Intrinsic Fatigue & Its Relation to Workload

by

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ABSTRACT

The study aimed to determine the relationship of subjective perception of wellness (Intrinsic Fatigue) and Global Positioning Satellite derived workload amongst elite high school soccer players. Twenty-nine (16.4 ± 1.54 years) male participants completed a mobile app-based wellness questionnaire comprising of 6 subjective markers prior to 10 workload variables being measured by STATSports 10Hz GPS units later that same day. Only instances where both wellness and GPS reports qualified for analyses (N=231 exposures). No significant differences were reported in reported wellness within- or between-weeks ($p > 0.05$) with average Effect Sizes (ES) ranging from 0.001 to 0.15. Total Distance (TD) was significantly different ($p < 0.05$) within week. All GPS variables except TD and Distance per Minute (DpM) were significantly different ($p < 0.05$) between-weeks. Average GPS ES sizes ranged from 0.02 to 0.58. Wellness and GPS or it's ESs were not correlated, with correlations ranging from -1.000 to 0.207. The results suggest monitoring of GPS reports to be a practical method of monitoring variation in player workload but does not support subjective questionnaires as a means of monitoring player wellness reflecting these workload variations in youth populations.

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Chapter 1

INTRODUCTION

For the recreational athlete, an injury can be one of the many causes of cessation of participation in a sport in its entirety. A 2019 study showed specifically non-contact injuries made up nearly 35% of 474 lost-time injuries over the course of two seasons, resulting in a 30.7% rate in lost days available for the athletes (Cousins et al., 2019). Injury has the ability to make a substantial contribution to a team's ability to win championships (Carling, Le Gall, McCall, Nédélec, & Dupont, 2015), as well as limit the earning potential of the professional and discourage the participation of the recreational athlete (Sonesson, Kvist, Ardern, Österberg, & Silbernagel, 2017). For a college athlete, an injury may be the difference between getting their degree or not due to the potential of loss of scholarship (Solman, 2016). For a professional, an injury can be the difference between renewal of a contract or cessation of participation. Unfortunately, a large number of acute injuries cannot be avoided, such as injuries caused as a result of impact. Evidence suggests that a significant relationship can be observed between training loads and injury incidence (Drew & Finch, 2016). Fatigue has been identified as a contributing factor of injury (Armstrong, Brogden, Milner, Norris, & Greig, 2018), and the management of fatigue is important in mediating adaption to training and ensuring the athlete is appropriately prepared for competition (Thorpe, Atkinson, Drust, & Gregson, 2017). There is a great deal of research on the impact of external loads on the athlete (Drew & Finch, 2016), but the depth of research as it pertains to Intrinsic Fatigue[1] is minimal in comparison. Researchers reference "intrinsic motivation" (Marcora, Staiano, & Manning, 2009; Martin, Thompson, Keegan, Ball, & Rattray, 2015) and "mental fatigue" (Badin, Conte, & Coutts, 2011; Smith, Coutts, et al., 2016; Smith, Zeuwts, et al.,

[1] Intrinsic Fatigue: Accumulation of internalized markers denoting how an athlete perceives their wellness to be by means of subjective questioning

2016), however Intrinsic Fatigue as it pertains to this research is not documented despite evidence suggesting monitoring players' individual physiological and perceptual responses appears critical (Campos-Vazquez et al., 2015). In this research, Intrinsic Fatigue refers to the athlete's subjective perception of self: How tired the athlete feels, how sore the athlete perceives their muscles to be, how well the athlete felt they slept last night, or even how well the athlete felt they hydrated over the last 24 hour time frame. One must ask the question: Is Intrinsic Fatigue related to Workload, can one predict the other?

There are numerous research studies and papers published that take into account external loads on the body, the impact this has on an individual and how external loads relate to injury. Gabbett describes external loads as activities such as speed and distance covered, in addition to non-locomotor sport-specific activities such as jumps (volleyball), collisions (rugby), and strokes (swimming) (Gabbett, 2016). These external loads have been further documented as variables such as distance covered, accelerations, decelerations and change of directions (Beato, Coratella, Schena, & Hulton, 2017) and summed up as the physical work performed during the training session or match (McLaren et al., 2018). These external loads are proving to be increasingly valuable for teams and individuals to track, however the cost association with it is impractical for the average athlete or team to do so successfully. The units and knowledge required to interpret the outcomes requires an infrastructure that most teams do not have the financial or time resources to invest in. Internal loads refer to the associated biochemical (physical and physiological) and biomechanical stress responses (McLaren et al., 2018). Common internal load measures include Heart Rate and variations of heart rate measurements, Rate of Perceived Exhaustion (RPE) and session RPE (Achten &

Jeukendrup, 2003; Akenhead & Nassis, 2016; Alexandre et al., 2012; Åstrand and Rodahl, 1986; Djaoui, Haddad, Chamari, & Dellal, 2017). Wiig sums up Internal Training Load as the interaction of the external load and individual characteristics of the athlete (Wiig, Andersen, Luteberget, & Spencer, 2020).

Recently, the intrinsic variable of mental fatigue and the relation to performance has been introduced into the literature. Mental fatigue refers to a psychobiological state induced by sustained periods of demanding cognitive activity and characterized by feelings of tiredness and lack of energy (Boksem & Tops, 2008; Marcora et al., 2009). This mental fatigue can have an impact on society, as the research suggests a strong association between fatigue, cognition reduction and occupational accidents, as well as increased metabolic and reproductive health sequelae and even some forms of cancer. Evidence also suggests a link between fatigue, mental, gastrointestinal, neurological and chronic pain sequelae (Lock, Bonetti, & Campbell, 2018). Mental fatigue can impact an individual's ability to effectively control body movements, affect their concentration level and decision-making ability, in addition to reducing their readiness to participate (Smith, Coutts, et al., 2016; Smith, Zeuwts, et al., 2016).

Fatigue as it relates to injury has been studied extensively in the world of sports medicine, evidenced by the nearly 7,500 research articles published on the search engine PubMed. However, the majority of these studies have all been surrounding external loads and their relationship to injury: there is a distinct lack of correlation between intrinsic fatigue factors and their associated relationships. Factors such as Distance Traveled, High Speed Distance, Heart Rate Analytics, Accelerations are all factors that have a scope of research backing up their impact to an athlete's wellbeing. A general consensus has formed that greater cumulative external loads following a “optimal” workload threshold have the ability to impact performance negatively and potentially predispose an athlete to injury (Rogalski, Dawson, Heasman, & Gabbett, 2013). Furthermore and to a lesser extent, internalized mental fatigue has been studied and its relationship to optimum functioning, technical performance, physical performance and decision-making. For the majority of these papers, the findings correlate with mental fatigue decreasing optimum function, technical performance, physical performance and decision making (Marcora et al., 2009; Smith, Coutts, et al., 2016; Smith, Zeuwts, et al., 2016).

There is a gap in the literature in regard to Intrinsic Fatigue biomarkers of athletes. That being said, how tired does the athlete *feel*, and will a decreased perception of wellness result in a decreased performance or workload for the next immediate session? In comparison to External Fatigue, there is very minimal research published attempting to find the relationship between internalized fatigue and workload, fewer than 100 articles on the same search engine referenced above. This opens an opportunity for future research to explore this topic and find the relationships. Due to the lack of evidence-based biomarkers associated with Intrinsic Fatigue, this study utilized subjective self-reported measures that were associated with the phone application utilized for data collection.

This research is important as the ultimate goal of all athletes is to perform optimally through continued participation in their elective sport. While the elite have the infrastructure and resources to track workloads with fine accuracy and support staff in place to prevent injury, the majority of athletes do not have the resources available to objectively measure their workloads. Self-report measures are suggested to be a simple and cost-effective approach to monitoring an athlete's response to training. Additionally the use of short questionnaires with the Session-RPE method for perceived changes are suggestively a useful tool to provide coaches additional information on the athletes' status and prevent states of overreaching and overtraining (Elloumi et al., 2012). This research has the potential to set a foundation for future workload management among the amateur/semi-professional athlete. By having the ability to track their fatigue levels, the non-professional athlete with limited resources will have the ability to quantify their fatigue and truly give it a meaning past simply "being tired" or "being sore." This research directly addresses the missing aspect of Intrinsic Fatigue in research and attempts to emphasize the value of Intrinsic Fatigue as a biomarker for workload management. In doing so, the research will potentially provide a free tool for amateurs and teams with less resources to monitor players wellness.

The purpose of this study is to evaluate and analyze the relationship between Intrinsic Fatigue and Workload in athletes. The research will attempt to answer the following aim and hypothesis:

- Aim: Determine a temporal relationship between workload and reported wellness scores as an indicator for Intrinsic Fatigue
    - Hypothesis 1 (null): *A high level of Intrinsic Fatigue does not result from any increase in external work load markers*
    - That is, external workload does not impact higher Intrinsic Fatigue markers in any way

<u>Aim of the Research</u>

Intrinsic Fatigue can be defined as the accumulation of internalized markers discovered through subjective questioning. The subjective wellness questions utilized in this research are as follows: 1) How did you sleep last night? 2) How stressed do you feel right now? 3) Do you feel any muscle soreness? 4) Do you feel tired or fatigued today? 5) How is your general Health? 6) How well do you feel you have hydrated in the past 24 hours? Following the questions, the athletes are given the opportunity to add any additional comments and self-report any injuries or further information. The response to the questions is all given a specific value (similar to Likert scaling) and an overall "Wellness Score" for the day is presented.

Workload is measured through 10Hz STATSports GPS Tracking Units. The units measure a number of variables including Total Distance Covered (TD), High-Speed Running (HSR), Maximum Speed achieved over the session (MS), Sprints completed during the session (Sp), Accelerations and Decelerations performed during the session (Acc & Dec).

The Wellness Score derived from subjective questioning will be compared to workload data to determine if a relationship exists.

Chapter 2

REVIEW OF LITERATURE

As discussed in Chapter 1, monitoring player welfare is becoming more and more important in modern sport competition. As advances in sport technology continue, the advancement in performance technology appears to parallel this. The ability to monitor workload is not currently feasible for many teams due to the technical expertise required, the time-consuming process of collecting the data and the cost of numerous telemetric systems (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). Training load is used to quantify training programs and to determine if athletes are performing prescribed training, with the intent of optimizing the training response (Arney et al., 2019). By monitoring the internal load such as a Session RPE, the sports science staff are able to utilize a method for monitoring player load without the use of expensive equipment (Coutts, Murphy, Pine, Reaburn, & Impellizzeri, 2003; Impellizzeri et al., 2004). The following review of literature will delve into the current practices being performed in the world of sport science and load monitoring.

Workload (used interchangeably as Training Load or Training Workload) can be broken down into Internal and External. External training load represents physical work performed during the training session or match, whereas Internal Training loads refer to the associated biochemical (physical and physiological) and biomechanical stress responses (McLaren et al., 2018). In 1996, Foster discovered through an observational research study that a 10 fold increase in training load resulted in a 10% increase in performance for elite runners (Foster, 1996), thus setting the foundation for monitoring loads in training in order to optimize performance.

Workload can also be broken into whether the measures are designated to be Absolute or Relative. Absolute Workloads are the sum of all training sessions, or a particular domain of training over a given period (i.e. a day or week). Relative Workload describe the changes in training either as a percentage increase over a period (week-to-week) or as a ratio of recent and historical loads (such as a week to month ratio) (Drew & Finch, 2016).

External Workload

The External Workload refers to the work completed by an athlete measured independently of his or her internal characteristics (Wiig et al., 2020), the quantification of work external to the athlete (Drew & Finch, 2016). As Foster simply states the External Workload is "what is actually done in training" (Carl Foster, Rodriguez-Marroyo, & De Koning, 2017).

Measures of External Workload are commonly measured through the use of Global Positioning Satellite (GPS) units on the athlete individually. Metrics often extracted are Total Distance (TD), High Speed Distance (HSD), Accelerometry Variables, with more recently Dynamic Stress or Body Load (DSL) and High Metabolic Load Distance (HMLD) (Dellaserra, Gao, & Ransdell, 2014; Govus, Coutts, Duffield, Murray, & Fullagar, 2018; McLaren et al., 2018; Wiig et al., 2020)

Total Distance

Total distance refers to the ground covered by the athlete throughout the entirety of the session completed. Often measured in meters (Dellaserra et al., 2014; Govus et al., 2018; McLaren et al., 2018), it frequently is used to quantify external training load (Haddad, Stylianides, Djaoui, Dellal, & Chamari, 2017).

High Speed Distance

High Speed Distance, similar to total distance is most commonly measured in meters traveled above a certain threshold speed. There are a wide variety of cut off values that classify a speed as "High Speed" – ranging from distance covered at a speed greater than 4.5m/s (Lovell, Sirotic, Impellizzeri, & Coutts, 2013) to the distance covered at a speed greater than 7.5m/s (Akenhead & Nassis, 2016).

Acceleration and Deceleration Variables

Acceleration can be classified into many differing variables; there is Peak Acceleration (m/s^2), velocity change load, to speed change required to be greater than 1.0 m/s^2 through to speed change required to be greater than 4.0 m/s^2 (Akenhead & Nassis, 2016).

Dynamic Stress Load or Dynamic Body Load

Dynamic Stress Load, also known as Dynamic Body Load, involves information derived from integration of accelerometers in the player's GPS devices. The accelerometers summate accelerations in 3 planes of axes to measure a composite magnitude vector expressed as a G-Force (Casamichana, Catellano, Calleja-Gonzalez, Sn Roman, & Castagna, 2013). This method of external load determination has shown a good relationship with both Total Distance (r=0.70) and Rating of Perceived Exhaustion (r=0.74) (Casamichana et al., 2013).

High Metabolic Load Distance

High Metabolic Load Distance is a representation of distance covered (m) by a player when their metabolic power is above 25.5 Watt/kg (Tierney, Young, Clarke, & Duncan, 2016). This value is a representation of a constant running speed of 5.5m/s or when they are performing significant acceleration or decelerations of 2-4m/s^2 (Martín-García, Casamichana, Gómez Díaz, Cos, & Gabbett, 2018).

Internal Workload

With improvements in technology beginning in the early 1980s, the scientific community was able to provide a better marker of the physiological responses to training, thus the concept of Internal Training Load emerged (Carl Foster et al., 2017). As explained previously, Internal Workload or Internal Training Load refers to the biochemical and biomechanical stress response of an individual to a training stimulus. The response is individualized to the athlete thus naturally differs between athletes (Wiig et al., 2020). Internal Workload has been defined as the interaction of the external load and the individual characteristics of the athlete (Wiig et al., 2020), and may offer more accurate predictions of injury risk than typical external load measurements (Thorpe et al., 2017). A recent review highlighted that athlete self-report measures demonstrate greater sensitivity to acute and chronic training loads than common objective measures such as immunological, cytokine or plasma markers (Saw, Main, & Gastin, 2016). Differing components of Internal Workload are broken down below:

Heart Rate

Heart Rate is reported as one of the most common physiological variables used to determine the internal training load of a particular exercise (Alexandre et al., 2012), and mainly used to determine exercise intensity in team sports such as soccer (Impellizzeri et al., 2004). Heart Rate can be used to monitor Training Load either a) during exercise with exercise Heart Rate, percentage of maximal Heart Rate and percentage of reserve Heart Rate; b) just after exercise with recovery Heart Rate; and c) to monitor training load and the stage of fatigue at rest by the means of Heart Rate Variability and resting Heart Rate.

Exercise Heart Rate

The use of a heart rate to determine exercise intensity is possible due to the well-known linear relationship between heart rate and VO_2 over a wide range of steady-state submaximal workloads (Åstrand and Rodahl, 1986). More recent discoveries note that it is plausible that the relationship also exists during varying non-steady state activities (Bot & Hollander, 2000). Heart Rate can be beneficial for determination of training load due to the ability of distinguishing training zones unique to an individual, based off resting and maximal heart rate (Lovell et al., 2013). It should be noted, during light and moderate exercise emotional factors may affect the heart rate (Åstrand and Rodahl, 1986), which results in a notable absence of a linear relationship between Heart Rate and VO_2 (Bot & Hollander, 2000).

Percentage of Maximal Heart Rate & Heart Rate Reserve

Further added benefits of utilizing heart rate as a means of exercise intensity determination is the ability to delineate lactate threshold or percentage of heart-rate reserve as cut off values (Akenhead & Nassis, 2016). It has been demonstrated that percent heart rate reserve does not correspond exactly to percent VO_{2max}, especially in the unfit population exercising at low intensities (Swain, Leutholtz, King, Haas, & David Branch, 1998), however percent heart rate reserve does appear to be an accurate measure of metabolic intensity when represented with its correlation to percent VO_2 reserve. This lends the question of whether Heart Rate Reserve as a means of determining exercise intensity is truly a useful function within the recreational populations.

Heart Rate Variability (HRV)

Heart Rate Variability is assessed by examining the beat-to-beat variations in a normal heart rates R-R intervals (Achten & Jeukendrup, 2003). Resting Heart Rate Variability is most commonly measured in a seated position for 5 minutes immediately after awakening in the morning and represents a reflection of cardiac parasympathetic activity, thus lending its usefulness as a means of monitoring both acute and chronic training adaptations (Djaoui et al., 2017).

Measuring Heart Rate Variability during exercise presents with several limitations due to the intensity-dependent, environment-dependent, and non-exclusively relation to the autonomic nervous system (Djaoui et al., 2017). Due to the multitude of factors that potentially hinder quality of readings, HRV monitoring during exercise presents with too many limitations to be a relevant tool for on-field use. However, HRV can still be attributed as a useful tool to monitor fatigue at rest (Djaoui et al., 2017).

Post-exercise HRV is the consequence of the parasympathetic reactivation and a retardation of sympathetic activity. A number of variables determine parasympathetic reactivation including arterial baroreflex activity, regulation of blood pressure, vessel vasodilation and stimulation of the metaboreflex (optimizing oxygen transport to the muscles) (Djaoui et al., 2017), each of these in turn influence post-exercise Heart Rate Variability. Post-exercise HRV does not appear to contribute much information beyond that which exercising Heart Rate already conveys, and its multifactorial influence results in ineffectiveness as a relevant, efficient and valuable monitoring tool for soccer players.

Training Impulse (TRIMP) and Perceived Exhaustion

Beginning in the mid-1970s, Eric Banister developed the concept of the "training impulse" or TRIMP. A training impulse is intended to result in a positive adaptation and improved performance (Achten & Jeukendrup, 2003). Training Impulse is yet another method of quantifying the internal training load and has evolved progressively and more recently become simplified to what we commonly understand as a "Session RPE."

Bannisters TRIMP

Bannister's TRIMP recognized that multiplying Percent Heart Rate Reserve (%HRR) by a non-linear factor then multiplied by duration yielded an integer that represented both the gain in fitness and the gain in fatigue contributed by that training session (Foster et al., 2017). An earlier study by the same lead researcher mentions it is worth noting that Bannister used a non-linear multiplier for the mean Heart Rate recorded during exercise, conceptually similar to the categorical ratio of a RPE scale (Foster, Florhaug, Franklin., Gottschall, Hrovatin, Parker, Doleshal, Dodge, 2001). Bannisters TRIMP has been shown to have high (r=0.74) correlations with conditioning-type training sessions, and moderate (r=0.68) correlations with technical sessions (Alexiou & Coutts, 2008).

Edwards TRIMP

The Edward's TRIMP method determines internal training load by summating the products of the accumulated training duration in minutes of the 5 HR zones by a coefficient relative to each zone. The time spent in Zone 1 (50-60% of Heart Rate max) is multiplied by 1, time spent in Zone 2 (60-70% of Heart Rate max) multiplied by 2 and so on to time spent in Zone 5 (90-100% of Heart Rate max by 5), then summating the individual scores produces a numerical Training Impulse for the day (Rabbani, Kargarfard, Castagna, Clemente, & Twist, 2019). Edwards TRIMP has been shown to convey very large associations with Session RPE methods (Alexiou & Coutts, 2008; Casamichana et al., 2013), especially in low-intensity & predominantly aerobic sessions (Campos-Vazquez et al., 2015). A r=0.25 association was reported in neuromuscular type sessions (i.e. resistance sessions) utilizing female subjects (Campos-Vazquez et al., 2015).

Rate of Perceived Exhaustion (RPE) and Session RPE (sRPE)

The Rate of Perceived Exhaustion is a robust and well documented method of quantifying intensity and homeostatic disturbance during a bout of exercise (Eston, 2012; Carl Foster et al., 2017). The RPE has remarkable value as a psychophysiological integrator that can be used to predict exercise capacity (Eston, 2012). It involves the collective integration of afferent feedback from cardiorespiratory, metabolic and thermal stimuli and a feed-forward mechanism enabling an individual to evaluate how hard or easy a task is (Eston, 2012). Put simply, the rate of perceived exhaustion allows an individual to quantify how hard a given physical task seems to be based on their subjective ability to maintain or increase the intensity for the foreseeable future.

The most well-known scales for rating perceived exhaustion comes from Borg, with both the 6-20 RPE scale, the 0-10 CR10 scale and the CR100 scale (Borg & Borg, 2001; Borg & Kaijser, 2006). The RPE method most commonly used in team sports is the Borg CR10 scale. This scale is a Categorical scale with Ratio properties (Categorical-Ratio-10) whereby the athlete is asked to rate their perceived level of exhaustion from a score of 0 (nothing at all) to 10 (extreme exhaustion, often implied with the inability to continue). It is common and quick practice for the athletes to rate their exertion for the given session as a reflection of the session intensity for that day.

Session RPE (sRPE) most frequently refers to the multiplication of the RPE for a given session by session duration in minutes (Gabbett, 2016; Haddad et al., 2017; Hulin et al., 2014; Wiig et al., 2020; Williams, Trewartha, Cross, Kemp, & Stokes, 2017), and is proven to be significantly ($p < 0.01$) related with indicators of external physical load (Casamichana et al., 2013). Experience suggests that most athletes can use the session RPE method fairly well with minimal instruction (Foster, Carl., Florhaug, Jessica., Franklin, J., Gottschall, L., Hrovatin, LA., Parker, S., Doleshal, P., Dodge, 2001). Session RPE has also been shown to have a significant correlation with all training types common to soccer (Alexiou & Coutts, 2008), to be a good indicator of global internal load of soccer training (Impellizzeri et al., 2004), while remaining an extensively valid and reliable load-monitoring tool in football and other team sports (Campos-Vazquez et al., 2015). Furthermore, the sRPE method has been considered a viable method to track internal training load at no cost and easily accessible procedures as the individuals global perception of effort and total training time (Casamichana et al., 2013). By multiplying the RPE by session duration, the athlete is able to produce a valid surrogate TRIMP score for training load that is far simpler than the original concept described by Bannister (Foster, Florhaug, Franklin, Gottschall, Hrovatin, Parker, Doleshal, Dodge, 2001; Foster et al., 2017).

A 2020 study of individual responses to external training loads in elite football players found that total distance, player load, and high intensity events had substantial within-player effects on sRPE (Wiig et al., 2020). Moreover, an additional study concluded that sRPE training loads provided variable-magnitude within-individual correlations with heart-rate derived measures of training intensity and load during different types of training sessions. It should be noted the researchers expressed that caution should be applied when attempting to use RPE or Heart Rate derived measured of exercise intensity/load interchangeably (Campos-Vazquez et al., 2015).

Scott et. al. aimed to examine the validity of the CR10 and CR100 scale of sRPE in quantifying training loads in Australian Football players. The results showed that both the CR10 and CR100 were valid in monitoring training load in team sports, however they both showed poor levels of assessing internal training load (Scott, Black, Quinn, & Coutts, 2013).

While Borg's CR10 is a common measure of intensity, Borg also came out with a 6-20 scale of perceived exhaustion (Borg-RPE). Arney et. Al. assessed the efficacy of substituting Borg-CR10 with Borg-6-20 scales athletes. The results show that despite producing different absolute numbers, both the Borg-CR10 and Borg 6-20 scales produced essentially interchangeable estimates of ratings in perceived exercise intensity (Arney et al., 2019).

Subjective Player Wellness

Subjective player wellness monitoring is arguably a modern age tool for player load monitoring and readiness to perform, and has been suggested as a useful means of providing information about the training output that can be expected from individual players during a training session (Malone et al., 2018).

Individual perceptions of wellness are often used by athletes and coaches as a reflection of their adaptive response to training, and has been shown to be sensitive to weekly training manipulations, periods of unloading and individual player characteristics (Gastin, Paul B., Meyer, Denny, Robinson, 2013).

Govus et. al. conducted a study to examine the relationship between pre-training subjective wellness, player load and ratings of perceived exertion in American College Football players. Through questioning of 3 factors (muscle soreness, sleep, energy) through the use of a 5 point Likert scale (1= worst, 5=best) 2 hours prior to training beginning. The researchers concluded that measuring pre-training subjective wellness may provide information about a players' capacity to perform within a training session. Hence, monitoring subjective wellness may assist the individualization of training prescription (Govus et al., 2018).

Wellness ratings can be physical in nature (fatigue, muscle strain, pain/stiffness), or psychological and lifestyle related (sleep quality, stress, well-being). Gastin et. al. used both types of ratings to monitor wellness as players arrived at the training or competition venue and reported subjective ratings of both categories to be sensitive to week-to-week training load manipulations (Gastin, Meyer, Denny, Robinson, 2013). This finding is aligned with the findings from Gallo et. al., by which five self-reported wellness reports (Muscle Soreness, Sleep Quality, Fatigue, Stress and Mood) completed in the morning of fifteen physical training days during the study period were significantly reduced ($p < 0.01$) 1 day after matches in Australian football players (Gallo, Cormack, Gabbett, & Lorenzen, 2016).

Acute:Chronic Workload Ratio

In 2016, Gabbett introduced the concept of Acute:Chronic workload ratios to predict injury. This ratio examines the absolute workload performed in 1 week (acute) relative to the 4-week chronic workload (average of the 4 weeks' acute workloads) (Hulin, Gabbett, Lawson, Caputi, & Sampson, 2016). This comparison attempts to provide an indication of whether the athlete's recent acute workload is greater, less than, or equal to that the athlete has been prepared for during the chronic period leading up to the acute period in question (Hulin et al., 2016).

A recent study from Bowen (2020) exemplified that spikes in Acute:Chronic workload ratios are associated with 5-7 times greater likelihood of injury in professional soccer players (Bowen, Gross, Gimpel, Bruce-Low, & Li, 2020), however there appears to be a "sweet spot" between 1:00-1:25 in regards to the Acute:Chronic workload ratio that offers protective application to the player (Malone et al., 2017).

In contrast to the above, Cousins (2019) found the ACWR to be less sensitive than an Exponentially Weighted Moving Average (EWMA), where greater weight is placed on the load completed in the acute phase compared to the preceding days/weeks due to the decaying nature of fitness and fatigue effects over time (Cousins et al., 2019).

Absolute versus Relative Workload

Absolute Workload is the sum of all training sessions, or a particular domain of training over a given period (Drew & Finch, 2016). Absolute workloads can be expressed as the sum of either the internal or external loads over a specific period of time (Rogalski et al., 2013), often a weeks period.

Relative Workload describes the change in training either as a percentage increase over a period (i.e. a week to week change) or as a ratio of recent and historical loads (i.e. a week:month ratio) (Drew & Finch, 2016).

Chapter 3

METHODS

Participants

The population of this research was the Barça Residency Academy (hereon "Academy") Student-Athletes (Or "player"). The Academy is a full-time residential soccer academy located at the Grande Sports World campus of Casa Grande, AZ. Here, the players sleep, train, eat and go to school, all in one centralized location. The inclusion criteria were as follows: being a healthy member of the Barça Residency Academy soccer club, aged 13-19 years old with the AthleteMonitoring App downloaded, and having no current long-term musculoskeletal injury restricting participation from activity. Participants were excluded if they were suffering from a chronic disease or long-term injury exceeding 4 weeks of required rehabilitation (such as a player recovering from an ACL tear) or are not enrolled as a Student-Athlete at the Barça Residency Academy.

Recruitment

An Academy-wide email was sent out informing the players' families of the research and inviting their child's participation. Parents had the option to sign the consent/assent form and send it back to the researchers. Once a parental signed copy was obtained, the players were brought into the researcher's office and provided an opportunity to sign their assent or decline their participation. The research protocol was reviewed and approved by the International Review Board of Arizona State University: STUDY00011332.

Sample size was determined by the number of Student-Athletes enrolled at the Academy and rostered into a Development Academy (DA) team. At the time of proposal, the Academy had 3 DA teams, each with rosters of 20 players; 60 participants were invited to join the study.

Research Design

A 4-week long observational prospective cohort study design was used. The players were assigned to respective teams based on age and ability. There was no blinding taken place on either the participants or researchers. Prior to initiation of research, coaching staff had the ability to observe the player wellness reports, this remained constant following data collection beginning.

Players were on site an average of 4 days per week training. Most players, but not all, played competitive games over the weekend. Intrinsic Fatigue and GPS data was taken for each exposure day the players had at the Academy. An exposure day is classified as any day a player participates in team wide activities on a soccer field and may include, but not be limited to training, games, and recovery sessions. A breakdown of data collection days can be seen in Figure 1, below:

Table 1: *Data Collection Breakdown*

Data Collection	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Week 1	✅		✅	✅	✅	✅	
Week 2	✅		✅	✅	✅	✅	✅
Week 3			✅	✅	✅	✅	
Week 4	✅		✅	✅			✅

Tuesday was the scheduled rest day across the entire Academy, thus no data was collected. During the period of data collection, there was a combination of games on only Saturday (Week 1 & Week 3), only Sunday (Week 4), or Saturday and Sunday (Week 2). For games occurring on a Saturday, Sunday was provided as a rest day. For games falling on a Sunday, Friday and Saturday were deemed as non-physical days where no GPS units were utilized (thus no data were collected). Monday of Week 3 was given as an additional rest day as the participants had played 2 full games over the 48 hours prior.

Participants were asked to complete an electronic wellness questionnaire each morning within 30 minutes of waking up. All teams had GPS Data collected on them while training. Data collection occurred for 4 weeks' spanning February – March 2020. Work Rate was measured as the Outcome Variable. Intrinsic Fatigue measured as the Exposure Variable.

Procedures & Measurement

The athletes typically trained Monday, Wednesday, Thursday and Friday. Throughout the season, games typically fell on Saturday however occasionally occurred on Sunday dependent on team and field availability. The breakdown of weekly practice intensities can be found below:

Table 2: *Weekly Breakdown of Training Sessions*

Day of the Week	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Session Denotion	+1	0	-3	-2	-1	GD	0
Session Description	Recovery Session	Rest Day	Physical Session	Technical Session	Pre-Game Session	Game Day	Game Day
Session Intensity	Extremely Light		High	Moderate	Low		

Note: -3 through +1 refers to the sessions timeframe in relation to gameday. Monday is considered a recovery session from the last game day. Wednesday begins a "countdown to gameday" for the upcoming game

As stated previously, the exposure variable (Intrinsic Fatigue) was measured through the use of a mobile based questionnaire each morning. The survey was completed on a mobile phone application (AthleteMonitoring) on participants' personal cell phone. The daily questionnaire should have taken no longer than 1 minute in its entirety. A 2015 systematic review of subjective measures of athlete well-being resulted in subjective measures reflecting acute and chronic training loads with superior sensitivity and consistency than objective (Saw et al., 2016). In this study, subjective questions were asked based on perceptual markers (sleep, perceived muscle soreness, mood and hydration), the format and questions can be seen in Figure 1. Saw, Main, & Gastin's 2016 review showed Sleep Quality was positively associated but Stress was strongly negatively associated with cortisol levels in the individual. Additionally, Fatigue is reported to be positively associated with epinephrine/norepinephrine as well as a Heart Rate Variability (Saw et al., 2016). Numerical results for the responses to each individual question as well as an overall wellness score for the day were then produced by an algorithm specific and unique to Athlete Monitoring, see figure 2. All Intrinsic Fatigue measures were tracked individually, independently of each other, and compared to workload.

Figure 1: *Daily Wellness Questions Format Example*

Figure 2: *Individual Player Wellness Scores Example Output*

Date	Fatigue (%)	Soreness (%)	Health (%)	Sleep Quantity (%)	Sleep Quality (%)	Stress (%)	Score (%)
2019-09-03	20	50	33.3	66.7	50	50	45
2019-09-04	20	50	33.3	50	50	50	42.2
2019-09-05	40	50	33.3	33.3	16.7	16.7	31.7
2019-09-06	20	16.7	33.3	66.7	50	50	39.5
2019-09-08	20	50	33.3	50	50	50	42.2
2019-09-09	20	33.3	33.3	66.7	50	50	42.2
2019-09-10	40	50	33.3	66.7	50	50	48.3
2019-09-11	40	50	33.3	33.3	50	50	42.8
2019-09-12	20	50	33.3	50	50	50	42.2
2019-09-13	60	50	33.3	66.7	66.7	66.7	57.2

Each Wellness Score was categorically scored from 1-7, these scores were then converted into percentage points and presented in table format by the Athlete Monitoring App. Above, a single players wellness report from September 3rd to September 13th is shown as an example.

The different components of the outcome variable (Work Rate) are measured independent of each other as they relate to Intrinsic Fatigue. Work Rate was measured through the use of 10Hz STATSports Global Positioning Satellite (GPS) units placed in between the athletes scapulae. These units produce many different data metrics, of the metrics used for this study were the individuals Total Distance (TD), Distance per Minute (Dpm), High Speed Running Absolute (HSRa), Max Speed (MS), Sprints (Sp), Accelerations (Acc), Decelerations (Dec), Dynamic Stress Load (DSL), High Metabolic Load (HML) and High Metabolic Load per Minute (HMLpm).

Statistical Analysis and Presentation

Statistical analysis was carried out per-protocol set analysis for the data of subjects using statistical software program SPSS (version 25). The data are presented in table format. Personal characteristics are presented as the mean and standard deviation (SD). All other results were analyzed for normality. Based on distribution, results were reported as median and interquartile range (IQR), or median and minimum/maximum where appropriate.

Friedman Analyses with a significance level of $p < 0.05$ were conducted for all variables as a whole before all combinations of variables, both within week (comparing scoring differences for Monday, Wednesday, Thursday, Friday, Saturday and Sunday), as well as between week (comparing scoring differences for Week 1, Week 2, Week 3, Week 4). Following Friedman results, within-variable effect sizes were conducted for all comparison's utilizing Cohen's D test protocols (comparing the effect a variable had on itself within the week as well as between weeks). Wilcoxon signed-rank test analyses were utilized for any significant within-variable differences reported in Friedman tests. Following effect size calculations, a Spearman's rho was run for unadjusted wellness and GPS reports, then to determine if there was any correlation in effect size between wellness and GPS reported effect sizes, for both within- and between-week outputs. Meaningful results are presented in table format.

Chapter 4

RESULTS

Participants

Sixty participants (all male) were originally invited into the research. Of all sixty invitees, consent and assent paperwork for twenty-nine participants was received (aged 16.4 ± 1.5 years). There was no participant drop out throughout the course of the study, but a number of instances (51%) occurred where subjects submitted only the Wellness Reports or without logging GPS Reports or vice versa. Only data for complete exposure days (meaning both Wellness Report and GPS Data received) was utilized for analyses: Of the 469 lines of data, 231 (49%) were considered complete and qualified for analysis.

Within-Week Analyses

Table 3 shows descriptive data for reported wellness scores and GPS reports across all days within the week.

Table 3: *Within-Week Reported Wellness and GPS Descriptive Data (Median and Interquartile Ranges reported)*

	Monday		***Wednesday***		***Thursday***		***Friday***		***Saturday***		***Sunday***		
Wellness Reports	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	*p*
Fatigue	2	1-3	1	1-3	2	1-3	2	1-3	2	1-2	2	1-2.75	0.88
Soreness	2	1-2	2	1-2	2	1-2	2	1-2	2	1-2	2	1-2	0.95
Health	2	1-2	1	1-2	1	1-2	2	1-2	1	1-2	1	1-2	0.85
Hydration	2	1-3	2	1-3	2	1-2.5	2	1-3	2	1-3	2	1-3	0.86
Sleep Quality	1.5	1-2.3	2	1-3	2	1-3	2	1-3	1	1-2	2	1-3	0.28
Stress	2	1-3	1	1-3	2	1-2	2	1-3	1	1-3	2	1-2.75	0.98
Overall Score	**2**		**2**		**2**		**2**		**2**		**2**		1.00
GPS Reports													
Distance Total (m)	5074	3913-6130	6966	5490-7977	6602	5358- 7245	4708	4149-5210	10133	6157-11801	6641	3638-9991	0.012*
Distance Per Min (m)	51.7	43.87-57.66	61.11	47.48-69.03	58.80	44.82-69.98	46.37	42.49-54.80	71.50	39.11-92.17	50.00	21.05-71.46	0.06
HSR Absolute	30.8	15.68-82.85	99.37	40.14-199	79.44	5.07-144	72.15	21.73-103	329.22	23.84-866	188.10	40.11-440	0.20
Max Speed (km/h)	6.7	6.10-7.16	7.25	6.575-7.76	6.99	5.91-7.86	6.89	6.27-7.34	8.09	6.36-8.62	7.13	6.38-8.12	0.08
Sprints	4.5	2-8.25	10.00	3.5-17	9.00	1-13.5	6.50	2-11.75	21.00	16-103	16.00	3-28.25	0.29
Acceleration	58.0	33.75-66.25	62.00	44-76	56.00	40.5-69	41.00	21.5-60	38.00	22-65	42.00	22.25-61.25	0.26
Decelerations	39.5	29.75-59.25	54.00	41-71	50.00	26.5-73.5	31.50	10.5-44	28.00	18-69	41.5	14.25-57.25	0.51
Dynamic Stress Load	111.8	74.15-163	171.00	110-242	183.00	108-270	137.00	85.33-217	360.00	92.8-644	220	97.3-464	0.08
High Metabolic Load Distance (m)	502.0	322-800	934.00	346-1168	728.00	350-1023	491	232-657	1374.00	351-1958	973	246-1313	0.20
HML Distance Per Min (m)	4.7	2.88-7.39	7.84	3.10-9.60	5.69	2.65-8.89	4.635	2.19-6.85	8.92	2.63-3.87	5.795	1.54-9.39	0.16

P values derived from post hoc analysis using Friedman comparing all 7 days
*significance level $p < 0.05$

Within-Week Wellness

The median reported Overall Wellness score for each day was 2, ranging from 1 to 5 on the various days. Within each week, no significant difference was observed amongst reporting in any of the reported Wellness variables ($p > 0.05$), shown in Table 3. Cohen's D effect sizes showed that there was negligible magnitude of average within-variable effects (impact of the variable on a future report of itself) across all combinations of exposure days. Individual ranges of Effect Sizes were observed from very low (0.002: effect of Mondays Soreness on Friday Soreness), through moderate (0.44: effect of Friday's Sleep Quality on Saturday Sleep Quality). The low effect sizes reported indicate there was no meaningful differences between the two variables, whereas if there was a greater effect size reported, a potentially meaningful interaction could be deduced; positive effects reporting positive associations and negative effects producing negative associations.

Each of the 15 effect sizes were then averaged for all variables and a mean effect size for each variable was calculated, shown in Table 4. All average within-variable effect sizes were minute ranging from -0.003-0.15: Therefore, averaged wellness scores did not substantially change between days during the week.

Within-Week *GPS Reports*

Workload for GPS reports noted some clear differences between days. A significant difference was observed in Total Distance covered ($p = 0.01$), however when divided by unit time (Distance per Minute) the difference was no longer significant ($p = 0.06$). Wednesday was the heaviest reported training workload (Total Distance 6,966m, with IQR 5,490m-7977m), Friday was the lightest reported training workload indicated by Total Distance covered of 4,708m, IQR 4,149m-5,210m. Across the entire week, Saturday's game day was the highest overall across all variables (Total Distance covered of 10,133m, IQR 6,157m to 11,801m). Although not significant ($p > 0.05$), within-week reports of GPS showed an expected variation of results per variable. The different training objective and suggestive workload resulted in larger effect sizes of GPS variables between days than Wellness Variables. Moderate magnitude effect sizes of variables on future reports for Distance Total (m) -0.42 (± 0.82), Max Speed -0.58 (± 0.54), High Speed Running -0.34 (± 0.44), Sprints -0.58 (± 0.57), Accelerations 0.32 (± 0.33), Dynamic Stress Load -0.55 (± 0.53) and High Metabolic Load Distance (m) -0.40 (± 0.59). When Total Distance was quantified by unit time (Total Distance to Distance per Minute), the effect size of the variable was reduced to -0.04 ± 0.50, the same effect was noted to a lesser magnitude with High Metabolic Load when quantifying by unit time (HML per Minute), the effect size is reduced from -0.40 to -0.21 (± 0.49).

Table 4: Average *Within-Week and Between-Week effect sizes (Cohen's d Magnitudes) for Wellness and GPS variables.*

	Within-Week		Between-Week	
	N	**Mean (± SD)**	**N**	**Mean (± SD)**
Fatigue	15	-0.03 ± 0.16	6	0.06 ± 0.17
Soreness	15	0.04 ± 0.22	6	0.05 ± 0.15
Health	15	0.15 ± 0.14	6	0.09 ± 0.07
Hydration	15	-0.03 ± 0.09	6	-0.002 ± 0.18
Sleep Quality	15	-0.01 ± 0.22	6	0.001 ± 0.08
Stress	15	0.06 ± 0.14	6	0.007 ± 0.15
Overall Score	15	0.02 ± 0.13	6	0.04 ± 0.15
Distance Total	15	-0.42 ± 0.82	6	-0.13 ± 0.37
Distance Per Min	15	-0.04 ± 0.50	6	0.07 ± 0.18
Max Speed	15	-0.58 ± 0.54	6	0.10 ± 0.32
HSR	15	-0.34 ± 0.44	6	-0.16 ± 0.31
Sprints	15	-0.58 ± 0.57	6	-0.14 ± 0.34
Acc	15	0.32 ± 0.33	6	-0.15 ± 0.89
Dec	15	0.21 ± 0.41	6	-0.12 ± 0.12
DSL	15	-0.55 ± 0.53	6	-0.16 ± 0.26
HML	15	-0.40 ± 0.59	6	-0.05 ± 0.44
HML Per Min	15	-0.21 ± 0.49	6	0.02 ± 0.36

Cohen's d magnitudes: < 0.2 = Small, 0.21-0.5 = Medium, > 0.8 = Large
Positive d's indicate positive effect and negative d's indicate negative effect
Note: Within-Week N=15 represents all combinations of days compared to one another. Between-Week N=6 represents all combinations of weeks compared to one another

Between-Week Analyses

As shown in Table 5, no significant difference in reports of Wellness was observed from one week to the next ($p > 0.05$). Additionally, the median overall score for Weeks' 1-3 remained steady at 2, before dropping to a median score of 1 for the final week of the data collection. GPS Reports returned significant differences in all variables except Distance Total & Distance Per Min.

Table 5: *Between-Week Reported Wellness and GPS Descriptive Data (Median and Interquartile Ranges)*

	Week 1		*Week 2*		*Week 3*		*Week 4*		
Wellness Reports	Median	IQR	Median	IQR	Median	IQR	Median	IQR	*p*
Fatigue	2	1-3	2	2-3	2	1-3	1	1-3	0.91
Soreness	2	1-2	2	1-2	2	1-3	1	1-2	0.56
Health	1	1-2	2	1-2	2	1-2	1	1-2	0.37
Hydration	2	1-3	2	1-3	2	1-3	2	1-3	0.79
Sleep Quality	2	1-3	2	1-3	2	1-3	2	1-3	0.99
Stress	2	1-3	2	1-3	2	1-3	1	1-3	0.46
Overall Score	**2**		**2**		**2**		**1**		0.50
GPS Reports									
Distance Total (m)	5471	4385-6965	6175.00	4573-7388	4971.00	3901-6787	6644.00	4786-8360	0.09
Distance Per Min (m)	54.67	45.29-63.6	54.38	44.28-70.74	50.65	39.2-62.16	53.48	43.07-6941	0.09
HSR Absolute	91.12	20.92-167	67.54	15.6-160	58.29	8.67-102	114.00	33.42-290	0.008*
Max Speed (km/h)	7.13	6.26-7.59	6.83	6.13-7.44	6.91	5.94-7.42	7.39	6.76-8.05	0.003*
Sprints	9.00	43.8-78	7.00	1.75-14	4.00	1-10.5	14.00	2.5-21.5	0.002*
Acceleration	61.00	40-75	42.00	24-64	41.00	14-56	69.00	53-84.5	0*
Decelerations	46.00	33-67	39.50	24-60.75	24.00	11.0-53.0	58.00	48.5-75.5	0*
Dynamic Stress Load	123.00	80.9-189	166.00	87.91-290	183.00	106-234	205.00	121-266	0.08
High Metabolic Load Distance (m)	741.00	435-1014	640.00	300-1042	446.00	196-793	951.00	342-1328	0.002*
HML Distance Per Min (m)	6.56	3.53-8.56	5.67	2.2125-8.68	4.05	1.735-7.71	7.34	2.89-10.09	0.016*

P values derived from post hoc analysis using Friedman comparing all 4 weeks

*significance level p < 0.05

Between-Week Wellness Reports

Between the four weeks of data collection, no significant differences in reporting were observed ($p > 0.05$), seen above. An average Between-Week effect size within each variable was calculated by determining the individual effect size of the variable against all combination of future weeks, and then averaging these scores to produce an overall effect size. These negligible effect sizes can be seen in the Table 4. That being, no wellness variable had any clear variation from one week to the next. The largest effect size returned was variable health: 0.09 ± 0.07, which is still considered small.

Between-Week GPS Reports

Following the process of within-week analyses, the same calculations were run for between-week GPS reports. Cohen's D effect sizes for within-variable magnitude can be seen in Table 4. The between-week effect size for each of the GPS reports are small, with the largest reported effect size being High Speed Running (-0.16 ± 0.31) and Dynamic Stress Load (-0.16 ± 0.26). This shows that when comparing these variables between weeks, variability between the reported week results is very limited.

Impact Between Wellness and GPS Reports

When initially ranking unadjusted Wellness and GPS reports against each other, no meaningful significant correlations were observed within or between week outcomes ($p > 0.05$). Because the aim of the study was to determine the relationship of subjective perception of Wellness and reports of Workload the effect sizes of wellness and GPS variables were correlated against each other using Spearman's rho. These correlations can be seen in Table 6.

The negative correlations indicate that with an increase of effect size in one variable, a decrease in effect size of the corresponding correlated variable is observed. As the effect sizes for wellness variables were very small this further emphasizes the trend shown that there was no meaningful relationship within variable outcomes.

The between week correlations showed, to a lesser degree, the same findings as the correlations of within-week effect sizes. Negative correlations are associated with a rise in effect size of one variable being associated with a decrease in effect size of its comparator. This finding duplicates the finding of within-variable, whereby there is no association of subjective perception of Wellness and resulting Workload derived by GPS reporting.

Table 6: *Spearman's rho Correlation of Effect Sizes between Variables*

Within-Week	**Fatigue**	**Soreness**	**Health**	**Hydration**	**Sleep Quality**	**Stress**	**Overall Score**
Distance Total	-0.53*	-0.16	-0.61*	-0.23	-0.55*	-0.84**	-0.83**
Distance Per Min	-0.57*	-0.14	-0.67**	-0.29	-0.45	-0.93**	-0.83**
Max Speed	-0.51	-0.30	-0.63*	0.21	-0.49	-0.62*	-0.65**
HSR	-0.71**	-0.37	-0.66**	0.13	-0.52*	-0.77**	-0.85**
Sprints	-0.54*	-0.36	-0.68**	-0.02	-0.60*	-0.74**	-0.79**
Acc	-0.24	-.55*	-0.39	-0.74**	-0.14	-0.47	-0.50
Dec	-0.29	-0.37	-0.55*	-0.75**	-0.24	-0.72**	-0.65**
DSL	-0.31	0.01	-0.60*	-0.01	-0.53*	-0.70**	-0.59*
HML	-0.60*	-0.31	-0.65**	-0.09	-0.60*	-0.81**	-0.86**
HML Per Min	-0.61*	-0.28	-0.62*	-0.18	-0.61*	-0.84**	-0.88**
Between-Week							
Distance Total	-0.09	-0.31	-0.26	-0.60	-0.94**	-0.09	-0.31
Distance Per Min	0.03	-0.14	-0.03	-0.49	-0.83*	0.03	-0.14
Max Speed	-0.09	-0.31	-0.26	-0.60	-0.94**	-0.09	-0.31
HSR	-0.37	-0.60	-0.54	-0.77	-1.0**	-0.37	-0.60
Sprints	-0.49	-0.66	-0.60	-0.89*	-0.94**	-0.49	-0.66
Acc	-0.83*	-0.89*	-0.77	-1.0**	-0.77	-0.83*	-0.89*
Dec	-0.66	-0.77	-0.66	-0.94**	-0.89*	-0.66	-0.77
DSL	0.77	0.54	0.37	0.37	-0.20	0.77	0.54
HML	-0.49	-0.66	-0.60	-0.89*	-0.94**	-0.49	-0.66
HML Per Min	-0.66	-0.77	-0.66	-0.94**	-0.89*	-0.66	-0.77

† A negative correlation indicates an increase in ES of one variable produces a decrease in ES of the other
* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

<u>Chapter 5</u>

DISCUSSION

The results suggest minimal interaction of subjective wellness scores and objective player workload for both within as between week analysis. A correlation analysis between subjective wellness and objective GPS reports effect sizes produced remarkably negative correlations; that being an increase in the effect size of a GPS variable decreased the effect size of the wellness variables (and vice versa), but with having very small wellness effect sizes it is unlikely that the variables made a significant impact on one another. However, when referencing as entities on their own, Wellness did not seem to have an effect on itself within- or between-weeks but the GPS variables did appear to impact future reports of the same variable in some cases, with the most apparent effects being seen within-weeks. While no statistically significant differences were observed analyzing within-variable differences, sporadic moderate and large magnitude effect sizes were able to be seen at various points inside the data set.

There was only one time loss injury, occurring in a game, across the 231 exposures. Although a single incident is not enough to deduce any inferences from, the injury occurrence was aligned with the finding of Cousins et. Al. where 87% of contact-derived time loss injuries across 2 seasons of elite rugby union occurred during games (Cousins et al., 2019).

Interpretation of Analyses

Within-Week Impact of Wellness and GPS Variables

No differences in Wellness were reported comparing individual days of the week together, despite changes in session intensity denoted by differing workloads. This is different to previously published findings where the researchers found significant differences (Z-Score = -1.99 ± 0.38) in well-being one day post-match (Malone et al., 2018), and reported as wellness score decreases external output within a session might also decrease (Gallo et al., 2016). Malone noted that a wellbeing Z-Score of -1 resulted in a significant reduction in workload variables high speed distance, maximal velocity, player load exposure. In addition to the aforementioned, a wellbeing Z-Score of -1 also resulted in negative impact of External:Internal Training Load, Total Distance:RPE, High Speed Distance:RPE ratios. As discussed prior, there was not significant differences in wellness scoring of this research study, thus no observations can be concluded in differences of wellness preceding or because of changes in workload.

The only within-week GPS variable report that differed statistically from one day to the next was Total Distance. It should be reported that this variable report was not delineated by unit time, and no two days sessions were over the same time. When quantified as distance per unit time (distance per meter), this significance disappears. Although no statistical difference was reported in GPS reports, the moderate effect sizes seen amongst the GPS variables show within any given week workload variables can be positively or negatively affected by the variable themself.

Furthermore, when speaking to the GPS workloads, each session was ultimately dictated by the coaching staff and the participants involvement in said session determined by the requirements of the session plan: The workload any participant was subject to on any given day was influenced by the coaching staff and outside the participants control. A similar concept of coach dictated session intensity is seen in Selmi (2020) where the researchers are encouraging coaches to choose small sided games over high intensity interval training (HIIT) due to the nature of positive outcomes in small sided games over HIIT (Selmi et al., 2020).

Interestingly, there does not appear to be an effect of the accumulation of training on wellness reports. That being said, wellness was not affected by multiple sessions running day after day. Literature (Drew & Finch, 2016; Williams et al., 2017) suggests that with an accumulation of workload, differences in wellness reporting is to be expected: especially shown by Roe et. Al., where the researcher found an increase in training load by means of inclusion of contact training resulted in greater perceptual fatigue (Roe et al., 2017). Roe (2017) attributed the increase in perceptual fatigue to be a result of greater upper-body neuromuscular and perceptual fatigue as well as greater elevations in creatine kinase, with this fatigue likely being from substantial involvement of upper body during collisions and resultant trauma to tissue locations (Roe et al., 2017). The workloads seen through GPS reporting in this study were aligned with what was anticipated: Wednesday was the heaviest training load of the week tapering down through Friday and Gameday's spiking workload above Wednesday's intensity. Monday was a light workload deemed recovery session. It is a reasonable expected observation to see that with an increase in workload, a consequential decrease in wellness is observed. The findings observed by Roe (2017) were not the case amongst the participants in this study: increases in workload did not lead to any changes in fatigue ratings. This lends to the query of whether the sensitivity of wellness measures was appropriate and sensitive enough for the population to answer the question: are subjective perception of fatigue (Intrinsic Fatigue) and GPS derived workloads linked?

Assessing correlation of effect sizes, there was a general overall negative effect size between most variables (Wellness vs. GPS): meaning as the effect size of one variable increases, the effect size of the other decreases. This finding argues against what the aim of the study attempted to find (a positive relationship between effects of Wellness and GPS metrics). The only positive correlations were small: Dynamic Stress Load & Soreness (0.011), Max Speed & Hydration (0.207) and High Speed Running & Hydration (0.129). The results of this study did not find any meaningful correlations in GPS and Wellness, this contrasts Malone et. Al., where an increase in training load caused a decrease in perceived wellness (Malone et al., 2018).

Between-Week Impact of Wellness and GPS Variables

There were no statistically different weeks when comparing wellness across all 4 weeks of data collection. No reported differences were seen for the overall wellness reports from weeks 1-3 (reported score 2), and week 4 reported a score one numeral lower than the first three (reported overall wellness score of 1). As the study was utilizing youth soccer players, there is possibility for these results to reflect the pliability of young athletes and ability to withstand stressors. A similar result has been seen in the literature whereby Codonhato studied the relationship between stress and resilience in elite gymnasts (mean age 20.4 ± 2.5 years) over the course of 12 months and found that despite controlling for physical stress, resilience and recovery levels remained constant (Codonhato et al., 2018). While supported by Codonhato, this finding does not align with Thorpe or Saw et. al.'s reviews surrounding monitoring fatigue in elite team-sports athletes: here the researcher's found that Athlete Self-Report Measures (ASRM) demonstrated greater sensitivity to acute and chronic training loads than commonly used objective measures (Saw et al., 2016; Thorpe et al., 2017). The Academy has a Sports Medicine department consisting of various healthcare professionals monitoring player loads and wellness; the consistency seen in the reported scores across weeks' may also be a result of an effectively implemented periodization program throughout the course of the 4 week study.

The effects seen in GPS metrics when looking within-week appear to be mitigated when expanding the comparison to between-weeks. Statistical differences were observed in workload for all variables except distance covered (Total and Per Minute). The largest within-variable effect sizes were High Speed Running (-0.16 ± 0.31), and Dynamic Stress Load (-0.16 ± 0.26). These effect sizes are minimal when compared to the effect sizes of High Speed Running changes observed in Carling: effect sizes for this study ranged from 0.62 to 1.08 across the course of 5 full seasons, 2008-2013 (Carling et al., 2015).

Limitations

As this study was utilizing infrastructure that was already present and operating within the Academy, there were preconceived understandings already in place. One of these understandings was that the coaching staff had the ability to view the results of the wellness reports. The researchers believe the inability to blind the coaching staff to wellness reports fundamentally impacted the accuracy of the reports due to fear of potential playing time implications associated with low level of wellness, a trend aligned with concussion reporting behavior in sport where the largest barrier f9r reporting was fear of losing current or future playing time (Clark & Stanfill, 2019).

The wellness reports were generated off a mobile based app on the players cellphones. The reports were derived from a questionnaire that was color scaled as well as a narrative option given. The use of color based RPE scales has been validated amongst young (21.7 ± 1.5 years) and older (60.3 ± 3.5 years) adult populations (Serafim et al., 2014). However, to the knowledge of the researcher color scales have not been validated amongst youth populations, which may have further impacted the validity of scoring from participants.

The wellness scales utilized for this research were similar to the color based RPE scales; traffic light based scoring with green being the best score through red corresponding with the worst. While RPE color scales have been validated in adult populations (Serafim et al., 2014), there does not appear to be any validated color scales present for subjective wellness specifically.

Furthermore, the anticipated timeline for data collection was February through June (4 months). Due to the COVID-19 global pandemic, this time frame was cut to February 10th – March 8th (4 weeks). The shortened timeframe potentially limited the ability to draw long-term conclusions based on the lack of longitudinal data collection to pull from. This can be seen in the literature where Rabbani (2019) was only able to deduce *likely* improvements over the course of a 5 week study (Rabbani et al., 2019), where Govus (2017) and Lovell (2013) were able to produce statistically significant results across 8 week and entire season studies respectively (Govus et al., 2018; Lovell et al., 2013).

Conclusions

The study aimed to determine the relationship of subjective perception of wellness and objective workload. No statistically significant relations between the two components of the study (Subjective perception of wellness and GPS derived Workload) were obtained. The study supports the literature where workload variability can be successfully monitored through GPS reports illustrated by moderate effect sizes. However, this research disagrees with the literature where the use of subjective wellness is suggested as a means of monitoring player response to training, especially when utilizing youth participants. This study warrants further investigation with a more stringent study protocol in place and greater sensitivity of Intrinsic Fatigue questioning utilizing an already validated scale of wellness questioning.

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APPENDIX A

UNIVERSITY APPROVAL FOR USE OF HUMAN SUBJECTS

APPROVAL: EXPEDITED REVIEW

Floris Wardenaar
Nutrition
(602) 827-2841
Floris.Wardenaar@asu.edu

Dear Floris Wardenaar:

On 1/23/2020 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Intrinsic Fatigue and its Relationship to Workload and Injury
Investigator:	Floris Wardenaar
IRB ID:	STUDY00011332
Category of review:	
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• 01172020 Hydration Further Analysis.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • 18+ Consent IRB Reviewed.pdf, Category: Consent Form; • Academy Director Approval.pdf, Category: Off-site authorizations (school permission, other IRB approvals, Tribal permission etc); • Athlete Monitoring Template.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Biomedical Research-1 CITI Scott Armistead.pdf, Category: Other; • HRP-503b INTRINSIC FATIGUE Reviewed IRB.docx, Category: IRB Protocol; • Parent Email Body.pdf, Category: Recruitment Materials; • Player Scoring Table.pdf, Category: Measures

	(Survey questions/Interview questions /interview guides/focus group questions); • U18 Assent IRB Review.pdf, Category: Consent Form; • U18 Consent IRB Reviewed.pdf, Category: Consent Form;

The IRB approved the protocol from 1/23/2020 to 1/22/2021 inclusive. Three weeks before 1/22/2021 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 1/22/2021 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc:

Scott Armistead