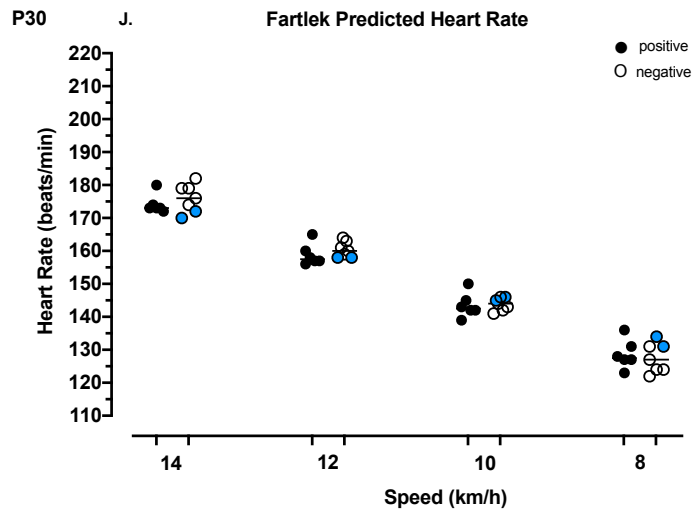
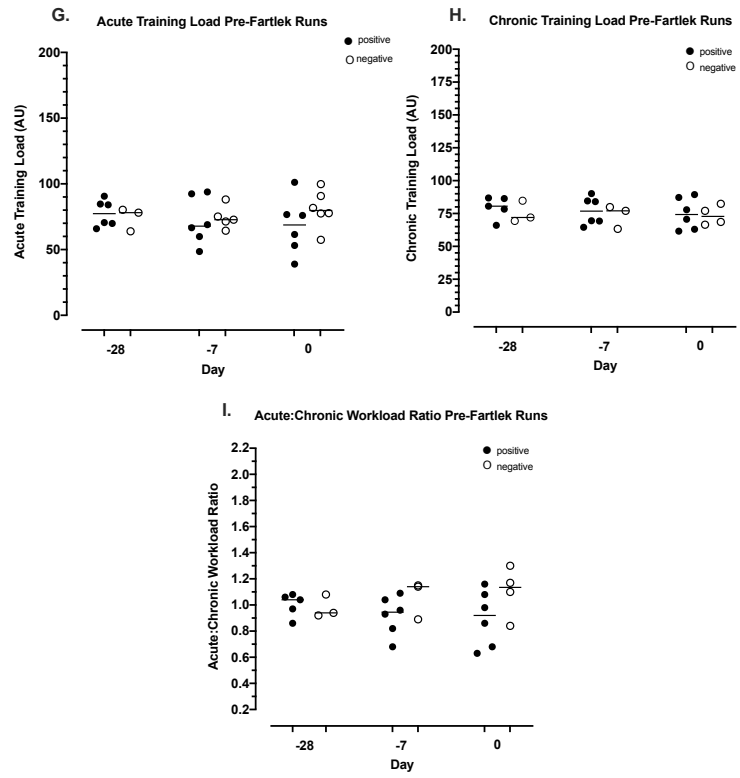
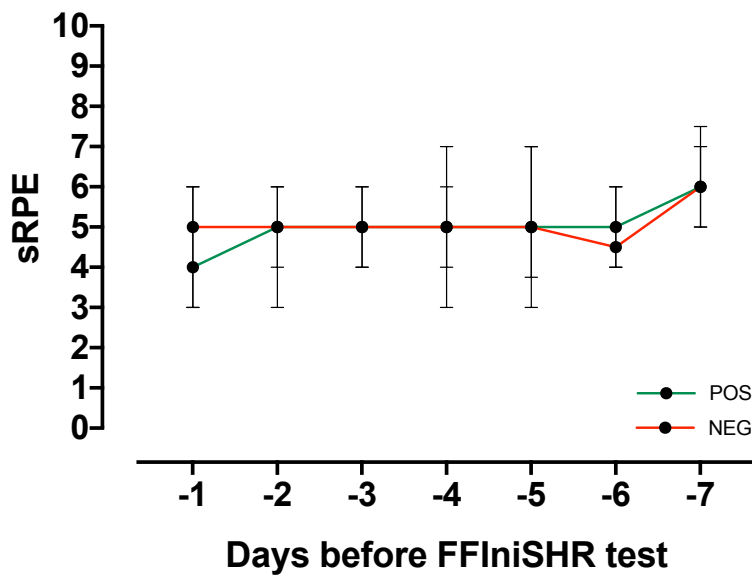


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