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Are All Running Training Loads Created Equal?

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ARE ALL RUNNING TRAINING LOADS CREATED EQUAL?

by

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ABSTRACT

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Training load (TL) is defined as the product of external and internal loads. Various types of external loads can be used in calculating running TL. The purpose of this study was to compare week-to-week changes among different TL in runners. Nine male cross-country runners participated in two consecutive weeks of training monitoring. Session rate of perceived exertion (sRPE) was collected after each run. External loads included miles, minutes, Step Count, Bone Stimulus™, and estimated cumulative peak vertical force. Paired t-tests and Cohen's *d* effect sizes were used to compare between-week percent change (%∆) among TL measures and minutes ($p \leq 0.05$). Different between-week %∆ were found between sRPExMinutes ($p = 0.002$), sRPExStep Count ($p = 0.006$), sRPExForce ($p = 0.002$), and miles ($p = 0.019$) compared to minutes. Findings suggest that using TL allows for more individualized monitoring of the training physiological loads in high school runners.

PREFACE

The findings from this thesis will be submitted for publication to the *Journal of Sports Science* and the formatted manuscript for this journal is presented in chapter II. Therefore, references are formatted specifically for this journal.

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ABBREVIATIONS

RRI	Running-Related Injuries
GRF	Ground Reaction Force
TL	Training Load
HR	Heart Rate
sRPE	Session Rate of Perceived Exertion
BMI	Body Mass Index
GPS	Global Positioning System
IMUs	Inertial Measurement Units
%Δ	Percent Change

CHAPTER I

INTRODUCTION

1.1 Statement of the Problem

Partaking in physical activity is associated with many different health benefits (Warburton et. al., 2017). Of these activities, running is a mode of exercise that has been gaining popularity and participation rapidly since the 1970s (Fields et. al., 2010; Worp et. al., 2016). Participation in running is convenient, inexpensive, a medium for community involvement, can provide competitive opportunities, and is associated with multiple health benefits (Blomqvist et. al., 1983; Fagrad, 2005; George et. al., 1991; Gleim et. al., 1986; Lee et. al., 2014; Lee et. al., 2017) such as mental, physiological, as well as musculoskeletal benefits (Richards et. al., 2015). Although the health benefits of running are numerous, running is also associated with high incidences and rates of injuries. The incidence of running related injuries (RRI) that occur range from 19%-79% in all participants (van Gent et. al., 2007). Of the RRI studied and analyzed, it was found that a majority of RRI occur in the lower extremity. The most common site of lower leg injury was reported greatest at the knee with an incidence up to 50%, while approximately 32% of other lower leg injuries occurred at the Achilles tendon, calf, heel, toes, hamstring and quad among other locations (van Gent et. al., 2007). RRI incidences are reported to result in 2.5 to 59 injuries for every 1000 hours of running (Lun et. al., 2004; Lysholm et. al., 1987; Oestergaard et. al., 2014). RRI are difficult to avoid considering the multifactorial nature and complexity in determining specific injury development causes (Hreljac, 2005). Understanding the complex factors that contribute to RRI would be highly beneficial to reduce injury risks and avoid interruptions in running training and overtraining to optimize performance and health benefits (Martinez-Silvan et. al., 2017).

Research suggests that RRI is a multifactorial problem that includes risk factors such as sex, anatomy, biomechanics, tissue structure, nutrition status, hormonal regulation, and training errors (Bertelsen et. al., 2017; Nielsen et. al., 2012), and therefore, the exact causes of RRI are widely debated and remain elusive. Recently, research has focused on the effects of training errors and their influence on RRI. Since training factors can be easily manipulated and adjusted by coaches and athletes, a better understanding of the influence of training factors on RRI would be beneficial to the running community.

Historically, running training has been tracked and quantified primarily using volume (duration or distance per week) and pace (minutes per distance). A major limitation of quantifying running training with volume or pace is that these measures only account for the external training load a runner will experience. However, different methods to quantify training load have been used by sports scientists and coaches for decades. In order to obtain a more complete picture of the training stimulus on athletes, practitioners now often quantify training loads (TL) defined as the product of an external and internal load measure (Foster, 1998; Foster et. al., 2001; Gabbett, 2018). Monitoring TL between training periods or cycles may give a better understanding of the overall training effects on athletes enabling coaches and athletes to make the best training adjustments to ensure optimal performance and potentially, better understand RRI risks (Foster, 1998; Halson, 2014). Currently, the simplest way for coaches and athletes to quantify external loads is by tracking training session volume, while internal loads can be quantified using session ratings of perceived exertion (sRPE) and/or heart rate (HR) (Foster et. al., 2001; Gabbett, 2018). However, the use of HR to quantify internal loads has recently been questioned due to its lack or reliability at higher exercise intensities (Haaf et. al., 2019). Quantifying external and internal loads with simple, convenient and cost-effective methods is highly valuable for coaches and athletes to monitor training. Although these common and simple methods are useful, they certainly have limitations. For example, training volume as an external load does not quantify the specific external loads applied to the body and thus, any given training volume might yield vastly different external loads between athletes during running. The use of more specific measures of external load (e.g., tibial accelerations, steps count, vertical forces) paired with a common measure of internal load (e.g., sRPE) could provide a more accurate representation of running TL and ultimately, improve monitoring of running training.

1.2 Literature Review

Running is a simple and convenient sport that provides an excellent mode of aerobic exercise. Participation in running and its overall popularity in the U.S. has been increasing since gaining recognition in the 1970s, and especially since 2000 (Fields et. al., 2010), with recent minor drops in participation the past 3 years (Running U, 2019). While participation has increased in general, participation at the high school level has increased by 145% from the 1970s to the 1990s (Henry, 1992; Worp et. al., 2016), and even more so since 2000 (Fields et. al., 2010; Worp et. al., 2016). Although running training is associated with high incidences of chronic injuries, running participation also provides numerous health benefits that can ultimately lead to improved population health and quality of life.

1.2.1. Health Benefits of Running

There are many important health benefits associated with running participation and training (Yeh et. al., 2017). Running participation can increase cardiovascular and pulmonary function (Cantwell, 1985), improve musculoskeletal function, and can also increase happiness and mental health (Grunseit et. al., 2017). Running has also been linked to lower body mass indices (BMI) which is associated with better overall health (Williams, 2013), has provided an overall increase in fitness, and ultimately decrease morbidities and mortality (van Gent et. al., 2007; Koplan, 1995). Cardiovascular, pulmonary, and musculoskeletal function benefits as a result of running training have been show to aide in improving short-term and long-term health when comparing runners and non-runners (Lee et. al., 2014).

Cardiovascular and Pulmonary Function

The cardiovascular and pulmonary system are vital in supplying the body with blood and oxygen via the heart, lungs, arteries, and veins. The cardiovascular system adapts and responds to increased activity at the musculoskeletal level in daily activities or exercise (Abernethy et. al., 1990). During exercise, the heart and lungs are placed under stress to increase blood flow around the body to enable the body to keep working at an above baseline level most efficiently. An increase in cardiac output occurs due to heart rate and stroke volume increasing as exercise intensity increases with the help of neural and hormonal regulation during exercise (Gleim et. al., 1986). When the system is under stress, physiological changes occur, allowing both the cardiovascular and respiratory systems to adapt to efficiently meet the demands placed on them and as a result, increased exercise intensity leads to increase in heart rate. With this relationship between heart rate and exercise intensity, heart rate has been used by athletes and coaches to monitor the intensity of training session to optimize training.

Long-term, the cardiovascular system has been shown to have an increase in cardiac output due to endurance training. This is caused by an increase in blood volume, increased capillarization (Terjung, 1995), hypertrophy of the left ventricle (Blomqvist et. al., 1983; George et. al., 1991), and a decrease in blood pressure (Fagard, 2005). Along with cardiovascular adaptations during exercise, respiratory adaptations also take place. With endurance training, the overall tidal volume increases as well as respiration rate, resulting in an increase in the maximal rate of pulmonary ventilation (Leith & Bradley, 1976). This increase allows for more oxygen to be circulated though the body during exercise and diffused to muscles aiding in endurance performance. In addition to the many cardiovascular and pulmonary benefits, running also improves musculoskeletal function, which further contributes to improved endurance performance.

Musculoskeletal Function

The body is comprised of muscles, tendons, ligaments, and bones that work together to help the body move. It is therefore important for these tissues to be function optimally to maximize movement performance. Running can aid in optimally loading musculoskeletal tissues for acute and chronic health benefits. As the skeletal system is loaded during running, adaptations begin to occur. The bone remodeling and adapting to the stress it is placed under can be explained by Wolff's Law. The stress on the skeletal system allows for bone remodeling, strengthening the system in order to increase performance and decrease the potential for injury. Both external and internal mechanical stresses, such as ground reaction forces (GRF) and muscles and tendons tensile forces on bone, and biochemical processes such as hormone control and remodeling agents, help to create a stronger, more resilient system (Bonewald & Johnson, 2008). When remodeling is occurring, the bone is resisting and withstanding daily loads (Bonewald & Johnson, 2008). Once the bone senses mechanical strain, the forces are translated to biochemical signals that include osteoblasts and osteocytes. Osteocytes are thought to be most sensitive in sensing these forces and can react to changes occurring within the bone and can sense the amount of load to a bone and the direction of loading happening on the bone (Clemente et. al., 2018). Osteoclasts work to break down damaged bone while osteoblasts work to remodel and rebuild bone. If there is more osteoclast activity than osteoblast activity, there will be an overall bone loss while if it was vice versa, there would be an overall increase in bone. With an appropriate amount of loading, the skeletal system will strengthen and be able to withstand injury more optimally.

Muscles and tendons become stronger when placed under stress as well. Similar to Wolff's Law, Davis's Law describes how soft tissue (muscles, tendons, ligaments) remodels to the stress and demands placed on it. This soft tissue will break down and heal in the manner at with it is loaded, making it stronger. With participation in physical activity, the musculoskeletal system will improve in strength and help to withstand RRI that may occur. Although this proves to be true, loading the musculoskeletal system past its threshold would result in a breakdown of that tissue. It is this line between loading tissues adequately and loading them past the breaking point that runners and coaches' straddle in order to maximize performance. Because of the repetitive nature of running, it was reported that 38.5% of high school cross country runners sustained an overuse injury of some kind over the course of the season (NFHS, 2018). This repetitive nature, coupled with training errors made by coaches and athletes during that are potentially avoidable, could be monitored more closely with the use of more accurate ways of tracking loads. This would help in deceasing the ever-present occurrences of RRI that are observed in runners.

1.2.2. Running-Related Injuries and Training

As previously mentioned, running is associated with high incidences and rates of chronic injuries. Approximately 19-79% of runners will sustain a RRI during while training (van Gent et. al., 2007; Lun et. al., 2004; Taunton et. al., 2003; Worp et. al., 2015) including novice, recreational, competitive, and elite runners. At the high school level, approximately 80% of track athletes experienced an injury with 27.5% to 36.3% of athletes experiencing an overuse injury (Pierpoint et. al., 2016). While the most common site of RRI is the knee joint (van Gent et. al., 2007), the most common injury site in high school runners are 1) shins, 2) the knee joint, and finally 3) the ankle joint (Mitchell et. al., 2006). The most common types of RRI are lower limb skeletal stress fractures of the tibia and metatarsals (Xu et. al., 2017), tendinopathy knee (e.g., patellar tendon) and ankle (e.g., Achilles tendon) (Cullum et. al., 2017), and muscle strains in the lower limb (Green & Pizzari, 2017). There are a multitude of factors that can determine why an injury would develop in an athlete (Mitchell et. al., 2006), most of which can be monitored.

Injury risk is explained by both intrinsic and extrinsic factors. **Extrinsic factors** are those that can be easily controlled by coaches and athletes such as training intensity, volume, environment, level of performance, frequency at which they train, as well as other training factors that are able to be manipulated. With each of the variables listed above, athletes and coaches are able to change each variable to fit an athlete's individual training requirements. **Intrinsic factors** are variables in an athlete that are not able to be changed acutely or in a short amount of time. These are variables such as an athlete's anatomical structure, athlete strength, flexibility, stiffness, previous injury history, and the athlete's physiological preparedness in training and performing. Intrinsic factors are those that take time to change and may not be able to change at all no matter how much training an athlete goes through. Both extrinsic and intrinsic factors can contribute together or separately to influence injury risks in distance runners. An overuse injury can be classified as an injury that occurs due to repetitive trauma sustained by the bone or soft tissue in a system. It can also be classified as a gradual onset of an injury with repetitive micro-trauma (Roos & Marshall, 2014). If the demands of training are too great relative to tissue capacity, an athlete is likely to sustain an overuse injury. Training and training adaptations occur as a result of external and internal loads placed on the body. If these external and internal loads are too great, the body will not be able to adapt, resulting in injury. Of all overuse injuries, the most common are lower leg stress fractures, iliotibial band syndrome, Achilles tendinopathy, patellofemoral pain syndrome, plantar fasciitis (Taunton et. al., 2002; Nielsen et. al., 2013), all of which could be related to over-training from an inability to monitor training efficiently. Therefore, overuse injuries are thought to be a result of training-related errors (Worp et. al., 2015) and our inability to accurately monitor training loads in runners.

The effects of RRI on athletes are highly individual, whether that be mentally, physically, or both. The effects these RRI have on the body negatively affect the benefits of running listed previously generally due to training cessation. Therefore, it would be beneficial to understand the direct causes of injury and factors that play a role in RRI development. Injury risk with training has been linked to repetitiveness and location of loading to the musculoskeletal system during a certain activity (Ristolainen et. al., 2010), training errors, insufficient recovery time (Gabbett, 2018), and scattered, inconsistent changes in training volume, intensity, frequency and duration (Kiely, 2018; Viru & Viru, 2000). It is therefore important to monitor running training to ensure that athletes are able to safely handle the demands of training during a given training cycle. To monitor running training, coaches and athletes can use both internal and external load variables (Bahr & Holme, 2003). In order to keep these athletes healthy and performing to their potential, a more accurate way of monitoring training loads and quantifying them is necessary. Without this, overuse injuries will continue to occur at a high rate.

1.2.3. Monitoring Training in Runners

To improve athletes' performance and reduce risks of RRI, athletes and coaches can manipulate training by changing volume, intensity, frequency (Kiely, 2018; Viru & Viru, 2000) thus, changing the density of a given training session. With the manipulation of these variables, a specific training response can be monitored using different metrics (Coutts et. al., 2018). In running training, typical external load measures include training volume (e.g. minutes or mileage) and intensity (e.g. pace), while internal load measures include heart rate (HR) and session rate of perceived exertion (sRPE). HR, however, has recently been questioned for exercise monitoring due to unreliable HR measures at higher intensities (Haaf et. al., 2019). Therefore, HR does not seem to be a reliable measure of internal loads for monitoring running training that often includes higher intensity efforts. Internal load measures are used to monitor the athlete's physiological response to external training loads. These external and internal training load measures are therefore related and influence the overall training load a runner experience. The majority of running coaches only use training volume in distance (e.g., km per week or miles per week) as tracking volume is simple and convenient (i.e., nearly all runners have GPS watches). Historically, coaches and runners have used the "10% rule" (Johnston et. al., 2003) to guide training progression by limiting weekly increases in volume to 10%. However, recent research shows that weekly volume increases between 20 and 60% might pose greater injury risks than increases below 20% (Damsted et. al., 2018). This massive range in potentially harmful weekly volume increase suggests that other factors might mediate the risk of injuries when it comes to training-related factors. Although weekly volume as a method of training monitoring is easy and convenient, it does not account for internal training loads and therefore might not represent the actual training stress experienced by runners within a session or training cycle.

Training load (TL) has become a popular metric to monitor training responses especially in team sport athletes (Foster et. al., 2001; Gabbett, 2018). TL is a product of external and internal training loads during a training session and provides a more complete understanding of training stress. Therefore, TL provide coaches and athletes with more information regarding the overall impact of training cycles to improve decision making with regards to training program design. Although much research has been done on different methods of monitoring training load in athletes, limitations exist (Impellizzeri et. al., 2019). The major challenge with monitoring TL is related to how specific external and internal load measures are obtained. Generally, simple measures of external load such as volume (e.g., time or distance) and intensity (e.g., pace) are used to calculate TL. Although these measures are simple and convenient, they may not provide an accurate representation of the external mechanical loads (e.g., ground reaction forces, tibial accelerations, etc…) that athletes experience during a training session. During running, every step results in a ground react forces (GRF) being applied below the foot and transmitting proximally. Therefore, GRF provide a measure of actual external load experienced by a runner during a run. Since GRF are typically measured in laboratory settings with force platforms, it is difficult to measure step-by-step GRF during daily training sessions in runners. With the recent emergence of wearable technology, it has become more and more possible to measure external loads without the use of costly, lab-based equipment. For example, wireless vertical force insoles (Loadsol, Novel, Inc.) are now available to collect vertical force data via a tablet application and these data are valid and reliable during walking, running, jumping/landing, and cutting (Burns et. al., 2017; Peebles et. al., 2018; Renner et. al., 2019). Peak vertical force, vertical impulse per step, and loading rate of the vertical force can all be used as true measures of external loads experienced by the lower limb loads during training sessions.

In addition, the axial or resultant acceleration experienced by the leg also provide a valuable measure of external load during running. Specifically, peak tibial acceleration (i.e., shock) is commonly used to assess lower limb external loads using wired impact-testing grade accelerometers secured to the distal tibia of runners. Recently, wireless accelerometers secured to tibias can provide measures of average and cumulative peak tibial shock (i.e., peak resultant or axial acceleration following foot strike) outside of laboratory settings (Brayne et. al., 2018).

Therefore, these specific external load measures can be combined with the commonly used internal load measures (e.g., sRPE) to give a more accurate representation of training loads for athlete monitoring purposes. A more accurate training load measure may give rise to more athlete-sensitive responses to training and help avoid periods of over-training and potentially, reduce risks of injury development. While, in theory, this more accurate approach of tracking and quantifying training session loads would yield a better representation of athlete training loads, research has yet to be completed in determining whether these methods would show different week-to-week changes in TL compared to typical measures of TL (e.g., volume X sRPE) or simple measures of volume (e.g., miles per week).

1.3 *Gaps in the Literature*

Understanding athlete training and how it relates to under/overtraining as well as how training relates to RRIs would be incredibly beneficial in ensuring athlete health and performance are being maximized. While there are many ways to track training, very few study and compare the different ways to quantify training to determine the best/most accurate way.

While recent studies (Gabbett, 2018) have assessed how internal and external loads affect training and contribute to injury, it still remains unclear on whether these methods accurately represent the biomechanical loads combined with internal loads acting on athletes during training. There are limitations due to this exclusion of more in-depth external load measures. At this time, not enough literature has been published relating to the quantification of training loads and there is still much to learn regarding it.

Simply using volume, pace, weekly monitoring, and athletes' physiological changes has not proven to be directly related to RRIs (Banister et. al., 1976; Foster et. al., 1999; Hulin et. al., 2016; Nielsen et. al., 2013). When observing the gaps in literature it is clear that more research needs to be done to determine direct causes of RRIs when monitoring training, and that it needs to be more accessible to coaches and athletes because at this point, not much is known about the best way to monitor training. Comparing different calculations of TL may give rise to a better understanding.

1.4 Research Question and Hypotheses

Purpose

The purpose of this study was to 1) compare changes in TL using different measure of internal and external load between coach-prescribed low and high load training weeks in high school cross country runners and 2) observe individual runner responses among the different TL measures between training weeks.

Research Questions

1) Will TL obtained from simple and more complex measures of internal and external loads during a high school cross-country season lead to different week-to-week changes in TL?

2) Will individual runner responses in between-week changes among the different training load measures differ compared to commonly used measures of quantifying running training of volume?

Hypotheses

1) The different TL measure will yield different between week TL changes in cross-country runners.

2) The TL measures will produce a wider range of between week changes among the individual runners.

1.5 Implications and Relevance

Findings from this study will provide useful information to practitioners and coaches regarding quantification of training in runners. If week-to-week changes in TL differ between simple and complex measures when assessing, it will provide evidence to highlight that coaches and practitioners should be cautious when assessing changes in running TLs using only one or certain methods of load monitoring in runners. If simple measures of TL (e.g. sRPE x Volume) provide the same information regarding week-to-week changes in training load compared to more complex measures (e.g. sRPE x estimated cumulative peak force), this would provide evidence that more complex/expensive measures to quantify running TL might not be necessary.

CHAPTER II

Are All Running Training Loads Created Equal?

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Introduction

Endurance running is a mode of exercise that is associated with many health benefits (Blomqvist & Saltin, 1983; Fagard, 2005; George, Wolfe, & Burggraf, 1991; Gleim, Coplan, & Nicholas, 1986; Lee et. al., 2014; Lee et. al., 2017), is inexpensive, and convenient for most. Running has a large participant base and participation in running events has greatly increased since 2000 (Fields et. al., 2010; Worp et. al., 2016). This participation growth is also observed at the high school level in the United States as the number of runners who competed in the 2017-18 high school cross-country season was approximately 490,000 participants, 1.45 times more than in 2000 (Georgina, 1992; NFHS, 2019). Thus, the betterment of coaching and training methods to optimize performance in high school runners is worthwhile. To improve fitness and ultimately running performance, runners and coaches can manipulate training prescription by changing training volume, intensity, frequency, and density (i.e., frequency of intense training) (Kiely, 2018; Viru & Viru, 2000). By manipulating these training variables, coaches aim to produce a specific response in their runners (Coutts, Crowcroft, & Kempton, 2018).

Response to a training stimulus (e.g., running session) can be monitored using multiple methods. Historically, most runners and coaches have used *external load* factors such as volume (e.g., distance or duration) and intensity (e.g., pace) as these methods are engrained in the running culture. However, *internal physiological load* factors such as rating of perceived exertion or average heart rate (HR) during runs as a measure of the physiological response to external loads have been used in the sports science setting and could be beneficial to implement within the coaching world. Both external and internal physiological loads interact with one another to dictate the overall training stress experienced by runners. Training load has become a popular monitoring approach among coaches and sport scientists to monitor training stress and is defined as the product of external and internal physiological loads experienced by an athlete (Foster, 1998; Gabbett, 2018). Monitoring training load between training periods or cycles in runners might provide a better quantification of training stress on a runner to enable the guidance of necessary training adjustments to ensure optimal performance and minimize risk of over- or under-training (Halson, 2014). One of the current challenges of using training load is identifying what external and internal load factors provide the most accurate or sensitive information for coaches and sport scientists.

Although HR is commonly used by distance runners to assess internal load since it can be easily measured with chest or wrist measures, it does not appear to predict performance outcomes and may not be an appropriate measure of internal loads, specifically at higher intensities (Haaf et. al., 2019). Session rating of perceived exertion (sRPE) (i.e., global RPE for an entire training session) has been used to assess internal physiological load, as it is highly correlated with blood lactate levels (Abe et. al., 2015) even at higher intensities during exercise. Therefore, the use of sRPE as an internal load measure provides a simpler method to collect internal physiological load. Running session duration, distance, and average pace are the simplest methods to collect external load since coaches and runners can monitor these measures with a global positioning system (GPS) wristwatch. These measures of monitoring external and internal training loads are simple, convenient, and cost effective making them valuable for coaches and runners daily training monitoring. Although these measures are valuable and practical when monitoring training loads, they have a number of limitations (Impellizzeri, Marcora, & Coutts, 2019). Specifically, commonly used running external training loads such as volume and pace do not necessarily reflect the specific and/or individual biomechanical demands of running. With the emergence of wearable technology, it is now possible to measure runner-specific biomechanical data without having to rely on advanced and costly laboratory-based instruments. For example, wireless inertial measurement units (IMUs) secured to the distal tibia can measure step-by-step axial and resultant peak tibial accelerations (Brayne et. al., 2018), while wireless vertical force insoles can collect peak vertical force and vertical impulse (Burns, Zendler, & Zernicke, 2017) as accurate measures of external load during training sessions. The measurement of more specific external loads such as tibial accelerations and vertical forces acting on the body in conjunction with the commonly used internal training load of sRPE, might provide more sensitive measures of training load. More sensitive measures of training load might improve our ability to monitor training stress and help detect periods of maladaptation or functional overreaching and potentially, periods of increased injury risk. Recent findings indicate that the inclusion of internal training load measures (i.e., sRPE) with external load measures provide more individualized measures of average week-to-week changes in training stress in a broad population of runners following a self-directed program (Napier et. al., 2020). However, it is unknown whether the use of specific biomechanical external load measures would yield different week-to-week changes in training load in a homogenous group of runners who have been prescribed the same training program.

Therefore, the primary purpose of this study was to compare week-to-week changes in training load obtained from simple and more complex measures of external load compared to training duration during coach-prescribed weeks of low and high training load in high school cross-country runners. We hypothesized that with the inclusion of sRPE, the different training load measures would yield different week-to-week changes and direction of change (e.g., increase or decrease) in training compared to volume alone. A secondary observational purpose of this study was to assess individual runner responses in between-week changes among different training load measures. We expected a wider range of responses in week-to-week changes in training load compared to duration or distance alone.

Materials and Methods

Participants

For this study, we recruited a convenience sample of twelve male high school (14-18 years of age) cross-country runners (i.e., the entire varsity team roster). Participants were excluded if they sustained a lower extremity injury within the past six months. An injury would be defined as an event that prevented a runner from training for at least 7 days, or 3 consecutive scheduled training sessions (Yamato, Saragiotto, & Lopes, 2015). Prior to participation, all runners and their parents were informed verbally and in writing of all the testing procedures, potential risks, and benefits associated with the study. Participants then signed an assent form while their parents signed a consent form with the procedures approved by the University Institutional Review Board for Human Participants Research.

Procedures

The collection of training-related data over a two-week period occurred during the middle of the cross-country season and all running session data were collected on the high school campus or training locations at a local park during scheduled team training sessions. This two-week data collection period occurred during a low training load week followed by a high training load week as planned and prescribed by the team coach (**Table 1**). All runners completed their coach-prescribed training.

Table 1. Details regarding the two prescribed low and high training by the team coach.

Week 1: Total volume: ~175 minutes (5-6 runs and/or cross-training)	
Monday	OFF
Tuesday	30-35 minutes
Wednesday	5 min. tempo w/3 min. rest + 6-8 x 400m at mile effort pace w/90s rest + drills
Thursday	30-40 minutes
Friday	35-45 minutes
Saturday	25% of your volume
Sunday	Shakeout Day 15-20 minutes
Week 2: Total volume: ~240 minutes (5-6 runs and/or cross-training)	
Monday	OFF
Tuesday	35-40 minutes
Wednesday	Tempo (30 minutes total)
Thursday	30-40 minutes
Friday	6 x 100m fast strides + easy volume + drills
Saturday	4-6 x 1K at interval at 3000m effort pace w/90s rest (45 minutes total)
Sunday	Long Run 25% of weekly volume (~60 min)

During the collection period, daily internal and external load measures were obtained daily. **Internal *physiological/psychological* load** was monitored using sRPE for each runner. sRPE was recorded using a 10-point visual analog scale within 10 minutes of the end of each training session (Fanchini et. al., 2015). The runners included in this study had already been using this subjective rating scale and were therefore accustomed to using the visual analog scale to rate their sRPE. **External loads** measured included session 1) run duration, 2) run mileage, 3)

Step Count, 4) “Bone Stimulus” (iMeasureU, VICON, USA), and 5) estimated cumulative vertical force. Running minutes or miles per training session was recorded using the runners' own GPS wristwatches (different models and brands). It is important to note that training duration (minutes) was the measure used by the team coach to prescribe training. Step Count was measured as the product of session minutes and average session cadence (Blue Thunder, IMeasureU). “Bone Stimulus” (Besier, 2019) as an external load measure was collected using the IMeasureU -Step software platform during each training session using bilateral IMU (1000Hz, Blue ThunderIMeasureU, VICON, USA) secured to the distal third of the medial tibias before the start of each run (**Figure 1**). Estimated cumulative vertical force of each training session was obtained from vertical force data measured using wireless vertical force insoles (200Hz, loadsol, Novel, USA) collected at different runner-specific running paces during a treadmill testing session before the start of the study. This testing was done since wireless force insoles require more pre-testing set up time and data from only one pair of insoles can be recorded at once on a device. It was therefore logistically difficult to collect force data for each runner during all runs. For this testing session, runners warmed up at a self-selected pace for five to seven minutes before completing one-minute intervals at three different paces (coach or performance guided): 1) easy running pace, 2) tempo pace, and 3) 5km race pace. These testing sessions took place at the training facility of the team high school. All testing was completed in the runners' own training footwear and forces were measured using size-appropriate wireless vertical force insoles (200Hz, loadsol, Novel, USA). Peak vertical force insole data was collected from all steps in the last 30s of each speed.

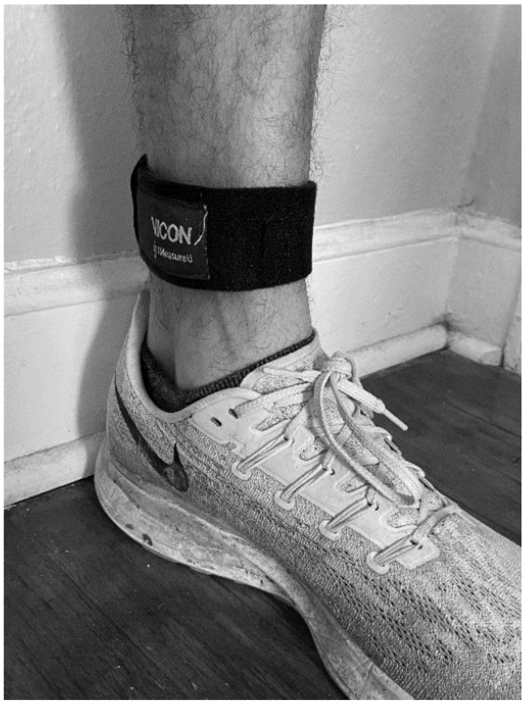


Figure 1. Position of IMUs on lower extremity.

Data Analyses

Session RPE (i.e., internal load) was multiplied with four external load measures (minutes, Step Count, "Bone Stimulus", and estimated cumulative vertical force) to obtain four different training load measures. In many sports, sRPE and training duration in minutes (sRPExMinutes) has been used to calculate training load (Gabbett, 2018). This training load measure is certainly the simplest and easiest one to use and calculate for coaches and support staff. For the more biomechanically-specific measures, sRPE was multiplied with "Bone Stimulus" and the estimated peak vertical force obtained from the advanced instruments. The use of bilateral "Bone Stimulus" and peak vertical force was expected to provide more runner-sensitive external load measures to quantify training load. From the manufacturer site, "Bone Stimulus" is dependent on "total number of steps taken" and "the size of the impact derived from each individual step" (IMU-Step Dashboard Summary, 2018). However, "Bone Stimulus" is "more responsive to the size of step impact rather than the number of steps taken" which means that high impact steps contribute more to “Bone Stimulus” than low impact steps (Swain et. al., 2016). Finally, the peak vertical force data from the treadmill testing session at the beginning of the collection period were used to estimate session average peak vertical force. Since the relationship between peak vertical force and running speed can be defined well with a second order polynomial (Tongen & Wunderlich, 2011), a trend line from a second order polynomial from the peak vertical force versus running speed curve was constructed to estimate the corresponding average peak vertical force at session average run paces for each runner. **Figure 2** provides an example of a peak vertical force and speed curve fitted with a polynomial trend line. For each run, the average vertical force was estimated based on the corresponding average speed on the vertical force vs speed curve for each runner. **Table 2** summarizes the internal and external training load measures used to calculate the different training load measures. Each of the six different measures to quantify running training (1. Minutes, 2. Miles, 3. sRPExMinutes, 4. sRPExStep Count 5. sRPEx“Bone Stimulus”, 6. sRPExForce) was used to determine the week-to-week percent change (%Δ) in running training for each measure during the two-week collection period. Training distance in miles was included as a training metric since it is a commonly used measure of monitoring running training.

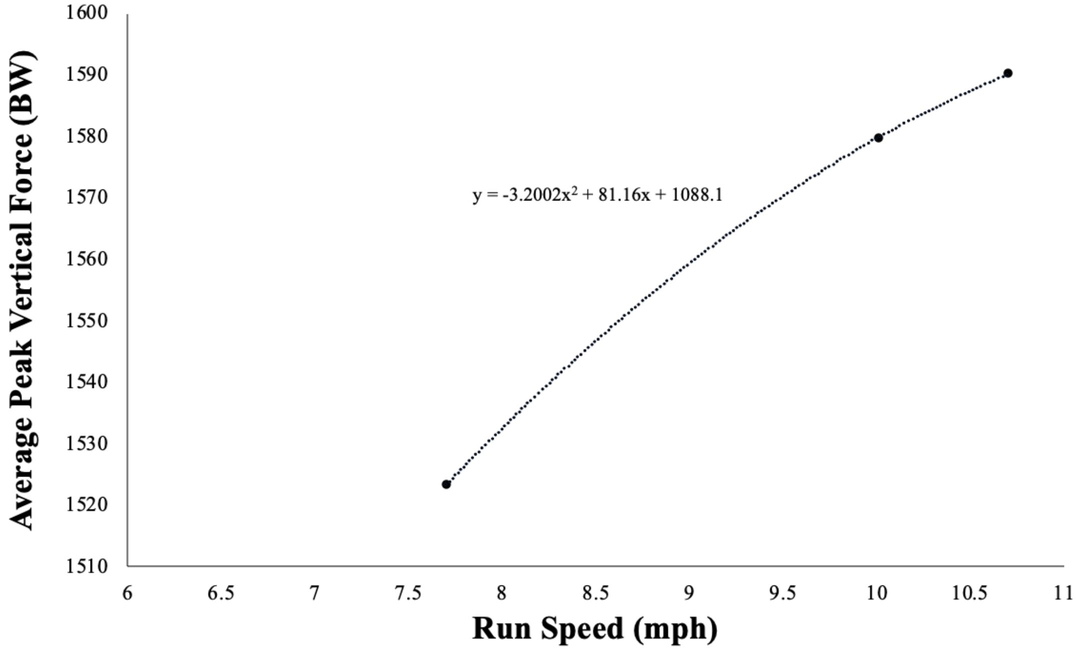


Figure 2 Average peak vertical force and running speed curve fitted with a second order polynomial trend line to identify a vertical force value corresponding to the average session running speed.

Table 2. Internal and external load measures used to obtain training loads.

Internal Training Load	**External Training Loads**
Session Rate of Perceived Exertion (sRPE)	Duration (minutes) Distance (miles) Step Count (number of steps) “Bone Stimulus” Estimated cumulative vertical force

Notes: The internal training load (sRPE) was multiplied by each of the four external training load measures to obtain different measures of training load for each daily training session. The daily training load was summed to obtain weekly training load for the first and second testing weeks.

Statistical Analysis

Paired t-tests were used to compare between-week percent change (%∆) in running training quantified using minutes run with other training load measures, as well as miles ($p \leq 0.05$). Cohen's *d* effect sizes were also computed to assess the magnitude of mean differences (small=0.2; medium=0.5; large=0,8; very large=1.3) (Cohen, 1988).

Results

Of the twelve runners who began the study, data from three runners were not included in analyses due to missing data collection during the two-week period (high school Fall break).

Between-week %∆ differed from minutes for sRPExMinutes ($p = 0.002$; $d = 1.83$), sRPExForce ($p = 0.004$; $d = 1.91$), sRPExStep Count ($p = 0.006$; d = 2.06), and miles ($p = 0.019$; $d = 0.71$) while there was no difference in between-week %∆ for sRPEx"Bone Stimulus" ($p = 0.113$; d = 0.74) compared to minutes (**Figure 3**).

Between-week %∆ "Bone Stimulus" ($p < 0.001$; $d = 2.85$) were different than %∆ in minutes while between-week %∆ Step Count ($p = 0.490$; $d = 0.12$) and Force ($p = 0.662$; $d = 0.17$) were not different than between-week %∆ coach-prescribed minutes (**Table 3**).

Table 3. Average weekly external loads for weeks 1 and 2, and week-to-week percent change for each external load measure.

External Loads	Week 1	Week 2	% Change
Minutes	1748	2108	20%
Step Count	279737	332745	19%
"Bone Stimulus"	28722	29358	2% *
Cumulative Force (10^8 N)	3.8	4.7	22%

Notes: % Change: week-to-week percent difference. *: external load is different than Minutes (i.e., the coach-prescribed training metric) ($p \leq 0.05$).

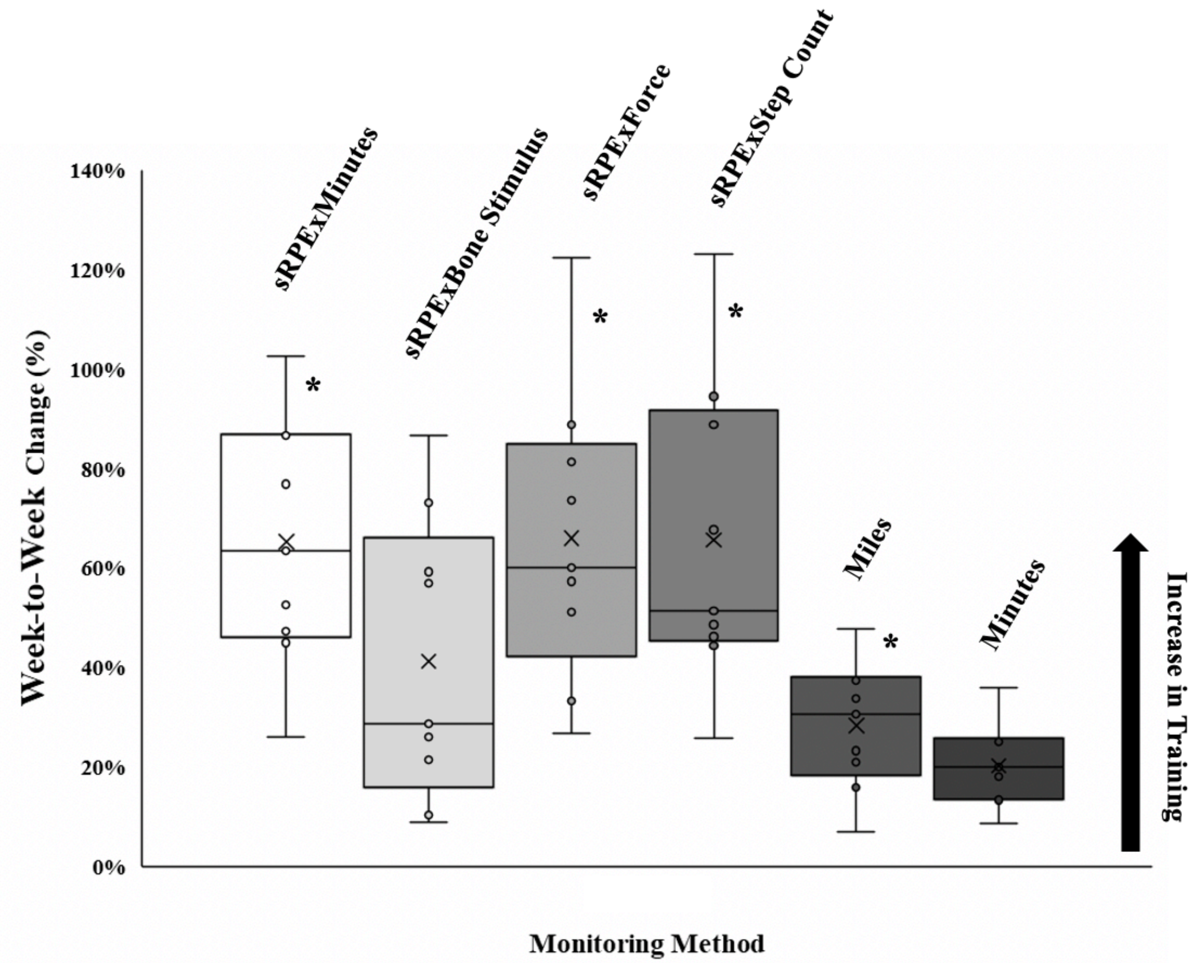


Figure 3. Box plots of week-to-week changes (%) among different methods of quantifying running training. **Force** (estimated cumulative peak vertical force from combination of wireless force insole peak vertical force and cadence), **Bone Stimulus** (proprietary metric from IMeasureU IMU-Step software), **Step Count** (minutes x average cadence), **Miles**, and **Minutes** were used as the external load measures in combination with sRPE to calculate four different training load metrics. *: different than Minutes (i.e., the coach-prescribed training metric) ($p \leq 0.05$). Box plots include the maximum and minimum values, first and third quartiles, and median.

When sRPE was combined with the external load measures, there were larger ranges in individual responses to week-to-week %∆ in training load measures (76% to 97%) compared to the two common measures to quantify training in runners: minutes (27%) and miles (41%) (**Figure 4**). The standard deviation among training load measures was between 25-31% while minutes run had a standard deviation of 8% and miles had one of 13%, emphasizing the wider range among training loads.

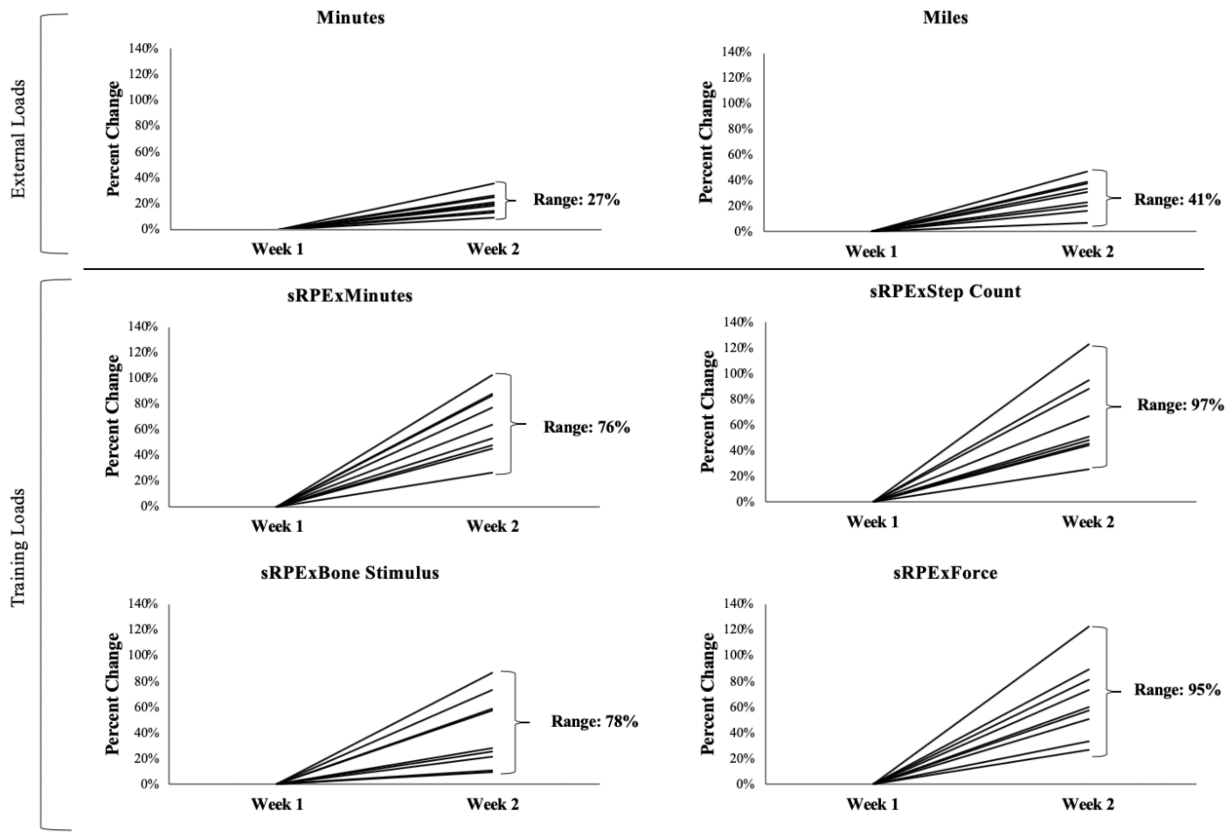


Figure 4. Individual runner responses for common external load measure (Minutes and Miles) and all four different training load measures. This figure illustrates the larger range of individual responses when using training load measures (below) compared to external load measures (above).

Discussion

The purpose of this study was to compare week-to-week changes in training load obtained from simple and more complex measures of external load compared to training duration alone during coach-prescribed weeks of low and high training load in high school cross country runners. The secondary observational purpose of this study was to assess individual runner responses in between-week changes among the different training load measures compared to commonly used measures to quantify running training using volume. Our primary hypothesis that the different training load measures would yield different week-to-week percent changes and direction of change (e.g., increase or decrease) compared to coach-prescribed training duration was supported.

Week-to-week %∆ was larger for all training load measures (which includes the internal physiological load of sRPE), except for sRPEx"Bone Stimulus", compared to the %∆ in training duration (**Figure 3**). Training load has been used extensively in team sports such as soccer, rowing, and cycling for years (Foster, 1998; Rodreguez-Marroyo et. al., 2012; Tran et. al., 2015) but studies on the use of training load measures in running to quantify training stress is lacking. Our current results are in agreement with recent findings that training load measures, combining various external load metrics and sRPE, yield different week-to-week %∆ in training compared to using training duration alone (Napier et. al., 2020). These findings are explained by the fact that quantification of running training by training duration alone does not account for the physiological response to training and only provides general information regarding the external training load of an athlete (Foster, 1998; Napier et. al., 2020; Rodreguez-Marroyo et. al., 2012; Tran et. al., 2015). Thus, if a coach only quantifies external load metrics such as training duration or distance, they may vastly underestimate the training stress experienced by runners. For example, a runner's training volume could remain constant during two consecutive training days or weeks despite increases in intensity and resulting physiological response (Paquette et. al., 2020). This misrepresentation of training stress could lead to maladaptation or periods of non-functional overreaching in runners. On the other hand, training load measures provide a more individualized and runner-sensitive assessment of the physiological training response (Abe et. al., 2015) and overall training stress experienced by a runner (Paquette et. al., 2020). These findings suggest that the use of training loads, which incorporate the physiological response to external training load, might provide better quantification of training stress in runners to help coaches identify periods of unplanned elevated training stress. Although certain running sessions need prescribed paces or interval splits, the use of prescribed session efforts instead of paces is likely useful to avoid unnecessary high internal physiological loads (e.g., sRPE) as a result of insisting to maintain a specific pace on "easy" or recovery training sessions. In fact, RPE can be used to prescribe treadmill running intensities during a graded exercise test in active men (Glass, Knowlton, & Becque, 1992). However, the use of sRPE to prescribe intensity during an entire training session in runners still remains to be studied. Additionally, these findings suggest that there may not be a need to use more complex biomechanical measures to monitor external loads since training load measured with training minutes and sRPE yielded the same average %Δ compared to training duration as the other training load measures including more complex biomechanical measures of external load (e.g., Step Count and Force) (Figure 3). Thus, the use of a convenient external load measure such as training duration for calculating training load would be recommended for coaches instead of more complex biomechanical measures of external load.

Although we only studied %Δ in training load from coach-prescribed low to high training load weeks, it is possible that a similar underestimation of training stress could be observed during planned periods of rest or reduced training load (e.g. "recovery weeks" or "tapering" for races) when only using training volume. In fact, recent evidence on a large population of recreational runners suggests that despite reductions in week-to-week %Δ in training volume (i.e., duration), increases in training stress, quantified with the training load of training duration and sRPE, can occur (Napier et. al., 2020). More work is necessary to better understand the relationship between training load measures and distance running performance, but currently available literature suggests that anecdotally reported variations in individual runner responses to "tapering" periods prior to competition could be explained by inappropriate quantification of training stress in runners. Future work on the use of training load to quantify "tapering" or "recovery" periods would be highly valuable for coaches and sport scientists.

Although all other week-to-week %∆ in training load measures were different than training duration, week-to-week %∆ in sRPEx"Bone Stimulus" was not different than %∆ in prescribed training duration. This is in part the result of how "Bone Stimulus" was calculated. The proprietary "Bone Stimulus" metric uses the 3D resultant acceleration of the IMU placed on the distal tibiae to calculate a surrogate measure of the "mechanical stimulus that would cause the bone to respond and remodel". The calculated "Bone Stimulus" from the proprietary algorithm reaches a plateau or saturation after repeated cyclical loading over the course of a training run since it is based on the biology of bone cells' adaptation to mechanical loading and remodeling. Thus, the measured "Bone Stimulus" metric remains relatively constant with only an average of 2% week-to-week change between training cycles and might not be the most appropriate external load metric to include in training load quantification.

Our secondary hypothesis was also supported as the combination of sRPE with the various external load measures led to larger ranges in individual responses to week-to-week %∆ in training load measures when (76% to 97%) compared to the two common measures to quantify training in runners: minutes (27%) and miles (41%) (**Figure 4**). The smaller range in week-to-week %∆ external loads (i.e., minutes and miles) conveys the message that the runners are experiencing similar training responses which can be misleading as observed in the current study. It is important to note that mileage did appear to have higher variance in week-to-week %∆ compared to minutes. This is due to 1) the fact that the team coach-prescribed training in minutes and 2) the differing fitness levels and resulting average run paces for each runner. However, the standard deviations of the team averages for the week-to-week %∆ in the various training load measures ranged between 25-31% while the standard deviations in week-to-week %∆ for miles and minutes was 13% and 8%, respectively. The larger standard deviations from the training load measures highlights the concept that the inclusion of sRPE provides an indication to coaches that runners are responding to prescribed training differently.

Although training load measures seem to provide a more sensitive measure of week-to-week changes in training stress, %∆ among the different training load measures appear to be variable for individual runners. Indeed, **Figure 5** demonstrates how week-to-week %∆ of the different training load measures vary greatly among individual runners. Specific training load measures might provide a slightly different quantification of training stress within specific runners which might highlight the need to individualize training quantification methods to ensure optimal training monitoring. Many factors can contribute to these varied responses for individual runners in %∆ among different training load measures including emotional/psychological state (e.g., family, school, relationship stress) and different changes in specific external load metrics due to higher training load (e.g., different cadence, different intensity of steps, different pace, etc…). Thus, future work should assess individual factors that might contribute to this individual response to various training load measures.

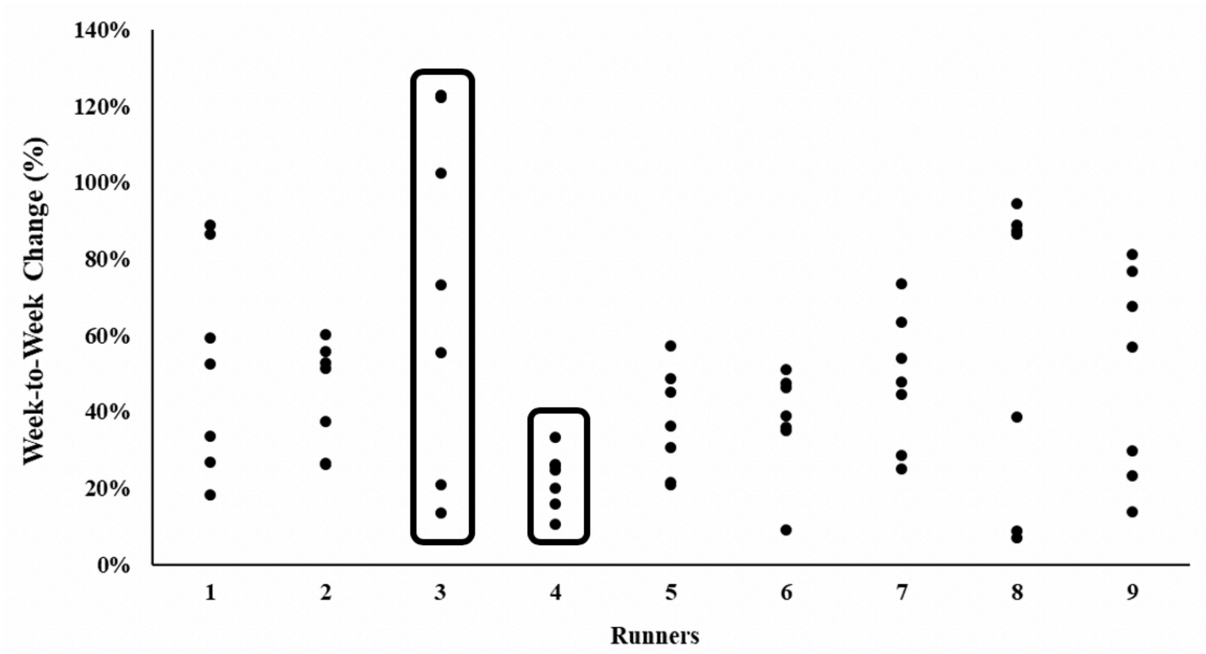


Figure 5. Week-to-week change (%) among training quantification methods (i.e., each black circle) for all runners included in the study. Black vertical rectangles illustrate the range in week-to-week changes in training among training monitoring methods for two specific runners (runners 3 and 4) to highlight individual responses in training stress among monitoring methods.

While using more runner-sensitive external load measures to track training (e.g. Force, "Bone Stimulus", and Step Count) might give a better representation of individual biomechanical loads, the measures used in the current study have limitations. The daily average peak vertical force used as an external load measure was an estimation of the force experienced by the runners at an average running pace using a second-order polynomial and therefore, is not a direct measure of average vertical force for each run. Unfortunately, daily wear of the insoles is currently not practical given the costs and expertise needed to operate the insoles. Finally, the use of Step Count may be limiting because using Step Count assumes that all steps produce the same mechanical load on the lower limb. In reality, some steps lead to greater magnitudes and different loading direction of the external force applied to the body. However, Step Count is a simple and convenient method to use as an external training load. The use of foot- or tibiamounted IMUs to quantify the intensity/magnitude of the tibial acceleration will allow better quantification and weighing of running steps (e.g., Impact Load by IMeasureU) over the course of a running session.

Conclusions

Our findings suggest that the use of an internal physiological training load (i.e., sRPE) combined with certain external loads, provides a more sensitive method to monitor week-to-week changes in training stress compared to using duration alone. These more individualized measures of quantifying training stress could provide coaches and runners better methods to monitor training and could prevent periods of maladaptation or functional overreaching for more optimal performance outcomes. Finally, the use of more complex measure of external loads used in the current study appears to be unnecessary and coaches can use simple measures of quantifying external loads such as minutes run in addition to a simple and convenient measure of internal loads such as sRPE to more optimally and individually monitor training stress in runners.

References

IMU-Step Dashboard Summary. (2018), 5.

Abe, D., Yoshida, T., Ueoka, H., Sugiyama, K. & Fukuoka, Y. (2015). Relationship between perceived exertion and blood lactate concentrations during incremental running test in young females. *BMC Sports Science, Medicine & Rehabilitation, 7*, 5.

Abernethy, P.J., Thayer, R. & Taylor, A.W. (1990). Acute and chronic responses of skeletal muscle to endurance and sprint exercise. A review. *Sports Medicine (Auckland, N.Z.), 10*, 365-389.

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

Banister, E.W., Calvert, T.W., Savage, M.V. & Bach, T. (1976). A Systems Model of the Effects of Training on Physical Performance. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-6*, 94-102.

Besier, T. (2019). IMU Bone Stimulus.

Bertelsen, M.L., Hulme, A., Petersen, J., Brund, R.K., Sørensen, H., Finch, C.F., Parner, E.T. & Nielsen, R.O. (2017). A framework for the etiology of running-related injuries. *Scandinavian Journal of Medicine & Science in Sports, 27*, 1170-1180.

Blomqvist, C.G. & Saltin, B. (1983). Cardiovascular Adaptations to Physical Training. *Annual Review of Physiology, 45*, 169-189.

Bonewald, L.F. & Johnson, M.L. (2008). Osteocytes, mechanosensing and Wnt signaling. *Bone, 42*, 606-615.

Brayne, L., Barnes, A., Heller, B. & Wheat, J. (2018). Using a wireless consumer accelerometer to measure tibial acceleration during running: agreement with a skin-mounted sensor. *Sports Engineering, 21*, 487-491.

Burns, G.T., Zendler, J. & Zernicke, R.F. (2017). Wireless Insoles to Measure Ground Reaction Forces: Step-by-Step Validity in Hopping, Walking, and Running. *International Society of Biomechanics in Sports,*

Cantwell, J.D. (1985). Cardiovascular aspects of running. *Clinics in Sports Medicine, 4*, 627.

Clemente F Arias, Miguel A Herrero, Luis F Echeverri, Gerardo E Oleaga & José M López (2018). Bone remodeling: A tissue-level process emerging from cell-level molecular algorithms. *PLoS One, 13*, e0204171.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* 2.ed., 2.print. edn. Hillsdale, NJ [u.a.]: Erlbaum.

Coutts, A.J., Crowcroft, S. & Kempton, T. (2018). Developing athlete monitoring systems: theoretical basis and practical applications. *Kellmann M, Beckmann J, eds. Sport, Recovery and Performance: Interdisciplinary Insights,* 19–32.

Cullum, C.K., Tran, P.H.T. & Døssing, S. (2017). Running and causes of running-related injuries. *Ugeskrift for laeger, 179*.

Damsted, C., Parner, E.T., Sorensen, H., Malisoux, L., Hulme, A. & Oestergaard, N.R. (2018). Preparing for Half-Marathon: The Association Between Changes in Weekly Running Distance and Running-Related Injuries-Does It Matter How the Running Is Scheduled? *The Journal of Orthopaedic and Sports Physical Therapy*.

Fagard, R.H. (2005). Physical Activity, Physical Fitness and the Incidence of Hypertension. *Journal of Hypertension, 23*, 265-267.

Fanchini, M., Ghielmetti, R., Coutts, A.J., Schena, F. & Impellizzeri, F.M. (2015). Effect of Training-Session Intensity Distribution on Session Rating of Perceived Exertion in Soccer Players. *International Journal of Sports Physiology and Performance, 10*, 426-430.

Fields, K.B., Sykes, J.C., Walker, K.M. & Jackson, J.C. (2010). Prevention of Running Injuries. *Current Sports Medicine Reports, 9*, 176-182.

Foster, C. (1998). Monitoring training in athletes with reference to overtraining syndrome. *Medicine and Science in Sports and Exercise, 30*, 1164-1168.

Foster, C., Snyder, A. & Welsh, R. (1999). Monitoring of training, warm up, and performance in athletes. *Overload, Performance Incompetence, and Regeneration in Sport*, 43-51.

Foster, Florhaug, Franklin, Gottschall, Hrovatin, Parker, Doleshal & Dodge (2001). A New Approach to Monitoring Exercise Training. *Journal of Strength and Conditioning research, 15*, 109-115.

Gabbett, T. (2018). Infographic: The training-injury prevention paradox: should athletes be training smarter and harder? *British Journal of Sports Medicine, 52*, 203.

George, K.P., Wolfe, L.A. & Burggraf, G.W. (1991). The 'athletic heart syndrome'. A critical review. *Sports Medicine (Auckland, N.Z.), 11*, 300-331.

Glass, S.C., Knowlton, R.G. & Becque, M.D. (1992). Accuracy of RPE from graded exercise to establish exercise training intensity. *Medicine and Science in Sports and Exercise, 24*, 1303.

Gleim, G.W., Coplan, N.L. & Nicholas, J.A. (1986). Acute cardiovascular response to exercise. *62*, 211-218.

Green, B. & Pizzari, T. (2017). Calf muscle strain injuries in sport: a systematic review of risk factors for injury. *British Journal of Sports Medicine, 51*, 1189-1194.

van Gent, R.N., Siem, D., van Middelkoop, M., van Os, A.G., Bierma-Zeinstra, S.M.A. & Koes, B.W. (2007). Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. *British Journal of Sports Medicine, 41*, 469.

Grunseit, A., Richards, J. & Merom, D. (2017). Running on a high: parkrun and personal well-being. *BMC Public Health, 18*, 59-11.

Haaf, T., Foster, C., Meeusen, R., Roelands, B., Piacentini, M.F., van Staveren, S., Koenderman, L. & de Koning, J.J. (2019). Submaximal heart rate seems inadequate to prescribe and monitor intensified training. *European Journal of Sport Science, 19*, 1082-1091.

Halson, S. (2014). Monitoring Training Load to Understand Fatigue in Athletes. *Sports Medicine, 44*, 139-147.

Henry, G., (1992). Boys, girls and the box. *The Guardian (1959-2003),* 23.

Hreljac, A. (2005). Etiology, Prevention, and Early Intervention of Overuse Injuries in Runners: a Biomechanical Perspective. *Physical Medicine & Rehabilitation Clinics of North America, 16*, 651-667.

Hulin, B.T., Gabbett, T.J., Lawson, D.W., Caputi, P. & Sampson, J.A. (2016). The acute:chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players. *British Journal of Sports Medicine, 50*, 231-236.

Impellizzeri, F.M., Marcora, S.M. & Coutts, A.J. (2019). Internal and External Training Load: 15 Years On. *International Journal of Sports Physiology and Performance, 14*, 270-273.

Johnston, C., Taunton, J., Lloyd-Smith, D. & Mckenzie, D. (2003). Preventing running injuries. Practical approach for family doctors.

Kiely, J. (2018). Periodization Theory: Confronting an Inconvenient Truth. *Sports Medicine, 48*, 753-764.

Koplan, Rothenberg & Jones (1995). The natural history of exercise: a 10-yr follow-up of a cohort of runners. *Medicine and Science in Sports and Exercise, 27*, 1180-1184.

Lee, Pate, Russell R., Carl, J., Sui, X., Church, T.S. & Blair, S.N. (2014). Leisure-Time Running Reduces All-Cause and Cardiovascular Mortality Risk. *JACC (Journal of the American College of Cardiology), 64*, 472-481.

Lee, D., Brellenthin, A.G., Thompson, P.D., Sui, X., Lee, I. & Lavie, C.J. (2017). Running as a Key Lifestyle Medicine for Longevity. *Progress in Cardiovascular Diseases, 60*, 45.

Leith & M. Bradley (1976). Ventilatory muscle strength and endurance training. *Journal of Applied Physiology, 41*, 508-516.

Lun, V., Meeuwisse, W.H., Stergiou, P. & Stefanyshyn, D. (2004). Relation between running injury and static lower limb alignment in recreational runners. *British Journal of Sports Medicine, 38*, 576-580.

Lysholm, J. & Wiklander, J. (1987). Injuries in runners. *American Journal of Sports Med,* , 168-171.

Martínez-Silván, D., Díaz-Ocejo, J. & Murray, A. (2017). Predictive Indicators of Overuse Injuries in Adolescent Endurance Athletes. *International Journal of Sports Physiology and Performance, 12*, 156.

Mitchell J. Rauh, Thomas D. Koepsell, Frederick P. Rivara, Anthony J. Margherita & Stephen G. Rice (2006). Epidemiology of Musculoskeletal Injuries among High School Cross-Country Runners. *American Journal of Epidemiology, 163*, 151-159.

Napier C, Ryan M, Menon C, Paquette MR. Session RPE in combination with training volume provides a better estimation of training responses in runners. *J Athletic Training*, Accepted Ahead of Press, 2020.

NFHS (2018). High School Sports Participation Increases for 29th Consecutive Year. *NASDAQ OMX's News Release Distribution Channel.*

Nielsen, R.O., Buist, I., Sørensen, H., Lind, M. & Rasmussen, S. (2012). Training errors and running related injuries: a systematic review. *International Journal of Sports Physical Therapy, 7*, 58.

Nielsen, R.O., Nohr, E.A., Rasmussen, S. & Sørensen, H. (2013). Classifying running-related injuries based upon etiology, with emphasis on volume and pace. *International Journal of Sports Physical Therapy, 8*, 172.

Oestergaard Nielsen, R., Rønnow, L., Rasmussen, S. & Lind, M. (2014). A Prospective Study on Time to Recovery in 254 Injured Novice Runners.

Paquette MR, Napier C, Willy RW, Stellingwerff T. (2020). Moving Beyond Weekly ‘Distance’ – Optimizing Quantification of Training Load in Runners. JOSPT, Workload Special Issue, Accepted Ahead of Press

Peebles, A.T., Maguire, L.A., Renner, K.E. & Queen, R.M. (2018). Validity and Repeatability of Single-Sensor Loadsol Insoles during Landing. *Sensors (Basel, Switzerland), 18*, 4082.

Pierpoint, L.A., Williams, C.M., Fields, S.K. & Comstock, R.D. (2016). Epidemiology of Injuries in United States High School Track and Field. *The American Journal of Sports Medicine, 44*, 1463-1468.

Renner, K.E., Williams, D.S.B. & Queen, R.M. (2019). The Reliability and Validity of the Loadsol ® under Various Walking and Running Conditions. *Sensors (Basel, Switzerland), 19*, 265.

Richards, J., Jiang, X., Kelly, P., Chau, J., Bauman, A. & Ding, D. (2015). Don't worry, be happy: cross-sectional associations between physical activity and happiness in 15 European countries. *BMC Public Health, 15*, 53.

Ristolainen, L., Heinonen, A., Turunen, H., Mannström, H., Waller, B., Kettunen, J.A. & Kujala, U.M. (2010). Type of sport is related to injury profile: A study on cross country skiers, swimmers, long-distance runners and soccer players. A retrospective 12-month study. *Scandinavian Journal of Medicine & Science in Sports, 20,* 384.

Rodríguez-Marroyo, J., Villa, G., García-López, J. & Foster, C. (2012). Comparison of Heart Rate and Session Rating of Perceived Exertion Methods of Defining Exercise Load in Cyclists. *Journal of Strength and Conditioning Research, 26*,2249-2257.

Roos, K. & Marshall, S. (2014). Definition and Usage of the Term "Overuse Injury" in the US High School and Collegiate Sport Epidemiology Literature: A Systematic Review. *Sports Medicine, 44*, 405-421.

Running, U. (2019). Running USA Releases 2019 U.S. Running Trends Report. *2019* (April 19, 2019).

Swain, D., Kelleran, K., Graves, M. & Morrison, S. (2016). Impact Forces of Walking and Running at the Same Intensity. *Journal of Strength and Conditioning Research, 30*, 1042-1049.

Taunton, J.E., Ryan, M.B., Clement, D.B., McKenzie, D.C., Lloyd-Smith, D.R. & Zumbo, B.D. (2002). A retrospective case-control analysis of 2002 running injuries. *British Journal of Sports Medicine, 36*, 95-101.

Taunton, J.E., Ryan, M.B., Clement, D.B., McKenzie, D.C., Lloyd-Smith, D.R. & Zumbo, B.D. (2003). A prospective study of running injuries: the Vancouver Sun Run "In Training" clinics. *British Journal of Sports Medicine, 37*, 239-244.

Terjung, R.L. (1995). Muscle Adaptations to Aerobic Training. *Sports Science Exchange, 8*, 1-4.

Tongen, A. & Wunderlich, R (2011). Biomechanics of Running and Walking, 315-328.

Tran, J., Rice, A.J., Main, L.C. & Gastin, P.B. (2015). Convergent validity of a novel method for quantifying rowing training loads. *Journal of Sports Sciences, 33*, 268-276.

Viru, A. & Viru M. (2000). Nature of Training Effects. *Exercise and Sport Science,* 67–95.

Warburton, D.E.R. & Bredin, S.S.D. (2017). Health benefits of physical activity: a systematic review of current systematic reviews. *Current opinion in cardiology, 32*, 541-556.

Williams, P. (2013). Effects of Running and Walking on Osteoarthritis and Hip Replacement Risk. *Medicine & Science in Sports & Exercise, 45*, 1292-1297.

Worp, M. P. van der, Haaf, D.S.T., Cingel, R.v., Wijer, A.d., Nijhuis-Van der Sanden, M. W. G & Staal, J.B. (2015). Injuries in runners; a systematic review on risk factors and sex differences. *Plos One, 10*, e0114937.

Worp, M. P. van der, Wijer, A.d., Cingel, R.v., Verbeek, A.L.M., Nijhuis-Van der Sanden, M. W. G & Staal, J.B. (2016). The 5- or 10-km Marikenloop Run: A Prospective Study of the Etiology of Running-Related Injuries in Women. *Journal of Orthopaedic and Sports Physical Therapy, 46*, 462-470.

Xu, C., Silder, A., Zhang, J., Reifman, J. & Unnikrishnan, G. (2017). A cross-sectional study of the effects of load carriage on running characteristics and tibial mechanical stress: implications for stress-fracture injuries in women. *BMC Musculoskeletal Disorders, 18*, 125.

Yeh, H., Stone, J.A., Churchill, S.M., Brymer, E. & Davids, K. (2017). Physical and Emotional Benefits of Different Exercise Environments Designed for Treadmill Running. *International Journal of Environmental Research and Public Health, 14*, 752

Appednix A

Table 1. Details regarding the two prescribed low and high training by the team coach.

Week 1: Total volume: ~175 minutes (5-6 runs and/or cross-training)	
Monday	OFF
Tuesday	30-35 minutes
Wednesday	5 min. tempo w/3 min. rest + 6-8 x 400m at mile effort pace w/90s rest + drills
Thursday	30-40 minutes
Friday	35-45 minutes
Saturday	25% of your volume
Sunday	Shakeout Day 15-20 minutes
Week 2: Total volume: ~240 minutes (5-6 runs and/or cross-training)	
Monday	OFF
Tuesday	35-40 minutes
Wednesday	Tempo (30 minutes total)
Thursday	30-40 minutes
Friday	6 x 100m fast strides + easy volume + drills
Saturday	4-6 x 1K at interval at 3000m effort pace w/90s rest (45 minutes total)
Sunday	Long Run 25% of weekly volume (~60 min)

Table 2. Internal and external load measures used to obtain training loads.

Internal Training Load	External Training Loads
Session Rate of Perceived Exertion (sRPE)	Duration (minutes)
	Distance (miles)
	Step Count (number of steps)
	"Bone Stimulus"
	Estimated cumulative vertical force

Notes: The internal training load (sRPE) was multiplied by each of the four external training load measures to obtain different measures of training load for each daily training session. The daily training load was summed to obtain weekly training load for the first and second testing weeks.

Table 3. Average weekly external loads for weeks 1 and 2, and week-to-week percent change for each external load measure.

External Loads	Week 1	Week 2	% Change
Minutes	1748	2108	20%
Step Count	279737	332745	19%
"Bone Stimulus"	28722	29358	2% *
Cumulative Force (10^8 N)	3.8	4.7	22%

Notes: % Change: week-to-week percent difference. *: external load is different than Minutes (i.e., the coach-prescribed training metric) ($p \leq 0.05$).

Appendix B

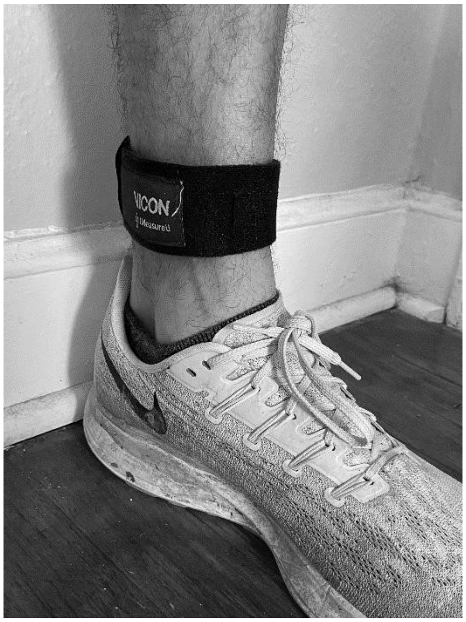


Figure 1. Position of IMUs on lower extremity.

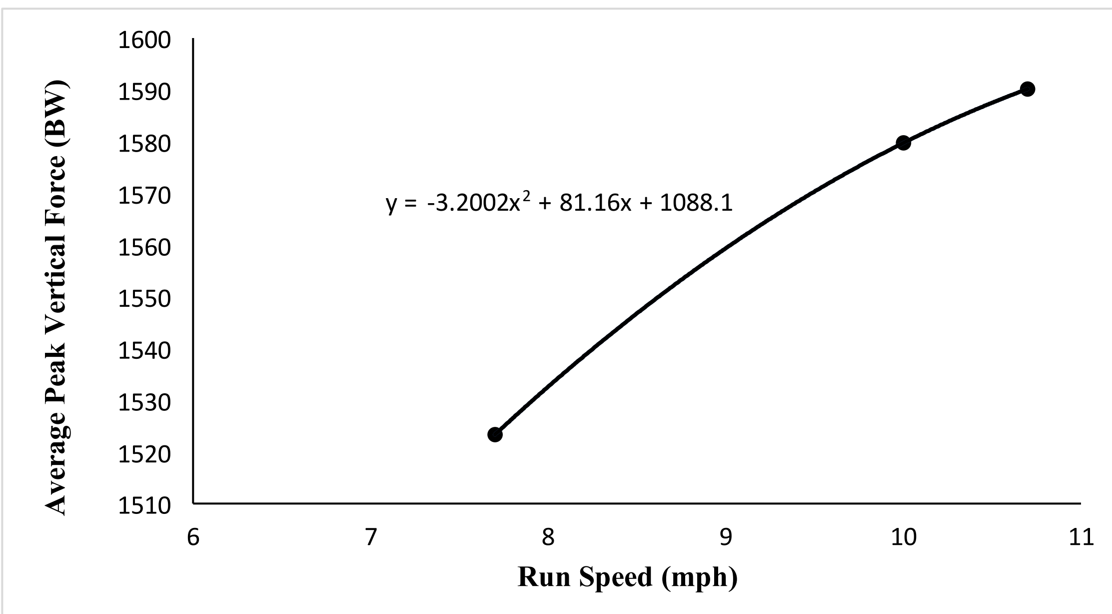


Figure 2 Average peak vertical force and running speed curve fitted with a second order polynomial trend line to identify a vertical force value corresponding to the average session running speed.

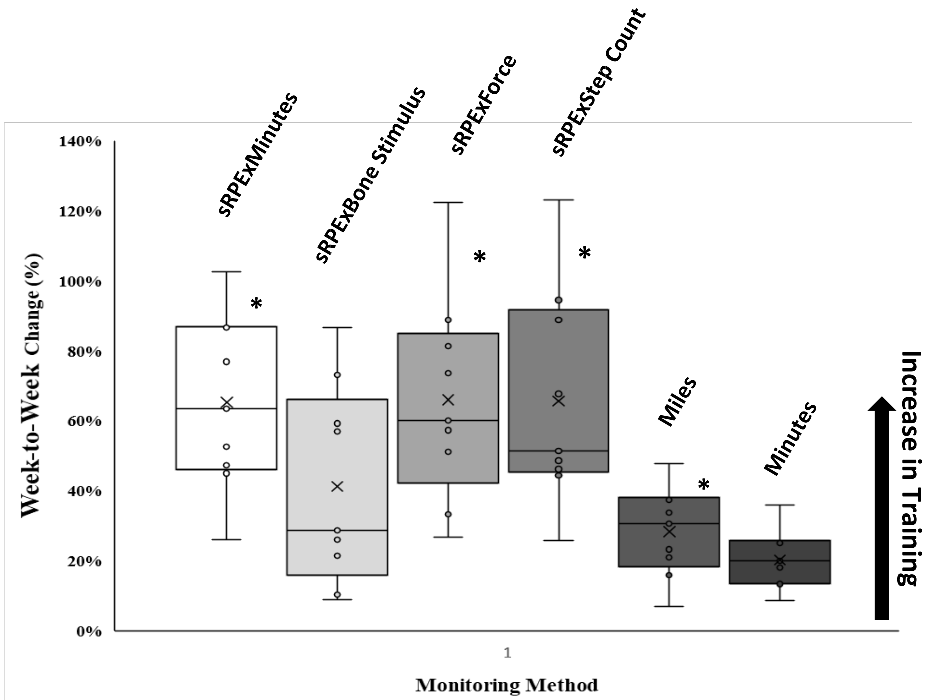


Figure 3. Box plots of week-to-week changes (%) among different methods of quantifying running training. **Force** (estimated cumulative peak vertical force from combination of wireless force insole peak vertical force and cadence), **Bone Stimulus** (proprietary metric from IMeasureU IMU-Step software), **Step Count** (minutes x average cadence), **Miles**, and **Minutes** were used as the external load measures in combination with sRPE to calculate four different training load metrics. *: different than Minutes (i.e., the coach-prescribed training metric) ($p \leq 0.05$). Box plots include the maximum and minimum values, first and third quartiles, and median.

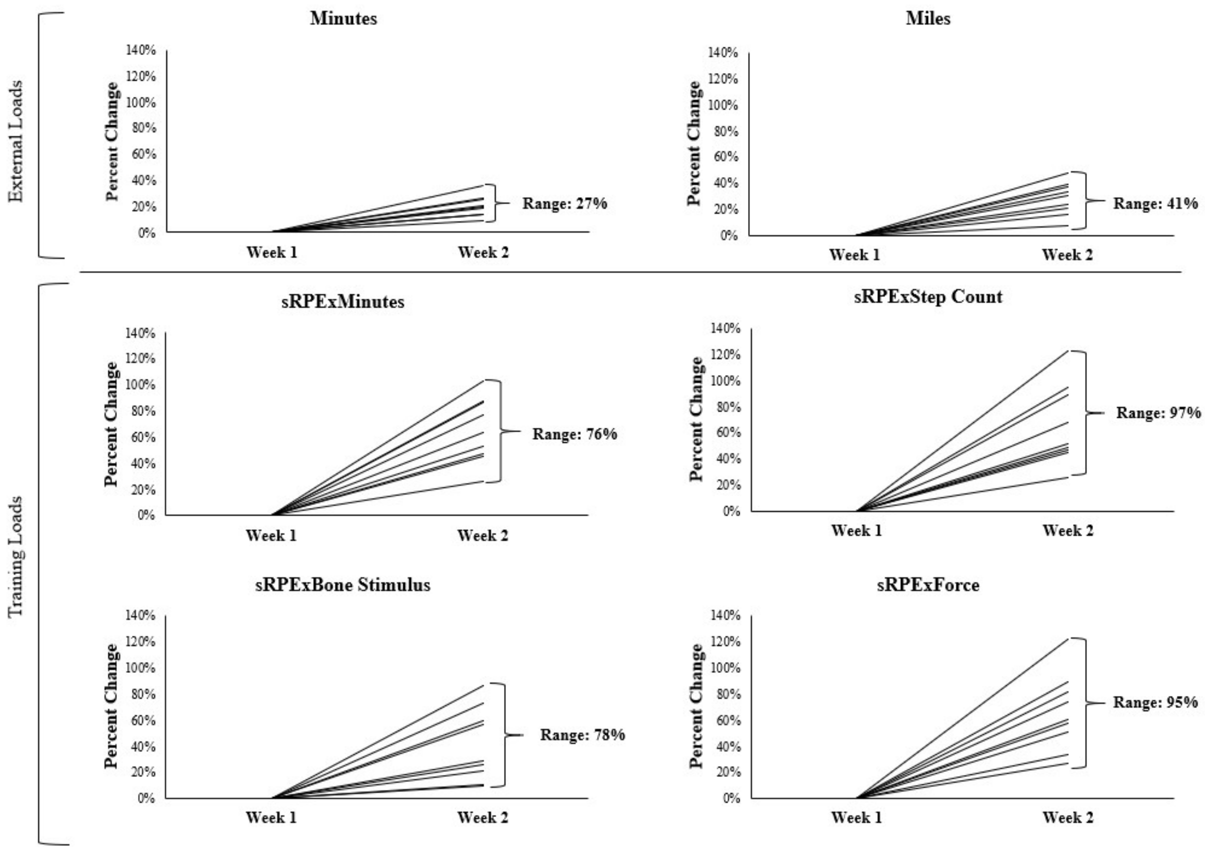


Figure 4. Individual runner responses for common external load measure (Minutes and Miles) and all four different training load measures. This figure illustrates the larger range of individual responses when using training load measures (below) compared to external load measures (above).

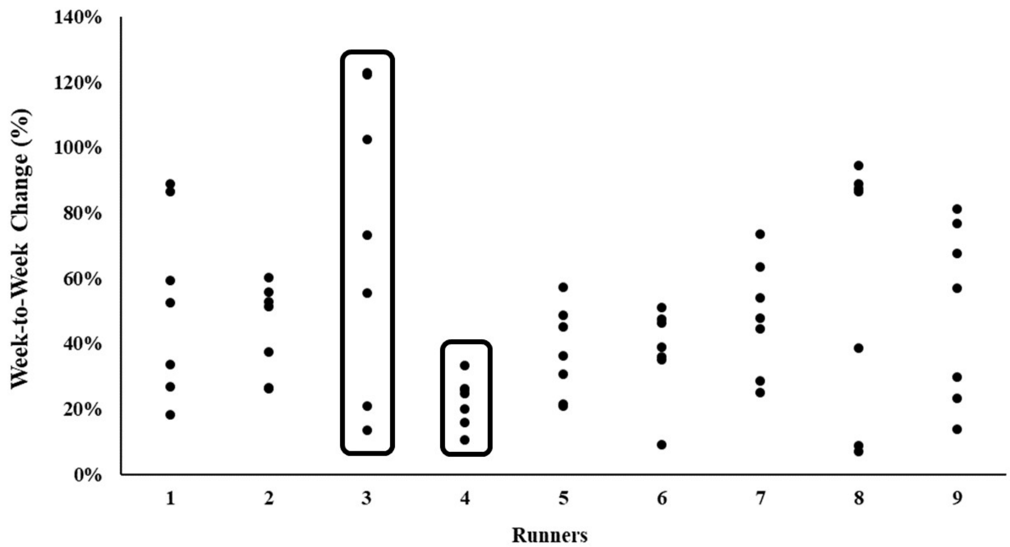


Figure 5. Week-to-week change (%) among training quantification methods (i.e., each black circle) for all runners included in the study. Black vertical rectangles illustrate the range in weekto-week changes in training among training monitoring methods for two specific runners (runners 3 and 4) to highlight individual responses in training stress among monitoring methods.

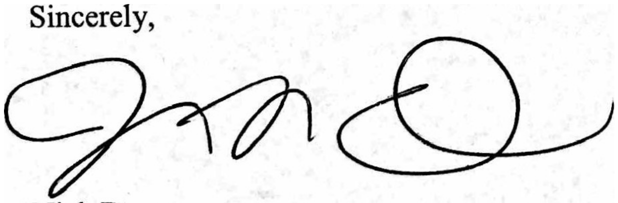
Appendix C

Beverly Jacobik
IRB Administrator
University of Memphis 901-678-4786
biacobik@memphis.edu

Dear IRB administrator,

I write this letter to support the research program of Dr. Max Paquette titled: "Are all running workloads created equal?". As the head cross-country and track coach at Christian Brothers High School (CBHS), I approve the participation of my athletes to the full extent of this research program. I addition, the participation of our team in this study has been discussed with our principle who approves of the team's participation. Finally, I also confirm that the participation of my athletes in this project will not change their usual training behavior and will not increase their injury risk. If you have any concerns or comments please feel free to contact me.

Sincerely,



Nick Dwyer

CBHS Head Cross Country and Track Coach ndwver@cbhs.orz

Appendix D

Institutional Review Board 315 Administration Bldg.
Memphis, TN 38152-3370
Office: 901.678.2705
Fax: 901.678.2219

Assent for Research Participation

Title	Different approaches to monitor running workloads in high school runners
Researcher(s)	Max R Paquette (U of Memphis) Megan Ryan (U of Memphis)
Researchers Contact Information	8653107820, mrpqette@memphis.edu

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You are invited to be in a research study being done by Dr. Paquette from the University of Memphis. You are invited because you are a cross country runner on the CBHS team.

If you agree to be in the study, you will be asked to first do one short treadmill run at CBHS with sensors in your shoes. This run will last about 8minutes. Then, for two weeks, you will wear sensors around your ankles for every run. After each run you will also tell us how your felt from 0 to 10 and you will tell us how long and far you ran that day. You will continue doing the training that coach Dwyer gives you.

You will not receive any payments for participating in this study.

Your family will know that you are in the study. If anyone else is given information about you, they will not know your name. A number or initials will be used instead of your name.

If something makes you feel bad while you are in the study, please tell Dr. Paquette or coach Dwyer. If you decide at any time you do not want to finish the study, you may stop whenever you want.

You can ask Dr. Paquette or coach Dwyer questions any time about anything in this study. You can also ask your parent any questions you might have about this study.

Signing this paper means that you have read this or had it read to you, and that you want to be in the study. If you do not want to be in the study, do not sign the paper. Being in the study is up to you, and no one will be mad if you do not sign this paper or even if you change your mind later. You agree that you have been told about this study and why it is being done and what to do.

____

Signature of Person Agreeing to be in the Study   Date Signed

PRO-FY2019-667

Appendix E

Consent for Research Participation

Title	Different approaches to monitor running workloads in high school runners
Sponsor	NA
Researcher(s)	Max R Paquette (U of Memphis) Megan Ryan (U of Memphis)
Researchers Contact Information	8653107820, mrpqette@memphis.edu

You are being asked to participate in a research study. The box below highlights key information for you to consider when deciding if you want to participate. More detailed information is provided below the box. Please ask the researcher(s) any questions about the study before you make your decision. If you volunteer, you will be one of about 16-20 runners on the CBHS team to do so.

Key Information for You to Consider
Voluntary Consent: You are being asked to volunteer for a research study. It is up to you whether you choose to participate or not. There will be no penalty or loss of benefit to which you are otherwise entitled if you choose not to participate or discontinue participation. **Purpose:** With this study we hope to learn more about how different methods of measuring training provide similar information for coaches **Duration:** The study will last two weeks with data being collected daily. **Procedures and Activities**: You will be asked to complete a treadmill run and the training your coach assigns to you while wearing some sensors on your shoes/ankles. **Risk:** There is a possibility to trip or fall when performing the treadmill run and that you could initially perceive some soreness from wearing the sensors. **Benefits:** The results from this study may help coaches better understand how to quantify training in runners by using different methods. **Alternatives**: Participation is voluntary, and the only alternative is to not participate

Who is conducting this research?

The person in charge of this study is Dr. Max Paquette, an Associate Professor in the School of Health Studies at the University of Memphis. There will be other individuals such as graduate students on the research team assisting at different times during the study.

Why is this research being done?

By doing this study, we are assessing week-to-week changes in running training obtained from simple and more complex measures in high school runners (i.e., 14 to 18 years old). These findings will help understand if different training monitoring approaches provide different information regarding training load in runners which could help design more specific monitoring programs to reduce risks of overtraining and injury development.

What happens if I agree to participate in this Research?

All testing will take place at Christian Brothers High School or at training sites (e.g. various Shelby Farms locations) during scheduled team practices with the head coach. You will be asked to bring your own exercise clothes including shorts, socks, and a t-shirt. During a session at CBHS, you will be informed of all procedures, potential risks, and benefits associated with the study through both verbal and written form. Before testing during the first session, you will fill out surveys to make sure you physically able to participate in the study. During the first study session, you will complete a treadmill run during which you will perform a 5min warm up and 1min bouts of running at three speeds: 1) easy run pace, 2) tempo pace, and 3) 5K race pace for a total of about 8 minutes. During this test you will wear insoles that measure forces under your feet. For the next two weeks, your coach will have a low and a high training week planned. During these two weeks, for each training run, you will wear sensors around both your ankles. Research staff members will help each day to make sure the sensors are placed on your ankles properly. After each run, you will also rate your effort using a 0-10 scale (0 is very easy, 10 is extremely hard). We will also record the number of minutes and miles you ran after each run. The data we collect will be used to analyze how you are responding to your training. The results that will be collected on you and your teammates will be shared with your coach to ensure the most optimal training practices. Your coach will be able to use these results to decide if any changes to your training need to be made. The researchers will not make your coach change your training however and any training decisions will be made by your coach.

What happens to the information collected for this research?

Information collected for this research will be used to prepare scientific conference abstracts and peer-reviewed journal articles. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be personally identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private. The information on the forms we will have you fill out will remain private, and only the study staff will see them.

How will my privacy and data confidentiality be protected?

We promise to protect your privacy and security of your personal information as best we can. Although you need to know about some limits to this promise. We will make every effort to keep private all research records that identify you to the extent allowed by law.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. After the forms you will fill out are completed, they will be kept in a locked file cabinet at which my research team will be the only ones to be able to access it. Any information that gets transferred electronically will be stored on a computer with passcode entry that only the research team will know.

We will keep private all research records that identify you to the extent allowed by law. However, there are some circumstances in which we may have to show your information to other people. If any medical situation arises at which the paramedics or any other form of emergency care have to be called, we may be required to provide health history forms and or contact information. For example, the law may require us to show your information to a court or to tell authorities if you report information that could pose a danger to yourself or someone else. Also, we may be required to show information which identifies you to people who need to be sure we have done the research correctly; these would be people from such organizations as the University of Memphis or any other funding agencies that may have ties with our research study.

What are the risks if I participate in this research?

Since this study does not require you to change your training, the potential risks and discomforts that may be experienced are minimal. The sensors wrapped around your ankles might cause some discomfort initially and the researchers will make sure to loosen the wraps if they are too tight. There is a chance that you may trip on the treadmill during the first test. A research staff member will be nearby at all times to prevent trips or falls.

What are the benefits of participating in this research?

The findings from this study will provide important information to the CBHS coach regarding athlete response to training between low and higher load training weeks in the runners which will help the coach make better decisions regarding which monitoring approaches to use during training. In addition, the findings from this study will allow sport scientists, practitioners and coaches better understand if different training monitoring approaches provide different information regarding training load in runners which could help design more specific monitoring programs to reduce risks of overtraining and injury development.

What if I want to stop participating in this research?

It is up to you to decide whether you want to volunteer for this study. It is also ok to decide to end your participation at any time. There is no penalty or loss of benefits to which you are otherwise entitled if you decided to withdraw your participation. Your decision about participating will not affect your relationship with the researcher(s) or the University of Memphis.

Will it cost me money to take part in this research?

There are no costs associated with taking part in the study.

What if I am injured due to participating in this research?

If you believe you are hurt or if you get sick because of something that is due to the study, you should call Dr. Max Paquette 865-310-7820 immediately. In case of illness or injury during participation in the study, you may reach Dr. Paquette on his mobile phone at 865-310-7820.

If any abnormal signs or symptoms are present during your participation, testing will be terminated and you will receive attention, following the Adverse Events plan of the Human Performance Laboratories. Otherwise, no treatment will be provided.

It is important for you to understand that the University of Memphis does not have funds set aside to pay for the cost of any care or treatment that might be necessary because you get hurt or sick while taking part in this study. Also, the University of Memphis will not pay for any wages you may lose if you are harmed by this study. Medical costs that result from research related harm cannot be included as regular medical costs. Therefore, the medical costs related to your care and treatment because of research related harm will be your responsibility. A co-payment/deductible from you may be required by your insurer or Medicare/Medicaid even if your insurer or Medicare/Medicaid has agreed to pay the costs. The amount of this co-payment/deductible may be substantial.

You do not give up your legal rights by signing this form.

Will I receive any compensation or reward for participating in this research?

You will not receive any compensation for participating in this study.

Who can answer my question about this research?

Before you decide volunteer for this study, please ask any questions that might come to mind. Later, if you have questions, suggestions, concerns, or complaints about the study, you can contact the investigator, Dr. Max Paquette at 865-310-7820 or mrpqette@memphis.edu. If you have any questions about your rights as a volunteer in this research, contact the Institutional Review Board staff at the University of Memphis at 901-678-2705 or email irb@memphis.edu. We will give you a signed copy of this consent form to take with you.

STATEMENT OF CONSENT

I have had the opportunity to consider the information in this form. I have asked any questions needed for me to decide about my participation. I understand that I can ask additional questions though the study.

By signing below, I volunteer to participate in this research. I understand that I am not waiving any legal rights. I have been given a copy of this form. I understand that if my ability to consent for myself changes, either I or my legal representative may be asked to consent again prior to my continued participation

Name of Adult Participant	**Signature of Adult Participant**	**Date**

Researcher Signature (To be completed at the time of Informed Consent)

I have explained the research to the participant and answered all of his/her questions. I believe that he/she understand the information described in this consent form and freely consent to participate**.**

Name of Research Team
Date Member

Signature of Research Team Member

Appendix F

Parental Permission for Your Child to Participate in a Research Study

Title	Different approaches to monitor running workloads in high school runners
Sponsor	NA
Researcher(s)	Max R Paquette (U of Memphis) Megan Ryan (U of Memphis)
Researchers Contact Information	8653107820, mrpqette@memphis.edu

Your child is being asked to participate in a research study. The box below highlights key information for you to consider when deciding if you want your child to participate. More detailed information is provided below the box. Please ask the researcher(s) any questions about the study before you make your decision. If you allow your child to participate in the study, your child will be one of about 16-20 runners on the CBHS team to do so.

Key Information for You to Consider

Voluntary Consent: Your child is being asked to volunteer for a research study. It is up to you whether you choose to let your child participate or not. There will be no penalty or loss of benefit to which your child is otherwise entitled if you choose not to let your child participate or discontinue participation.
Purpose: With this study we hope to learn more about how different methods of measuring training provide similar information for coaches
Duration: The study will last two weeks with data being collected daily during CBHS practices
Procedures and Activities: Your child will be asked to complete a treadmill run and the training your child's coach assigns to them while wearing some sensors on their shoes/ankles. **Risk:** There is a possibility to trip or fall when performing the treadmill run and that your child could initially perceive some soreness from wearing the sensors.
Benefits: The results from this study may help coaches better understand how to quantify training in runners by using different methods.
Alternatives: Participation is voluntary, and the only alternative is to not participate

Why is your child being invited to take part in this research?

Your child is being invited to take part in a research study to understand if different methods to quantify running training provide different week-to-week information to coaches. Your child is being invited to take part in this research study because he is a high school cross country runner without any current injuries. If your child takes part in this study, your child will be one of about 16-20 boys to do so.

Who is conducting this research?

The person in charge of this study is Dr. Max Paquette, an Associate Professor in the School of Health Studies at the University of Memphis. There will be other individuals such as graduate students on the research team assisting at different times during the study.

What is the purpose of the study?

By doing this study, we are assessing week-to-week changes in running training obtained from simple and more complex measures in high school runner. These findings will help understand if different training monitoring approaches provide different information regarding training load in runners which could help design more specific monitoring programs to reduce risks of overtraining and injury development.

Are there reasons why your child should not take part in this study?

We will be recruiting healthy, high school boys between grades 9 and 12 (i.e., 14 years to 18 years old) that are currently on the CBHS high school varsity cross country team and have no current injuries. If your child does not fall into that school grade range, or have a current injury, then we apologize, but your child cannot participate in the study.

Where is the study going to take place and how long will it last?

The initial treadmill test will take place at CBHS in the Brothers Development Center. Daily data collection will take place at scheduled practices at CBHS or at practice meeting locations (e.g., Shelby farms). The total time commitment for the study is two weeks.

What will your child be asked to do?

During the first day, your child will be asked to run on a treadmill for about 8 minutes while forces under his feet are measured using a wireless insole. During the run, your child will warm up for 5minutes, then complete 1 minute bouts at three speeds: 1) their easy run pace, 2) their “tempo” pace, and 3) their 5K race pace. For daily collection of training data, your child will be asked to wear sensors around his ankles for all runs. After each run, your child be asked to rate his effort on a scale of 0 to 10 and report daily run time and distance. None of the study procedures will change your child's training program assigned by coach Dwyer.

What are the possible risk and discomforts?

The potential risks and discomforts that may be experienced during testing and training are minimal since none of the training sessions assigned by coach Dwyer will be altered by the study procedures. Your child could trip or fall during the treadmill test but a research staff member will be present during testing to minimize falling risks. The ankle sensors might present some discomfort on the skin but the foam padding on the sensors should prevent any discomfort.

Will your child benefit from taking part in this study?

There is no guarantee that your child will get any benefit from taking part in this study. However, your child's coach may obtain valuable information regarding training to prepare more optimal training plans to maximize performance during races and to prevent injuries. Your willingness to allow your child to take part, however, may, in the future, help society as a whole better understand this research topic.

Does your child have to take part in this study?

If your child decides to take part in the study, it should be because he really wants to volunteer. Your child will not lose any benefits or rights he would normally have if he chooses not to volunteer. Your child can stop at any time during the study and still keep the benefits and rights he had before volunteering. If your child decides not to take part in this study, his decision will have no effect on the quality of care, services, etc., he receives from the University or his coach. As a student, if your child decides not to take part in this study, his choice will have no effect on his academic status or grade in any classes, or his membership on the team.

If your child doesn't want to take part in the study, are there other choices?

If your child does not want to be in the study, there are no other choices except not to take part in the study.

What will it cost you for your child to participate?

There are no costs associated with taking part in the study.

Will your child receive any rewards for taking part in this study?

Your child will not receive any rewards or payment for taking part in the study.

Who will see the information that your child provides?

We will make every effort to keep private all research records that identify your child to the extent allowed by law. Your child's information will be combined with information from other children taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. Your child will not be personally identified in these written materials. We may publish the results of this study; however, we will keep your child's name and other identifying information private.

We will make every effort to prevent anyone who is not on the research team from knowing that your child gave us information, or what that information is. After the forms you will fill out are completed, they will be kept in a locked file cabinet at which my research team will be the only ones to be able to access it. Any information that gets transferred electronically will be stored on a computer with passcode entry that only the research team will know.

We will keep private all research records that identify your child to the extent allowed by law. However, there are some circumstances in which we may have to show your child's information to other people. For example, the law may require us to show your child's information to a court or to tell authorities if your child reports information about a child being abused or if your child poses danger to someone else. Also, we may be required to show information which identifies your child to people who need to be sure we have done the research correctly; these would be people from such organizations as the University of Memphis

Can your child's taking part in the study end early?

If your child decide to take part in the study your child still have the right to decide at any time that your child no longer want to continue. Your child will not be treated differently if your child decide to stop taking part in the study. The individuals conducting the study may need to withdraw your child from the study. This may occur if your child are not able to follow the directions they give your child, if they find that your child's being in the study is more risk than benefit to your child, or if the agency funding the study decides to stop the study early for a variety of scientific reasons. *(Any consequences of withdrawing should be included along with any procedures necessary for withdrawing.)*

Are your child participating or can your child participate in another research study at the same time as participating in this one?

Your child may not take part in this study if your child are currently involved in another research study. It is important to let the investigator/your child's doctor know if your child are in another research study. Your child should also discuss with the investigator before your child agree to participate in another research study while your child are enrolled in this study.

What happens if your child get hurt or sick during the study?

If your child believes he is hurt or if your child gets sick because of something that is due to the study, your child should call Dr. Max Paquette 865-310-7820 immediately. In case of illness or injury during participation in the study, your child may reach Dr. Paquette on his mobile phone at 865-310-7820.

If any abnormal signs or symptoms are present during your participation, testing will be terminated and your child will receive attention, following the Adverse Events plan of the Human Performance Laboratories. Otherwise, no treatment will be provided.

It is important for your child to understand that the University of Memphis does not have funds set aside to pay for the cost of any care or treatment that might be necessary because your child get hurt or sick while taking part in this study. Also, the University of Memphis will not pay for any wages your child may lose if your child are harmed by this study.

Medical costs that result from research related harm cannot be included as regular medical costs. Therefore, the medical costs related to your child's care and treatment because of research related risks will be you responsibility. A co-payment/deductible from you may be required by your child's insurer or Medicare/Medicaid even if your child's insurer or Medicare/Medicaid has agreed to pay the costs. The amount of this co-payment/deductible may be substantial. Your child does not give up your child's legal rights by signing this form.

What if your child have questions, suggestions, concerns, or complaints?

Before you decide whether to accept this invitation for your child to take part in the study, please ask any questions that might come to mind now. Later, if you have questions, suggestions, concerns, or complaints about the study, you can contact the investigator, Dr. Max Paquette at 865-310-7820, or come by the researcher's office located in Fieldhouse room 308 at The University of Memphis. If you have any questions about your child's rights as a volunteer in this research, contact the Institutional Review Board staff at the University of Memphis at 901-678-3074. We will give you a signed copy of this permission form to take with you.

What if new information is learned during the study that might affect your child's decision to participate?

If the researcher learns of new information in regards to this study, and it might change your willingness for your child to stay in this study, the information will be provided to you. You may be asked to sign a new permission form if the information is provided to you after your child has joined the study.

Statement of consent

I have had the opportunity to consider the information in this form. I have asked any questions needed for me to decide about my child's participation. I understand that I or my child can ask additional questions though the study.

By signing below, I agree to allow my child to volunteer to participate in this research. I understand that my child not waiving any legal rights. I have been given a copy of this form. I understand that if my ability to consent for my child changes, either I or my legal representative may be asked to consent again prior to my child's continued participation

____ ____________ Signature of parent agreeing for child to take part in the study   Date

____

Printed of parent agreeing for child to take part in the study

____

____

Name of [authorized] person obtaining informed consent Date

Appendix G

Questionnaire - PAR-Q

PAR--Q & YOU

Physical Activity Readiness

(revised 2002)

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR--Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____

SIGNATURE ____

DATE______________________________

SIGNATURE OF PARENT

____

WITNESS ____ or GUARDIAN

(for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

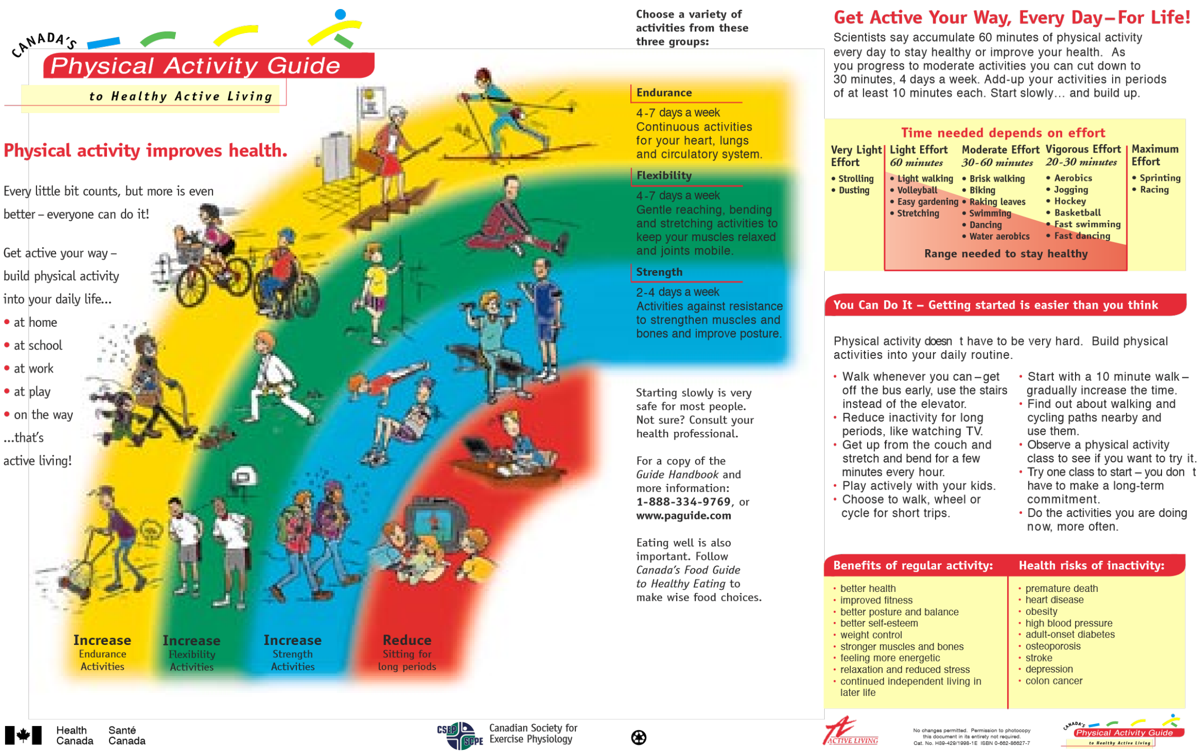
continued on other side...

...continued from other side

PAR--Q & YOU

Questionnaire - PAR-Q

(revised 2002)



Source: Canada's Physical Activity Guide to Healthy Active Living, Health Canada, 1998 http://www.hc-sc.gc.ca/hppb/paguide/pdf/guideEng.pdf © Reproduced with permission from the Minister of Public Works and Government Services Canada, 2002.

FITNESS AND HEALTH PROFESSIONALS MAY BE INTERESTED IN THE INFORMATION BELOW:

The following companion forms are available for doctors' use by contacting the Canadian Society for Exercise Physiology (address below):

The **Physical Activity Readiness Medical Examination (PARmed--X)** – to be used by doctors with people who answer YES to one or more questions on the PAR-Q.

The **Physical Activity Readiness Medical Examination for Pregnancy (PARmed--X for Pregnancy)** – to be used by doctors with pregnant patients who wish to become more active.

References:

Arraix, G.A., Wigle, D.T., Mao, Y. (1992). Risk Assessment of Physical Activity and Physical Fitness in the Canada Health Survey Follow-Up Study. **J. Clin. Epidemiol.** 45:4 419-428.

Mottola, M., Wolfe, L.A. (1994). Active Living and Pregnancy, In: A. Quinney, L. Gauvin, T. Wall (eds.), **Toward Active Living: Proceedings of the International Conference on Physical Activity, Fitness and Health**. Champaign, IL: Human Kinetics. PAR-Q Validation Report, British Columbia Ministry of Health, 1978.

Thomas, S., Reading, J., Shephard, R.J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). **Can. J. Spt. Sci.** 17:4 338-345.

Appendix H

Rating of Perceived Exertion (RPE Scale)	
10	Maximal
9	Really, Really, Hard
8	Really Hard
7	
6	Hard
5	Challenging
4	Moderate
3	Easy
2	Really Easy
1	Rest

Appendix I

Study Information Session Outline

This information session will take place at CBHS and coach Dwyer will not be present in the room with parents.

1. Dr. Paquette will introduce himself to the parents.
2. Dr. Paquette will go over the purpose of the study.
3. Dr. Paquette will go over all the procedures (i.e., the treadmill testing session at the start of study and the use of ankle sensors for daily runs for two weeks).
4. Dr. Paquette will go over the risks and benefits of the study.

Appendix J

Date: 1-14-2020

IRB #: PRO-FY2019-667

Title: Different approaches to monitor running workloads in high shool runners Creation Date: 6-19-2019 End Date:

Status: Approved

Principal Investigator: Maxime Paquette

Review Board: University of Memphis Full Board Sponsor:

Study History

Submission Type Initial	**Review Type Expedited**	**Decision Approved**

Key Study Contacts

Member Maxime Paquette	**Role Principal Investigator**	**Contact mrpqette@memphis.edu**
Member Maxime Paquette	**Role Primary Contact**	**Contact mrpqette@memphis.edu**