An interdisciplinary monitoring approach to understanding health and performance in English Premier League Soccer players.

Sophie Grimson

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Abstract

In team sports, monitoring an athlete's response to training is common practise to assess readiness to train, enhance performance and reduce injury and illness incidence. Physical and mental health monitoring are poorly understood, with limited knowledge regarding mental health screening, musculoskeletal tests, and subjective wellbeing in English Premier League soccer players. Research has investigated monitoring tools and relationships with injury, illness, and internal training load, yet limited research exists surrounding relationships with external training load. This thesis examined mental health and the ability of monitoring tools to detect changes in external training load which trend with injury and illness occurrence. *Study One* showed a declining trend in psychological wellbeing, an aspect of mental health, assessed via the 'Warwick Edinburgh Mental Wellbeing Scale' in-season compared to an increase during the COVID-19 lockdown, with individual differences identified. Psychological wellbeing was greater when weekly training volume was > 250 min < 250 min during lockdown (52.5 ± 4.7 vs. 50.4 ± 6.6) (P < 0.05) respectively. These findings suggest that greater stressors could be imposed upon players during the season vs. lockdown, and subsequently imply individual longitudinal monitoring of psychological wellbeing should be implemented. *Study Two* demonstrated periods of high intensity training and match play were related to psychological wellbeing. In addition when winning compared to losing all matches over a period of two weeks can impact on psychological wellbeing (52.7±4.7 vs. 50.9±5.6) (P < 0.05), and therefore the implementation of interventions designed to improve psychological wellbeing should be considered. *Study Three* reported subjective recovery markers (perceptions of fatigue, soreness, and wellness) were associated with objective recovery markers (sit and reach and adductor strength test scores) (r = -0.053 to -0.098, n = 1749, P <0.05) and were consistently related to all previous day and 7-day total distance, explosive distance, sprint distance and high-speed distance (r = 0.084 to 0.330, P <0.05). Objective markers were related to previous day total distance and sprint distance and 7-day total distance (r = 0.052 to 0.119, P < 0.05). Findings provide practitioners with low-cost objective markers which are sensitive to perceived recovery and specific GPS metrics. *Study Four* demonstrated goalkeeper specific GPS metrics (previous day and 7-day total distance, Player Load, total dives, total dive load, average time to feet, and high, medium, and low jumps) were related to subjective recovery (r = 0.073 to 0.278, P < 0.05). However, between all positions (Goalkeepers, Central Defenders, Fullbacks, Central Midfielders, Wide Midfielders and Forwards) differences in subjective wellbeing were not evident. Results suggest goalkeeper-specific metrics could be monitored to highlight perceptions of wellness which might lead to enhanced prescription of recovery practises. Notably, goalkeepers are no more vulnerable to poor subjective wellness when compared to outfield players. *Study Five*, reported daily mood assessed via the subjective wellbeing questionnaire may provide an early insight of injury occurrence. Total distance and explosive distance acute:chronic workload ratio, left and right adductor strength, and daily mood may also provide an early insight of illness occurrence. Practitioners are therefore encouraged to monitor and implement strategies to improve mood, as this may help reduce the instances of illnesses and injury. Whilst adductor strength could detect illness and underperformance, alternative monitoring tools may better demonstrate trends with injury and illness. Findings of the current thesis, provide a strong rationale for the inclusion of mental health monitoring. Findings also provide an understanding of the efficacy of monitoring tools and external training load prescription to augment player health and wellbeing.

Publications

Peer Reviewed publications arising from this course of investigation

Grimson, S., Brickley, G., Smeeton, N. J., Abbott, W & Brett, A. (2021). Physical activity on mental wellbeing in senior English Premier League Soccer players during the COVID-19 pandemic and the lockdown. *European Journal of Sport Science,* 1-10.

Grimson, S., Brickley, G., Smeeton, N. J., Abbott, W & Brett, A (2022). The effects of injury, contextual match factors and training load upon psychological wellbeing in English Premier League soccer players via season-long tracking. *European Journal of Sport Sciences,* 1: 9.

Grimson, S., Brickley, G., Smeeton, N. J., Abbott, W & Brett, A (2022). The relationship between subjective wellness and external training load in English Premier League goalkeepers and a comparison with outfield soccer players. *International Journal of Sports Physiology and Performance, In Press.*

In preparation:

Musculoskeletal tests and subjective wellness are related to external training loads of Premier League football players: A season-long analysis.

The predictive ability of subjective wellbeing, musculoskeletal screening, psychological wellbeing, and training load to predict injury and illness in elite Premier League Soccer Players.

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Abbreviations

The following abbreviations have been defined in the text in the first instance.

ACWR	Acute Chronic Workload Ratio
AFL	Australian Football League
ATF	Average time to feet
AS	Adductor Strength
BLa	Blood Lactate
CD	Central Defender
CM	Central Midfielder
CMJ	Counter movement Jump
CV	Coefficient of Variation
DOMS	Delayed Onset Muscle Soreness
ED	Explosive Distance
EPL	English Premier League
ETL	External Training Load
EWMA	Exponential weighted moving averages
FWD	Forward
GPS	Global Positioning System
GK	Goalkeeper
HF	Hamstring Flexibility
HR	Heart Rate
HRV	Heart Rate Variability

HSD	High Speed Distance
ITL	Internal Training Load
MD	Match Day
MH	Mental Health
MHD	Mental Health Disorders
PA	Physical Activity
PWB	Psychological Wellbeing
RPE	Rating of Perceived Exertion
RTT	Return to training
RU	Rugby Union
SD	Sprint Distance
sRPE	Sessional Rating of Perceived Exertion
TD	Total Distance
TL	Training Load
TRIMP	Training Impulse
sd	Standard Deviation
sIgA	Salivary Immunoglobulin A
S&R	Sit and Reach
URTI	Upper respiratory tract infection
WD	Wide Defender
WEMWBS	Warwick Edinburgh Mental Wellbeing Scale
WM	Wide Midfielder

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1.0 Introduction

1.1 Introduction

The provision of a holistic overview of an athlete's full physical health, mental health (MH) and performance status, requires both subjective and objective recovery markers (Heidari *et al.,* 2019). Importantly, soccer players are at a high risk of developing MH disorders and symptoms, with anxiety and depression symptoms 16% higher than the general population (Junge *et al.,* 2016; Kilic *et al.,* 2018; Office for National Statistics, 2013). However, research examining current monitoring practises predominantly utilise physiological based measures (Halson, 2014; Thorpe *et al.,* 2016), neglecting the psychological demands on MH which can decline with insufficient recovery. Limited research investigating monitoring athlete MH is likely due to the focus upon clinical disorders (e.g., depression and anxiety) which are sensitive to discuss, and further limited by the associated stigma surrounding MH (Bird *et al.,* 2018). Moreover, the competitive nature of professional sport, could cause a fear of admitting a weakness which could have a perceived effect on competition selection. Consequently, practitioners are unaware of the prevalence of poor MH and how to monitor MH suitably in English Premier League (EPL) soccer players. Just as training is monitored and balanced with adequate recovery to manage physical injuries, so too must the psychological strategies to support MH (Kuettal *et al.,* 2019). It is recommended that monitoring 'Psychological Wellbeing' (PWB) in athletes is more appropriate than the presence of clinical disorders, which includes positive aspects such as the functioning and flourishing of individuals and allows for the consideration that athletes are not healthy in the absence of a MH disorder (Keyes, 2007; Henriksen *et al.,* 2019; Kuettal *et al.,* 2021b). Currently the only available questionnaire to assess PWB is the 'Warwick Edinburgh Mental Wellbeing Scale' (WEMWBS) which is practical, positive, and non-invasive and has been utilised to assess contextual factors upon PWB in academy soccer players (Abbott *et al.,* 2019). The questionnaire has also demonstrated high reliability (a = 0.94) (Rice *et al.,* 2020). This makes it advantageous over clinical based questionnaires which are negatively worded and time consuming. Yet, no knowledge regarding EPL soccer players exists, where contextual stressors and coping abilities are different. Such omissions can leave soccer players exposed to developing poor MH, increasing injury and illness risk, and reducing performance. Overcoming such obstacles, can increase the understanding of monitoring MH in EPL soccer players, which allows the identification of stressors and periods where PWB could fluctuate and help guide subsequent interventions to maintain PWB.

Notably, monitoring tools should be sensitive to training load (TL). To date there is limited guidelines for the prescription of external training Load (ETL) and suitable objective monitoring tools to enhance physical health specifically in EPL soccer players. Previously, research has focused upon subjective recovery markers and TL in soccer (Clemente *et al.,* 2017; Draper *et al.,* 2021; Fields *et al.,* 2021), or focused upon associations between internal TL (ITL) or limited ETL metrics (e.g., total distance (TD) and high-speed distance (HSD)) and objective recovery markers (Tiernan *et al.,* 2019; Esmaelli *et al.,* 2018a; Weaving *et al.,* 2021). Whilst subjective measures could be more sensitive to TL than objective measures and provide insights into an athlete's own psychosocial state, less is known regarding objective recovery markers and their associations with ETL (e.g., musculoskeletal tests; adductor strength (AS) and sit and reach (S&R)) in EPL soccer players. From this perspective, practitioners are yet to understand the ecological validity of the 'hip-strength testing system' when quantifying AS and how this relates to ETL in EPL soccer players. This is important to address as previous research has utilised the sphygnamometer rather than the 'hip-strength testing system'. The 'hip-strength testing system' is known to be more accurate than the sphygnamometer in quantifying AS (Coefficient of Variation (CV) 6.3 vs. 7.6%) (Buchheit *et al.,* 2017; Ryan *et al.,* 2019a), This is because the sphygnamometer requires hip and knee joint angle estimation, visual data collection and pushing against a variable force, in contrary to newer methodologies which are digitalised and requires force applied against a consistent force (Buchheit *et al.,* 2017; Ryan *et al.,* 2019b). Such a knowledge gap surrounding new methodologies prevents practitioners to successfully overcome the limitations associated with subjective recovery, such as contextual factors and social bias (Abbott *et al.,* 2018a). Additionally, the limited research examining ETL is important as ETL metrics rather than ITL could also better represent the musculoskeletal responses to training stress, given the disparities between adaptation, pathways from physiological and biomechanical loads (Vanrenterghen *et al.,* 2017). Such paucity in research, prevents the utilization of commonly utilised Global Positioning System (GPS) parameters in an applied sporting context such as 'Explosive Distance' (ED), which neglects metabolically demanding actions such as accelerations and decelerations, which can induce muscular fatigue (Osgnach *et al.,* 2010; Dalen *et al.,* 2016). Subsequently examining specific ETL GPS parameters and application of objective monitoring markers that reflect subjective recovery status, offers practitioners with vital information regarding the monitoring of physical health and how this can inform ETL prescription. By conducting research specifically in EPL soccer players, the findings reveal novel insights into ecologically valid monitoring tools sensitive to ETL specifically endured by EPL soccer players. This is important and presents a strong rationale for investigation into different sports and populations.

To date, only one previous study has investigated associations between wellness and common GPS metrics (e.g., TD) in one elite Goalkeeper (GK) (Malone *et al.,* 2018). Limited research is likely due to previously a lack of available GK-specific GPS metrics at a practitioner's disposal as well as the difficulty in obtaining a high sample size. Therefore, there is little research surrounding the prescription of GK specific external GPS metrics to enhance subjective wellbeing, as well as the vulnerability of GKs developing poor physical and MH

(Carfagno & Hendrix, 2014; Muracki, 2020). Importantly, GKs are exposed to inherently different physical demands than their outfield counterparts, and subsequently, may possess a unique wellness profile post training and match (Malone *et al.,* 2018; White *et al.,* 2020). Therefore, investigation into more accurate GK-specific metrics available to the practitioner, and their associations with subjective wellbeing, provides important information which could help inform GK-specific training.

To overall develop a monitoring battery that reflects a player's risk to poor physical and MH, research is required to investigate the effectiveness of potential monitoring tools such as the 'WEMWBS', 'AS' and 'Hamstring Flexibility (HF)' to predict injury and illness. No previous research has examined such monitoring tools in EPL soccer players, where training demands and injury susceptibility differs between different ages and sports. Overall, the provision of a players physical and MH, may provide practitioners with novel insights into PWB, subjective and objective markers and subsequent prescription of ETL in EPL soccer players.

1.2 Research aims and objectives

The overall aim of the thesis was to consider monitoring both physical and MH in professional soccer. This was addressed in five experimental chapters which aimed to:

1. Analyse the presence of poor PWB in professional soccer players across an EPL season. (Study One)
2. Examine the effects of contextual match related stressors (win-rate, match selection, and playing status), injury and illness, and TL upon PWB during an EPL season (Study Two)
3. Determine whether ETL elicited by EPL soccer players during training and competition are sensitive to subjective wellness and objective recovery markers. (Study Three)

4. Determine whether ETL elicited by EPL GKs during training are sensitive to subjective wellness. In addition, examine whether there are any positional differences in subjective wellness. (Study Four)
5. Determine whether the addressed monitoring markers can predict injury and illness occurrences. (Study Five)

1.3 Organisation of Thesis

This thesis is presented in nine main chapters. The review of literature (Chapter 2) examines all available studies focusing upon the following areas:

- Physical and Physiological demands of soccer
- Prevalence of Injury, Illness, and Mental Health
- Training load monitoring
- Training load, Injury, and Illness
- Quantifying the training response
- Predicting Injury and illness

The literature review was conducted to evaluate the physical and mental demands in soccer, the prevalence of poor MH, injury and illness occurrence and the available monitoring tools to monitor workload and a response to workload.

Search Strategy: Literature searches of PubMed were undertaken to identify suitable journal articles.

- Searches for "Physical and Physiological demands of soccer" included the following keywords as search terms: "Soccer", "Football", "Physiological demands", "Psychological demands"
- Searches for "Prevalence of Injury, Illness and Mental Health" included the following keywords as search terms: "Soccer", "Football", "Elite Sport" "Mental Health" "Injury" "Illness" "Prevalence"

- Searches for “Training load monitoring” included the following keywords as search terms: “Soccer”, “Football”, “Athletes”, “Elite Sport” “Training Load” “Monitoring” “Internal” “External”
- Searches for “Training load, injury and illness” and “predicting injury and illness” included the following keywords as search terms: “soccer” “football” “sport” “athletes” “elite” “training load and injury” “training load and illness”, “prediction”
- Searches for “quantifying the training response”: included the following keywords as search terms: “soccer”, “sport”, “athletes”, “monitoring” “heart rate monitoring” “multidisciplinary approach” “blood biomarkers” “sIgA”, “testosterone”, “cortisol”
- Articles were included at the authors discretion on the suitability.

The general methods (Chapter 3) provide details on the following procedures and processes:

- Participant Recruitment
- Participant exclusion criteria
- Data collection procedures
- GPS data analysis
- GPS data quality and accuracy
- Measuring Internal and External Training load
- Monitoring testing procedures (Objective and Subjective)
- Data Analysis
- Statistical Analysis

Chapter Four (Study One) explored changes to PWB during ‘lockdown’[1] and subsequent ‘return to sport’ protocols in comparison to the normal ‘in-season’ in professional soccer. The

[1] In wake of the COVID 19 pandemic the English Premier League 2019/2020 season fixtures were suspended on the 13th of March 2020. To facilitate the safe return of football, the Premier League introduced ‘Project Restart’ which consisted of Stage 1 ‘Return to Training’ protocol, where small group training was allowed from 19 May 2020. Stage 2 allowed the return of contact training on the 27th of May 2020. The 2019/2020 season then restarted on the 17th June behind closed doors.

aim was to determine whether a period away from sport-related stressors when compared to the season, had an impact upon PWB.

Chapter Five (Study Two) investigated the impact of stressors imposed on elite soccer players during the season that could augment PWB. The aim was to determine whether contextual match factors, including match result, playing status, injury, illness, and TL had an impact on PWB to determine periodised interventions.

Chapter Six (Study Three) investigated the relationship between musculoskeletal tests (AS and S&R scores) and subjective wellness markers (wellness, fatigue, soreness, mood, sleep hours and sleep quality) and their subsequent relationship with ETL. The aim was to determine timely and efficient objective recovery markers that reflect subjective wellness. Additionally, determine the relationship between recovery markers and ETL because if absent, it questions the use of both the dose and response measures to accurately reflect fatigue and suitably inform ETL prescription.

Chapter Seven (Study Four) investigated the relationship between GK specific ETL and subjective wellbeing markers. This study also examined the positional differences in subjective wellbeing responses. The aim was to determine GK specific metrics that could be prescribed to obtain a favourable wellness response and determine how GKs differ in subjective wellbeing responses compared to their outfield counterparts.

Chapter Eight (Study Five) investigated the predictive ability of monitoring tests to predict injury and illness incidence in elite soccer. The aim was to determine monitoring tools or combinations of monitoring tools, which could identify athletes at risk of injury or illness.

Chapter Nine (General Discussion) provides an overview of the thesis findings. The findings related to an interdisciplinary approach to monitoring and tracking player health within EPL soccer players.

2.0 Review of Literature

2.1 – Physiological and Physical demands of soccer

2.1.1 - Physical demands of soccer

Soccer is an intermittent sport with unpredictable transitions, typically occurring every 72 seconds between multidirectional high intensity running interspersed with longer periods of low intensity running (Mohr *et al.,* 2003; Bangsbo *et al.,* 2006; Di Salvo *et al.,* 2008). During a 90-minute match, players cover a TD of 10-13km, with 10% covered at high speed and 1-4% sprinting (Mohr *et al.,* 2003; Bangsbo *et al.,* 2006; Bradley *et al.,* 2009; Di Mascio *et al.,* 2013 & Barnes *et al.,* 2014). Typically, sprints last 2-3 seconds, cover 10-20m and can reach up to 32 km.h^{-1} (Spencer *et al.,* 2005; Mohr *et al.,* 2005). Compared to sprints, players complete up three-to-eight-fold greater number of accelerations and decelerations, which contribute to 7-10% and 5-7% of PlayerLoad respectively (Varley *et al.,* 2012; Dalen *et al.,* 2016). PlayerLoad, is an instantaneous rate of change of acceleration divided by a scaling factor, and is a measure of workload, particularly considering movements within short distances (Malone *et al.,* 2017a). Barnes *et al.,* 2014, examined evolution of the work demands in the EPL and observed increases of 30-35% in both HSD (>19.8 km.h^{-1}) (1151 ± 337m vs. 890 ± 299m) and sprint distance (SD) (>25.1 km.h^{-1}) (350 ± 139m vs. 232 vs. 114m) over a 7-year period between the 2006-2007 and 2012-2013 playing seasons. Physical outputs can vary due to physical capacities, playing position, playing standard, and tactical role (Gregson *et al.,* 2010; Bangsbo, 2014). Therefore, tentative comparisons should be made when comparing physical outputs, as global or individualised thresholds are utilised to calculate high speed locomotion. In International players, HSD (>18 km.h^{-1}) and SD (>30 km.h^{-1}) could be 2400m vs. 650m respectively (Mohr *et al.,* 2003). Yet, in EPL and Championship players, HSD (>19.8 km.h^{-1}) and SD (>25.1 km.h^{-1}) ranged between 670-681m and 235-248m, respectively (Bradley *et al.,* 2009; Bradley *et al.,* 2013a).

When comparing physical outputs based upon position, wide and central midfielders (CM) cover greater TD (11535 ± 993m and 11450 ± 608m), respectively, in comparison to wide and central defenders (CD) (10710 ± 589m and 9885 ± 555m) and strikers (10304 ± 1175m) (Bradley *et al.,* 2009). CD and defensive midfielders cover the least HSD and SD in the EPL (Dellal *et al.,* 2011). CM and wide midfielders (WM) cover the most HSD (Carling *et al.,* 2008; Bradley *et al.,* 2013b). Bradley *et al.,* (2009), reported that wide defenders (WD) (287 ± 98m) and WM (346 ± 155m) covered greater SD compared with CM (204 ± 89m), central attackers (264 ± 87m) and CD (152 ± 50m). Additionally, wide vs. central players endure a higher acceleration count (Ingebrigtsen *et al.,* 2015; Dalen *et al.,* 2016; Abbott *et al.,* 2018b). Changes in traditional to modern day formations can also determine physical outputs (Bush *et al.,* 2015). For example, the compact 4-2-3-1 system requires increased HSD and SD in WD (Bush *et al.,* 2015). GKs perform a unique physical output, comprising of sharp explosive actions including diving, catching, accelerations and decelerations (Ziv *et al.,* 2011). During a match, GKs cover a TD and SD of 5611m and 61m respectively and may perform less than two 10m sprints (Malone *et al.,* 2018; White *et al.,* 2018). Additionally, from a technical perspective perform 8-14 kicks, 6.2 ± 2.7 dives, 3.8 ± 2.3 jumps and 18.7 ± 6 very dynamic displacements (De Baranda *et al.,* 2008). Positional differences in physical outputs may have implications for individual consideration of training specificity, recovery, and TL prescription.

Physical outputs can fluctuate during a match (Mendez-Villanueva *et al.,* 2013; Russell *et al.,* 2015; Fransson *et al.,* 2017). Generally, greater HSD and SD is achieved in the first half, with reductions towards the end of both halves, with match intensity declining specifically after the most intense 5-minute period (Mohr *et al.,* 2003; Di Mascio et al., 2013; Rampinini *et al.,* 2007; Carling *et al.,* 2011; Fransson *et al.,* 2017). Moreover, a 10% decrement in accelerations and decelerations were revealed during extra time compared to the initial 15-

mins (Russell *et al.,* 2015). Such declines are often attributed to acute fatigue induced by high physiological demands (Dolci *et al,* 2020). However, reductions in physical outputs cannot solely be related to fatigue, due to the myriad of factors that determine physical outputs. Notably, the temporal nature of match-play differs between GKs and outfield positions. For example, GKs cover less TD between first and second halves (2887 vs. 2663m) (White *et al.,* 2020). Yet, dive frequency and HSD covered were similar between halves, and actions including explosive efforts (7.4 ± 6.4) and high-speed changes (4.0 ± 3.3) could be greater in the second half (White *et al.,* 2020).

Players compete over a 9-month season comprising of single game weeks (Dolci *et al*., 2020). Nevertheless, the involvement in multiple domestic cups often result in multiple matches per week (Rollo *et al.,* 2014). During single game weeks, players endure a progressive reduction in TL, when approaching a match day (MD) (TD; 5223 ± 406m; 3097 ± 149m and 2912 ± 192 m, for MD-3, -2 and -1 respectively) (Anderson *et al.,* 2016; Kelly *et al.,* 2020). Therefore, TL prescription is largely influenced by competition frequency, with in-season microcycles typically lasting 3 to 7 days (Kelly *et al.,* 2020). Indeed, higher accumulative TD occurs in a three (35.5 ± 2.4 km) vs. two (32.5 ± 4.1 km) vs. one (25.9 ± 2km) game weeks (Anderson *et al.,* 2016). In contrary to outfield positions, GK training demands could be greater than competition. For example, GKs perform 51 ± 11 dives, 43 ± 15 jumps, 34 ± 12 high speed changes of direction and 70 ± 18 explosive efforts, during a ~ 79-min training session which is higher than a 90-min match (Stolen *et al.,* 2005; White *et al.,* 2020). Consequently, the training demands placed upon GKs with regards to ETL metrics and the subsequent fatigue response in GKs is pertinent to consider.

2.1.2 - Physiological demands of soccer

The intermittent stochastic nature of a soccer match involves both submaximal and maximal work intensities and is characterised by the interplay of both aerobic and anaerobic energy systems (Stolen *et al.,* 2005). During a match, 90% of the energy production comes from the aerobic energy system (Bangsbo, 1994), and subsequently an individual's average and maximum heart rate (HR) can reach between 85-98% of their relative maximal HR and core temperatures can peak at 39-40ºC (Mohr *et al.,* 2004; Krustup *et al.,* 2006; Bangsbo, 2014). Prudent, no data exists regarding the precise values of the aerobic energy system contribution during a match, due to the feasibility and impractical nature of the methods utilised (e.g., gas analyser systems or 'metabolic power' calculated via GPS) (Osnagch *et al.,* 2010; Castagna *et al.,* 2017; Dolci *et al.,* 2020). Global Positioning Systems are limited in quantifying the metabolic energy demand due to its inability to quantify contact movements, with limited displacement (e.g., tackling) (Gray, *et al.,* 2019). Physiological factors may also lead to an overestimation (dehydration and hypothermia) (Bangsbo *et al.,* 2006) or underestimation (e.g., HR lag) of the subsequent aerobic energy system contribution (Achten *et al.,* 2003; Borresen *et al.,* 2008). Energy expenditure during recovery periods and soccer specific actions (e.g., kicking) can also not be quantified (Buchheit *et al.,* 2015). Nevertheless, HR is often converted to oxygen uptake using athletes associated linear relationship obtained during treadmill running (Bangsbo 1994; Esportio *et al.,* 2004). Subsequently, estimations suggest oxygen uptake ranges from 2.5 to 4.5 $l.min^{-1}$, corresponding to a relative aerobic exertion of 70-95% VO_2max (Esportio *et al.,* 2004). Aerobic capacity is likely different amongst individuals, due to positional differences in physical outputs (Bangsbo, 1994; Reilly *et al.,* 2000; Arnason *et al.,* 2004; Bradley *et al.,* 2009). GKs have lower VO_2 max (48.41 ± 11 $ml.kg^{-1}min^{-1}$ vs. outfield players 57.7 – 62.4 $ml.kg^{-1}min^{-1}$) and blood lactate (BLa) concentration during a game than outfield positions (Sporis *et al.,* 2009; Ziv *et al.,* 2011). During a match, players could endure around 150-250 brief intense actions. Therefore, the work: rest ratios for high intensity efforts is approximately 1:12 but can drop to 1:2 during the most intense playing periods (Di Mascio *et al.,* 2013). Average [BLa] are between 2-10 mM, indicating a high production of muscle lactate and therefore anaerobic energy production through glycolysis, during high intensity periods (Krustup *et al.,* 2006; Bangsbo *et al.,* 2006). Anaerobic energy contribution may also be underestimated due to the timing of blood samples (Stolen *et al.,* 2005).

It is likely, [BLa] accumulation is higher during intermittent activities, supported by 40-90% muscle glycogen depletion evident post-match (Krustup *et al.,* 2006; Bangsbo *et al.,* 2007). Likewise, the breakdown of creatine phosphate may be high during high intensity efforts, with the resynthesis occurring during recovery periods of low intensity exercise (Bangsbo, 1992). Post-match creatine phosphate levels can be 70% lower compared to pre-match values (Bangsbo, 1994; Krustup *et al.,* 2006). Moreover, free fatty acid concentration in the blood increases during a game (Krustup *et al.,* 2006) which indicates a high turnover of glycerol (Bangsbo, 1994). Therefore, a high aerobic and anaerobic demand during periods of a match, facilitate metabolic changes contributing to fatigue accumulation during and towards the end of the game (Bangsbo *et al.,* 2007). Unsurprisingly, a high aerobic capacity can help delay fatigue through indirectly enhancing recovery between intensive activities which may enhance match performance and post-match fatigue accumulation, helping to optimise recovery between matches (Ziv *et al.,* 2011).

2.1.3 - Recovery in soccer

The evolving nature of soccer and increased physical demands highlights the necessity of monitoring a player's recovery from match play (Barnes *et al.,* 2014). It is evident post-match, players have an attenuated neuromuscular function (countermovement jump (CMJ) and sprint performance), and altered biochemical profiles indicative of muscle damage, inflammation, and immune function (e.g. creatine kinase, C-Reactive Protein and Salivary Immunoglobulin A (sIgA) and perceptual markers (e.g., delayed onset muscle soreness (DOMS)) (Ascensao *et al.,* 2008; Ispiridis *et al.,* 2008; Ascensao *et al.,* 2011; Thorpe *et al.,* 2012; Nedelec *et al.,* 2014). Increased DOMS obtained during the eccentric muscle actions during training and match play could be portrayed in declines in sprint performance as much as 7-9%, 24 hours and 5% 48 hours post-match (Ispiridis *et al.,* 2008; Fatouros *et al.,* 2010; Magalhaes *et al.,* 2010; Silva *et al.,* 2013). Delayed onset muscle soreness is highest 24 hours post-match (Ispiridis *et al.,* 2008) and remains elevated for 48 hours post-match (Fatouros *et al.,* 2010). Additionally, creatine kinase has increased by 84%, post-match compared to pre-match (Thorpe *et al.,* 2012), despite not being significantly different, this could reveal the perceptual, physical, and physiological muscle damage endured. Noteworthy, recovery can be dependent upon playing position (outfield vs. GKs) (Nedelec *et al.,* 2019a). In comparison to GKs, outfield players took longer to restore their six second sprint performance post-match (Nedelec *et al.,* 2019a). Moreover, muscle damage (measured via changes in creatine kinase and myoglobin) also appears dependent upon the SD and HSD accumulated during a match (r= 0.89. and 0.92, respectively) (Thorpe *et al.,* 2012). Subsequently, players can accumulate substantial fatigue during match play, which can result in decline in performance and physical health indicators. It is therefore pertinent soccer players appropriately recover from match-play.

2.2 Prevalence of injury, illness, and mental health

2.2.1 - Injury and illness incidence

Between 2001-2016, injury incidence has augmented in elite senior soccer from 1.3 to 1.9 injuries per player per season, respectively (Hawkins *et al.,* 2001; Jones *et al.,* 2019). A typical 25-player EPL squad can sustain two injuries per player per season, resulting in 50 injuries overall (Ekstrand *et al.,* 2011; Jones *et al.,* 2019). Specifically, 50% of these injuries are minor with a typical injury burden of < 1 week, however around 12% of injuries can result in a typical injury burden of > 4 weeks, equating to 881 player day's (total days missed from training) (Ekstrand *et al.,* 2011; Ekstrand *et al.,* 2013). In the EPL, an average weekly wage is approximately £50,000 per week (Sporting Intelligence, 2017), therefore injuries are associated with a financial burden of approximately £12.5 million per club per season (Fuller *et al.,* 2019).

Increased periods of injury incidence can coincide with higher training volumes and/or fixture congestion, typically occurring across July-August (pre-season) and December (Jones *et al.,* 2019). Additionally, injury incidence is higher during match play (24.29/1000h) compared to training (6.84/1000h) (Jones *et al.,* 2019) and interestingly, is greater in English leagues compared to their European counterparts (9.11 vs. 8.0 injuries/1000h) (Ekstrand *et al.,* 2011). The most common injuries are hip/groin injuries contributing to 12-16% of all injuries per playing season, creating an injury burden of 50 player day's per team (Werner *et al.,* 2009; Ekstrand *et al.,* 2011; Walden *et al.,* 2015). Also, hamstring injuries have increased by 4% annually in men's professional soccer since 2001 (Ekstrand *et al.,* 2015).

Despite being less severe, illnesses are as common as injuries (Theron *et al.,* 2013). Illnesses including upper respiratory (74.5%) and gastrointestinal illnesses (13.7%) can be as high as 2.5 incidents per player per season (Orhant *et al.,* 2010). However, not all illness incidences result in time loss and could result in under performance. This is likely due to the inability to sustain heavy training, making the potential deleterious effects of illnesses difficult to quantify (Gleeson, 2007; Orhant *et al.,* 2010). Both injury and illness can be deleterious to performance and team success due to missed training sessions and matches (Hagglund *et al.,* 2013; Eirarle *et al.,* 2013). Therefore, by reducing injury and illness occurrence, this can significantly improve team performance (Jones *et al.,* 2017). As fixture congestion and high physical match demands which are associated with injury and illness are likely to increase in the future (Nassis, 2020), future research should be conducted to provide insights into ways practitioners could try and reduce injury and illness risk and optimise performance.

2.2.2- Prevalence of Mental Health disorders

MH has been defined as a 'state of wellbeing in which every individual realises his or her own potential and can cope with the normal stressors of life, can work productively and fruitfully and is able to contribute to his or her community' (WHO, 2014). In elite sporting environments there is an emerging interest into MH, with athletes experiencing a wide range of MH disorders (MHD) (Appaneal *et al.,* 2009; Gulliver *et al.,* 2015; Rice *et al.,* 2016). A MHD is characterised by 'a clinically significant disturbance in an individual's cognition, emotional regulation, or behaviour. It is usually associated with distress or impairment in important areas of functioning'(WHO, 2022). Some examples of MHDs include depression, anxiety and eating disorders. MHD are associated with MH symptoms, which can include yet not exhaustive, sweating, nervousness, and low mood. Within athletic populations the prevalence of MHD and symptoms could exceed the general population (Reardon *et al.,* 2019). This is unsurprising given the peak competitive years of an athlete's career correlates with the peak age for risk of MHD (Gulliver *et al.,* 2012). A position statement reported MHD and symptoms in team sport athletes were 5% for burnout and adverse alcohol behaviours and 45% for adverse anxiety and depression (Reardon *et al.,* 2019). Moreover, in a meta-analysis of 22 studies, 19% reported alcohol misuse, and 34% reported anxiety and depression symptoms (Gouttebarge *et al.,* 2019). Notably, these are higher than the UK general population, whereby 18.3% reported symptoms of anxiety or depression, with a higher percentage of females (21%) reporting anxiety or depression compared to males (16%) (Office for National Statistics, 2013).

Within professional soccer, a review suggests the prevalence of MHD, and symptoms were in-keeping with the general population (Woods *et al.,* 2022). However, it could be a greater prevalence exists within soccer than alternative sports (Gouttebarge *et al.,* 2015a; Gouttebarge *et al.,* 2015b; Junge *et al.,* 2016; Kilic *et al.,* 2018; Kilic *et al.,* 2021). Within

262 players from 5 European Countries (Finland, Norway, Spain, France, and Sweden), 37% reported symptoms of common MHD over 12-months (Kilic *et al.,* 2018). Additionally, in 607 players, 9% reported alcohol misuse, 38% anxiety and depression and 58% adverse nutrition (Gouttebarge *et al.,* 2015a). The prevalence of MHD and symptoms may be dependent upon age, gender and playing position (Junge *et al.,* 2016; Prinz *et al.,* 2018). Higher rates of depression have been reported in youth vs. senior athletes (15 vs. 6.6%) (Kuettal *et al.,* 2021b). Moreover, attackers report higher anxiety and depression symptoms in contrary to their midfield counterparts (Junge *et al.,* 2016; Prinz *et al.,* 2018). Interestingly, service provision for athletes can vary largely across different sport settings (Larsen *et al.,* 2021). Specific to soccer, in the current elite players performance plan category 1 academy guidelines, one full-time (or equivalent) health care professional council accredited academy psychologist should be employed (Football Association, Premier League Limited, 2020, P. 153). Yet, in contrary, there are no requirements for the psychological support in EPL soccer players. Therefore, potentially making soccer players vulnerable to experiencing poor MH. As with injury and illness, the development of poor MH can elicit significant burdens including injury risk, poor performance and athlete wellbeing. For example, daily hassles, trait anxiety, and negative life events stress accounted for 24% of the variance when predicting injury (Ivarsson *et al.,* 2013). Additionally, worse daily mood was a predictor of injury (Watson *et al.,* 2016). Poor MH could also attenuate performance (Reardon *et al.,* 2019).

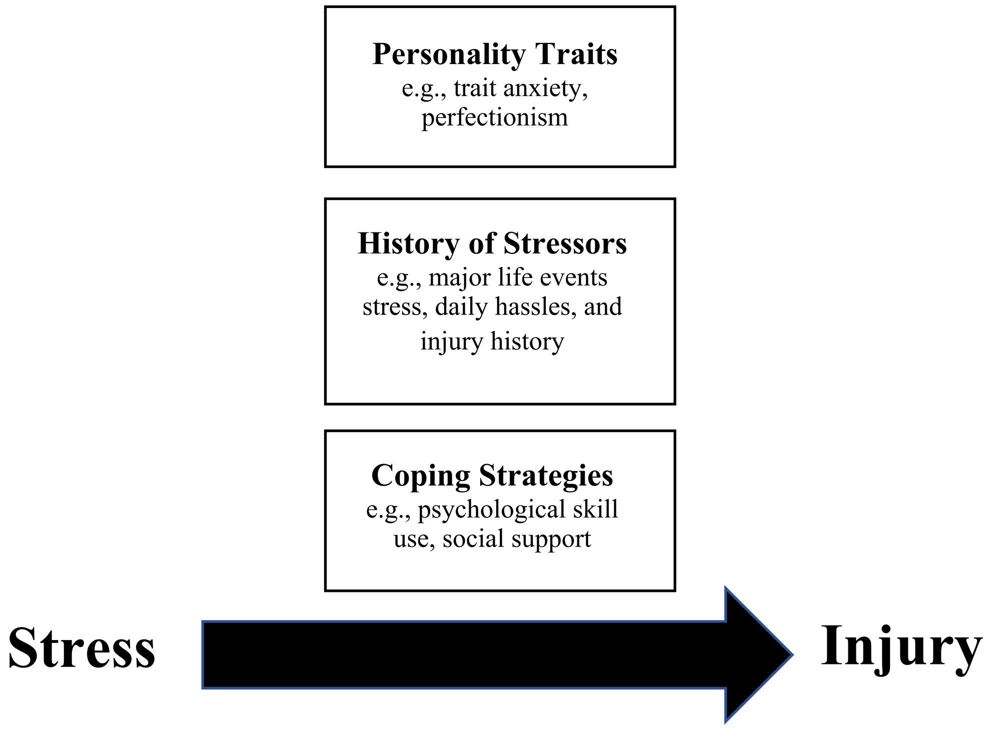

Figure 2.1 The Williams and Andersen Stress-Injury Model (Williams and Andersen, 1998).

Indeed, the Williams and Andersen Stress-Injury Model (1998) demonstrated in Figure 2.1 can describe the casual link between psychological stress and injury risk. An individual with a heightened stress response could be at increased injury risk due to attentional and somatic changes including an increased distractibility and peripheral narrowing, as well as muscle tension, fatigue, and reduced timing/coordination (Ivarsson *et al.,* 2013; Williams and Andersen, 1998). In the context of football, a professional soccer player may be worried about obtaining a professional contract (e.g., a major life stressor), and when placed in a stressful situation (e.g., competitive fixture) heightened attentional and physical deficits can prevent adequate reactions in game play to avoid injury and poor performance.

Overall, given MH could attenuate performance and augment injury and illness risk, and is an determinant on an athletes individual wellbeing (Giles *et al.,* 2020), it is an important aspect of an athlete's health status.

2.3 Training load monitoring

2.3.1 – Theoretical basis of athlete monitoring

Originally, the 'general adaptation syndrome' model describes the training process in four stages (Selye, 1956). A sufficient stimulus is required to disrupt the physiological homeostasis (alarm reaction stage), which through fatigue and sufficient recovery, causes an enhanced resistance (resistance stage) to future training stimuli (supercompensation) (Eaton *et al.,* 2006; Selye, 1956). Stressors applied beyond adaptive capabilities and coincided with insufficient recovery, can result in a reduced resistance (exhaustion stage). This is also termed the 'dose-response' relationship (Smith, 2003), whereby the 'dose' represents the physiological stress imposed on an athlete and the 'response' is the physiological training adaptations that occur following sufficient recovery (Smith, 2003; Lambert *et al.,* 2010). Nevertheless, the relationship between performance, fitness, and fatigue is often too simplistic. Subsequently, a fitness- fatigue model is proposed to explain performance (performance = fitness – fatigue) (Bannister *et al.,* 1975). Associations between TL and performance are limited because of complex interactions and individual effects (Coutts *et al.,* 2014). Therefore an 'inverted-U' model has been utilised to explain an optimal individualised turning point, where maladaptive responses past this point will occur (Moxnes *et al.,* 2008). The concept of 'functional' overreaching suggests fatigue and acute decrements in performance is essential during the training process (Halson *et al.,* 2004; Coutts *et al.,* 2014) resulting in training adaptations and performance enhancement following sufficient recovery (Kentta *et al.,* 1998; Meeusen *et al.,* 2013). In contrary, 'non-functional' overreaching can occur, which is a combination of exposure to high chronic TL with insufficient recovery (Budgett, 1994; Meeusen *et al.,* 2013), resulting in maladaptation and staleness and if prolonged and coupled with daily life demands and psychological stressors, the 'overtraining syndrome' can occur (pain sensations, physical complaints, and endocrinological disturbances) (Kentta *et al.,* 1998; Meeusen *et al.,* 2013; Kellmann *et al.,* 2018). Pertinent, underloading an athlete can be just as intolerable as overloading an athlete (Gabbett *et al.,* 2016). Therefore, in or excessive TL may increase injury and illness risk, maladaptation, and attenuate performance (Halson *et al.,* 2004; Meeusen *et al.,* 2013; Veuglers *et al.,* 2016).

The training dose may elicit individual adaptation or overtraining responses (Budgett *et al.,* 1998). It is likely, individuals adapt to training and competition stress over varied time courses, which is dependent upon individual characteristics and recovery rate (Borresen *et al.,* 2008). These can include both modifiable (i.e., psychological skills such as coping skills) and non-modifiable factors (i.e., age and training history) (Smith, 2003; Borresen *et al.,* 2009). Psychological characteristics such as social or non-training stressors, are also pertinent (Kellmann, 2002). An optimal balance between training prescription and rest is required to ensure improvements in performance, reduce illness and injury risk and subsequent non-functional overtraining and overreaching.

In elite soccer during fixture congestion, adequate rest may not be feasible and therefore load periodisation is pertinent. Load periodisation considers the training process performed not only on a single basis but the application of training stimuli across a week or longitudinally. Given the importance of recovery, non-invasive monitoring tools that are indicative of fatigue status, non-exhaustive, time-efficient, and are related to TL are required to help manage the prescription of load (Gabbett *et al.,* 2016; Thorpe *et al.,* 2017). As multifaceted adaptations can occur, this makes it difficult to predict an athlete's subsequent fitness and fatigue response (Coutts *et al.,* 2018), highlighting the importance of an interdisciplinary approach to tracking an athlete's training response.

2.3.2 – Training load monitoring techniques

Training load monitoring is required to determine the effectiveness of the training process by accurately quantifying the TL completed by an athlete. Too high or too low TL could result in under performance and increased injury and illness risk. Therefore, it is pertinent that TL is accurately prescribed to elicit desirable recovery responses and training adaptations to stimuli, which will enhance injury prevention and performance. The quantification of both ITL and ETL is recommended (Impellizzeri *et al.,* 2019). External Training Load provides an objective measure of work performed by an athlete during training and competition, whilst ITL indicates the relative physiological and psychological stressors imposed on an athlete (Bourdon *et al.,* 2017). Typically, to quantify ITL (i.e., training session intensity), both subjective (e.g., ratings of perceived exertion (RPE)) and objective (e.g., HR and BLa monitoring) measures are recorded (Bourdon *et al.,* 2017). In applied sport settings, both ITL and ETL can be interpreted through multiple derivatives. These include, acute (7-day) and chronic (28-day) workloads, the acute: chronic workload ratio (ACWR), exponentially weighted moving averages (EWMA), training monotony and training strain.

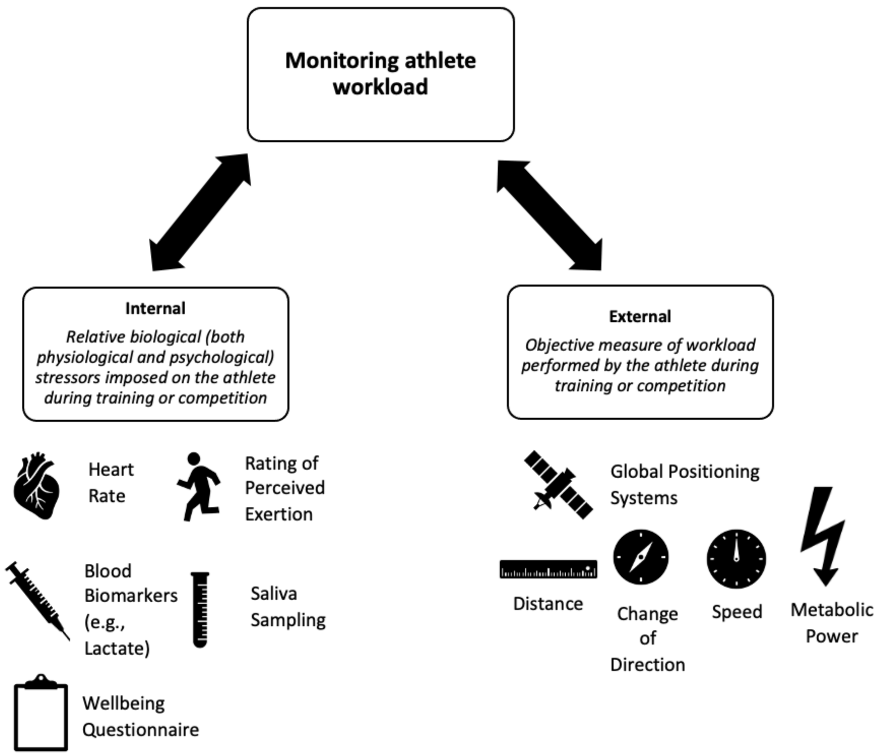

Figure 2.2: A summary of the available tools to monitor athlete workload (Miguel *et al.,* 2021)

2.3.3 – Rating of Perceived Exertion

Rating of perceived exertion is commonly utilised within sports due to being practical and cost-effective (Akenhead *et al.,* 2016; Williams *et al.,* 2017). Individuals subjectively rate their perceived session intensity utilising the 1-10 Borg-Scale (Borg *et al.,* 1982). Rating of Perceived Exertion is then multiplied by the session duration (min) to calculate a session RPE (sRPE) (Arbitrary unit) (Foster *et al.,* 1998). Subsequently, RPE can reflect both the physiological (work completed) and psychological demands (mental fatigue, effort, stress, and motivation) (Halson, 2014; Coyne *et al.,* 2018). By not being able to differentiate between the physiological and psychological demands, this can result in sRPE misrepresenting the actual workload performed. Therefore, differential RPEs have been explored including local (leg-based), central (breathlessness) and a rating of overall physical exertion, in addition to technical demands to distinguish between both perceived effort and fatigue (Weston *et al.,* 2015).

The differentiating RPE is related to HR, demonstrating the validity of both HR and RPE to reflect training intensity in soccer (Impellizzeri *et al.,* 2004; Coutts *et al.,* 2009; Casamichana *et al.,* 2013; Gaudino *et al.,* 2015;). sRPE has revealed moderate-strong associations to HR in soccer training (r = 0.5 to 0.97) (Impellizzeri *et al.,* 2004; Borresen *et al.,* 2008; Alexiou *et al.,* 2008), such as between sRPE and training impulse (TRIMP) (r = 0.50 to 0.77) (Impellizzeri *et al.,* 2004). Moreover, sRPE is moderately related to the number of impacts performed (r = 0.45) (Gaudino *et al.,* 2015). Nevertheless, associations between HR and RPE are dependent upon exercise modality and contribution of energy systems. As such, sRPE and HR-based measures are strongly related to technical (r= 0.68 to 0.82), conditioning (r= 0.60 to 0.79) and speed sessions (r= 0.61 to 0.79). However, resistance sessions (typically involving short high intensity efforts) are moderately related to HR (r = 0.25 to 0.52). During high intensity soccer drills, physiological demands can be mis-captured as HR responses have a latent tendency (Little *et al.,* 2007). Therefore, HR responses are limited when quantifying the high intensity demands of the sport (Castellano *et al.,* 2013; Domene *et al.,* 2013; Hogson *et al.,* 2014). Despite, RPE providing a global response to training and competition, given the above limitations, ETL may better represent training demands.

2.3.4 – Training Impulse

Heart Rate monitoring is common practise to determine exercise intensity and ITL in sport (Borresen *et al.,* 2008; Halson, 2014; Miguel *et al.,* 2021). Session intensity is often described as a percentage of an individual's maximal or average HR (Achten *et al.,* 2003). Based upon the assumption that a linear relationship between rate of oxygen consumption and HR exists, a TRIMP is calculated by multiplying the HR indices by the session duration (min) (Bannister, 1991; Borresen *et al.,* 2009). Whilst this assumption may reflect the session intensity of steady state sports (e.g., running) (Borresen *et al.,* 2009), its application to intermittent sports is limited, which comprise of high-intensity components and non-field-based work (resistance and plyometric training) (Coutts *et al.,* 2014). To overcome this, numerous TRIMP variations have been utilised including the Edwards TRIMP (time spent in each HR zone) (Edwards, 1993), the Lucia's TRIMP, (evaluation of TL according to ventilatory thresholds) (Lucia *et al.,* 2000), the Stagnos TRIMP (evaluating the BLa profiles and obtaining a standard curve of response to increased exercise intensity) (Stagno *et al.,* 2007) and the iTRIMP (which utilises individualised BLa profiles and has an individualised weighting factor) (Manzi *et al.,* 2009). Nevertheless, such methods are limited due to requiring technical expertise, and produces a substantial time and financial burden which reduces the application in team-based sports (Manzi *et al.,* 2009).

Importantly, associations between TRIMP models and sRPE in both female and male soccer players have been examined (r = 0.49 to 0.85; P < 0.01) (Impellizzeri *et al.,* 2004; Alexiou *et al.,* 2008). However unsurprisingly, stronger associations were reported in the training sessions which required a greater aerobic contribution. In a recent meta-analysis of 295 athletes and 10148 individual session observations, TD correlated most with ITL in comparison to alternative ETL metrics (McLaren *et al.,* 2018). Taken together, enhances the notion that HR-based measures are limited in intermittent sports (Alexiou *et al.,* 2008). Silva *et al.,* (2018a) reported associations between accelerations (>2.5 $m.s^{-1}$), number of high intensity bursts and the Banisters TRIMP, yet not for HSD. These findings, further reinforce HR measures are poor at quantifying short high intensity efforts with a heavy neuromuscular component (Silva *et al.,* 2018a). Consequently, this emphasises the necessity of quantifying ETL. External Training Load is utilised to quantify workload, in combination with sRPE rather than HR-based TRIMP methods (McLaren *et al.,* 2018; Impellizzeri *et al.,* 2019).

2.3.5- External Training Load

Global Positioning Systems and accelerometery technology are extensively utilised in professional sport to provide a practical and objective method to evaluating locomotive and non-locomotive ETL in both training and competition (Casachimchana *et al.,* 2013; Cummins *et al.,* 2013; Colby *et al.,* 2014; Jones *et al.,* 2015; Malone *et al.,* 2017a). GPS devices provide extensive athlete profiles by measuring position, velocity, and acceleration in which multiple ETL metrics can be quantified (e.g., TD, accelerations, work rate, and time and distance covered within specified speed thresholds) (Cardinale *et al.,* 2016). Specifically, within EPL soccer, metrics such as TD, HSD, ED, and SD are frequently monitored both in real time and longitudinally (Portas *et al.,* 2010; Akenhead *et al.,* 2016; Tabener *et al.,* 2020). In contrary to ITL measures (e.g., HR and RPE), objectively quantifying soccer specific actions that represent the true physical demands of training, can ensure training responses to given ETL can be monitored, and prescribed to periodise acute fatigue, mitigate injury and illness risk, and enhance performance (Bowen *et al.,* 2019). Additionally, ETL can assist in developing capacities to cope with future competition demands, characterise match demands, positional workloads, tactical demands, and rule modifications (Aughey, 2011; McLellan *et al.,* 2011; Gabbett *et al.,* 2012; Cummins *et al.,* 2013; Hausler *et al.,* 2016).

Global Positioning System devices function by satellites orbiting the earth and relaying precise time information from an autonomic clock to GPS receivers (Malone *et al.,* 2017a). The time it takes the receiver to obtain signal transmission from the satellites, allows for the distance between them to be calculated (Malone *et al.,* 2017a). To locate the GPS receiver position trigonometrically and determine displacement, a minimum of four satellites are required (Malone *et al.,* 2017a). Whilst GPS can provide practitioners with a wealth of valuable information, the validity and reliability of GPS units can be influenced by a myriad of factors, including sampling frequency, velocity, duration, and type of task (Aughey *et al.,* 2011). Due to technological advancements, GPS units are available and sample at a frequency of 1Hz, 5Hz, 10Hz or 15Hz, with the validity and reliability between sampling frequencies over various running speeds, distances, and soccer specific movements previously investigated (Portas *et al.,* 2010; Jennings *et al.,* 2010; Akenhead *et al.,* 2014; Rampinini *et al.,* 2015). Generally, the higher sampling rate, the increased validity and reliability (Aughey, 2011; Cummins *et al.,* 2013). Higher frequency sample rates increase the amount of data points recorded during a second, which coincides with a more sensitive measure of velocity than lower sample rates (Malone *et al.,* 2017). Initial 1Hz and 5Hz units are limited when quantifying accelerations, decelerations, changes of direction and high-speed running (9-32.4 CV%) (Jennings *et al.,* 2010; Coutts *et al.,* 2010; Aughey, 2011; Scott *et al.,* 2016). However, the development of 10Hz has allowed for two-three times more accurate data compared to 5-Hz units (Varley *et al.,* 2012). Scott *et al.,* (2016) reported 10Hz units have good to moderate interunit reliability (5.1 CV%) when quantifying high speed locomotion and is reliable in detecting TD and number of efforts performed at high and low running speeds (< 10 CV%) (Johnston *et al.,* 2014). Ten Hz and 15Hz units are still limited however at high velocities and quantifying small changes of direction (Jennings *et al.,* 2010; Aughey, 2011), which is limited by technological advancements (Malone *et al.,* 2017). Indeed, movements requiring horizontal displacement (e.g., player contacts) and soccer specific movements (e.g., tackling) can exert a substantial load which cannot be detected in GPS. Therefore, an athlete's load could be underestimated utilising time-motion analysis (Boyd *et al.,* 2013). To overcome limitations in velocity-based metrics, high sampling frequency (100Hz) accelerometers have been integrated into GPS. Triaxial accelerometers measure the total number of accelerations performed in the three axes (x, y and z), producing a composite vector magnitude, expressed as a g-force (Waldron *et al.,* 2011). This allows metrics such as changes in direction, PlayerLoad and total body contacts to be derived (Cummins *et al.,* 2013; Boyd *et al.,* 2013). PlayerLoad is calculated by the square root of the sum squared instantaneous rate of change in acceleration in each of the three movement vectors divided by 100 (Boyd *et al.,* 2011). Ten Hz devices provide sufficient accuracy and a CV of 1.2-6.5% when recording accelerations and decelerations, however the validity and reliability of quantifying these actions are still questioned (Shergill *et al.,* 2021; Crang *et al.,* 2021). Monitoring accelerations and decelerations counts are pertinent in soccer, as players are required to perform rapid changes in direction and sport-specific movements both in and out of possession (Bowen *et al.,* 2017). Subsequently these metrics represent a significant proportion of an athletes ETL (Delves *et al.,* 2021) and are responsible for both metabolic demands and implications on muscle damage through eccentric loading respectively (Hewitt *et al.,* 2011; De Hoyo *et al.,* 2016). Therefore, such measures are important in evaluating associations between TL and injury risk.

Technological advancements have allowed for player movements to be monitored utilising GK-specific 10-Hz MEMS units. Sampling at 10Hz has demonstrated (2.0-5.3 CV: Varley *et* *al.,* 2012) for measuring instantaneous velocity and the accelerometers within the devices have produced good intra and inter-unit reliability (0.9-1.1 CV; Boyd *et al.,* 2011) in both laboratory and field test environments. Non-locomotive movements (e.g., jump count and flight time) have also been validated in Rugby and Volleyball (Gaegler *et al.,* 2015; Reardon *et al.,* 2017). Overall, the true potential of GPS technology is unknown (Hennessy *et al.,* 2019). Global Positioning Systems can be expensive and require labour-intensive analysis. Additionally, cannot quantify all football specific movements (e.g., ball striking) which contributes to physical workloads. These limitations rationalise the utilisation of both ITL and ETL to calculate a player's workload. However practically, it is not always possible to quantify both in elite environments.

2.4 – Training Load, Injury, and Illness

2.4.1- Training load and injury

In a systematic review, intensified training periods, and changes in both acute and cumulative loads have been associated with increased injury risk (Jones *et al.,* 2017). For example, Piggott *et al.,* (2009) revealed a 10% increase in TL was related with 40% of injuries, during a 15-week preseason in Australian Football players (AFL). However sufficient TL can also 'protect' against injury occurrence. From this perspective, in a systematic review of 31 studies, 93% observed associations between TL and injury and 31% reported 'protective' effects of TL (Jones *et al.,* 2017). The extent to which a TL dose is protective or detrimental to injury risk, can be best explained by the 'TL-injury prevention paradox model' proposed by Gabbett *et al.,* (2016), and the utilisation of the ACWR. A ratio between 0.8-1.3 is considered the 'sweet spot', whereas ratios below 0.8 and above 1.3 increase injury risk (Gabbett *et al.,* 2016). In support of the ACWR and injury risk, associations have been revealed in cricket (Hulin *et al.,* 2013), AFL (Colby *et al.,* 2017; Murray *et al.,* 2017;

Esmaelli *et al.,* 2018b; Stares *et al.,* 2018), and soccer (Bowen *et al.,* 2019; Bowen *et al.,* 2016; Jaspers *et al.,* 2018; McCall *et al.,* 2018). Moreover, increased acute: chronic TL have been related to injury in multiple sports, including AFL (Rogalski *et al.,* 2013), soccer (Jaspers *et al.,* 2018) and in rugby union (RU) (Cross *et al.,* 2016; Williams *et al.,* 2017). Specifically, within soccer, the relationships and predictive value of TL and injury are discussed in Table 2.1. Prudent, multiple inconsistencies exist between studies, such as different definitions of injury, the nature of injury (contact vs. non-contact), the TL derivative used, the sport studied, and inclusion of match and training data. Nevertheless, generally TL is associated with injury risk and should be considered when predicting injury risk. Such relationships could be best explained by mechanical load and psycho-physiological load-response pathways (Kalkhoven *et al.,* 2021). It is likely when a force (e.g., high training loads) are applied to a tissue this results in mechanical fatigue damage and failure in biological tissues (e.g., bones, muscles, and tendons) termed 'stress' and 'strain' which is linked to injury occurrence. Given that psycho-physiological pathways reflect the stress and strain endured by an athlete also, this interrelation suggests that both pathways could be responsible for injury. Nevertheless, a clear aetiology between athletic injuries and training load is yet to be established (Kalkhoven *et al.,* 2021).

Table 2.1: A summary of studies specifically investigating associations between training load and injury in male soccer players.

Study	Sample	Injury Type/Severity	Training load	Main Findings
Bowen *et al.,* (2016)	32 elite English youth players	138 time-loss injuries (22.1±52.8 days absence)(6.9/1000hrs non-contact vs. 5.2/1000hrs contact). Over two seasons	GPS variables; TD, HSD, SD and ACC and total load.	3-week ACCs (>9254) were associated with injury. Non-contact IR was associated with high acute and low chronic load HSD (RR = 0.47). Contact IR was associated with ACWR TD and ACCs (1.76 and 1.77) (RR = 4.98).
Malone *et al.,* (2017b)	48 Professional players	75 contact and non-contact time-loss injuries. Over one season	ITL sRPE 1 weekly loads and ACWR.	ACWR of > 1.00 to < 1.25 (OR = 0.68, *P* = 0.006) lowered IR compared to <0.85.
Delecroix *et al.,* (2018)	130 elite players	237 non-contact injuries. Over one season	ITL 1,2,3 and 4 weekly loads and daily monotony strain.	3-week monotony was associated with IR (RR = 0.72, 95% CI [0.58-0.90], *P* = 0.004).
Fanchini *et al.,* (2018)	34 elite Italian players	90 non-contact time-loss injuries (18 re injuries) and excluded. Over three seasons	1,2,3 and 4 weekly and ACWR ETL and IR (TD, LID, HSD, ACCs, DCCs)	Acute:chronic markers showed association with injury however poor prediction ability.
McCall *et al.,* (2018)	171 elite European	123 non-contact injuries over a season	ITL acute weekly changes and ACWR	ACWR at 1:3 and 1:4 weeks were associated with injury (P <0.05).
Jaspers *et al.,* (2018)	35 professional male	64 overuse non-contact injuries, over two seasons	1,2,3,4 weekly loads and ACWR for sRPE, HSD, ACCs, DCCs, cumulative 1,2,3,4, weekly loads and ACWR.	Higher 2- to 4- weekly TD, DDCs and sRPE were related to higher IR. A high ratio for HSD (>1.18) resulted in a higher IR.
Bowen *et al.,* (2019)	33 professional players	132 non-contact injuries, over three seasons	Cumulative 1,2,3, and 4 weekly loads and ACWR and IR were examined over three seasons.	IR high when the chronic exposure to DCCs was low (<1731) and the ACWR was >2.0 (RR = 6.7). Additionally, 5-6 times higher for ACCs and LID when the chronic workloads were low and the ACWR was >2.0 (RR = 5.4-6.6),
Raya-Gonzalez *et al.,* (2019)	22 U19 Spanish players	27 non-contact injuries, one season	Weekly and ACWR ITL (sRPE)	No associations between weekly load or ACWR.
Howle *et al.,* (2019b)	42 elite players	100 time-loss injuries. 32 contact and 68 non-contact injuries over three seasons	1 and 2 game week loads (sRPE and low, high and very high intensity running)	Total injury rates were increased during multi-match weeks (*P* = 0.001).
Tiernan *et al.,* (2020a)	15 elite players	35 time-loss injuries. 21 non-contact and 14 contact injuries, over one season	1,2,3 4 weekly, and ACWR ITL	An increase in EMWA ACWR was associated with contact and non-contact injury (OR = 1.30 and 1.35). 2- and 3-week cumulative load was associated with contact injury. (OR = 1.77 and 1.55).

- **TD – Total Distance, HSD – High Speed Distance, LID, Low Intensity Distance, RR – Relative Risk, TL- Training Load, ACWR – Acute: chronic workload ratio, sRPE – sessional rating of perceived exertion, ITL – Internal Training Load, ETL – External Training Load, OR – Odds Ratio, IR – Injury Risk, ACCs – Accelerations, DCCs - Decelerations.**

2.4.2 – Training load and illness

In athletes, 74.5% of illness incidences are categorised as an 'upper respiratory tract infection' (URTI) (Orhant *et al.,* 2010). URTIs are likely during periods of intense training, competition, and inadequate recovery (Bishop *et al.,* 2009; Simpson *et al.,* 2020). Noteworthy, there is strong theoretical rationale to suggest TL and illness incidences are related. Associations between TL and illness incidences can be explained by the 'J Shaped' model whereby, insufficient, or prolonged intensive exercise and moderate intensity exercise increases and decreases the risk of URTI, respectively (Nieman, 1994). Post intensive exercise can result in an immune suppression response for infection up to 72 hours post-exercise (Nieman, 2000). However, the overall impact of TL on innate and acquired immune parameters (magnitude, direction of changes, and recovery time) is dependent upon the intensity and duration (Simpson *et al.,* 2020).

Associations between illness and TL have been examined extensively (Drew *et al.,* 2016). A systematic review reported insufficient recovery from initial spikes in TL may cause an extended period of suppressed immune function, increasing their illness risk (Jones *et al.,* 2017). For example, IgA is an immune marker, and provides a first line of defence to viruses and antigens (Mazanec *et al.,* 1993). Indeed, increased TL has been associated with a reduction in IgA (Mortatti *et al.,* 2012). Moreover, immune function biomarkers including NK cell and neutrophil function, T and B-lymphocyte function, could be altered for several hours to days during recovery from prolonged and intensive endurance exercise (Shaw *et al.,* 2017). Additionally, a systematic review revealed a significant moderate relationship between TL and illness incidence (n = 6, 75%) (Drew *et al.,* 2016). Previously research has demonstrated TL to be related to illness in multiple sports including soccer (Putlur *et al.,* 2004; Watson *et al.,* 2016; Tiernan *et al.,* 2020b), RU (Cunniffe *et al.,* 2011) futsal players (Moriera *et al.,* 2013) and AFL (Piggott *et al.,* 2009; Veuglers *et al.,* 2016). These findings are summarised in Table 2.2. Nevertheless, associations between TL and illness have not always been reported (Andersen *et al.,* 2003; Fitzgerald *et al.,* 2019; Tiernan *et al.,* 2020b). The investigation between illness incidences and TL could be confounded due to close contact with others, but also illnesses such as self-reported URTIs could be misreported as allergens. Yet, due to the strong theoretical rationale between TL and illness, and some evidence behind associations between TL and illness, TL should be considered when predicting illness risk.

Table 2.2: A summary of studies specifically investigating associations between training load and illness.

Study	Sample	Study Design	Main Findings	Number of illnesses
Foster *et al.,* (1998)	25 Speed Skaters (male – 16, female – 9)	The relationship between training monotony strain and rolling 6-week average ITL and illness incidence were investigated over a 15-week preseason	1-week sRPE identified lower illness odds (OR = 0.083 – 0.182*,* P <0.05) Training monotony score was higher >2.0 AU explained 77% of illnesses and previous weeks TL explained 84% illnesses	13 banal illnesses
Andersen *et al.,* (2003)	12 women's collegiate basketball players	21 weeks. The relationship between weekly ITL (sRPE), training monotony and strain and illness risk were investigated over 21 weeks.	Weekly TL and illness risk were not related.	36 time-loss
Putlur *et al.,* (2004)	14 female soccer players	The relationship between weekly ITL (sRPE), training monotony and strain and illness incidence over 9 weeks were investigated.	55% and 64% of illnesses could be explained by a preceding spike in TL and training strain and monotony, respectively.	11 time-loss illnesses (e.g. cold, flu and virus)
Piggott *et al.,* (2009)	16 AFL Players.	The relationship between ITL (sRPE, min >80% max HR), ETL (TD, TD <12km) were investigated over 20 weeks.	A 10% spike in TL could explain 42% of illnesses	12
Cunniffe *et al.,* (2011)	31 RU Players	Over 11 months, the relationship between weekly ITL (sRPE) and URTI were investigated.	Peaks in URTI (December and March) were preceded by increased TL	123 URTI
Moreira *et al.,* (2013)	12 Brazilian Futsal Players	The relationship between weekly ITL (sRPE) and URTI severity were investigated over 4 weeks.	Weekly TL and URTI severity (week 4) (r = 0.75, P <0.05)	URTI Symptoms.
Watson *et al.,* (2016)	75 adolescent soccer players	Over a 20-week training period. The relationship between daily, weekly, and monthly ACWR ITL (sRPE) and illness incidence were investigated.	Monthly TL was higher preceding with an illness (12442 ± 409 vs. 12627 ± 403, P = 0.043). Monthly TL (P = 0.007, OR = 1.54) predictors of illness	52 time-loss
Fitzgerald *et al.,* (2018)	44 male AFL Players	Over a 46-week season. The relationship between ACWR ITL (sRPE), ETL (TD, HSD and SD) and illness incidence were investigated.	No relationship between ETL and illness	67 time-loss
Tiernan *et al.,* (2020b)	19 elite male RU Players	Over a 10-week training period. The relationship between weekly ITL (sRPE) and sIgA were investigated.	No association with sIgA and TL.	15 URTI

- **ITL – Internal Training Load, sRPE – sessional rating of perceived exertion, HR – Heart Rate, sIgA – Salivary Immunoglobulin A, TL – Training Load, ETL – External Training Load, TD – Total Distance, HSD – High Speed Distance, SD – Sprint Distance, URTI – Upper Respiratory Tract Infection, AFL – Austrailian Football League, RU – Rugby Union,**

2.5 – Quantifying the athlete training response

2.5.1 – An interdisciplinary monitoring approach

Player monitoring cycles comprise of monitoring ETL, ITL, wellness status and readiness to train (Gabbett *et al.,* 2017). A mismatch between ITL and ETL may indicate an increased fatigued or maladaptive state (Halson, 2014). Subsequently, to understand an athlete's full health and performance status, a multi-dimensional approach, consisting of biological, psychological, and social monitoring methods should be employed (Heidari *et al.,* 2019; McGuigan *et al.,* 2020). These often require a combination of both subjective and objective measures recorded weekly, or monthly (Saw *et al.,* 2016; Heidari *et al.,* 2019; Montull *et al.,* 2022). The exclusive focus on objective monitoring may anaesthetize athletes' sensitivity to TL, whilst subjective monitoring can become over simplistic (Montull *et al.,* 2022). By no means exhaustive, physiological (e.g., cardiac parameters), biochemical (e.g., creatine kinase), hormonal (e.g., salivary cortisol), immunological (i.e., immunological A) and biomechanical (e.g., musculoskeletal tests) monitoring tools are all examples of measures utilised to understand an athlete's full health and performance status (Heidari *et al.,* 2019). From a psychological perspective, subjective measures of perceived recovery and wellness (e.g., the REST-Q) are typical questionnaires aimed to target the psychological consequences of training induced fatigue which may help to determine recovery activities (e.g., relaxation techniques) (Heidari *et al.,* 2019). Within this context, it is pertinent MH is integrated into this approach. Just as physical training is monitored and balanced, so too must the psychological demands be balanced with strategies to support MH (Kuettall *et al.,* 2019). From a social monitoring methods perspective, questionnaires such as the DALDA can examine the importance of social factors (e.g., coaches, family, and teammates) for performance and provide context to compliance and susceptibility to dealing with recovery (Heidari *et al.,* 2019). Based upon these responses, individualised recovery protocols and strategies can be implemented. Considering that both injury and illness are multifaceted in nature (Simpson *et al.,* 2020), it is surprising interdisciplinary approaches to quantifying the dose-response relationship, changes in fatigue status and predicting global anchors such as injury, illness and performance is less explored (Thorpe *et al.,* 2017).

Previously, research has utilised a reductionist approach where factors are studied in isolation (Gabbett *et al.,* 2020), suggesting the dose-response is linear. However, it is likely, the dose-response is non-linear, and an interaction of multiple variables describe the relationships among load, load capacity, health, and performance (Verhagen *et al.,* 2019). Verhagen *et al.,* (2019) describes an imbalance between load, increases the risk of a decline in health status such as injury or illness and reduced health can attenuate performance (e.g., through pain sensations) but also indirectly through a decline in load capacity (e.g., through reduced stress, strength, and changes in tissue integrity). Ultimately, the consideration of all variables such as optimal loading, and the consideration of load capacity will help optimise performance whilst protecting health status (Verhagen *et al.,* 2019).

2.5.2 – Heart Rate Indices

To objectively quantify the physiological response to training, HR monitoring is attractive due to its cheap and non-invasive nature (Schneider *et al.,* 2018). Technological advancements have allowed for HR-derived indices to be calculated in smart-phone applications, making it desirable and applicable in team sport environments (Flatt *et al.,* 2016; Chrismas *et al.,* 2019). These indices include resting HR, exercising HR, HR recovery, and HR variability (HRV), which can all evaluate the responsiveness of the autonomic nervous system, and therefore provide insights into cardiovascular adaptation, training, and fatigue status (Borresen *et al.,* 2008; Buchheit, 2014; Le Meur *et al.,* 2016; Thorpe *et al.,* 2017). Nevertheless, a caveat is HR information should be combined with a myriad of antecedents such as wellness, fatigue markers and training context to identify which response (cardiovascular adaptation, fatigue status or training status) the athlete is experiencing (Schneider *et al.,* 2018). For example, an accelerated HR recovery could reflect a positive cardiovascular adaptation of a fatigued state athlete (Daanen *et al.,* 2012), therefore in this context, training information is required to interpret such indices (Bellinger *et al.,* 2016). Currently, the relationship between HR measures and TL is unknown (Bellinger *et al.,* 2016). Studies have reported HRV indices may be related to TL (e.g., weekly/monthly) in endurance sports such as cycling (Borresen *et al.,* 2007; Lamberts *et al.,* 2010) and team-based sports (Buchheit *et al.,* 2013). Buchheit *et al.,* (2013) reported RPE-TL to be related during a pre-season camp in AFL players (r= 0.50). Nevertheless, few studies have investigated HRV and TL within soccer. Previously, only weak or no relationships between HRV and TL have been revealed (Thorpe *et al.,* 2015; Thorpe *et al.,* 2016; Rabbani *et al.,* 2019; Chrismas *et al.,* 2019). For example, HRV measures only changed with low and high loads with a positive trivial effect (range – 2.1; 8.2% [-7.1: 16.7%]), ES: -0.15: 0.15 [-0.50; 0.44]) and small associations were revealed between changes in HR and sRPE (r = 0.21; 0.10) (Rabbani *et al.,* 2019). Additionally, HRV has been associated with daily fluctuations in TL (r = 0.20) (Thorpe *et al.,* 2015). Yet, across a weekly cycle, HR indices were not related to TL (Thorpe *et al.,* 2016). Finally, morning HRV were related to equivalent distance index (r= 1.89) (Chrismas *et al.,* 2019). Disparities could be likely as daily fluctuations in HR, could reflect a measurement error (Stanley *et al.,* 2013; Buchheit, 2014). Additionally, the test position, athlete compliance, number of tests and magnitude of changes in TL could influence findings (Kiviniemi *et al.,* 2007; Plews *et al.,* 2013; Plews *et al.,* 2016; Flatt *et al.,* 2016; Nakamura *et al.,* 2016). Moreover, HR can be influenced by temperature, plasma volume, cardiovascular disease, stress, sleep, and exercise intensity (Schneider *et al.,* 2018). Therefore collectively, despite some evidence behind association between HRV, TL, and injury risk (Williams *et al.,* 2017), the use of HR recovery and HRV is not widespread in professional soccer (Rave *et al.,* 2018). This is likely due to the insufficient evidence behind HR monitoring and its limitations, exacerbated by the time-consuming and impractical nature in application in team sports, particularly in the EPL whereby busy competition schedules exist. Practically, the regular monitoring of an athletes HRV over the course of a season (~10 months) could be tiresome for players even if a test lasts 5 min (Rave *et al.,* 2018). Moreover, factors such as stress or sleep can influence HRV (Goncalves *et al.,* 2015), which most senior soccer players are exposed to psychological stress and poor sleep particularly post-match (Fullagar *et al.,* 2016). Subsequently, questions exist surrounding the utility of HR monitoring in testing batteries to identify fatigue status in elite soccer players (Schneider *et al.,* 2018).

2.5.3- Salivary Biomarkers

IgA

Saliva collection is non-invasive, time efficient and easy to collect, making it a plausible monitoring tool in elite athletes (Papacosta *et al.,* 2011). Endocrine responses are obtained via the saliva e.g., sIgA, Cortisol & Testosterone) and are induced by multiple stressors that can modulate immune function (Moriera *et al.,* 2013). Indeed, sIgA has been inversely related to URTI's in 75 varsity colleague football athletes (Fahlman *et al.,* 2005), and a significant 28% reduction in sIgA has been reported 3 weeks prior to an illness in 38 elite yacht racing athletes (Neville *et al.,* 2008). In a review by Jones *et al.,* (2017), the suppression of sIgA (7-21 days) combined with increased TL can increase URTI risk by 50%. Specifically, within soccer, sIgA responses over acute time periods (0-4 weeks) have been related to TL, and are demonstrated in Table 2.3 (Morgans *et al.,* 2014; Owens *et al.,* 2014; Morgans *et al.,* 2015). Therefore, the relationship between TL and sIgA, could increase susceptibility to URTIs.

In summary, fixture congestion can attenuate sIgA responses (Morgans *et al.,* 2014; Owens *et al.,* 2014; Morgans *et al.,* 2015), which can subsequently increase illness risk. However, associations between TL and sIgA are not always reported (Tiernan *et al.,* 2020c). Multiple factors, independent of TL can affect susceptibility to illness, such as an increased exposure to the bacteria/virus, in addition to proximity to others (Gleeson *et al.,* 2000; Fahlman *et al.,* 2005). Whilst a reduction in sIgA seems to be related to URTI risk, little longitudinal data exists and the costs of samples counteract its benefits as an effective tool in an applied environment (Thorpe *et al.,* 2017).

Table 2.3: A summary of studies specifically investigating associations between sIgA, TL and URTI risk in soccer and rugby.

Study	Sample	Study Design	Main Findings
Mortatti *et al.,* (2012)	14 U19 Brazilian soccer championship players	The difference of salivary cortisol, sIgA and match RPE were assessed for each match. The relationship between sIgA and URTI occurrences were also investigated. Data were collected for 7 games across 20 days.	Reduced sIgA was significantly moderately related to URTI incidence post-match 6 (r = -0.65, P < 0.05), and match 2 (r = -0.60, P < 0.05). sIgA compared to baseline was significantly lower post-match 2 and 6.
Moriera *et al.,* (2013)	26 young soccer players	The changes in sIgA were assessed at four time points (T1 = before preseason, T2 = after preseason, T3 = after the competitive phase and T4 = after the detraining phase) over a 21-week period.	A significant increase in sIgA secretion rate and a decrease in URTI symptoms were observed after the 2-week detraining period (p < 0.05).
Morgans *et al.,* (2014)	21 EPL soccer players	Differences in 48h post-match sIgA were examined. Data were collected for 7 games over a 30-day period.	sIgA decreased at 48h post game 3 (45 ± 9 μg.mL^{-1}), 4 (52 μg.mL^{-1}) and 5 (41 ± 10 μg.mL^{-1}) compared with game 1(139 ± 25 μg.mL^{-1}). When normal fixture schedule resumed (i.e., one game per week), sIgA returned to baseline and therefore game 6 and 7 were no different from game 1.
Owens *et al.,* (2014)	10 elite soccer players	The difference in sIgA pre and post 4 low and high intensity sessions were examined. The relationship between TL (sRPE and GPS metrics) and sIgA were also investigated.	sIgA and training intensity were significantly related. The % change in sIgA post training compared to baseline was significantly differently. There was no significant difference in % change of sIgA between low and high intensity sessions.
Morgans *et al.,* (2015)	13 International soccer players	The difference in sIgA were examined for 4 days pre match. Data were collected preceding 7 matches.	sIgA significantly declined during the 4-day training period. MD-1 (256 ± 90 μg.mL^{-1}) were significantly lower than MD-4 (365 ± 127 μg.mL^{-1}) and MD-3 (348 ± 154 μg.mL^{-1}).
Tiernan *et al.,* (2020b)	19 elite male RU players	Changes in sIgA were investigated over a 10-week period. In addition to associations between sIgA and TL (sRPE) and between URTI and TL.	No significant associations were evident between both URTI incidence, sIgA and TL. In addition, no significant differences across weeks were evident for sIgA.

***sRPE – Session Rating of Perceived Exertion, sIgA – Salivary IgA, URTI – Upper Respiratory Tract Infection, MD- Match Day, TL – Training Load, EWMA – Estimated Weighted Moving Averages, RU – Rugby Union**

Cortisol and Testosterone

Cortisol and testosterone are markers utilised to represent higher physiological stress. Nevertheless, disparities exist between associations with TL demonstrated in Table 4. Salivary cortisol was significantly elevated on a Monday and Friday, indicating increased physiological stress from the preceding match and TL (Tiernan *et al.,* 2020c). By understanding the physiological stress, the body has been exposed to may provide an indication of the players recovery state from the preceding match or TL. Furthermore, double vs. single sessions have been related to increase in cortisol and testosterone (Sparkes *et al.,* 2020). In contrary, Mortatti *et al.,* (2012) reported no change in salivary cortisol. Where discrepancies in the literature exist could be because cortisol is highly variable and can differ because of the diurnal rhythm (Pritchard *et al.,* 2017). Consequently, due to the high variability and again cost of samples, prevents cortisol and testosterone being effective monitoring tools in elite environments.

Table 2.4: A summary of studies specifically investigating associations between Cortisol, Testosterone, TL and URTI risk in soccer and rugby.

Biomarker	Study	Sample	Study Design	Main Findings
	Mortatti *et al.,* (2012)	14 U19 Brazilian soccer championship players	The difference in salivary cortisol and match RPE were assessed for each match. Data were collected for 7 games across 20 days.	Resting concentrations of salivary cortisol did not change significantly across any time point.
	Rowell *et al.,* (2018)	23 A-League soccer players	The effects of EWMA TL (sRPE) on pre-match testosterone and cortisol concentrations were investigated. Data collection occurred over 34 matches.	A 1 *sd* increase in TL caused a reduction in the testosterone: cortisol ratio, an acute 3-day load increase was associated with large to moderate increases in cortisol and testosterone respectively (102 ± 58% vs. 24±18%)
	Tiernan *et al.,* (2020c)	19 elite male rugby union players	Data collection consisted of cortisol being measured bi-weekly (Monday and Friday morning) for a 10-week period. Association between salivary cortisol and testosterone and weekly TL (sRPE) were investigated. Additionally, differences in weekly salivary cortisol.	No significant associations between salivary cortisol and TL were evident. Compared to baseline (week 1) Monday salivary cortisol was higher week 4 (14.94 $ng.mL^{-1}$), week 8 (16.39 $ng.mL^{-1}$), and week 9 (15.41 $ng.mL^{-1}$) and Friday salivary cortisol was higher week 5 (15.81 $ng.mL^{-1}$) and week 10 (15.36 $ng.mL^{-1}$).
	Sparkes *et al.,* (2020)	12 semi professional soccer players.	Differences in Cortisol and Testosterone between single and double sessions were investigated. Data collected occurred over a 6-month period.	Likely to very likely small favourable responses occurred following the single session for testosterone (-15.2 ± 6.1 $pg.mL^{-1}$), cortisol (0.072 ± 0.034 $ug.dL^{-1}$) and testosterone: cortisol ratio (-96.6 ± 36.7 AU) at 24 hours post a double session compared to a single.

***sRPE – Session Rating of Perceived Exertion, URTI – Upper Respiratory Tract Infection, MD- Match Day, TL – Training Load, EWMA – Estimated Weighted Moving Averages, RU – Rugby Union**

2.5.4 - Biochemical Markers

Biochemical markers allow for an objective quantification of an individual's ITL (Djaoui et al., 2017). Yet, there is a paucity in research, on associations between specific blood parameters and performance and injury and illness incidence, and its role in detecting overreaching (Djaoui *et al.,* 2017). Table 2.5 demonstrates common biochemical markers and associations with soccer match play and TL. Across all biochemical markers, it appears that they are responsive to training and match load. Nevertheless, the measurement of biochemical markers is currently not justified due to its time consuming, costly, and impractical nature, in applied environments (Twist *et al.,* 2013; Halson, 2014). Biochemical measures at best are taken monthly, which limits its practical use in the daily and weekly prescription of TL, particularly pertinent in sporting environments whereby weekly TLs are associated with injury and illness incidences.

Table 2.5: A summary of studies specifically investigating associations between biochemical markers and training load in soccer.

Marker	Study	Sample	Study Design	Main Findings
CK				
	Meyer *et al.,* (2011)	467 males	CK were assessed over 4 time points in the season.	CK changed from 183 UL^{-1} at preseason to 301 UL^{-1} at time point 1, 331 UL^{-1} 2, and 3, 320 UL^{-1}.
	Heisterberg *et al.,* (2013)	27 Danish males	CK were assessed over 5 time points over a 6-months.	CK at time point 1 was (292 ± 27 UL^{-1}), 2(544 ± 168 UL^{-1}) 3(274 ± 31 UL^{-1}) 4(258 ± 36 UL^{-1}) and 5 (279 ± 30 UL^{-1}) CK significantly was different at time point 3,4 and 5 compared to time point 2.
	Russell *et al.,* (2015)	14 reserve EPL players	CK responses were measured at pre, 24h and 48h post-match. Data were collected for 1-4 matches per players.	CK was elevated at both 24h (334.8 ± 107.2 UL^{-1}) and 48h (156.9 ± 121.0 UL^{-1}) after match play.
	Coppalle *et al.,* (2019)	26 professional males	CK and pre-season TL (sRPE and GPS metrics (TD > 12km.h^{-1}, 12-16km.h^{-1}, 16-20km.h^{-1} and >20km.h^{-1}) were measured. CK pre and post preseason were measured.	CK was no different pre and post both pre-seasons. CK was not related to TL.
CRP				
	Ispiridis *et al.,* (2008)	24 elite males	CRP were assessed pre, immediately post and at 24h, 48h, 72h, 96h, 120h and 144h one single match.	Immediately and 24h post-match, CRP levels were significantly elevated.
	Renato Silva *et al.,* (2014)	14 elite males	CRP were assessed at pre-season (T1), middle (T2) and end (T3) of the season, and the end of the transition (T4).	CRP was significantly higher at T2 (0.90 ± 0.69 mg.L^{-1}) and T3 (0.69 ± 0. 50mg.L^{-1}) than T1 (0.39 ± 0.25 mg.L^{-1}).
	Coppalle *et al.,* (2019)	26 professional players.	CRP and pre-season TL (sRPE and GPS metrics) were examined. CRP pre and post pre-season were also examined over 6-weeks.	A negative correlation was found between TD > 20km.h^{-1} and CRP ($r = -0.863$, $P = 0.027$). CRP was no different pre- and post-pre-season.
Ferritin				
	Meister *et al.,* (2011)	88 elite German males	Ferritin was assessed over 4 time points across a season a	No difference in Ferritin levels were found between high (>270min) and low exposure (<270min) to games three weeks before.
	Huggins *et al.,* (2018)	92 collegiate males and females	Ferritin was examined preseason, and week 1, 4, 8 and 12.	Ferritin did not significantly change across the season.
	Owens *et al.,* (2018)	17 male elite European Players	Ferritin was examined 72hrs post last match of the beginning, middle and end of the season.	Ferritin did not change during season or associated with competitive minutes.
Vitamin D				
	Morton *et al.,* (2012)	20 EPL players	Vitamin D levels between August and December were examined.	Vitamin D decreased between August (104.4 ± 21.1 nmol.L^{-1}) and December (51.0 ± 19.0 nmol.L^{-1}).
	Huggins *et al.,* (2018)	92 collegiate players	Vitamin D levels were examined over a 12-week period, consisting of preseason and then in season week 1,4,8 and 12.	Vitamin D was different week 12 (31 ± 7 ng.mL^{-1}) compared to week 1 (36 ± 8 ng.mL^{-1}), week 4 (35 ± 8 ng.mL^{-1}) and week 8 (35 ± 9 ng.mL^{-1}).
IGF-1				
	Huggins *et al.,* (2018)	92 collegiate players	Changes in IGF-11 were examined over a 12-week period, consisting of preseason and then in season week 1,4,8 and 12.	IGF-1 did not change across the time course of the season.
SHBG				
	Huggins *et al.,* (2018)	92 collegiate players	Changes in SHBG were examined over a 12-week period, consisting of preseason and then in season week 1,4,8 and 12.	SHBG did not change across the time course of the season.

***TD- Total Distance, sRPE- Session Rating of Perceived Exertion, TL – Training Load., CK – Creatine Kinase. SHBG – Sex Hormone Binding Globulin, CRP- C-Reactive Protein.**

2.5.5 - Subjective Wellness Markers

Subjective wellbeing is commonly utilised to assess athlete wellbeing by determining adaptive and non-adaptive responses to training and competition (Hooper *et al.,* 1995a; Kentta *et al.,* 1998; Gallo *et al.,* 2015; Saw *et al.,* 2016;). Subjective measures are often described as superior to objective measures, due to self-monitoring enhancing an athlete's awareness, autonomy, and self-regulation (Montull *et al.,* 2022). Furthermore, subjective measures could be more strongly associated with acute and chronic TL, fitness, and fatigue (Saw *et al.,* 2016). Subjective measures also provide a global insight by compressing psychological, biochemical, and physiological information that can identify underlying psychological, social, and non-training stressors which may influence an athlete's adaptive capacities (Kentta *et al.,* 1998; Kellmann *et al.,* 2002; Montull *et al.,* 2022). Reductions in wellness can also indicate burnout, poor health status, and a reduction in motivation and sport performance (Hooper *et al.,* 1995a; Barte *et al.,* 2017). Therefore, such information is vital for health/performance regulation (Coyne *et al.,* 2018; Sturmberg *et al.,* 2019). Previously, subjective questionnaires have been utilised to assess subjective wellbeing, including the profile of mood states (POMS) (McNair *et al.,* 1971), recovery-stress questionnaire (REST-Q) (Kellmann *et al.,* 2001), athlete burnout questionnaire (Lonsdale *et al.,* 2009), multi-component training distress scale (Main *et al.,* 2009), and the daily analysis of life demands for athletes (DALDA) (Rushall, 1990). However, such questionnaires are impractical for daily evaluation in soccer, due to their time-consuming nature, and therefore practical use in periods of fixture congestion characteristics of elite soccer. Subsequently, in-expensive, simple and time efficient questionnaires are required to evaluate wellbeing daily (Saw *et al.,* 2016; Thorpe *et al.,* 2017).

Custom-based subjective wellbeing questionnaires are widely utilised in soccer clubs to monitor a player's response to TL, assess injury and illness risk and readiness to train (Akenhead *et al.,* 2016; Saw *et al.,* 2016; Thorpe *et al.,* 2017). These are based upon the 'Hooper's Index' and include 5-items (sleep quality, fatigue, soreness, stress, and mood) typically graded by 1-5, 1-7 and 1-10 Likert scales (Hooper *et al.,* 1995b; Taylor *et al.,* 2012; Gallo *et al.,* 2015). Moreover, can consist of contextual information including (life stress, sleep quality, family issues, team stress and physiological stress), which could influence the training response, specifically advantageous on an individual level and the subsequent implementation of individual interventions.

These items have been found to be reliable measures (Gastin *et al.,* 2013; Roe *et al.,* 2016; Sawczcuk *et al.,* 2018). The between day reliability of the subjective recovery markers (sleep, fatigue, muscle damage, stress, and mood), using a Likert scale 1-5 (1 = not sore, 5 = sore), has reported a CV value of 7.1% in team-sports (Roe *et al.,* 2016). Gallo *et al.,* (2017) also found the subjective recovery markers (sleep quality, stress, fatigue, mood, and muscle soreness) had a good face validity, as Cronbach's Alpha, a was 0.70. Subsequently, subjective wellbeing markers, appear to be reflective of fatigue as, Sekiguchi *et al.,* (2021) revealed a moderate inverse relationship between perceived recovery and creatine kinase and muscle soreness ($r^2 = 0.58$, $P < 0.05$). The relationship between wellness markers, ITL and ETL within soccer are demonstrated in Table 2.6. Overall, it is unclear on whether subjective wellness markers are related to ETL variables.

Table 2.6: A summary of studies specifically investigating associations between subjective wellbeing and training load in soccer.

Study	Sample	Wellness Markers	TL	Main Findings
Moalla *et al.,* (2016)	19 professional male players	Sleep Quality, Stress, Fatigue, Mood and Soreness (LS: 1-7)	Daily ITL (sRPE) over 16-weeks	ITL were significantly related to sleep (*r* = 0.23), stress (*r* = 0.30), fatigue (*r* = 0.48), soreness (*r* = 0.48) and HI (*r* = 0.47).
Clemente *et al.,* (2017)	35 Portuguese Premier League Players	Sleep Quality, Fatigue, Stress, Soreness and HI (LS: 1-7)	One and Two game weeks ITL (sRPE) over a season.	Two game week ITL were significantly related to soreness (*r* = -0.156), sleep (*r* = -0.109), fatigue (*r* = -0.225), stress (*r* = -0.188) and HI (*r* = -0.238).One game week ITL were significantly related to stress (*r* = -0.080).
Thorpe *et al.,* (2017)	10 EPL players	Sleep Quality, Fatigue and Soreness (LS: 1-7).	Previous 1,-2,-3- and 4-day HSD over a 17-day period.	Fatigue was significantly related to previous 2-,3- and 4-day HSD (*r* = 0.28-0.42).
Malone *et al.,* (2018)	One professional male GK	Wellness	Previous day min, TD, average speed, accelerations, decelerations, playerload, playerload/min) over a season (4-week preseason, 39-week in season)	Wellness was significantly related to min (*r* = 0.35), TD (*r* = 0.28), decelerations (*r* = 0.27) and PlayerLoad (*r* = 0.31) .
Fitzpatrick *et al.,* (2019)	12 male U18 EPL players	Fatigue, Sleep Quality, Stress and Mood (LS: 1-5).	Two exercise bouts	No wellness markers were sensitive to the two exercise bouts.
Perri *et al.,* (2021)	28 sub elite Italian players	HI (LS: 1-5)	Daily ITL (sRPE) over a season.	Daily ITL was significantly related to next day wellness index (*r* = 0.72).
Draper *et al.,* (2021)	24 major A-League Players	Stress, Soreness, Sleep, Recovery, Nutrition, Mood, Energy and Hydration (LS: 1-10).	Previous day ITL (HR, HR TRIMP, sRPE) and ETL (TD, HSD and SD) over 6-months (6 week pre-season).	Within-player correlations between TL and next day fatigue was trivial to moderate (*r* = -0.42 to -0.04). In-season large correlations between soreness and TD (*r* = -0.55) and PlayerLoad (*r* = -0.54) were evident, but preseason correlations between TD (*r* = -0.15) and PlayerLoad (*r* = -0.13) were small.
Nobari *et al.,* (2021)	21 elite youth players	Sleep Quality, Soreness, Fatigue, Stress and HI	Weekly (Acute) and 4-weekly (Chronic) ITL, training monotony and strain over 36 weeks.	Acute TL was significantly related to soreness, fatigue, stress, and HI (*r* = 0.62- 0.66) Chronic TL was significantly related to soreness, fatigue, stress, and HI (*r* = 0.53- 0.65). Training monotony was significantly related to sleep and stress (*r* = 0.43-0.52).Training Strain was significantly related to sleep, soreness and fatigue (*r* = 0.34- 0.56),
Sekiguchi *et al.,* (2021)	60 NCAA Division one male collegiate players	Stress, Soreness, Fatigue, Sleep Quality (LS: 1-10).	Previous day low, moderate and high ITL ACWR (sRPE) over one season.	Fatigue levels were significantly higher when high ACWR was compared with low and moderate, and when moderate was compared with low. Soreness was higher when high ACWR was compared with low.

***ITL – Internal Training Load, sRPE – Session Rating of Perceived Exertion, HSD – High Speed Distance, GK – Goalkeeper, ETL – External Training Load, EPL – English Premier League, ACWR – Acute:chronic Workload Ratio, TD – Total Distance, LS – Likert Scale, HI – Hoopers Index.**

The role of subjective wellness with respect to TL (more specifically the demonstrated associations with ITL), advocates wellbeing markers to assess injury and illness risk (Schwellnus *et al.,* 2016; Ivarsson *et al.,* 2017). In female soccer players, a lower mood and higher chronic TL have been related to increased illness risk (Watson *et al.,* 2016). A reduction in wellbeing <7.25 AU and an increased TL > 2252 AU contributed to self-reported illness (Thornton *et al.,* 2016). However, wellness scores were not related to non-contact injury in the subsequent 7 days (Colby *et al.,* 2017). Future work is required to establish the predictive value of wellness on injury and illness.

Prudent, there are methodological challenges surrounding the collection of subjective wellbeing data within applied elite sporting environments which can influence athletes' perceptions of wellness and therefore associations between wellness and TL. It is likely, subjective wellbeing is vulnerable to social desirability such as over and under reporting favourable or unfavourable responses to obtain team selection or not want to admit weakness (Meeusen *et al.,* 2013; Saw *et al.,* 2015b). Moreover, subjective wellbeing is often monitored 'daily', therefore questionnaire frequency can lead to questionnaire fatigue and reduce motivation and subsequent athlete buy in (Halson, 2014). Additionally, contextual variables including match location, outcomes, and quality, could confound associations between wellness and TL (Abbott *et al.,* 2018a; Fessi *et al.,* 2018). For example, stress, mood, and sleep were >12% worse when playing against a higher level of opposition (Abbott *et al.,* 2018). Specifically, the relationship between perceptions of wellness and TL could be confounded by varying analysis techniques such as individual subscales (studies adopting the 1-10 scale may have an enhanced sensitivity of wellness measures to TL), cumulative scores and the utilization of Z-scores may provide equivocal findings. Within applied environments, the modification of load based upon wellness responses, could subsequently mis lead interpretation. Nevertheless, importantly this could reflect a positive monitoring system.

Lastly, but not exhaustive, constructs such as fatigue or soreness are known acute responses to demanding exercise and can be influenced by psycho-physiological factors or lifestyle (sleep and nutrition) (Draper *et al.,* 2021).

Given the limitations still associated with subjective monitoring, there is still a considerable emphasis required on measuring both subjective and objective data to provide a better understanding of player's needs, recovery, and training status (Thorpe *et al.,* 2017; Hills *et al.,* 2018). Subjective measures could provide the ability to measure constructs and dimensions that are not objectively measurable. Nevertheless, adopting objective monitoring markers can be challenging as they must be non-fatiguing, time efficient, cost-effective and cause minimum disruption to a player's schedule.

2.5.6 - Psychological Wellbeing

PWB is popular in elite sporting environments to assess one's MH. MH status is pertinent, not only in detecting the development of adverse MHD and symptoms but also its contribution to inadequate recovery, and a prerequisite of detrimental health development, including mental fatigue, burnout, and anxiety disorders. When monitoring MH, the concept that athletes are 'healthy without a clinical disorder' is over simplistic. Therefore, the negative conceptualisation of MH, as the absence of mental illness (e.g., depression and anxiety) has shifted towards more positive MH aspects, such as the functioning and flourishing of individuals (Tennant *et al.,* 2007; Schinke *et al.,* 2017; Kuettall *et al.,* 2021b). Subsequently, an athletes' MH should be viewed through the Keyes continuum (Keyes, 2007), which represents MH status by two components, the hedonic and eudemonic components, crucial for flourishing across life domains (Lundqvist, 2011). The hedonic perspective relates to general happiness, and life satisfaction achieved through striving for reward and pleasurable experiences that reinforce positive feelings and satisfaction. Moreover, the eudemonic perspective focuses on the personal quality of life together with the social and PWB that promote living well (Keyes, 2007). Given the ability to positively assess MH status, understanding levels of hedonic and eudemonic wellbeing, is important in athletes (Ryan *et al.,* 2001; Nicholls *et al.,* 2020). Nevertheless, this reconceptualization of MH has not been properly addressed in elite sport yet (Poucher *et al.,* 2021). Moreover, there is limited research regarding monitoring tools to assess MH in addition to assessing a players readiness to train and injury/illness risk.

There is growing interest in the development of athlete specific screening and identification processes for the early identification of MH problems in athletic populations (Donohue *et al.* 2018). However, currently there is a lack of widely validated athlete specific screening tools (Purcell *et al.,* 2019). When measuring MH or wellbeing, psychological stress issues remain a widely ignored taboo because teams and the media consider them to be a weakness (Gouttebarge *et al.,* 2015; Lebrun *et al.,* 2017). Previously, research, has assessed elite athletes MH utilising clinical psychometric validated questionnaires such as the centre for epidemiological studies depression scale (CESD; Radloff, 1977) or the general anxiety disorder scale (GAD-7, Spitzer *et al.,* 2006). Or utilised athlete MH measures such as the recovery-stress questionnaire (REST-Q) (Kellmann *et al.,* 2001) profile of mood states (POMS) (McNair *et al,* 1971). Nevertheless, common caveats with all previous questionnaires includes their length and ability to be implemented on a daily or weekly basis (Taylor *et al.,* 2012). Moreover, are often negatively worded and not validated in elite populations, making their applicability in sporting environments debatable (Nicholls *et al.,* 2020).

The WEMWBS has been referred to as positively worded and freely accessible in comparison to some more clinically based questionnaires such as the CED-S scale (Abbott *et al.,* 2019). The WEMWBS covers both the hedonic and eudemonic aspect of wellbeing, and is correlated with MH symptoms (e.g., depression (r = -0.58, P < .001) and anxiety (r = -

.049, $P < 0.001$)) (Kuettal *et al.,* 2021b). Furthermore, is strongly correlated with other psychiatric scales (Bianca, 2012; Zadow *et al.,* 2017) and has been utilised to monitor PWB in elite athletes (Abbott *et al.,* 2019; Nicholls *et al.,* 2020). Recent research utilised the WEMWBS (Stewart-Brown *et al.,* 2009) to assess potential MH disturbances in professional male soccer players (Abbott *et al.,* 2019; Kuettal *et al.,* 2021a). One study to date investigated PWB in U23 EPL soccer players and demonstrated the WEMWBS to be sensitive to perturbations in PWB caused by sport-specific contextual factors (Abbott *et al.,* 2019). Given the associations between PWB and injury is not a direct causal relationship, it is plausible PWB could augment injury risk (Abbott *et al.,* 2019). Instead of focusing on the mental illness (symptoms of depression and anxiety), research is required to investigate the implementation of PWB into a battery of tests to determine MH status and predict injury and illness in elite soccer.

2.5.7 - Musculoskeletal measures

Musculoskeletal screening aims to identify athletes who are at injury risk by measuring and monitoring modifiable-related injury risk factors, such as muscular strength and flexibility (Meeuwise, 1994; Bahr, 2016). The injury profile of the sport determines the tests selected and should focus on a specific risk factor (Batt *et al.,* 2004). Musculoskeletal measures should also be valid, reliable, practical, and sensitive to TL (Thorpe *et al.,* 2017). In soccer, hip/groin and hamstring injury are most common, accounting for a third of the overall injury burden (~5-19 days, time loss per injury) (Ekstrand *et al.,* 2020). Key injury risk factors include both AS and HF (Markovic *et al.,* 2020; Salter *et al.,* 2021). For AS, during running, the adductor muscles, are acting to stabilise the thigh (with respect to the pelvis) during the swing phase, and (with respect to the thigh) during the stance phase (McClay *et al.,* 1990). Therefore, soccer specific actions such as twisting, kicking, can augment load placed upon anatomical structures surrounding the groin area (Falvey *et al.,* 2009; Roe *et al.,* 2016). For

HF, during high-speed locomotion and acceleration and deceleration activities (typical of elite soccer) the late swing phase is most pertinent in sustaining a hamstring strain or injury (Liu *et al.,* 2017; Picerno *et al.,* 2017). During this phase, the knee nears full extension, and the hamstring muscles are maximally stretched and therefore a considerable force is endured (Clark, 2008). Within the EPL, players are exposed to fixture congestion, high physical match demands and long training hours resulting in residual localised fatigue, muscle tendon stiffness, and therefore subsequent reductions in AS and HF (Ekstrand *et al.,* 1982; Roe *et al.,* 2016; Silva *et al.,* 2018b).

Previous research has examined associations between pre-season musculoskeletal screening scores with injury occurrence in the upcoming season. (Engebretsen *et al.,* 2010; Delahunt *et al.,* 2017). Previously, reduced AS in 508 amateur soccer players was associated with an increased injury risk (odds ratio 4.3, 95% CI: 1.3-14) (Engebretsen *et al.,* 2010). Moreover, in 55 Gaelic soccer players, reduced AS was associated with increased injury risk (odds ratio 7.8), with strength reductions exceeding 12% the week proceeding injury (Delahunt *et al.,* 2017). Nevertheless, the relationship between preseason HF and injury in soccer is conflicting (Witvrouw *et al.,* 2003; Van Doormal *et al.,* 2017). Witvrouw *et al.,* (2003) revealed a 7% lower HF in injured players to be associated with injury risk. Nevertheless, hamstring injury and flexibility were not related elsewhere (Van der Horst *et al.,* 2017; Van Doormal *et al.,* 2017; Versteeg *et al.,* 2021). For example, HF measured via the S&R test were not related to injury in 114 soccer players (P = 0.534) nor when adjusted for confounders such as age, weight, and height (1.027 (0.989-1.066) (RR 95% CI) (P = -0.164) (Versteeg *et al.,* 2021). Discrepancies could exist due to the timing of measurement. HF can increase by 9% throughout the day (Manire *et al.,* 2010), which is larger than the deficit reported in injured players (Witvrouw *et al.,* 2003). Notably, Witvrouw *et al.,* (2003) utilised a single leg raise test, which mimics the risk movement. During a S&RT, the hamstring muscles are utilised in a different way than during the late swing phase and therefore emphasises a mismatch between the biomechanical aspects and the sporting context. Additionally, discrepancies could exist as alternative mechanisms that influence hamstring muscle injury is the high mechanical energy that a muscle absorbs, which is affected by muscle strength and contraction velocity (Liu *et al.,* 2012). Therefore, generally HF measured during pre-season, is not associated with injury risk. Subsequently overall, preseason screening is limited and insufficient when predicting injuries (Bahr, 2016). Musculoskeletal characteristics of athletes can change throughout the season due to exposure to competition and training, as well as the occurrence of new injuries or complete resolution of deficits from previous injuries (Creighton *et al.,* 2010; Whiteley, 2016). Therefore, it is common practise to adopt regular screening, also applied to various measures of recovery (e.g., wellness scores) (Taylor *et al.,* 2012; Thorpe *et al.,* 2017), which involves the repeated measurements of injury risk factors which allows changes in screening scores to be identified and may better reflect the athletes condition, response to training and therefore enhance ability to subsequent injury risk (Paul *et al.,* 2014; Thorpe *et al.,* 2017). For example, muscle strength is not a constant variable (i.e., prone to biological fluctuations) and the demands of soccer (e.g., sprinting, and changes of direction) alters the strength profile in response to neuromuscular fatigue and induced muscle damage. Moreover, changes in strength (resistance) and changes in length of muscle (stiffness) can increase injury risk (McHugh *et al.,* 1992; Magnusson, 1998; Walsford *et al.,* 2010).

2.5.8- Adductor Strength Test

The AS test is a popular objective monitoring tool to detect acute fatigue and highlight potential injury risk (Roe *et al.,* 2016; Esmaelli *et al.,* 2018a; Tiernan *et al.,* 2019). Muscle fatigue can reduce the stress-bearing capacity of the tissues, impairing neuromuscular control and dynamic stability, which may increase injury risk (Lenhert *et al.,* 2017; Vanrenterghen *et* *al.,* 2017). High intensity running during soccer match play has been related to an increase in CPK levels (an indicator of muscle damage) (Silva *et al.,* 2018; Hader *et al.,* 2019). Muscle damage is accompanied with a transient muscle strength (Peake et al., 2005), subsequently AS deficits have been related to CPK levels (Khaitin et al., 2021). Therefore, early identification of declines in AS could protect against injury occurrence (Coughlan *et al.,* 2014). Adductor strength is commonly measured via isometric adductor muscle contractions utilising a handheld dynamometer or Sphygnamometer, which can highlight reductions from normative values of force output (Delahunt *et al.,* 2011; Ryan *et al.,* 2019b). Both measures are valid, time efficient and have good reliability in team-sports including AFL (ICC = 0.80 to 0.92) (Toohey *et al.,* 2017) and RU (CV%: 2.7, ICC = 0.95) (Roe *et al.,* 2016). However, such methodologies require the estimation of the hip and knee joint angle, visualising outputs, and the requirement to push against a variable resistance which can affect the validity and reliability. New technologies, such as the 'hip strength-based testing system' have reported an excellent test-retest reliability for hip adduction (ICC = 0.97) and acceptable level of CV (4.65-6.30%) and can detect groin pain (Ryan *et al.,* 2019b).

A summary of research investigating relationships between AS and TL and match loads are reported in Table 2.7. Previously, declines in AS have been demonstrated up to 96-hours post-match (Paul *et al.,* 2014; Roe *et al.,* 2016; Buchheit *et al.,* 2017; Howle *et al.,* 2019a; Salter *et al.,* 2021). However, weak or no relationships between AS and TL have been revealed (Esmaelli *et al.,* 2018a; Tiernan *et al.,* 2019; Lonie *et al.,* 2020; Weaving *et al.,* 2021). Based upon previous research, it could be total and individualised HSD are not related to AS (Esmaelli *et al.,* 2018a; Weaving *et al.,* 2021). However, assessment modality and fluctuations in AS across a season could result in disparities within the literature (Lonie *et al.,* 2020). This is supported by findings by Esmaelli *et al.,* (2018a) who reported small to moderate within-individual variability in weekly AS (7.8 ± 0.8%) across pre-season and in-season periods within AFL. Additionally, Lonie *et al.,* (2020) reported significant changes in pooled AS across pre, mid, end and post-season. These changes could be explained by the proportion of training spent performing sport specific skills (e.g., kicking) compared with general strength and conditioning, as the intensity and volume of each type of training changes during different phases (Lonie *et al.,* 2020). Alternatively, a true change in an athlete's performance (e.g., adaptation to training) may contribute to week-to-week changes in test score (Esmaelli *et al.,* 2018a). It is therefore likely, daily vs. weekly measures maybe superior to closely monitor players in-season and detect acute strength deficits to facilitate early groin problems (Thorborg *et al.,* 2014).

In contrary to ITL, investigations into the dose-response relationship between ETL and muscular fatigue responses are limited (Weaving *et al.,* 2021). Associations between ETL rather than ITL could be more sensitive when considering musculoskeletal response given the disparities between adaptation pathways from physiological and biomechanical based loads (Vanrenterghen *et al.,* 2017; Esmaelli *et al.,* 2018a; Weaving *et al.,* 2021). Future research utilising the hip-strength based testing system and assessing daily measures of AS should be conducted. Moreover, ETL could provide a useful surrogate dose-response relationship with musculoskeletal responses when measured over longitudinal periods. If such relationships are evident, this could detect need for early intervention to reduce injury risk and inform TL prescription.

To date, only two studies have investigated AS assessments across a season and their ability to predict injury (Colby *et al.,* 2017; Esmaelli *et al.,* 2018b). Within AFL players, Esmaelli *et al.,* (2018b) reported a standard deviation (*sd*) ±, was associated with a 2.9 times greater risk of injury. In contrary, Colby *et al.,* (2017) found musculoskeletal measurements were not predictive of injury utilising multivariate modelling and this was not improved despite individualised criterion (a 1*sd* decline from the norm). Disparities within the literature could exist due to the analysis of data. Current changes in AS were either compared to a rolling average (created combining both pre-season and in-season) or just in-season phases (Esmaelli *et al.,* 2018a). Given AS fluctuates across a season, and training session emphasis can change between pre-season and in-season this could help explain the discrepancies. Future research may need to consider optimal time frames, when calculating rolling averages and subsequent deviations in AS, to enhance the sensitivity and prediction of injury. Both injury studies considered musculoskeletal measures in a multivariate model with additional information such as TL. Both studies utilised ITL rather than ETL.

2.5.9- Sit and Reach Test

The S&R test is quick, simple, reliable, and commonly utilised to assess lower back/HF, which can inform subsequent recovery, readiness to train and injury risk status (Ayala *et al.,* 2012; Esmaeili *et al.,* 2018b) Previously, the S&R test has been utilised during pre-season to identify athletes who are at most risk of injury (Gabbe *et al.,* 2004; Bahr, 2016). However more recently, has been utilised as a repeated measures tool in evaluating responses to TL and potential injury risk (Gabbe *et al.,* 2004; Dawson *et al.,* 2005; Esmaelli *et al.,* 2018b; Weaving *et al.,* 2021). Sit and Reach scores have been related to match load at 15-hours post-match and returns to normal at 48 hours post-match (Dawson *et al.,* 2005). In contrary, weekly S&R scores 2-3 days post training were not related to ITL (Esmaelli *et al.,* 2018a). Moreover, Weaving *et al.,* (2021) revealed that 2-day EWMA TD (0.73) and 3-day EWMA TD (0.68) were not related to S&RT scores in elite RU players. Subsequently a greater variability in TL than the musculoskeletal response across the longitudinal observational period was revealed (Esmaelli *et al.,* 2018a; Weaving *et al.,* 2021). Notably, Esmaelli *et al.,* (2018a) reported small-moderate within individual variability in weekly S&R scores (0.92 ± 0.14cm) which is smaller than standard error of estimate of S&RT (Gabbe *et al.,* 2004). Therefore, it could be the S&R test may only be sensitive to acute loading, or high loads e.g., a match. Regarding multiple S&R scores and injury prediction only two studies to date exist. Reductions in S&R have been related to higher injury risk in AFL (Esmaelli *et al.,* 2018a), but this is not always the case (Colby *et al.,* 2017). Overall, limited research examining associations between S&RT, TL and injury risk exists, therefore requiring future investigation

Table 2.7: A summary of studies specifically investigating associations between adductor strength and training load in soccer.

Study	Sample	Study design/ analysis	Main Findings
Paul *et al.,* (2014)	20 youth male soccer players	A meaningful change in abduction and adduction pre-post-match were calculated.	12.5% meaningful detectable decline in AS.
Roe *et al.,* (2016)	14 RU academy players	The change between pre-match and 24,48- and 72h post-match AS and the relationship between AS and SD were examined.	Trivial decreases in AS occurred immediately (-1.3 ± 2.5% ES = -0.11 ± 0.21 likely, 74%) and 24h post-match (-0.7 ± 3%, ES = -0.06 ± 0.25, likely 78%). Yet small increases were evident at 48h (3.8 ± 1.9%, ES = 0.32 ± 0.16, likely, 89%), and trivial increases at 72h post-match (3.1 ± 2.2%, ES = 0.26 ± 0.18, possibly 72%).
Buchheit *et al.,* (2017)	41 AFL players	The change in AS between day of match, and day 1,2,3,4 and 5 were examined.	AS was very likely moderately decreased (-17.4%, -23.4 to -11.0), the day following a match and remained lower on day 4.
Esmaelli *et al.,* (2018b)	44 elite AFL players	AS assessed on day 2 or 3 post-match or training and the effects of ITL (sRPE) were examined over the 10-month season.	TL had trivial effects on AS. Normal variability ± 90% CI = 7.4 ± 0.6%.
Wolin *et al.,* (2018)	22 elite international youth soccer players	The relationship between AS and cumulative ITL (sRPE) obtained from matches were investigated during an international tournament (7 matches in 14 days).	AS reduced with time and cumulative sRPE. sRPE were related to AS (b = -0.008, SE = 0.0032, 95% CI = -0.014-0.002). For every 100 match sRPE units AS reduced by 0.8N. 16 players obtained above 15% reductions in AS during the tournament.
Tiernan *et al.,* (2019)	19 elite male RU players	The relationship between AS and weekly ITL (sRPE) were investigated during a 10-week preseason.	A weak correlation was observed between Monday AS and previous week TL (r = -0.235, r^2 = 5.5%, P < 0.001), and Friday AS and same weeks TL (r = -0.211, r^2 = 4.5%, P < 0.05).
Howle *et al.,* (2019b)	42 AFL players	Baseline AS were compared against 48h AS following one and two game weeks. AS was assessed across 2- A league seasons.	AS was reduced post-match for both one and two game weeks and further decline during two game weeks (P < 0.05).
Lonie *et al.,* (2020)	35 AFL players	Changes in AS across the four phases of the season (pre-season, early, middle and late) were examined. In addition, the relationship between average ITL (sRPE) during the season were examined.	AS varied across the four phases of the season. TL was not examined with AS.
Weaving *et al.,* (2021)	16 elite male RU players	The relationship between AS and previous 2–7-day ETL (TD, and individualised threshold speed distance) were investigated.	2–3-day EWMA TD had the highest relative importance to musculoskeletal response (P < 0.0001). Trivial to Small relationships were evident on a group level (r = 0.20) and individual (r = 0.06).
Salter *et al.,* (2021)	71 male student athletes	The changes in AS after a 5min standardised warm up, half time and post-match (90min simulated soccer match) were examined.	Likely to very-likely substantial changes in AS (9.9-15.7%) were evident.

***AS – Adductor Strength, SD – Sprint Distance, AFL – Austrailian Football League, TL – Training Load, TD – Total Distance, ETL – External Training Load, EWMA – Estimated Weighted Moving Averages, sRPE – Session Rating of Perceived Exertion, ITL – Internal Training Load, RU – Rugby Union**

2.5.10 - Countermovement Jump

Neuromuscular fatigue and rate of force development have been associated with both performance and injury occurrence. Athletes who can utilise the stretch reflex and muscular force optimally have increased force producing capacities, reducing the metabolic cost of movement and fatigue (Markovic *et al.,* 2004; Turner *et al.,* 2010). To assess neuromuscular fatigue, the CMJ is commonly utilised due to being reliable, non-fatiguing and simple (Twist *et al.,* 2013; Garcia-Lopez *et al.,* 2013; Halson, 2014). It has good levels of reliability (2.6-5.0 CV%) within team sports. Within soccer, associations between CMJ (jump height) and match play have been revealed with impairments in neuromuscular function of up to 72 hours post-match (Nedelec *et al.,* 2014; Rowell *et al.,* 2017; Hagstrom *et al.,* 2018; Nedelec *et al.,* 2019b).

Disparities exist within previous research investigating associations between CMJ derivatives and TL. Previously, *trivial* to *small* associations were revealed between CMJ height and 2-4 days HSD (r = 0.15 to 0.23) (Thorpe *et al.,* 2017). Countermovement Jump peak velocity produced a CV smaller than the SWC in response to TL in AFL players (Garrett *et al.,* 2020). In adolescent soccer players, CMJ height, 24 and 48 hours post training could not detect a reproducible fatigue response (Fitzpatrick *et al.,* 2019) or during an in-season training microcycle (Malone *et al.,* 2014). Moreover, Rowell *et al.,* (2018) revealed *unclear* or *trivial* associations with flight time: contact time in 23 A-League players. Disparities could exist due to different CMJ derivatives being utilised. For example, flight time: contact time reflects changes in movement strategies associated with neuromuscular fatigue (Gathercole *et al.,* 2015). Additionally, 'average' vs. 'peak' jump height may offer superior sensitivity (Claudino *et al.,* 2017). This is because a practitioner has a much higher probability (10:1) of finding the 'true score' indicative of a true change in performance when the average value is used over the highest value (Claudino *et al.,* 2017). The plethora of available CMJ derivatives is challenging to practitioners and limits its application. Some variables require using time-consuming time-analysis, which is impractical in team environments. Further, limitations are the methodology (Jump mat vs. force platform), real vs. simulated soccer, timing of data collection, and trial number (Taylor *et al.,* 2010). Moreover, when considering the validity of the tests to assess a response to load this could be confounded by motivation factors, and the sincerity of effort. Overall, the CMJ can identify fatigue associated with match play, however, no clear evidence exists for CMJ to be related to TL.

2.6 Predicting Injury and Illness

Whilst the suitability of monitoring tools has been verified to be sensitive to TL, monitoring tools should also be related to outcome measures such as injury or illness, to further establish their efficacy as monitoring tools (Ryan *et al.,* 2019a). Nonetheless, studies in this area are challenging because practitioners modify planned TL in response to perceived subjective wellness and objective measures, which could mask the ability to reduce the effectiveness to predict injury and illness, due to less injury and illness occurrences in practise (Colby *et al.,* 2017).

3.0 General Methods

3.1 - Participant Recruitment

The participants recruited for all studies within the current thesis were all First Team professional male soccer players, participating in the EPL (2019-2020, 2020-2021 and 2021-2022 seasons), and all contracted to Brighton and Hove Albion Football Club. All participants completed routine training sessions, matches and monitoring procedures. Additionally, all participants were well trained individuals, who have been training 4-5 times and play in at least one competitive match per week. Moreover, are familiar with all monitoring procedures (>2 years). New players also underwent a familiarisation period of the monitoring procedures (>2 weeks) before their data was included. Upon recruitment, all participants were provided with an information sheet and informed of any potential risks and were recruited upon providing written informed consent. Subsequently, up until data analysis, participants were free to withdraw. All studies received full ethical approval from the University of Brighton ethical review board and conformed with the requirements by the Declaration of Helsinki and followed all health and safety procedures. Ethical Approval ID: 5545 and 7156.

3.2 – Exclusion Criteria

For Study One and Two, participants were excluded if they did not complete the PWB questionnaire (WEMWBS) at least once during each phase of the season (in-season, lockdown, RTT, and restart), or less than eight months over a two-year period, respectively. For studies, Two, Three and Five, GKs were excluded, due to a difference in nature of activity completed during training sessions. For Study Four, GKs had to compete for at least a six-month period during the 2019-2020, 2020-2021 and 2021-2022 season.

This resulted in one participant being excluded from Study One and Two, and six participants (three 3GKs) being excluded from Study Three and Five.

3.3 – Data collection procedures

For Study One, MH data and the type of training session and duration were collected for twenty-five full time EPL soccer players across the 2019-2020 season. Due to the COVID-19 pandemic, data collection spanned 58-weeks, and the questionnaire was administered 28 times, across four phases of the season, in-season (12-weeks), lockdown (9 weeks), RTT (3 weeks) and restart (4 weeks). Training schedules in-season were determined by the head coach and typically followed a routine of training, Monday, Tuesday, Thursday, and Friday and typically a match on a Saturday. During the lockdown, an alternative training programme was prescribed by the strength and conditioning coach consisting of cycle ergometer, circuit, steady state runs and yoga sessions.

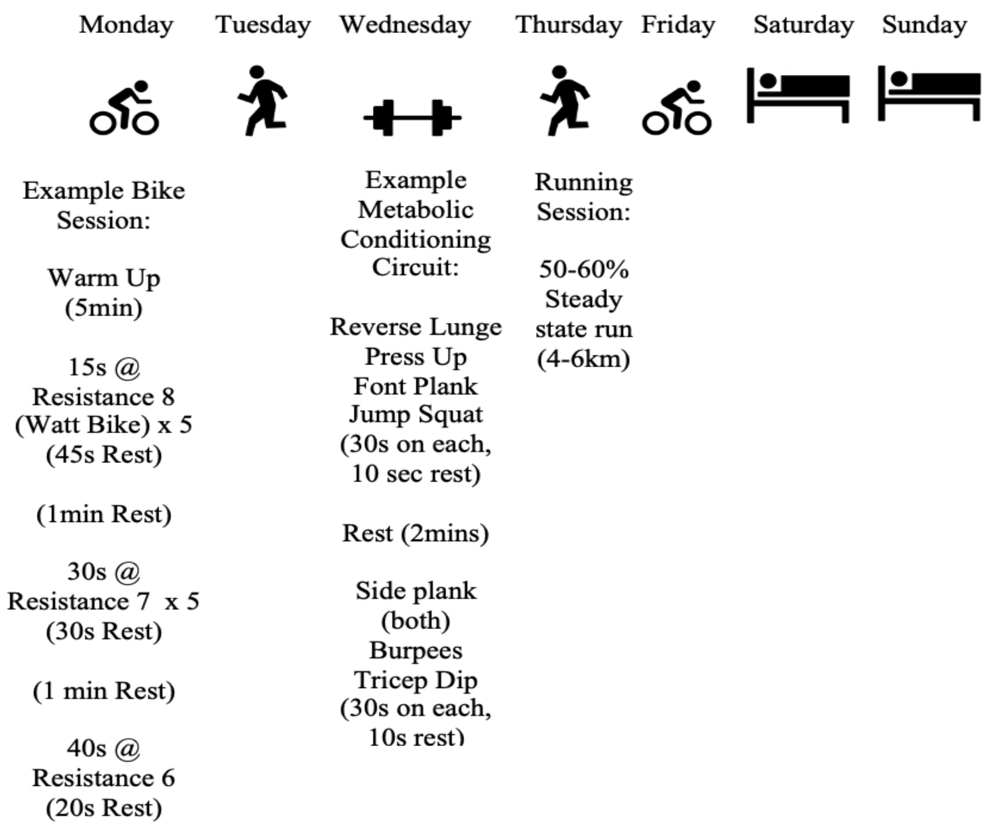

Figure 3.1 An example training week prescribed during the lockdown and subsequent intensity training was performed at.

For Study Two, MH data and GPS data from both 42 matches and 300 training sessions were collected for 32 professional full-time soccer players over two-consecutive seasons (2019-2020 and 2020-2021). Additionally, injury and self-reported illness data, and contextual match factors (win-rate, playing status and match selection) were collected. Unlike Study One, the COVID-19 pandemic suspended data collection, due to the suspension of the routine training and games programme, and therefore the lockdown period was excluded from analysis, as the data collection panned 86 weeks and the questionnaires were administered 42 times. Fixtures utilised for the contextual match factors consisted of pre-season friendlies, the EPL, Carabao Cup, and FA Cup Fixtures.

For Study Three, MH, GPS and monitoring data were collected for nineteen professional soccer players over one the 2019-2020 season. Data collection spanned 37 weeks and consisted of 115 training and monitoring sessions, and 33 competitive matches. Prior to data collection, participants were familiarised with the monitoring procedures. Training schedules were determined by the head coach and typically followed a routine of training Monday, Tuesday, Thursday, and Friday, with a match on a Saturday. Prior to a training session at the training ground, daily monitoring markers (subjective wellness, S&R and AS) were collected. In addition, a MH questionnaire was administered every two weeks, 15 times. Data was only considered when a player was fully fit and took part in both training and monitoring procedures.

During Study Four, for each training session, GPS data and daily monitoring data were collected for 34 full time EPL soccer players, over a two and a half season long period. Data collection was comprised of 113 weeks, consisting of 410 training sessions. Player's data were grouped upon position (GK = 7, CD = 5, WD = 5, CM = 7, WM = 5, FWD = 5). In similarity to Study Two, the COVID-19 pandemic suspended data collection and therefore the lockdown period and resumption of the 2019-2020 season was excluded in this study due to the suspension of the EPL, suspending routine training and games programme, and upon RTT, due to the COVID-19 pandemic, monitoring markers were not able to be collected. During Study Five, the exact same data collection procedures were utilised as Study Three, however injury and self-reported illness data were also recorded. In addition to the MH questionnaire was administered every two weeks, 15 times.

For all studies data was collected as part of a routine monitoring assessment by the sports science and medical team. The tests involved were determined in collaboration with the sport science and medical team and decided based upon previous research and the practicality of such measurements in an elite sporting environment. Such tests must be practical and meet both the goals of the research, but also be of ecological validity to implement within a football club. Scientific rationale and reliability data is presented below.

3.4 - GPS Data Analysis

To collect match and TL data, GPS units were downloaded to a laptop for data analysis using Catapult Openfield Cloud (Version 2.0.1, Catapult Innovations, Melbourne, Australia) by myself and the sport scientist. GPS units, require time and location data obtained through satellites orbiting the earth and relaying precise time information from an atomic clock to GPS receivers, and a minimum of four satellites are required to obtain location data (Malone *et al.,* 2017a). Subsequently, locomotor activities can be quantified including distance, speed, acceleration, and deceleration. Velocity and distance are calculated utilising the doppler shift and positional differentiation respectively. Acceleration and deceleration are typically derived from doppler shift velocity (Malone *et al.,* 2017a), the increasing or decreasing rate of change in instantaneous velocity across time (Hogdson *et al.,* 2014). Data was excluded if the number of available satellites were below the minimum acceptable range (8-11) (Jennings *et al.,* 2010). For training sessions, GPS data was calculated for the 'active time' and the time between drills was excluded. For matches, GPS data was calculated for the 'first half' and ‘second half’ and the warmup was not calculated for MDs. For Study Four, GKs did not wear GPS during match play. During studies Two, Three, Four and Five, if their GPS unit did not work properly or participants did not wear their unit, a positional average from the training session or their average match output multiplied by the min played would be given to the participant.

3.5 - GPS Data Quality and Accuracy

For Study Two, Three and Five, 10Hz GPS units and 100Hz triaxial accelerometer devices (Vector, Catapult Innovations, Melbourne, Australia) were utilised for data collection within the current thesis. For Study Four, both 10Hz GPS and 10Hz – MEMS GK specific units were utilised for data collection. GPS units were worn in manufacturer vests, with the units positioned between the scapulae. The vests were tightly fitted to the participants to prevent unwanted movement of the GPS devices, to enhance the accuracy of the inertial sensor derived metrics, such as player load (McLean *et al.,* 2018). Devices were always turned on a minimum of 15 min prior to data collection to allow for the acquisition of satellite signals (Waldron *et al.,* 2011). Additionally, each participant wore the same GPS units throughout the season to avoid interunit error (Jennings *et al.,* 2010). Ten Hz units have been reported to have acceptable reliability for acceleration and deceleration, and at high speeds (Varley *et al.,* 2012; Scott *et al.,* 2016). Ten Hz units have demonstrated a sufficient accuracy for quantifying HSD in field-based team sports (Rampinini *et al.,* 2015), and has a moderate to good intra-unit reliability (mean CV = 5.1%) (Scott *et al.,* 2016). Additionally, 10 Hz GPS units were sufficiently accurate to quantify the acceleration and deceleration running phases in team sports (Varley *et al.,* 2012) and has demonstrated moderate to good interunit reliability (CV = 1.2 – 6.9%) (Delaney *et al.,* 2018). Moreover, GPS devices have been validated to measure non-locomotive movements in rugby and volleyball (Gageler *et al.,* 2015; Reardon *et al.,* 2017).

3.6 - GPS parameters and respective definitions utilised

In Study Two, Three and Five, the GPS utilised, and their respective definitions are demonstrated in Table 3.1. In Study Four, the GPS utilised, and their respective definitions are demonstrated in Table 3.2.

Table 3.1: GPS parameters and their respective definitions and the global thresholds applied in Study Two, Three, Four and Five

GPS Parameter	Definition
TD (m)	Total distance covered walking, jogging, fast running and sprinting.
HSD (m)	A distance covered at a speed between 5.5 $m.s^{-1}$ – 7 $m.s^{-1}$.
SD (m)	A distance covered at a speed > 7 $m.s^{-1}$.
ED (m)	A distance covered accelerating > 2 $m.s^{-2}$ + decelerating > $2m.s^{-2}$.
Low Intensity Distance (LID) (m)	A distance covered at a speed between 0 $m.s^{-1}$ and < 5.5 $m.s^{-1}$.
Player load (AU)	Instantaneous rate of change in acceleration in each of the three vectors (x, y and z) (Malone *et al.,* 2017a).

*These global thresholds were applied for Study Two, Three and Four. TD – Total Distance, HSD – High Speed Distance, ED – Explosive Distance, SD – Sprint Distance.

Table 3.2: GK-specific GPS parameters and their respective definitions utilised in Study Four.

GPS Parameters	Definitions
High Jumps	Jumps above >0.4m in height
Medium Jumps	Jumps between 0.2-0.4m in height
Low Jumps	Jumps below 0.2m in height
Total Dives	Number of dives completed
GK total dive load	Instantaneous rate of change in acceleration in each of the three vectors (x, y and z) (Malone *et al.,* 2017a).
Average time to feet (ATF)	Instances where a dive was followed by a GK returning to standing within 1s

*These thresholds were determined by utilising recommended thresholds within soccer GK, utilised by (White *et al.,* 2020).

In the current thesis global vs. individualised thresholds were utilised. Global thresholds were routinely utilised in the club environment. It is also noteworthy that individualised speed thresholds do not enhance the dose-response determination to daily fluctuations in external load (Scott *et al.,* 2018). Therefore, to improve the ecological validity of the current thesis results, the decision was made to utilise these thresholds.

3.7 – Internal workload – Session Rating of Perceived Exertion

sRPE for each training session were obtained during Study Two, Three and Five. sRPE can be a global indicator of an individual's load combining both physiological and psychological load. Participants were familiarised with the RPE scale prior to the data collection period. Participants rated their perceived intensity of each session straight after the session (30 min), utilising the modified Borg CR-10 scale (Borg *et al.,* 1982). Each individual RPE was collected separately, to ensure independence in responses. sRPE was calculated by multiplying a participant's RPE by the duration of the training session (min) (Foster *et al.,* 1998).

3.8 - Monitoring Testing Procedures – Objective

In soccer, hip/groin and hamstring injury are most common, accounting for a third of the overall injury burden (~5-19 days, time loss per injury) (Ekstrand *et al.,* 2020). Key injury risk factors include both AS and HF (Markovic *et al.,* 2020; Salter *et al.,* 2021). Therefore, the AS test and S&R test were selected as suitable, valid, and practical musculoskeletal measures that could determine injury risk in elite sporting environments.

3.8.1 - Adductor Strength Test

The AS test was conducted once a week, on the second day following a match during morning monitoring (9~9:30 am). The AS test, utilising the 'Hip-Strength Testing System' (Force Frame. Vald Performance, USA), has been reported to demonstrate a CV of 6.3% and increased groin pain reduced groin squeeze force production (Ryan *et al.,* 2019b). During testing, participants were required to lie beneath the 'Hip Strength Testing System' and adopt a supine position with a hip flexion at 45 degrees known to be the optimal position for maximal AS (Delahunt *et al.,* 2011) (Shown in Figure 3.2). Bar height was set at 18 for each player and was consistent throughout the data collection period. Participants would place the femoral medial condyle of both knees on the pads fixed to the strength testing system and push inwards. The testing procedure consisted of one warm up rep around 60-80% of maximum effort, followed by two maximal repetitions, each 5 seconds in length interspersed with a short 30 second break in-between. Data was collected utilising the Vald hub, in which uploaded data from the tests were accessed. A subsequent maximum force (N) was then obtained for both right and left adductors, of which the peak score obtained on either repetition for each leg was recorded. Participants were familiarised with the AS test prior to the data collection period.

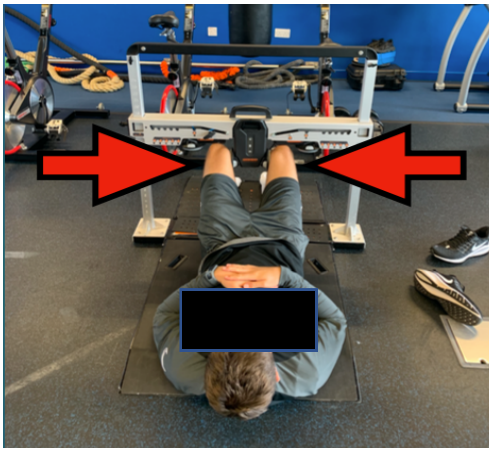

Figure 3.2: Participant demonstration of the adductor squeeze strength test set up.

Table 3.3 demonstrates example individual data measures of the AS test in the current cohort recruited in the current thesis. The typical error of measurement for left and right AS was 20.0N and 23.0N respectively. Whilst the smallest worthwhile change for left and right AS was 13.9N (2.7%) and 9.10N (1.8%) respectively. This is in line with current research demonstrating a smallest worthwhile change of 5% in both limbs (Ryan *et al.,* 2019a). The AS test demonstrated good reliability as on the left and right AS for example, an ICC 0.95 (95% CI: 0.81-0.99), and 0.88 (95% CI: 0.60-0.97) respectively.

Table 3.3: Example individual data of the adductor strength test

Subject	Trial 1		Trial 2	
	Left	Right	Left	Right
1	444.8	480.5	479.8	490.5
2	602.3	536.8	602.5	518.3
3	487.3	478.0	481.5	470.0
4	419.5	425.5	412.8	403.8
5	494.8	488.5	489.0	489.8
6	474.3	484.0	432.3	446.8
7	596.0	590.5	650.3	673.3
8	465.5	466.0	439.5	470.9
9	506.3	492.0	483.5	472.5
10	614.8	533.3	611.8	547.3

3.8.2 Sit and Reach Test

The S&R test is a reliable and valid test to estimate HF with a test-retest reliability of ICC 0.98-0.99 (95% CI: 0.94- 1.00) (Gabbe *et al.,* 2004). The S&R test has a standard error of estimate of 1cm (Gabbe *et al.,* 2004). The S&R test was conducted once a week, on the second day following a match during morning monitoring (9-9:30 am). During testing, participants sit down with their feet placed against a S&R box (shown in Figure 2). Participants without bending their knees stretch their arms as far as they can forwards and hold for 1 second. The distance between the toe line and highest point (middle finger) was visualised by the practitioner and recorded (Gabbe *et al.,* 2004). Participants were familiarised with the S&R test prior to the data collection period. The testing procedure consisted of two repetitions, interspersed with a twenty second break. Prior to this a warmup repetition would be conducted where each participant would reach to 60-70% of maximal effort.

3.9 - Monitoring Testing Procedures – Subjective

Just as physical training is monitored and balanced, so too must the psychological demands be balanced with strategies to support MH (Kuettall *et al.,* 2019). Therefore, a measurement of MH (e.g., PWB) was selected in the battery of tests. Moreover, subjective wellbeing questionnaire was also selected due to its inclusion in a battery of monitoring tests, and routinely utilised by the club.

3.9.1 Psychological Wellbeing Questionnaire

Psychological wellbeing was assessed using the WEMWBS (Stewart-Brown *et al.,* 2009) (Appendix 1). The questionnaire comprised of a 14-item self-report scale that assesses positive thoughts and feelings in relation to the previous 2-weeks. Each statement is scored on a 1-5 Likert Scale (1 = "none of the time". 5 = "all of the time"). A global score ranging between 14-70 is then calculated by adding up item scores. The higher the score, the higher levels of PWB. The 'WEMWBS' is a valid, reliable measure of MW in the general population (Tennant *et al.,* 2007; Maheswaran *et al.,* 2012), and is responsive to changes in intervention (Maheswaran *et al.,* 2012). The WEMWBS also strongly correlates with psychiatric scales for depression and anxiety symptoms (Zadow *et al.,* 2017; Smith *et al.,* 2017). This questionnaire has been utilised to monitor MW in the general and athletic populations (Abbott *et al.,* 2019; Nicholls *et al.,* 2020) and acceptable reliability has been indicated within male athletes (a = 0.94) (Rice *et al.,* 2019). For Study One, good reliability of the questionnaire was calculated for the sample as the Cronbach Alpha was 0.89. For Study Two, excellent reliability of the questionnaire was calculated for the sample as the Cronbach Alpha was 0.90.

3.9.2 Subjective Wellness Questionnaire

Participant's wellbeing was assessed using a custom-based 'subjective wellness questionnaire' based upon previous recommendations (Hooper *et al.,* 1995b) (Appendix 2).

The items included fatigue, sleep quality, muscle soreness, general health, and mood, using a five-point Likert Scale, ranging from 1 (best score) to 5 (worst score). A total wellness score of 5 was calculated by a summation of the item scores. Higher wellness scores highlighted poor wellbeing scores. In addition, quantity of hours sleep was recorded and a simple yes/no reporting of common cold symptoms. These items have been used extensively to examine subjective wellbeing and have previously reported CV of 7.1% in team sport athletes (Roe *et al.,* 2016). Players were familiarised with the questionnaire prior to data collection. The subjective wellness questionnaire was completed upon arrival, during morning monitoring (9~9:30 am). Players were not asked to report wellness scores on match and rest days.

3.10 – Monitoring Testing Procedures – Data Analysis.

Musculoskeletal screening scores (AS & S&R) and subjective wellness scores were converted into Z-scores for Study Three. Z-scores were calculated by: (Current Assessment – rolling average) / rolling *sd*)). Z-scores were then interpreted via a ‘flag-based’ approach (Robertson *et al.,* 2016), whereby a Z-score between 0-1 was green, >1-2 was amber, and >2 was considered a red flag.

3.9 Statistical Analysis

All statistical analysis within the current thesis was completed via SPSS (Version 26.0; SPSS, Inc, Chicago, IL, USA). Normal distribution was assessed utilising the Shapiro-Wilks and Kolmogorov-Smirnov tests and assumed with a significance value ($P > 0.05$).

As the data within Study One was normally distributed, parametric statistical tests were applied.. A one-way repeated measures analysis of variance (ANOVA) was used to determine within subject differences in PWB overtime (in-season, lockdown, RTT and restart). Partial eta-squared values were calculated to estimate the effect size of the ANOVA. Paired and independent samples t-tests were utilised to determine differences in PWB and physical activity (PA). Cohen’s *d* effect sizes were used to determine the strength of the differences obtained within the test. Pearson correlation coefficients were used to determine the relationship between PA and PWB. Participants within subject variability, were interpreted using mechanistic magnitude-based inferences (Hopkins *et al.,* 2009). The uncertainty effect was expressed as 90% confidence limits and with likelihood that the true value of effect represented substantial or trivial changes expressed as possible (25-75%), likely (75-95%) and most likely (>99.5%) (Hopkins *et al.,* 2009).

As the data within Study Two was normally distributed, parametric statistical tests were applied. A one-way repeated measures ANOVA was used to determine within subject differences in PWB over 10 phases across two seasons. Partial eta-squared values were calculated to estimate the effect size of the ANOVA. Multiple paired t-tests were utilised to assess the differences in PWB, with respect to contextual match factors, prior to injury and illness. Cohen's *d* effect sizes were used to determine the strength of the differences obtained within the t-test. Pearson correlations were utilised to assess the relationship between PWB and TL. A multivariate regression was utilised to assess any predictors (independent variables: contextual match factors, injury, and illness) upon PWB (dependant variable).

As the data within Study Three was normally distributed, parametric statistical tests were applied. Monitoring markers were calculated as 'Z-Score', using the following equation: Current Assessment – (mean score (season-long rolling average)/ *sd*). To investigate differences in weekly monitoring and ETL GPS parameters Z-scores across the season (pre, early, mid and late), a one-way repeated measures ANOVA was used. Partial eta squared values were calculated to estimate the effect size of the ANOVA. Bonferroni tests were used post-hoc to assess where differences occurred, with Cohen's *d* tests used to calculate effect sizes. Stepwise regressions were utilised to assess the extent recovery markers (dependant variable) can predict ETL (independent variable), to derive partial correlations. The magnitude of correlations was interpreted.

As the data within Study Four was normally distributed, parametric statistical tests were applied. To investigate the difference in ETL parameters (TD) and subjective wellbeing between MDs, a one-way ANOVA was utilised. In addition, was utilised to assess the positional differences (GK, FB, CD, CM, WM and FW) in TD and subjective wellbeing. Partial-Eta Squared values were calculated to estimate the effect size of the ANOVA. Bonferroni tests were utilised post-hoc to assess where differences occurred, with Cohen's *d* tests utilised to calculate effect sizes. Stepwise regressions were utilised to assess the extent subjective wellbeing (dependant variable) can predict ETL (independent variable) and derive partial correlations. The magnitude of correlations were interpreted.

As the data within Study Five was normally distributed, parametric statistical tests were applied. To investigate the difference in monitoring tools and TL on days with and without an illness or injury, independent samples t-tests were utilised. Cohen's *d* were utilised to determine the strength of t-tests. To investigate the predictive ability of monitoring tools and TL upon self-reported illness and injury a mixed effects logistic regression model was utilised. The fixed variable was the 'monitoring tool or TL' and the random effect was each 'individual'.

Statistical significance for all studies was assumed at (P <0.05). For all studies to determine the strength of the differences obtained within the t-tests, Cohen's *d* effect sizes were used to determine the strength of the differences (0.1 = small, 0.3 = medium, and 0.5 = large) (Cohen, 1988). To interpret the magnitude of correlations between the partial correlations: <0.1 *trivial*, 0.1 to 0.3 *small*, 0.3 to 0.5 *moderate,* 0.5 to 0.7 *large,* 0.7 to 0.9 *very large,* and 0.9 to 1.0 *almost perfect* (Hopkins, 2000).

4.0 - Study One – Physical activity on Psychological wellbeing in senior English Premier League Soccer players during the COVID-19 pandemic and the lockdown.

Publication arising from this chapter: Grimson, S., Brickley, G., Smeeton, N. J., Abbott, W., & Brett, A. (2021). Physical activity on mental wellbeing in senior English Premier League Soccer players during the COVID-19 pandemic and the lockdown. *European Journal of Sport Science,* :1-10.

4.1 - Abstract

The COVID-19 pandemic and the subsequent lockdown created new stressors that could potentially attenuate PWB in athletes, who are already susceptible to poor PWB. This study aims to describe fluctuations to PWB during 'lockdown' and subsequent 'return to sport' protocols, in comparison to the normal 'in-season' in professional soccer.

Twenty-five EPL soccer players completed the WEMWBS every two weeks, during the 2019/2020 season, and every week during 'lockdown' and 'RTT' for 28 weeks. The duration of each PA session completed was recorded. No significant differences were found for PWB between time points (In-season, lockdown, RTT, and the restart) (51.5±5.6 vs. 50.7±4.8 vs. 50.8±5.7 vs. 50.7±5.6 (P >0.05)) respectively. Individually, differences were identified; in-season weekly session duration (243±38 min) was higher than during lockdown (180±62 min) (P <0.05). During lockdown, weekly PWB scores were related to the previous 7-day number of sessions (r = 0.151) and active min (r = 0.142) (P <0.05). Furthermore, participants that exercised >250 min in lockdown, had higher PWB scores (52.46 ± 4.65) than <250 min (50.35±6.55) (P <0.05). Psychological wellbeing responses to lockdown were best understood on an individual basis in comparison to the group. Additionally, PA only had a measurable effect on PWB when >250 min. Further, stressors imposed upon players during an EPL season, are potentially greater than those inflicted by the lockdown. Implications for monitoring PWB in EPL soccer players and the potential inclusion of an in-season break are discussed.

Keywords: *COVID-19 Pandemic, Professional Soccer, Mental Health, Wellbeing, Physical Activity.*

4.2 Introduction

Mental Health symptoms and disorders in athletes exceed those in the general population (Reardon *et al.,* 2019). When compared to the general population, elite rugby players were reported to have a 5.5% lower PWB score (Fat *et al.,* 2017; Nicholls *et al.,* 2020). Further, the prevalence of MHD might be greater in soccer than alternative sports (Gouttebarge *et al.,* 2015b). Within 262 soccer players, 37% reported MHD over a 12-month period (Kilic *et al.,* 2018). In 607 male soccer players, 9% reported addictive alcohol behaviours, 38% anxiety and depression, and 58% adverse nutrition, such as eating disorders (Gouttebarge *et al.,* 2019). Vulnerability to poor MH may be related to both sporting and non-sporting factors (Rice *et al.,* 2016). A professional sports career is characterised by over 640 distinct stressors that could potentially augment poor MH (Arnold *et al.,* 2012). EPL soccer players are exposed to excessive TL and fixture congestion therefore exacerbating physical demands (Carling *et al.,* 2015; Rice *et al.,* 2016). This creates a PA paradox, whereby the usual health benefits of PA are absent, and may compromise PWB through overtraining, injury and burnout (Peluso *et al*., 2005). Injuries have been reported to negatively impact athlete PWB, a result of absence from sport, threatening athletic identity (Abbott *et al.,* 2019). Further, sleep deprivation as a consequence of travel and evening matches, career transitions, performance difficulty, and media scrutiny could all attenuate PWB (Rice *et al.,* 2016; Nedelec *et al.,* 2019a). Alternatively, non-sporting factors such as negative life events (Gouttebarge *et al.,* 2017), may potentially attenuate PWB. It is therefore imperative health and wellbeing are monitored to help identification of decline and support early intervention. The WEMWBS (Stewart-Brown *et al.,* 2009), has been utilised and demonstrated as a simple and cost-effective way to monitor for potential MH disturbances in professional male soccer players

(Abbott *et al.,* 2019). This study highlighted that injury and contextual match factors, such as non-match selection accounted for 50% of the variability in PWB.

The COVID-19 pandemic, and implementation of lockdowns, caused the suspension of all professional sporting events, including the EPL (13th March 2020). This created new stressors on athletes, exacerbating their susceptibility to poor MH (Reardon *et al.,* 2020). Athletes' usual routines and competition schedules were terminated and reduced all in-person communication with players and coaches in which athletic identity is fundamentally derived (Jukic *et al.,* 2020). The pandemic also led to a reduction in PA. In 692 elite and semi-elite South African athletes, 75% reduced their TL and intensity and 50% were depressed and lacked motivation to train (Pillay *et al.,* 2020). This significantly changed athletes' livelihoods and identities, which can proliferate vulnerability to poor PWB (Reardon *et al.,* 2020). In contrast, it has been argued the pandemic has provided an opportunity to augment PWB, in the form of increasing non-athletic identity (Reardon *et al.,* 2020). Further, athletes could spend increased time with their immediate family, which is somewhat challenging in-season. Additionally, the prolonged recovery from sport related stressors, such as training and competition, could have allowed a complete physiological and mental reset (Jukic *et al.,* 2020). Support practitioners have attempted to maintain positive wellbeing throughout this period. Examples of strategies include individualised training programmes, and regular team sessions utilising online communication tools. Research suggests that 25% of athletes engaged in digitally directed programmes from sporting personnel (Pillay *et al.,* 2020). Upon return to sport, additional stressors were placed upon athletes. A sudden increase in TL and congested fixture periods potentially exacerbated the risk of injury (Reardon *et al.,* 2020). Further, the return to sport protocols took place during the lockdown, meaning the risk of players contracting COVID-19 were elevated, potentially placing greater risk upon their families (Reardon *et al.,* 2020). Nevertheless, research suggested that 50% of athletes were comfortable to RTS when advised (Pillay *et al.,* 2020).

Currently, the majority of research investigating the effect of lockdown upon MH focused upon clinical populations (Paules *et al.,* 2020), rather than athletic populations. In student athletes, reduced PA during the lockdown reduced sleep quality, quantity and increased depressive symptoms (NCAA, 2020). Moreover, depression and anxiety symptoms were lower in athletes than their novice counterparts (Senisik *et al.,* 2020).

Considering the recent research focusing upon the COVID-19 pandemic, specifically the reduction in PA during lockdown, and increased depressive symptoms in student athletes (NCAA, 2020), and the uncertainty surrounding the RTS (Pillay *et al.,* 2020). The current study aimed to explore the influence of the pandemic on PWB during the 'lockdown' and 'RTS' protocols in contrast to the 'normal' in-season, in EPL soccer players. This provides an opportunity to understand responses to PWB during the COVID-19 pandemic in elite athletes and allow novel comparisons between the psychological stressors of the EPL, and their subsequent absence.

4.3 Methods

Participants

Twenty-five first team professional male soccer players from an EPL club participated in this study (stature: 183.3 ± 8.7 cm; body mass: 81.15 ± 8.58 kg; age: 27.2 ± 4.0 yr). All participants competed in the 2019-2020 season and completed routine training sessions, matches, and training prescribed during the lockdown. Full approval was received from the local ethics review board and participants provided informed written consent.

Experimental Procedure

The participants completed a questionnaire to assess PWB across the different phases of the season (Figure 1). This was completed on a bi-weekly basis during the normal in-season, between 9:00-9:30 am, and on the second day following a match. This day was selected as it was considered the optimum time to reduce the impact of the preceding or following match, given the fixture congestion experiencing in the EPL. This model was replicated during the restart. During the lockdown and RTT, participants were sent a digital questionnaire to complete on a Monday morning once a week. Each match, training session type and duration were recorded. The specific sessions recorded during lockdown are demonstrated in Figure 3.

Psychological Wellbeing Questionnaire.

Psychological Wellbeing was assessed using the WEMWBS (Stewart-Brown *et al.,* 2009). The WEMWBS has been utilised to monitor PWB in athletic populations (Abbott *et al.,* 2019; Nicholls *et al.,* 2020). The WEMWBS is a validated reliable measure of PWB in the general population (Tennant *et al.,* 2007), and acceptable reliability has been indicated within male athletes ($\alpha = 0.94$) (Rice *et al.,* 2020). The questionnaire is comprised of a 14-item self-report scale that assesses positive thoughts and feelings. Responses are made relative to the previous two weeks in-season, and previous week during lockdown and RTT. Each statement is scored on a 1-5 Likert Scale (1 = 'none of the time', 5 = 'all of the time'). A global score ranging between 14-70 is then calculated by adding up item scores. The higher the score, the higher the level of PWB.

Data Analysis

Data analysis was completed via SPSS (SPSS Version 26.0). Normal distribution was considered if the Shapiro-Wilks test was $P > 0.05$. A one-way repeated measures analysis of variance (ANOVA) was utilised to assess changes in PWB at the group level across the different phases of the season, in-season (12 weeks), lockdown (9 weeks), RTT (3 weeks) and restart (4 weeks). A paired samples t-test was utilised to determine the difference in weekly active min during lockdown and normal in-season. Pearson correlations were utilised to determine the relationship between PWB, and the previous week number of sessions completed, and active min. An independent samples t-test was utilised to determine the difference between PWB, when PA was >250 and <250 min. Cohen's *d* effect sizes were used to determine the strength of the differences obtained within the t-test (0.1 = small, 0.3, medium, and 0.5 = large) (Cohen, 1988). Each participant's within-subject variability was analysed using the predicted linear trend, based on the in-season PWB values, and then identifying the subsequent weeks scores fell outside the typical range. These findings were interpreted using mechanistic magnitude-based inferences (Hopkins *et al.,* 2009). The uncertainty in the effect was expressed as 90% confidence limits and with likelihoods that the true value of the effect represented substantial or trivial changes expressed as possibly (25-75%), likely (75-95%), very likely (95-99.5%) and most likely ($>99.5\%$) (Hopkins *et al.,* 2009). The smallest worthwhile change was determined by 0.2 x within subject *sd*. Statistical significance was determined at ($P < 0.05$).

4.4 Results

Group level PWB responses across the season phases are presented, followed by the individual level PWB responses. The weekly breakdown of PA during lockdown is then presented in Figure 4.3, succeeded by the subsequent relationships between PA and PWB during lockdown, and the in-season.

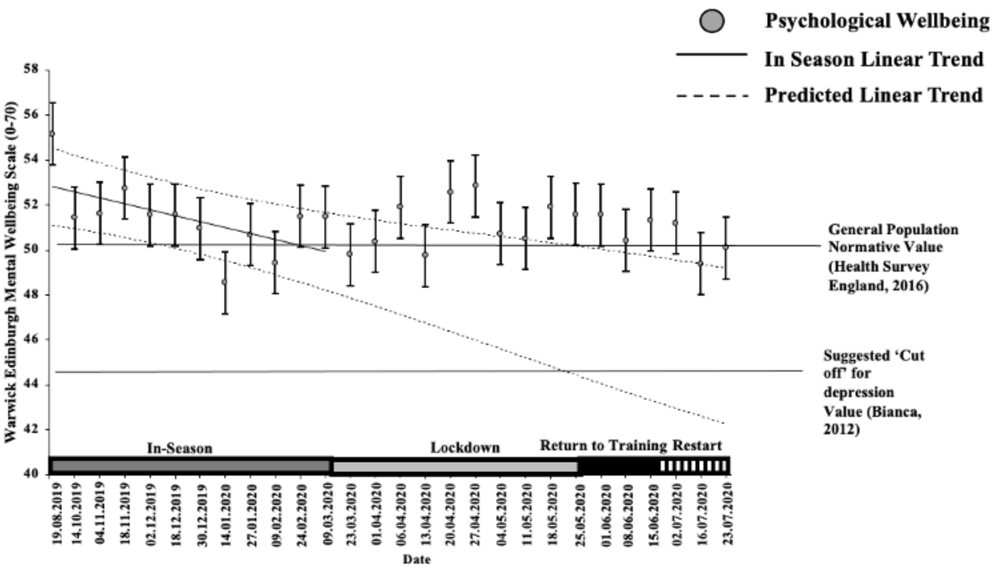

Figure 4.1: The average group modelled in-season trend vs. subsequent lockdown, return to training and restart periods. Values and error bars beyond the dashed lines represent a true change that is above 90% likelihood.

Group Analysis

A one-way repeated measures ANOVA revealed no main effect for time ($f_{(3,72)} = 0.628$, $P = 0.599$, $\eta^2_{partial} = 0.025$), and therefore no changes in PWB between, in-season, lockdown, RTT and the restart (51.52 ± 5.64 vs. 50.74 ± 4.84 vs. 50.79 ± 5.68 vs. 50.70 ± 5.61) respectively. Trends across the phases, revealed a trivial drop in PWB scores during the in-season of 0.26 every two weeks, and during the lockdown an increase of 0.16 every week. Followed by a decrease in PWB scores during RTT of 0.58 every week, and during the restart of 0.55 every two weeks. The modelled in-season trend analysis, demonstrated in Figure 4.1, revealed 90% likely true increases in PWB occurred during the fifth, sixth and ninth week of the lockdown, first and second week of RTT and the first two weeks during the restart.

Table 1: The individual responses to the modelled in-season trend vs. lockdown, return to training and restart periods.

						Lockdown						Return to Training				Restart	
Week		23.03	01.04	06.04	13.04	20.04	27.04	04.05	11.05	18.05	25.05	01.06	08.06	15.06	02.07	16.07	23.07
	1	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
	2	–	–	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	–
	3	↑	↑	–	–	–	–	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
	4	–	–	–	–	↑	↑	–	↑	↑	↑	↑	↑	↑	↑	–	–
	5	–	–	–	–	–	–	↑	–	↑	↑	↑	↑	↑	↑	↑	↑
	6	–	↑	↑	–	↑	↑	–	–	–	–	–	–	–	–	–	–
	7	–	–	–	–	–	–	–	–	–	–	–	–	↑	↑	↑	↑
	8	–	–	↑	–	–	↑	↑	–	–	–	–	–	–	–	–	–
Participant	9	–	–	–	–	–	–	–	–	↑	–	–	–	–	–	–	–
(Rank order of	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
change)	11	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	12	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	13	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	14	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	15	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	17	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	18	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	19	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	20	↓	–	–	–	–	–	–	↓	–	–	–	–	–	–	–	–
	21	–	↓	–	–	↓	–	↓	–	–	–	–	–	–	–	–	–
	22	–	–	–	–	–	↓	–	↓	–	↓	↓	↓	–	↓	↓	–
	23	<–>	–	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
	24	–	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
	25	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓

*A change with the chances >90% is very likely or decisive and is indicated with a ↑, <–> and ↓. An increase in PWB during the retrospective phases in comparison to the modelled in-season trend are demonstrated with a ↑ symbol. A decrease in PWB during the retrospective phases in comparison to the modelled in-season trend are demonstrated with a ↓ symbol, A significant maintenance in PWB during the retrospective phases in comparison to the modelled trend are demonstrated with a <-> symbol. A – symbol represent any changes with a chance of <90% likelihood.

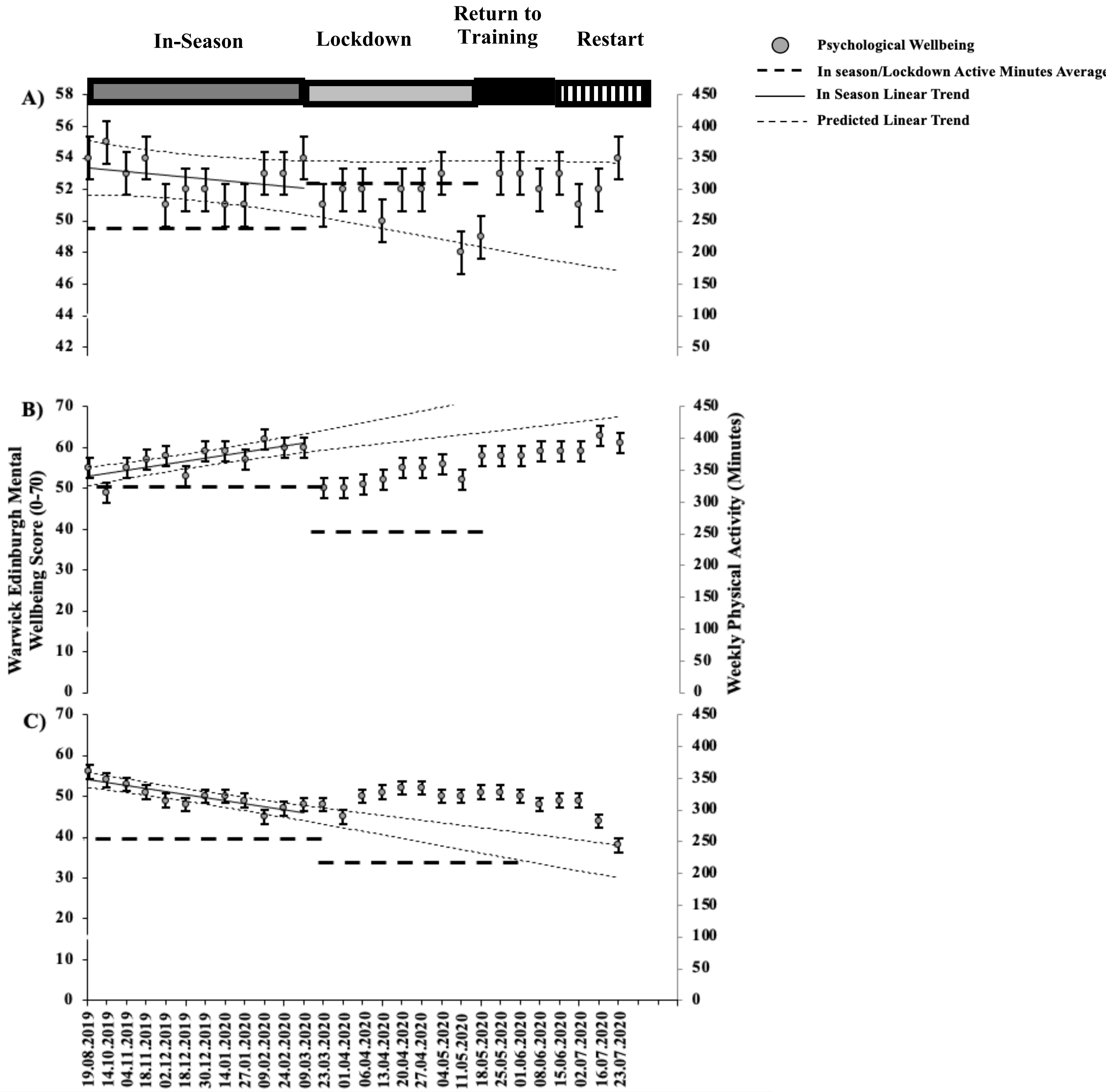

Figure 4.2: Individual participants modelled in-season trends and subsequent PWB scores during lockdown, return to training and in-season. Values and error bars beyond the dashed lines represent a change that is above 90% likely true.
Graph A) demonstrates an example participant whose PWB scores were maintained.
Graph B) demonstrates an example participant whose PWB scores were decreased (poor PWB).
Graph C) demonstrates an example participant whose PWB scores were increased (better PWB).

Individual Analysis

The modelled in-season trend analysis on an individual level when compared to lockdown, RTT and the restart that were 90% likely true are demonstrated in Table 4.1. During lockdown, PWB increased in 8 out of 25 participants, decreased in 6 out of 25 participants and remained constant in 11 out of 25 participants. During RTT, PWB increased in 6 out of 25 participants, decreased in 5 out of 25 participants and remained constant in 14 out of 25 participants. Lastly, during the restart, PWB increased in 6 out of 25 participants, decreased in 4 out of 25 participants and remained constant in 15 out of 25 participants. Examples of individual participants data are shown in Figure 4.2.

Lockdown and Physical Activity

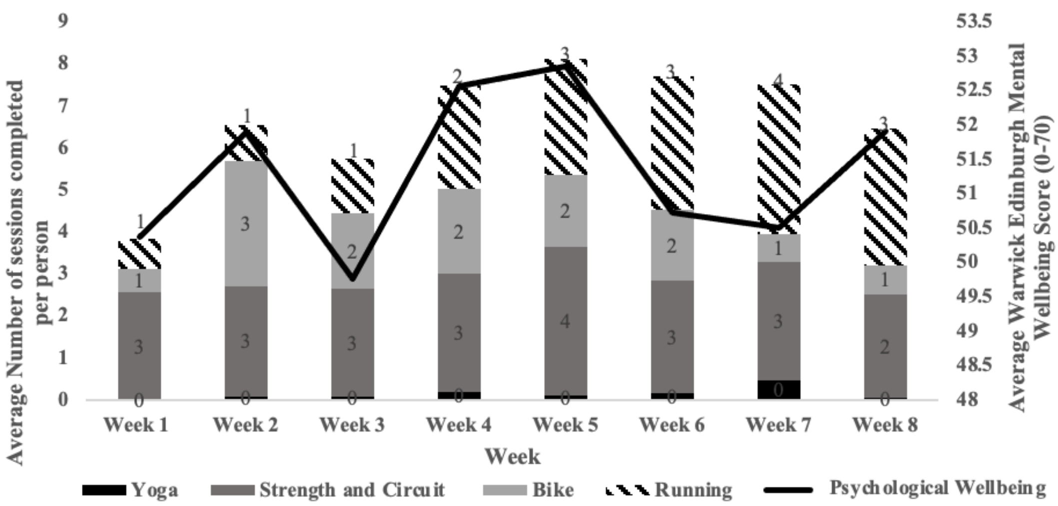

Figure 4.3: The weekly breakdown of the average number and types of sessions completed during the lockdown and the subsequent weekly PWB score.

Each participant completed on average 7 sessions per week, covering an average load of 21.1km on the bike, and 12.8km running (demonstrated in Figure 4.3). In-season weekly session duration (243± 23min) was higher than the lockdown (180±62 min) ($t_{(24)} = 4.403$, $P = .000$, $\eta^2_{partial} = 0.87$). The percentage of training sessions which were running-based from the start to end of the lockdown increased from 20% to 50%. Weekly PWB and number of sessions completed during the lockdown revealed a small correlation (*r* (189) = 0.151, *P* = 0.037). Weekly PWB and active min completed during lockdown revealed a small correlation (*r* (189) = 0.142, *P* =0.050). Additionally, participants that exercised >250 min in lockdown had higher PWB scores (52.46 ± 4.65) than <250 min (50.35 ± 6.55) ($t_{(129)}$ = 2.488, *P*= 0.014, *d*= 0.35). The Levene's test for equality of variances showed a difference in the amount of variance in PWB when participants exercised >250 min, compared to those <250 min (F = 6.116, *P*=. 014). PWB scores associated with <250 active min were not correlated (*r* (139) = 0.136, *P* = 0.108). PWB scores associated with >250 active min were not correlated (*r* (48) = -0.250, *P*= 0.080).

In-season and PA

PWB and previous 7-day active min, excluding the lockdown and when a player was injured revealed a small correlation (*r* (330) = 0.130, *P* =0.017, *d* = 0.02). Further, participants that exercised >250 min in-season had no difference in PWB (51.62 ± 6.22) than <250 min (50.72 ± 6.33) ($T_{(320)}$ = 1.310, *P* = 0.191, *d* = 0.14).

4.5 Discussion

Findings of the study revealed PWB did not change significantly across the season, in contrary to previous research, which reported that higher depressive symptoms were revealed in student athletes during the lockdown (NCAA, 2020). Interestingly however when looking at the trend analysis 90% likelihood changes were evident, revealing a decline in PWB during the in-season, RTT and the restart, yet an increase during the lockdown. On an individual level, some participants PWB increased, decreased or remained constant from in-season to lockdown (demonstrated in Table 4.1). Whilst no direct comparisons exist examining changes in PWB from in-season to lockdown, tentative arguments can be created using current research, specifically regarding the upward trend in PWB during the lockdown. Athletes were reported to have lower anxiety and depression symptoms than their non-athletic counterparts during the lockdown (Senisik *et al.,* 2020). As the ability to cope is skill dependant (expert vs. novice), athletes could potentially be more resistant to unpredictable events (di Fronso *et al.,* 2020). Moreover, elite athletes ascertain how to deal with possible sport related stressors, which could be transferred to alternative life domains (Pensgaard *et al.,* 2003; di Fronso *et al.,* 2020).

Psychological Wellbeing and Physical Activity.

Lower PA occurred during lockdown in contrary to the in-season. PWB and active min were related during both the in-season and lockdown phases. However, only during lockdown did undertaking >250 active min per week reveal a significantly higher PWB than <250 min. The in-season active min average is (243±23min). Therefore, it could be argued that there is a protective effect of exercising >250 min per week during lockdown, which is close to that of normal in-season. This could partly explain the individual variability in PWB responses during the lockdown, with those that maintained their PA levels, having an increased or maintained PWB. The notion that regular PA reduces anxiety and depression symptoms has been extensively reviewed (Rebar *et al.,* 2015). In contrast, reduced PA could increase body fat content, attenuate muscle mass and potentially lead to depression and insomnia (Chen *et al.,* 2020; Halabchi *et al.,* 2020).

During the lockdown, maintenance of PA may counteract the physical and emotional exhuastion associated with isolation, as a result of antidepressant properties (Peluso *et al.,* 2005; Sors *et al.,* 2020). Thus, the training programmes prescribed could have had positive implications on athlete's fitness and physical performance and can partly explain the stable PWB reported in this study compared to non-athletic populations. During the lockdown, elite soccer players trained more hours at higher intensities than their amateur and novice counterparts (Mon-Lopez *et al.,* 2020). Student athletes' mental distress has been associated with a lack of resources and available training facilities (Mon-Lopez *et al.,* 2020; Bullard, 2020). Thus, the 'privileged' position of the current participants, with regards to training programmes, provision to equipment, and guidance from support staff, may have helped to maintain MW. Organised compulsory indoor group-based sessions via online platforms allowed 'social distancing' to be replaced with 'physical distancing' (Van Bavel *et al.,* 2020). Previous research suggests that athletic identities became stronger during the lockdown, which was attributed to social support from teammates, and strengthened 'social identity' and 'exclusivity' (Graupensberger *et al.,* 2020; Costa *et al.,* 2020). However, it should be considered that higher athletic identities have been associated with an increased tendency to ruminate and catastrophize (Costa *et al.,* 2020). Considering in the current study, players participated in prescribed sessions, and therefore the restoration of 'normal training' and the amount of PA undertaken could have been a moderating factor to attenuate the tendency to ruminate and catastrophize, and thus PWB was maintained in the current study.

If elite sport was suspended again, routine training programmes consisting of >250 active min and maintaining social connections should be encouraged. Within a sporting context, if an individual is injured and absent from sport, strategies need to be implemented to sustain PWB.

Finally, during the in-season, PWB correlated with active min, in contrary to findings that TL does not predict PWB in academy soccer players (Abbott *et al.,* 2019). Therefore, PA levels could be as important during in-season. However, as PWB was no different when PA levels were >250 and <250 active min, it is yet to be known a threshold of PA during a typical in-season is yet to be identified, and therefore an area for future research.

Psychological Wellbeing and in-season

Findings of a declining trend in PWB in-season, and the predicted in-season trend supported a further potential decline in PWB. Without the lockdown where PWB increases, continuation of the competitive season could have resulted in a further decline in PWB. This is particularly important given the impact PWB has upon injury risk and performance (Watson *et al.,* 2016; Reardon *et al.,* 2019). These results suggest EPL soccer stressors are greater than those imposed by the pandemic and providing further rationale for the importance of longitudinally tracking PWB (Abbott *et al.,* 2019). The implementation of a mid-season break to alleviate these stressors could contribute to augmenting PWB during a season. Nevertheless, the PWB decrement during the restart could be due to the uncertainty surrounding RTS, and the exposure of COVID-19 to athletes and their family, rather than sport related stressors. Although, athletes were willing to compete behind closed doors, with male athletes more accepting than females (Pillay *et al.,* 2020). Moreover, upon RTS the confidence in ability and skilfulness could have reduced during the COVID-19 lockdown. Both confidence in ability and skill execution have been described as important factors facilitating successful RTS (Conti *et al.,* 2019). Thus, the PWB decrement upon the restart could have been a result of both COVID-19 related and EPL stressors. It should also be considered that the WEMWBS was administered on a MD+2 as this seemed the most appropriate given the congested fixture scheduling and double game weeks. However, two days post-match DOMS can still be evident, which could confound reduced PWB during the in-season when the games schedule is resumed. Importantly across the study, the group average range was between 48.55 to 52.75, which is higher than the suggested cut off for depression (44.50; Bianca, 2012) and comparative with the general population norm (50.20, Health Survey England, 2016). Interestingly, during lockdown, the group average PWB scores ranged between 49.76 and 52.57, which is higher than those reported by injured academy soccer players (43.60; Abbott *et al.,* 2019). However, caution should be taken when making this assumption as academy youth players have a greater risk of poor MH (Junge *et al.,* 2016). The exact sport related stressors that could attenuate PWB in EPL senior soccer players is unknown, and an area for future research.

Psychological Wellbeing and individual differences

During the lockdown PWB scores ranged between 32 and 69, suggesting some individuals had scores lower than the depression cut off (Bianca, 2012). This provides further rationale that PWB should be considered on an individual and group level, particularly as there were as many individuals that PWB scores went up during lockdown as went down. Other than PA, other factors that could explain the individual responses in PWB were not measured. In some individuals, increased PWB during the lockdown could be rationalised by the increased ability to spend more time with family, particularly for homegrown players. Yet for others, their family may live overseas, resulting in increased time apart. For these individuals, they may be increased concerned for their families, in countries whereby the pandemic was particularly worse than the UK. Moreover, elite soccer players reported an increase in sleep hours during the lockdown, which could have had a potential impact upon PWB (Mon-Lopez *et al.,* 2020). Life events were also not recorded and thus fluctuations in PWB could have been the result of an independent event to COVID-19.

Further Limitations

Current findings may not be attributable to individual sports, as the investigation utilised team sports athletes. Caution should also be applied when transferring results to females. Despite no differences between genders reported when looking at anxiety and depression symptoms during lockdown (Senisik *et al.,* 2020), mental distress has been found to affect women approximately twice as much as men (Salk *et al.,* 2017).

4.6 Conclusion

At a group level, but not individual level, PWB remained consistent from a normal in-season period to lockdown, and RTS protocols. Thus, these findings highlight the importance of individual differences in order to understand the demands of professional sport on athletes' PWB. Elite athletes may also be better able to cope with stressors and that this protected their PWB during a break from competition such as that experienced during COVID-19 lockdown. They also highlight that PA above 250 min per week, even in a well-trained population is important for it having a positive influence on PWB. From a practical perspective these findings encourage longitudinal monitoring and strategies to be implemented to prevent further in season declines in PWB, such as a 'mid-season' break and the maintenance of PA.

Link to Next Chapter

Findings from the current chapter suggest that during an EPL soccer season, subsequent exposure to potential sport-related stressors can decline a players MH status, in comparison to a period of rest. Moreover, the individual monitoring of PWB is pertinent due to the individual differences identified. Given that MH is associated with both performance and injury risk (Ivarsson *et al.,* 2013; Reardon *et al.,* 2019), understanding when and what contextual sport related stressors may affect PWB can help inform periodised interventions which can help maintain PWB. Subsequently, the next chapter aims to longitudinally monitor and examine sport-related stressors on PWB levels.

5.0 Study Two – The effects of injury, contextual match factors and training load upon psychological wellbeing in English Premier League soccer players via season-long tracking.

Publication arising from this chapter: Grimson, S., Brickley, G., Smeeton, N. J., Abbott, W., & Brett, A (2021) The effects of injury, contextual match factors and training load upon psychological wellbeing in English Premier League soccer players via season-long tracking, *European Journal of Sport Science,*

5.1 - Abstract

This study aimed to track PWB across two consecutive soccer seasons examining the effects of injury, illness, TL, and contextual match factors (playing status, match selection and individual win-rate). In addition to, exploring PWB levels prior to an injury or illness event. Thirty-two EPL soccer players completed the WEMWS every two weeks. No differences were found for group averaged PWB across the seasons (52.2 ± 0.3 vs. 51.8 ± 1.1) (P >0.05). Previous 7-day TL (session duration, TD, ED, low-intensity distance, HSD and SD) measured by GPS were not related to current PWB (P > 0.05). However, previous 14-day HSD (r *(385)* = -0.095) and 21-day SD (r *(385)* = 0.100) were related to current PWB (P < 0.05). Moreover, only 100% (vs. 0%) win-rate in the previous 14-days to the questionnaire revealed a higher current PWB score (52.7 ± 4.7 vs. 50.9 ± 5.6 (P < 0.05)). PWB did not differ prior to an injury or illness event, when players were injured or ill or as a consequence of the remaining contextual match factors at time of questionnaire or previous match, and the previous 7 and 14-days (P > 0.05). In conclusion, if PWB fluctuations across the season occur these could be best explained by prior TL and multiple negative results. Importantly, prior PWB was not linked to injury or illness events. Implications for prioritising interventions to improve PWB during periods of chronic high intensity TL and losing streaks, monitoring PWB, and use in injury and illness prediction are discussed.

Keywords: *Football, Stressors, Hedonic Wellbeing, Eudaimonic Wellbeing, Monitoring*

5.2 - Introduction

Recent research in professional soccer has indicated the prevalence of MH symptoms and disorders are pertinent and potentially greater in soccer than alternative sports (Gouttebarge *et al.,* 2015a; Gouttebarge *et al.,* 2015b; Junge *et al.,* 2016; Kilic *et al.,* 2018). Within 262 soccer players, 37% reported symptoms of common MHD over a 12-month period (Kilic *et al.,* 2018). Additionally, within 607 male soccer players, 9% reported alcohol misuse, 38% anxiety and depression, and 58% adverse nutrition (Gouttebarge *et al.,* 2015a). The prevalence may also vary upon age (Kuettel *et al.,* 2021a), as higher rates of depression (15 vs. 6.6%) and lower PWB (48 vs. 52) in youth vs. senior male soccer players have been reported (Abbott *et al.,* 2019; Grimson *et al.,* 2021).

Sporting and non-sporting risk factors such as negative life events, performance difficulty, media scrutiny and injury, are just a few challenges faced by elite athletes which could negatively impact MH and PWB (Rice *et al.,* 2016; Purcell *et al.,* 2019). Moreover, EPL soccer players are no exception, given their exposure to stressors which could be detrimental to MH such as, excessive TL, fixture congestion, contextual match factors and sleep deprivation because of travel and evening matches (Carling *et al.,* 2015; Rice *et al.,* 2016; Abbott *et al.,* 2019). These stressors could fluctuate across seasons or career phases, causing the potential for periodised vulnerability to poor MH and PWB (Hughes *et al.,* 2012). Previously, research has identified that lower PWB in EPL soccer players may occur in the 'late' vs. 'early' stages of a season, in addition to 'in-season' rather than 'lockdown' (Grimson *et al.,* 2021). This is likely due to sport rather than non-sport related stressors (e.g., injury), often singled out as having the greatest influence on MH and PWB (Schinke *et al.,* 2017). Additionally contextual factors such as playing position and level of play have also been related to increased depression and anxiety (Junge *et al.,* 2016).

Importantly, poor MH has been associated with injury risk and performance in soccer players (Ivarsson *et al.,* 2013; Watson *et al.,* 2016; Reardon et al., 2019). Therefore, just as training is monitored and balanced with adequate recovery to manage physical injuries, so too must the psychological demands with strategies supporting MH (Kuettal *et al.,* 2019). By monitoring MH and gaining an understanding of how and when sport-related psychological demands (e.g., injury, win-rate, match selection) in EPL soccer players could impact upon MH, this could then inform practitioners of when to periodise interventions to help optimise subsequent performance, wellbeing, and injury risk (Donohue *et al.,* 2018; Purcell *et al.,* 2019; Poucher *et al.,* 2021).

Notably, subjective, and objective monitoring tools are widely utilised to assess physical wellbeing and manage physical injuries yet omit monitoring tools to manage psychological demands and subsequent injury and illness risk (Heidari *et al.,* 2019). Indeed, questionnaires are simple, low cost and time efficient and could encourage help seeking behaviour in athletes (Halson, 2014; Souter *et al.,* 2018; Bird *et al.,* 2018). However, whilst research exists regarding MH in elite athletes, the focus has predominantly been upon the presence of MH symptoms and utilising diagnostic questionnaires such as the GAD-7 and CED-S scales. These diagnostic scales are impractical to monitor MH in elite athletic environments whereby they are negatively worded, time consuming and limited by the stigma surrounding MH (Bird *et al.,* 2018). Moreover, it's important to consider the notion that athletes are healthy without a clinical disorder is over simplistic (Henrikson *et al.,* 2019). Therefore, more recently, the negative conceptualization of MH, as the absence of mental illness (e.g., depression and anxiety) has shifted to encompass positive MH aspects and the functioning and flourishing of individuals (Tennant *et al.,* 2007; Schinke *et al.,* 2017; Kuettal *et al.,* 2021b). Subsequently, it is recommended that PWB is monitored in athletes rather than the presence of clinical disorders to help understand levels of happiness and pleasure (hedonic wellbeing) and extent to which a person is functioning fully (Eudemonic wellbeing) (Ryan *et al.,* 2001; Nicholls *et al.,* 2020). The WEMWBS covers both the Hedonic & Eudaimonic aspect of wellbeing which represent the MH component of the Keye's 'Two continua model' (Keyes, 2007) and is correlated with MH symptoms (e.g., anxiety and depression) (Kuettal *et al.,* 2021b). Recent research has utilised the WEMWBS (Stewart-Brown *et al.,* 2009) to assess potential MH disturbances in professional male soccer players (Abbott *et al.,* 2019; Kuettal *et al.,* 2021a; Grimson *et al.,* 2021). Therefore currently, the utilisation of the WEMWBS to assess PWB in elite athletic environments seems favourable. However, only one previous study has investigated the effect of contextual match factors upon PWB in academy soccer players (Abbott *et al.,* 2019), and reported injury and or match (de)selection, accounted for 50% of the variability within PWB (Abbott *et al.,* 2019). Given particular risk factors may vary across career phases (Purcell *et al.,* 2019) and the potential for age related differences in PWB (Abbott *et al.,* 2019; Kuettal *et al.,* 2021a), knowledge on how sport-related stressors such as injury and match (de)selection in EPL senior players impacts PWB requires investigation. Notably, the previous research predominantly focusing upon symptoms of depression and anxiety and the effects of contextual factors such as age, gender, playing position, injury and in elite senior male and female soccer players remains equivocal and limited (Junge *et al.,* 2016; Junge *et al.,* 2018). Cross-sectional research designs have previously been adopted, whereby MH symptoms were captured at one time point, and omits the fact that MH can fluctuate overtime (Hughes *et al.,* 2012). Therefore, as well as the assessment of the impact of contextual match factors upon PWB, a longitudinal monitoring approach may be more favourable as players can act as their own control, and fluctuations to PWB can be captured.

Overall, instead of focusing on the mental illness (symptoms of depression and anxiety), the current study therefore aimed to examine and enhance the understanding of the impact injury and contextual match factors (individual win-rate, match selection and playing status) and TL upon PWB (e.g., positive wellbeing). Moreover, to explore the potential relationship between PWB and subsequent injury and illness occurrence. Based upon previous literature, that injury and match deselection in U23 soccer players resulted in lower PWB, it was hypothesised that similar findings would be reported. It was also hypothesised that PWB would be lower prior to an injury.

5.3 - Methods

Participants

Thirty-two first team professional male soccer players from an EPL club were invited to participate in this study (stature: 183.7 ± 8.8 cm; body mass: 80.8 ± 8.3 kg; age: 26.6 ± 4.0 yr). All participants were classified as elite athletes (Swann *et al.,* 2015), and competed in the 2019-2020 and/or 2020-2021 seasons, comprised of routine training sessions and matches. Full approval was received from the local ethics review board and participants provided informed written consent for access to their routinely collected anonymous data.

Procedure

Participants completed a questionnaire to assess PWB across the different phases of the two seasons (Figure 5.1). This was completed on a bi-weekly basis between 9:00~9:30 am on the second day following a match. This day was selected as it was considered the optimum time to reduce the impact of the preceding or following match. The questionnaire was optional and administered by the club doctor to complete in a confidential manner. Any issues raised could be identified to the individual and necessary interventions could be put in place. Questionnaire data was then anonymised and connected to the remaining data through participant ID numbers before being given to the researcher. Session duration and external workload calculated by 10Hz GPS units (Vector, Catapult Innovations, Melbourne, Australia) worn during training session and matches, were recorded. Data was downloaded using

Catapult Openfield Cloud Software for analysis (Catapult Cloud Version 2.0.1, Catapult Innovations, Melbourne, Australia). Specific variables collected and respective definitions are displayed in Table 5.1. An injury was defined as any injury that resulted in time loss from training or matches (Fuller *et al.,* 2006). An illness was defined as a player self-reporting cold symptoms on the daily wellness questionnaire or that resulted in time lost from training or matches. Match selection was defined as participants that were available being named in the MD squad (11 players, 7 substitutes).

Psychological Wellbeing Questionnaire

Psychological wellbeing was assessed using the WEMWBS (Stewart-Brown *et al.,* 2009). The WEMWBS has been utilised to monitor MW in athletic populations (Abbott *et al.,* 2019; Nicholls *et al.,* 2020). The WEMWBS had excellent levels of reliability within our sample, with a Cronbach alpha of 0.90. The questionnaire is comprised of a 14-item self-report scale that assesses positive thoughts and feelings. Responses are made relative to the previous two-weeks. Each statement is scored on a 1-5 Likert Scale (1 = 'none of the time', 5 = 'all of the time'). A global score ranging between 14-70 is then calculated by adding up item scores. The higher the score, the higher the level of PWB.

Data Analysis

All data analysis was performed with SPSS (SPSS Version 26.0). Normal distribution was checked and considered normally distributed if the Shapiro-Wilks test was $p > 0.05$. A one-way repeated measures analysis of variance (ANOVA) was utilised to assess changes to PWB across the different phases of the two seasons outlined in Figure 5.1. Pearson correlations were utilised to determine the relationship between PWB and cumulative previous 7, 14 and 21-day workload for each GPS parameter. Multiple paired t-tests were utilised to assess differences in PWB scores, when 100 vs. 0% Injured vs. Not Injured, Ill vs. Not Ill, Selected vs. Unselected, Played vs. Not Played and Win vs. Loss, at the time of the questionnaire (TOQ), one- and two-weeks prior to the questionnaire. Furthermore, utilised to assess differences in PWB scores, one and two weeks prior to an Illness and Injury Occurrence vs. Non-Occurrence. Cohen's *d* effect sizes were used to determine the strength of the differences obtained in the t-test (0.1 = small, 0.3 = medium and 0.5 = large) (Cohen, 1988). A multivariate regression was utilised to examine the effects of each previous 7- day workload variable and contextual match variable presented in Table 5.2, upon PWB (dependent variable). Independent variables for each player were calculated and entered into the regression. Statistical significance was determined at $P < 0.05$.

5.4 – Results

Psychological Wellbeing across the two seasons.

Average PWB scores during the two seasons were 52.2 ± 0.3 and 51.8 ± 0.5 respectively and ranged between 50.6 and 53.0. A one-way repeated measures ANOVA revealed no main effect for time ($f_{(9,81)} = 0.630$, $P = 0.768$, $\eta^2_{\text{partial}} = 0.034$), and therefore no changes in PWB between the phases of the season (Figure 5.1).

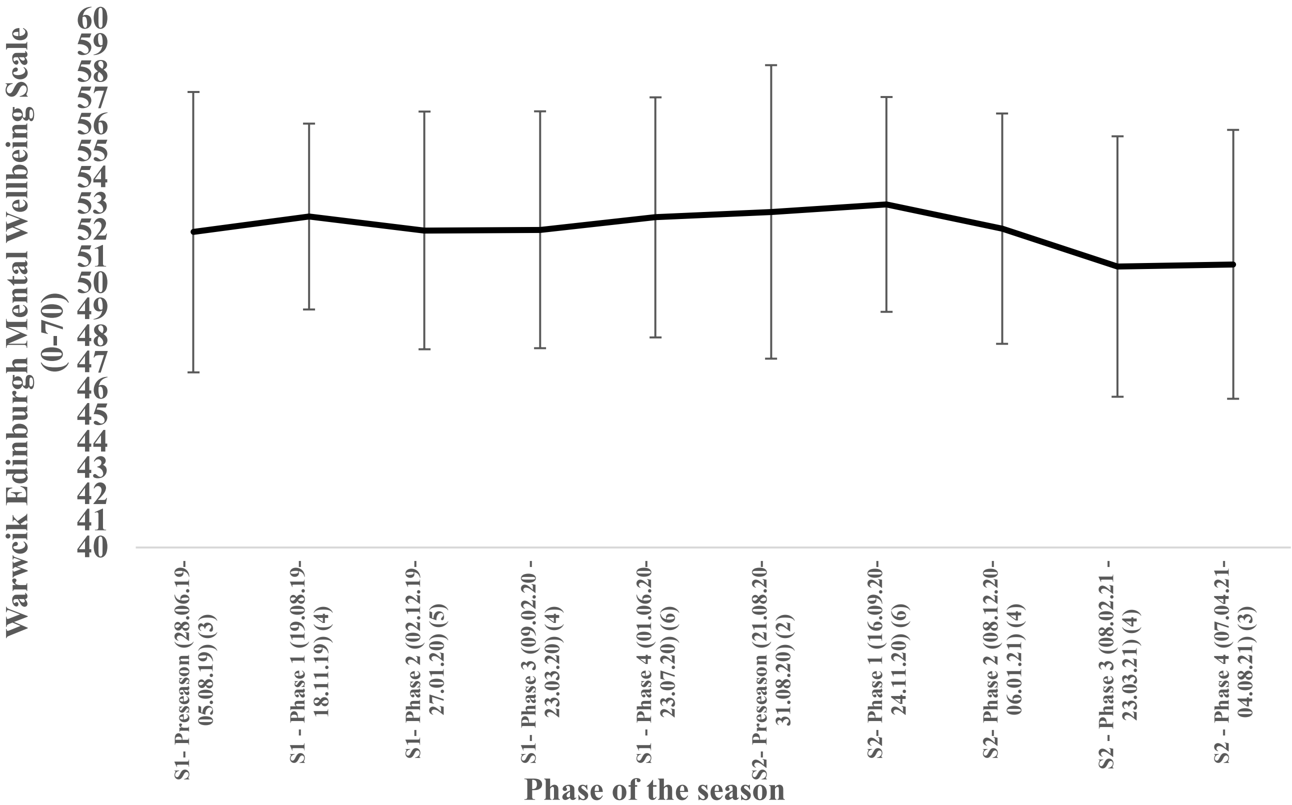

Figure 5.1: Group average psychological wellbeing scores across the 2019-2020 and 2020-2021 season.

Psychological Wellbeing and Training Load

Previous 7, 14 and 21-day workloads are presented in Table 5.1. Previous 14-day HSD (r (385) = -0.095, P = 0.039) and previous 21-day SD (r (385) = 0.100, P = 0.030) revealed small correlations with PWB. All other workload variables were not related to PWB scores (P > 0.05).

Table 5.1: Absolute GPS parameters, previous 7-day, 14-day and 21-day training load (mean ± *sd*)

Training Load	Previous 7-day	Previous 14-day	Previous 21-day
Session Duration (min)	242±68	492±85	700±147
TD (m)	20909±6156	42960±9970	63106±13809
Low-intensity Distance (m)	19888±5851	40881±9489	62004±13577
ED (m)	1345±437	2716±677	3988±967
HSD (m)	831±327	1690±556**	2539±807
SD (m)	190±129	388±220	551±277**

*Low intensity distance (distance covered at speed, 0-5.5m.s^{-1}), ED (distance covered accelerating and decelerating > 2m.s^{-2}), HSD (distance covered at speed 5.5-7m.s^{-1}) and SD (distance covered at speed >7m.s^{-1}). **Reveals a statistical significance (P <0.05). TD – Total Distance, HSD – High Speed Distance, ED – Explosive Distance, SD- Sprint Distance.

Table 5.2: The contextual match factors across the two seasons (mean ± *sd*)

Contextual Match Factor	**Previous Match/Time of Questionnaire**	**Previous 7-days to Questionnaire**	**Previous 14-days to Questionnaire**
Injury (Time out Injured %)	8.1 ± 10.6	7.9 ± 11.2	7.4 ± 11.1
Illness (% of time with an illness)	1.4 ± 3.1	1.4 ± 2.0	1.3 ± 1.8
Match Selection (% of matches selected for)	76.0 ±2 6.4	75.1 ± 25.5	74.9 ± 24.8
Individual Win-Rate (% of games won)	25.0 ±17.3	23.9 ± 13.3	25.5 ± 8.5
Playing Status (% of games started or subbed)	76.6 ± 23.2	72.7 ± 22.9	70.1 ± 21.6

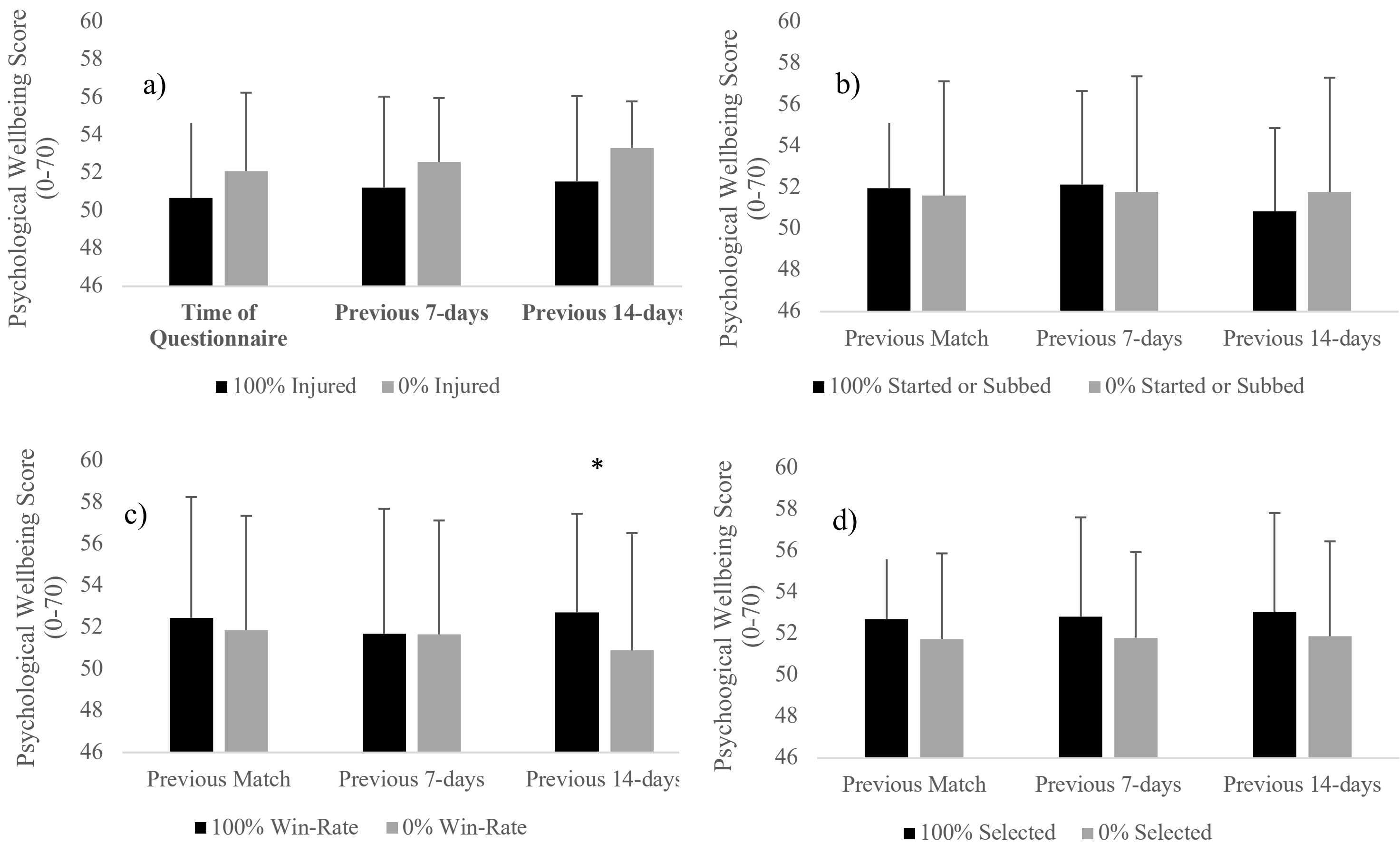

Figure 5.2: The influence of contextual match factors upon psychological wellbeing, at the time of questionnaire, and previous 7 and 14 days. *Indicates statistical significance (*P* < 0.05).
Graph a) demonstrates psychological wellbeing effect upon injury status.
Graph b) demonstrates psychological wellbeing effect upon playing status.
Graph c) demonstrates psychological wellbeing effect upon win rate.
Graph d) demonstrates psychological wellbeing effect upon match selection.

A multiple linear regression revealed no contextual factors or TL, in respect to the previous match/TOQ outlined in Table 5.2 predicted PWB ($P > 0.05$).

The influence of contextual match factors upon PWB, at the TOQ, or in relation to the previous 7 and 14 days are displayed in Figure 5.2. No difference in PWB was revealed when Winning (52.5 ± 5.8) vs. Losing (51.9 ± 5.5) the previous match ($t_{(25)} = 1.103$, $P = 0.281$, $d = 0.22$), or when 100 % Winning (51.7 ± 6.0) vs. Losing (51.6 ± 5.5) in the matches in previous week ($t_{(24)} = 0.144$, $P = 0.887$, $d = 0.03$). Higher PWB was revealed when 100% Winning (52.7 ± 4.7) vs. Losing (50.9 ± 5.6) the matches in the previous two weeks ($t_{(27)} = 2.945$, $P = 0.007$, $d = 0.57$).

No difference in PWB was revealed when Played (52.0 ± 4.6) vs. Not Played (51.6 ± 5.5) in the previous match ($t_{(21)} = 0.606$, $P = 0.551$, $d = 0.13$). Additionally, when 100% Played (52. 1 ± 4.5) vs. Not Played (51.8 ± 5.6) in the previous week ($t_{(21)} = 0.570$, $P = 0.575$, $d = 0.12$), or when 100 % Played (50.9 ± 4.0) vs. Not Played (51.8 ± 5.5) in the previous two weeks ($t_{(11)} = -0.901$, $P = 0.387$, $d = 0.27$).

No difference in PWB was revealed when Selected (52.7 ± 4.9) vs. Unselected (51.8 ± 4.1) for the previous match ($t_{(21)} = 1.944$, $P = 0.065$, $d = 0.42$). Additionally, when 100% Selected (52.8 ± 4.8) vs. Unselected (51.8 ± 4.1) for the matches in the previous week ($t_{(21)} = 1.958$, $P = 0.064$, $d = 0.43$), or when 100% Selected (53.1 ± 4.8) vs. Unselected (51.9 ± 4.6) for the matches in the previous two weeks ($t_{(16)} = 1.709$, $P = 0.107$, $d = 0.43$).

No difference in PWB was revealed when Injured (50.6 ± 4.5) vs. Not Injured (52.1 ± 4.1) at the TOQ ($t_{(16)} = 1.551$, $P = 0.140$, $d = 0.38$). Additionally, when 100% Injured (51.2 ± 4.8) vs. Not Injured (52.6 ± 3.4) the previous week ($t_{(14)} = 1.079$, $P = 0.300$, $d = 0.29$), or when 100% Injured (51.5 ± 4.5) vs. Not injured (53.3 ± 2.5) the previous two weeks ($t_{(12)} = 1.241$, $P = 0.241$, $d = 0.36$). No difference in PWB was revealed when Ill (48.9 ± 7.1) vs. Not Ill (49.8 ± 7.1) at the TOQ ($t_{(6)} = 0.996$, $P = 0.358$, $d = 0.41$).

Psychological Wellbeing prior to an Injury and Illness

No differences were demonstrated in PWB the week prior to an Injury (50.3 ± 7.2) vs. Non-Injury Occurrence (50.7 ± 5.9) ($t_{(12)}$ = 0.380, P = 0.710, d = 0.11), or two weeks prior to an Injury (50.3 ± 7.1) vs. Non-Injury Occurrence (51.2 ± 5.9) ($t_{(18)}$ = 0.935, P = 0.363, d = 0.21). No difference in PWB occurred the week prior to an Illness (50.9 ± 6.2) vs. Non-Illness Occurrence (51.5 ± 4.9) ($t_{(11)}$ = 0.850, P = 0.413, d = 0.25), or two weeks prior to an Illness (50.8 ± 7.3) vs. Non-Illness Occurrence (50.9 ± 5.7) ($t_{(19)}$ = 0.105, P = 0.917, d = 0.02).

5.5 – Discussion

This study aimed to examine the influence of injury, contextual match factors and TL upon PWB in EPL soccer players and explore PWB levels prior to an injury or illness. In contrary to both hypotheses, only previous two-week win-rate significantly influenced PWB, and previous 14-day HSD and 21-day SD were related to PWB. Moreover, PWB was no different prior to an injury or illness.

Psychological Wellbeing and contextual match factors

The findings PWB was unaffected by the proceeding match result, has previously been reported in academy soccer players (Abbott *et al.,* 2019). Therefore, the current study adds to the current literature that PWB in both youth and senior soccer players is unaffected by acute match result. It should be also be considered that both studies administered questionnaires on a specific MD, therefore sufficient recovery from the match could have prevented perturbations to PWB. It could also be the case that multiple rather than single match results attenuate PWB, as novel findings suggest higher PWB was evident with an 100% vs. 0% two-week win-rate. In speculation, player contracts are based upon success and reflect results and performance, exacerbating incentives to win. The WEMWBS specifically assesses levels of competence, autonomy, and positive relationships (Giles *et al.,* 2020). Therefore, a prolonged period of negative results could deteriorate an athlete's perceived competency and relationships overtime which causes detriments to PWB levels, in contrary to acute match results.

Interestingly however, the current study suggests alternative contextual factors which could also be indicative of perceived competency, such as playing status and match selection, did not influence PWB, in agreement with research in senior players (Junge *et al.,* 2018). Pertinent as in contrary to current findings, in academy players 10% variability in PWB were related to match selection (Abbott *et al.,* 2019). It is plausible, senior players attribute not playing and match (de)selection to reasons, such tactics, player rotation, fixture congestion, and physical demands rather than attributing these factors to their competency. In contrast, younger athletes if unselected, may experience heightened anxiety trying to impress key stakeholders to earn professional contracts (Abbott *et al.,* 2019) which causes an increased tendency or bias towards attributing match deselection to competency. Age could also be a predictor of anxiety and depression symptoms in athletes (Junge *et al.,* 2016; Junge *et al.,* 2018), with youth athletes potentially more vulnerable to poor MH. This could help explain the heightened impact of contextual match factors upon youth soccer players PWB levels. This may not always be the case however as younger athletes have reported higher PWB and lower stress scores than their senior counterparts (Belz *et al.,* 2018; Kuettall et al., 2021a).

In agreement with previous research, PWB could not be explained by previous 7-day TL (Abbott *et al.,* 2019). Therefore, it could be the physical demands of EPL senior soccer as well as the EPL academy soccer, may not be sensitive enough to predict PWB. Noteworthy, associations were evident between PWB and 14-day HSD (r = -0.095) and 21-day SD (r = 0.100). The weak associations with TL are like those reported between PWB and in-season active mins (Grimson *et al.,* 2021) and could reflect a high n number. Alternatively, the tendency to accrue a higher SD and HSD during match play and training respectively, could mean higher HSD accrued in unselected players. Therefore, associations between SD, HSD and PWB could be confounded by match selection, reported to influence PWB (Abbott *et al.,* 2019). Notably, a moderate effect size of match selection upon PWB was also reported in the current study. Therefore, the results from the current study should be interpreted with caution.

The current study also revealed no difference in PWB when injured or not. Gouttebarge *et al.,* (2015b) reported no difference in anxiety and depression symptoms in current/former soccer players. In contrast, U23 soccer players reported lower PWB (Abbott *et al.,* 2019) and higher anxiety and depression symptoms in Swiss senior and U21 soccer players (Junge *et al.,* 2016). Moreover, associations were reported between severe injuries and distress (r = 0.15), and anxiety (r = 0.13) (Gouttebarge *et al.,* 2015a). Subsequently, discrepancies could exist due to injury severity and age. Studies reporting attenuated PWB with injuries, examined severe injuries resulting in over a week absence from sport (Gouttebarge *et al.,* 2015b; Abbott *et al.,* 2019). In contrary, this study examined any time-loss injury, but revealed a moderate effect size when injured vs not injured over two-weeks. Together, prolonged absence from sport may attenuate PWB. Noteworthy however, the higher duration of injury prior to the questionnaire, revealed higher PWB. From this perspective, it could be that the availability of physical and psychological support could be pertinent. The current study, and Gouttebarge *et al.,* (2015b) studied senior vs. youth athletes (Junge *et al.,* 2016; Abbott *et al.,* 2019). Senior soccer typically has increased staff: player ratios and greater financial burdens associated with injured players, emphasising quick return to sport. Absence from sport whilst injured could threaten athletic identity, in addition to the uncertainty upon return to support could decline PWB in youth athletes to a greater extent than senior athletes

(Abbott *et al.,* 2019). The current findings also suggest, Interventions/Psychological support may be more beneficial to implement as soon as an injury occurs.

Overall, the current findings regarding contextual match factors upon PWB, could help explain the negative trend identified in PWB during an EPL season (Grimson *et al.,* 2021), which could be result and TL dependant rather than alternative contextual match factors including playing or selection status and injury. Given lower PWB could attenuate performance and increase risk of injury/illness (Ivarsson *et al.,* 2013; Watson *et al.,* 2016 Reardon *et al.,* 2019), without timely interventions during poor results and chronic high intensity TLs, such consequences could remain. Noteworthy however, a 3-point change in PWB is 'clinically meaningful' (Maheswaran *et al.,* 2012), and a 1-point higher PWB score was identified when winning 100% of matches in the current study. Previous research by Abbott *et al.,* (2019), identified a 6.3 decline in PWB score when injured, perhaps illustrating the current findings as a statistical but not clinically meaningful change or sensitive enough to apply interventions to augment PWB.

Psychological Wellbeing prior to an injury or illness

Psychological wellbeing was no different prior to an injury vs. non-injury. This is in contrary to previous research, that when predicting injury, daily hassles, trait anxiety and negative life events stress accounted for 24% of the variance (Ivarsson *et al.,* 2013). Moreover, worse daily mood was an independent predictor of injury (Watson *et al.,* 2016). Both studies revealed associated risk of injury with 'daily' indications of MH status rather than 'fortnightly' measured in the current study. Therefore, only acute changes in mood could be sensitive enough to determine injury risk. Alternatively, the previous research examined youth and sub-elite soccer players. Highly skilled soccer players have highly adaptive coping mechanisms (Ivarsson *et al.,* 2013), and therefore psychological risk factors upon injury might be dependent upon skill level. That said, the current study revealed a moderate effect size prior to an injury vs. non-injury, and therefore in isolation PWB might not predict injury but could be employed in a battery of tests to monitor injury risk. Particularly important given that injury is complex and multifactorial. Given the limited feasibility of daily monitoring MH in professional sport, further research should investigate the usefulness of the WEMWBS.

Psychological Wellbeing across the two seasons

No significant change in PWB across two-seasons was identified. Athletes ascertain how to deal with sport-related stressors, potentially leading to effective emotional regulation in sport and alternative life domains (Pensgaard *et al.,* 2003). Therefore, EPL soccer players PWB could be resistant to both sporting and non-sporting related stressors. Notably, within sporting organisations, increasing emphasis is on athlete MH and provision of support (Henriksen *et al.,* 2020). It is now mandatory in most soccer clubs to employ a sports psychologist (Kuettal *et al.,* 2021a) and adopt regular screening and interventions (Purcell *et al.,* 2019). The ability of current participants to have access to full-time psychological support may encourage help-seeking behaviour (Gulliver *et al.,* 2012). Given that languishing athletes generally receive lower social support perceive higher stress levels and rate their sporting environment as less autonomy supportive compared to flourishing athletes (Kuettel *et al.,* 2021b), it is prudent that support could explain steady PWB overtime. Nevertheless, declining trends in PWB exist during a season (Grimson *et al.,* 2021). When considering the influence of stressors, these may still influence PWB but not significantly. Moreover, PWB varies on an individual level (Grimson *et al.,* 2021), and therefore may mask fluctuations to PWB examined at a group level. Further investigation is required to understand contextual match factors on an individual level. It should be noted, the stigma surrounding MH and one's willingness to provide information (which may interfere with factors such as team selection) could lead to underreporting (Bird *et al.,* 2018). Nevertheless, questionnaires were administered confidentially and only made available to the medical team to facilitate genuine responses. From a team perspective susceptibility to poor performance and injury/illness risk, are augmented with poor PWB (Watson *et al.,* 2016; Reardon *et al.,* 2019) and less likely to occur from a PWB perspective, based upon the current findings. Importantly throughout the study, PWB scores ranged from 50.6 and 53.0, higher than the general population norm and depression threshold (50.2; Health Survey England, 2016; 44.5 Bianca, 2012) respectively. Limitations of the current investigation include that data collection occurred during the COVID-19 pandemic. Nevertheless, data analysis excluded the COVID-19 lockdown period. Additionally, PWB did not change significantly pre vs. post lockdown in previous research (Grimson *et al.,* 2021). Moreover, the lockdown caused a build-up of fixtures and increased physical demands; however, this was still insufficient to reveal associations between PWB and TL. Therefore, the authors believe the COVID-19 pandemic had little impact upon the current investigation. Further limitations include, the WEMWBS fails to adopt an assessment of physical wellbeing (including physical health, sleep, financial, living and work circumstances) (Giles *et al.,* 2020). Moreover, caution should be applied when attributing these findings to alternative populations.

5.6 Conclusion

This study demonstrates that match result is the most important investigated contextual match factor upon PWB. Therefore, interventions when multiple negative results occur could prevent decline in PWB. Elite athletes PWB may also be influenced by cumulative previous 14-day and 21-day TL. Practically high intensity load manipulation could help maintain positive PWB. When implementing such interventions and interpreting PWB scores, providing context surrounding match form and TL might provide a clearer indication on which factor may be having more of an impact upon PWB. However, it should be cautioned the weak correlations and clinically meaningful perturbations in PWB, could affect the influence of a) identifying meaningful changes in PWB, whereby interventions can be implemented and b) the effect manipulation of load will have upon PWB given the weak correlations evident. Furthermore, the efficacy of the WEMWBS predicting illness/injury risk, is unlikely.

Link to next chapter

Findings from the current chapter suggest that sport-related stressors, including two-week win-rate and previous 14-day HSD and 21-day SD can decline a players MH status. Moreover, prior PWB was not linked with a subsequent injury or illness occurrence, suggesting that PWB in isolation cannot predict an injury. The aim of the thesis is to examine both mental and physical health. The previous and current chapter focused upon understanding athletes MH. An understanding of the ability to monitor PWB (an indicator of MH status) in elite footballers and subsequent factors that can affect PWB has now been provided to help inform interventions to maintain PWB. Therefore, the next chapter aims to understand potential recovery markers that are sensitive to ETL, to provide information on an athletes physical health status.

6.0. Study Three: Musculoskeletal tests and subjective wellness are related to external training loads of English Premier League soccer players: A season long analysis

6.1 Abstract

The ability of practitioners to monitor individual responses to TL is important to inform recovery, maximise performance and provide sufficient stimulus for training adaptations. This study aims to investigate the relationship between subjective and objective recovery markers and ETL in EPL soccer players. Nineteen players completed daily objective monitoring tests including AS and S&R, and a daily subjective wellbeing questionnaire containing five ratings of wellness (fatigue, mood, sleep quality, sleep hours and soreness) over a 37-week period. Previous day and 7-day TL were calculated from 10Hz GPS devices worn during all training sessions and matches to calculate TD, SD, ED and HSD. Wellness, fatigue, and soreness were related to objective recovery markers (r = -0.053 to -0.098, n = 1749, P <0.05). All previous day and 7-day TL variables were related consistently to fatigue, soreness, and wellness (r = 0.084 to 0.330, P <0.05). Previous day TD and SD were related to AS (r = 0.085 to 0.119, P <0.05) and 7-day TD were related to both objective recovery markers (r = 0.052 to 0.060, P <0.05). Noteworthy, the data indicates weak relations and therefore meaningful associations should be interpreted with caution. Nevertheless, results demonstrate AS, and S&R scores could provide practitioners with low-cost objective markers that reflect perceived ratings of soreness, fatigue, and wellness, and are sensitive to all TL variables. Moreover, previous 7-day TD and previous day TD and SD may be more useful to reduce objective fatigue.

Keywords: *Athlete monitoring, recovery, in-season, adductor strength, hamstring extensibility and injury prevention.*

6.2 Introduction

To maximise performance and training adaptations, sport practitioners modify ETL to prescribe an ITL that elicits a suitable fitness and fatigue response (Bannister *et al.,* 1975). However, a mismatch between workload and sufficient recovery can result in poor mental and physical health (Buchheit *et al.,* 2013). Therefore, it is pertinent individual responses are monitored via ETL, ITL, wellness status and readiness to train, to inform recovery and TL prescription (Gabbett *et al.,* 2016; Thorpe *et al.,* 2016). This response is often complex and multifactorial, with one monitoring tool deleterious to representing an athlete's full health and performance status (Heidari *et al.,* 2019; Draper *et al.,* 2021). Subsequently, obtaining both subjective and objective recovery markers could provide coaches with an holistic overview of an athletes complete physical and MH status (Heidari *et al.,* 2019). In practise, flag-based approaches are common, and regular measures are often obtained and compared to an individual's normative value, creating an individualised Z-score by which deviations are monitored (Esmaeili *et al.,* 2018a). Pertinent as when quantifying fatigue, recovery is likely mediated by individualised antecedents, including fitness, genetics, prior recovery and prescribed ETL (Faude *et al.,* 2014). It is therefore important that non-invasive, time-efficient, and sensitive to TL monitoring tools are revealed, which can be utilised in sporting environments.

Subjective wellness questionnaires are commonly utilised in team sports to monitor players' response to TL, injury and illness risk and performance readiness (Saw *et al.,* 2016; Thorpe *et al.,* 2017). In team sports, subjective wellness is related to ITL (Clemente *et al.,* 2017; Sekiguchi *et al.,* 2021) and ETL (Thorpe *et al.,* 2016; Draper *et al.,* 2021; Fields *et al.,* 2021). Within elite soccer, fatigue is related to high intensity running over a 17-day period (Thorpe *et al.,* 2016). Additionally, TD and player load are related to muscle soreness (Draper *et al.,* 2021). Previous research, however, has omitted GPS metrics, including accelerations and decelerations performed within discrete acceleration bands, typically monitored in team sports and characteristic of fatigue (Fields *et al.,* 2021). By understanding the dose-response relationship between practically relevant GPS metrics such as ED and subjective recovery markers, could provide practitioners with an increased understanding of TL prescription to inform recovery status, enhance performance and reduce subsequent injury and illness risk.

Musculoskeletal screening (e.g., AS and S&R scores) is commonly adopted to assess objective recovery and can assess the stress induced upon the musculoskeletal system, which could result in maladaptation and increased injury risk (Vanrenterghen *et al.,* 2017). In soccer, hip and groin injuries account for a third of the injury burden and absence (~5-19 days, time loss per injury) (Ekstrand *et al.,* 2020). Therefore, the utilisation of musculoskeletal screening in the EPL is particularly relevant to understand, considering the exposure to high physical demands and fixture congestion (Carling *et al.,* 2015), which are related to AS and HF, subsequent risk factors for injury (Roe *et al.,* 2016; Silva *et al.,* 2018b).

Previously, research has demonstrated 2- or 3- days post training AS were not related with ITL during an AFL season (Esmaelli *et al.,* 2018a) or daily measures when pooled into season phases (Lonie *et al.,* 2020). However, previous weeks ITL and AS were related in Rugby (Tiernan *et al.,* 2019). Disparities may exist because of frequency (e.g., daily vs. weekly) or equipment utilised (e.g., Sphygnamometer and Dynamometer). Such equipment requires hip and knee joint angle estimation, visual data collection and pushing against a variable force (Buchheit *et al.,* 2017; Ryan *et al.,* 2019b). Technological advancements (e.g., strength-based testing system) may be superior to previous methodologies 'Sphygnamometer' CV 6.3 vs. 7.6% (Buchheit *et al.,* 2017; Ryan *et al.,* 2019b). Subsequently, further research is required to understand the efficacy of new technological advanced equipment available to applied sporting practitioners to detect a change in objective or subjective recovery status and responses to TL demands. This is particularly relevant in soccer, as currently there is no research investigating the dose-response relationship between soccer specific TL demands and musculoskeletal screening tests.

Historically research has predominantly focused upon the dose-response relationship between TL and objective recovery utilising ITL. Nevertheless, ITL could underrepresent the true load imposed on the musculoskeletal system and it could be ETL can provide superior associations with the musculoskeletal response given the disparities between adaptation pathways from physiological and biomechanical based loads (Vanrenterghen *et al.,* 2017; Esmaelli *et al.,* 2018a; Weaving *et al.,* 2021). Only two studies to date, have investigated ETL and objective recovery. Weaving *et al.,* (2021) revealed *trivial* to *small* associations between 2- and 3-day exponential weighted moving rolling average (EWMA) TD and musculoskeletal responses in Rugby (P <0.0001). Moreover, SD from Rugby match play was related to immediate and 24 and 48-hour post AS (Roe *et al.,* 2016). Therefore, it is pertinent future research investigates the associations between ETL and AS.

When assessing lower back and HF, the S&RT is commonly utilised (Gabbe *et al.,* 2004; Esmaelli *et al.,* 2018a; Weaving *et al.,* 2021). Previously, no association between S&R scores and ITL (Esmaelli *et al.,* 2018a) or 2- 3- day EWMA TD (Weaving *et al.,* 2021) have been revealed. Yet, 10% reduction in S&R scores were evident 15-hours post-match (Dawson *et al.,* 2005). S&R scores could be sensitive to acute or require sufficient loads to identify fatigue and inadequate recovery. Subsequently, future research is required to understand the relationship between ETL and the S&RT in EPL soccer.

Subjective markers such as fatigue can indicate recovery status (Buchheit *et al.,* 2013; Buchheit *et al.,* 2017), however the relationship between subjective and objective recovery markers is under investigated. One study to date, revealed AS was associated with fatigue and soreness during a 10-week pre-season (Tiernan *et al.,* 2019). However, the relationship between AS and S&R scores and subjective markers in-season is unknown, and AS varies across an in-season period (Lonie *et al.,* 2020). It is therefore important that relationships between subjective and objective markers are investigated to provide practitioners with objective markers that indicate subjective recovery, which can often be manipulated and influenced by social bias.

The current study, aimed to examine the relationship between AS, S&R scores, and subjective recovery markers. Secondly, to examine the relationship between ETL and monitoring markers. Based upon the research of (Tiernan *et al.,* 2019; Weaving *et al.,* 2021), it was predicted that subjective and objective markers would be associated and related to ETL. If such relationships are absent, it questions the use of both dose and response measures to accurately reflect fatigue and suitably inform ETL prescription.

6.3 Methods

Participants

Nineteen first team male soccer players from an EPL club participated in this study (stature: 183.1 ± 8.6 cm; body mass: 81.8 ± 8.7 kg; age: 27.2 ± 3.7 years). Participants competed in the 2019-2020 EPL season (July 2019- March 2020) and completed routine training, matches and monitoring procedures. Player's data were excluded from analysis if they were currently injured. An injury was defined as any injury that resulted in time loss from training or matches (Fuller *et al.,* 2006). Full approval was received from the local ethics review board and participants provided informed written consent.

Experimental Procedure

Physical data were collected over 37-weeks consisting of 115 training sessions and 35 competitive matches, displayed in Table 6.1. Training would typically occur on a Monday, Tuesday, Thursday, and Friday for one game weeks. For congested fixture periods training would typically occur on a Monday, Tuesday, Thursday (non-starting players) and on a Friday, with matches on a Wednesday and Saturday. Prior to training, at the training ground, monitoring data (Subjective wellness, S&R, and AS) were collected between 9:00~9:30 am and supervised by science and medical practitioners. Players were familiar with all testing protocols (>2 years).

Table 6.1: The breakdown of the training sessions and matches across the 2019-2020 season phases.

	Pre (01.07.2019-11.08.2019)	Early (12.08.2019-19.10.2019)	Mid (20.10.2019-28.12.2019)	Late (29.12.2019-16.03.20)
Number of weeks	6	10	10	11
Number of training sessions	22	36	42	38
Number of games	6	9	11	10

Adductor squeeze strength test

Participants adopted a supine position beneath the Groin-Bar Strength Testing System (Force Frame, Vald Performance, USA) with a hip flexion at 45 degrees, the optimal position for maximal AS (N) (Ryan *et al.,* 2019b). The femoral medial condyle of both knees were placed on the fixed pads. Bar height was kept consistent for each participant. Verbal encouragement was given to ensure maximal effort. One warm up repetition (60-80% maximum effort) was followed by two maximal repetitions, each five seconds, interspersed by 30 seconds. The testing system has excellent test-retest reliability with intraclass correlation coefficients (ICC) for hip adduction (0.97) and acceptable level of CV% (4.65-6.30) (Ryan *et al.,* 2019b). Additionally in the current cohort, the AS test demonstrated good reliability as on the left and right AS a test-retest reliability of ICC 0.95 (95% CI: 0.81-0.99), and 0.88 (95% CI: 0.60-0.97) respectively.

Sit and Reach Test

Participants sat down with their feet placed flat against the S&R box. Then maintaining extension through both knees, stretch their arms with one hand directly on top of the other as far as they can forward and hold for one second. The distance between the toe line and middle finger was visualised by the practitioner (Gabbe *et al.,* 2004). Two repetitions were interspersed by twenty seconds. The S&R test is reliable and valid to estimate hamstring extensibility with a test-retest reliability of ICC (0.98-0.99) (95% CI: 0.94-1.00) (Gabbe *et al.,* 2004).

Subjective recovery markers

Participants completed a custom-based subjective wellness questionnaire based upon previous recommendations (Hooper *et al.,* 1995b). These items included fatigue, sleep quality, muscle soreness, health, and mood, using a five-point Likert scale ranging from 1 (best) to 5 (worst). A total wellness score was calculated by a summation of the 5-item scores. Sleep hours were recorded. These items have previously reported a CV of 7.1% in team sport athletes (Roe *et al.,* 2016).

External Training Load

External training load was calculated by 10Hz GPS units and 100Hz triaxial accelerometer devices, worn during all training sessions and matches. Ten Hz units have demonstrated acceptable reliability for acceleration, deceleration and at high speeds (Scott *et al.,* 2016). The mean number of satellites during data collection was 14±1. External training load parameters included were TD, HSD, SD and ED. Respective definitions are displayed in figure 5.1. Session data was subsequently downloaded utilising Catapult Openfield Cloud Software for data analysis (Catapult Cloud Version, 2.0.1, Catapult Innovations, Melbourne, Australia).

Data Analysis.

Data analysis was completed via SPSS (SPSS Version 26.0). Normal distribution was considered if the Shapiro-Wilks test was ($P > 0.05$). Recovery markers were calculated as 'Z-scores', using the following equation: Current assessment – (mean score (season-long rolling average)/*sd*). A one-way repeated measures analysis of variance (ANOVA) was utilised to assess changes in weekly average Z-scores across the four phases of the season (pre, early, mid, and late), for all recovery markers and ETL. Pearson correlation coefficients were utilised to determine the relationship between subjective and objective recovery markers. General linear models were utilised to analyse the data and allowed for data being collected overtime (Bland *et al.,* 1996). A multiple stepwise regression was utilised to assess the extent recovery markers (dependant variable) can predict previous day or 7-day ETL (independent variable). The relationship between various predictors and outcomes using model 1(unadjusted model) and model 2 (fully adjusted model) to derive partial correlation coefficients for each recovery marker. To interpret the magnitude of the correlation (*r*) between test measures: <0.1 *trivial*, 0.1 to 0.3 *small*, 0.3 to 0.5 *moderate*, 0.5 to 0.7 *large*, 0.7 to 0.9 *very large*, and 0.9 to 1.0 *almost perfect*. Statistical significance was determined at (P <0.05).

6.4 Results

The relationship between subjective and objective recovery markers.

The relationship between subjective and objective markers are reported in Table 6.2. Increased wellness, fatigue and soreness were related to reduced AS and S&R scores. Reduced mood was related to lower S&R scores and sleep quality was related to right AS (P <0.05).

Table 6.2: The relationship between wellness markers and AS and S&R scores (Z-scores).

	AS Left		AS Right		S&R	
	r	*p*	*r*	*p*	*r*	*p*
Sleep Quality	-.046	.052	-.058*	.016	-.084	.158
Sleep Hours	.042	.077	.053	.028	.011	.659
Mood	-.047	.051	-.035	.148	-.077*	.001
Fatigue	-.074*	.002	-.086*	.000	-.066*	.005
Soreness	-.069*	.004	-.078*	.002	-.053*	.027
Wellness	-.073*	.002	-.098*	.000	-.080*	.001

**P < 0.05 = significant. AS – Adductor Strength*

The average weekly Z-scores for recovery markers across the season.

Weekly average Z-scores for AS, S&R, and subjective wellness across the season are demonstrated in Table 6.3. A one-way repeated measures ANOVA revealed no main effect for time, for left and right AS, and therefore no seasonal changes ($P > 0.05$). A one-way repeated measures ANOVA revealed a main effect for time for S&R scores ($f_{(3,51)} = 2.975$, $P = 0.040$, $\eta^2_{partial} = 0.149$). S&R scores were higher during late vs. early ($t_{(17)} = 2.292$, $P = 0.035$, $d = 0.54$), and late vs. pre-season ($t_{(17)} = 2.464$, $P = 0.025$, $d = 0.58$). S&R scores were no different between late and mid-season.

A one-way repeated measures ANOVA revealed no main effect for time, for sleep quality and hours, mood, soreness, wellness, and therefore no seasonal changes ($P > 0.05$). A one-way repeated measures ANOVA revealed a main effect for time for fatigue ($f_{(3,45)} = 3.477$, $P = 0.024$, $\eta^2_{partial} = 0.188$). Fatigue was higher during pre vs. early ($t_{(15)} = 2.464$, $P = 0.026$, $d = 0.62$), mid ($t_{(15)} = 2.172$, $P = 0.046$, $d = 0.54$) and late season ($t_{(15)} = 3.112$, $P = 0.007$, $d = 0.78$).

A one-way repeated measures ANOVA revealed a main effect for time for absolute left AS ($f_{(3,51)} = 12.88$, $P = 0.000$, $\eta^2_{partial} = 0.431$). Left AS was no different between late and mid-season respectively ($P > 0.05$). However, left AS was higher during late vs. early ($t_{(17)} = 3.788$, $P = 0.001$, $d = 0.89$) and late vs. pre-season ($t_{(17)} = 4.133$, $P = 0.001$, $d = 0.97$). A one-way repeated measures ANOVA revealed a main effect for time for absolute right AS ($f_{(3,51)} = 13.935$, $P = 0.000$, $\eta^2_{partial} = 0.450$). Right AS was no different between late vs. mid-season ($P > 0.05$). However, was higher during late vs. early ($t_{(17)} = 3.825$, $p = 0.001$, $d = 0.90$) and late vs. pre-season ($t_{(17)} = 4.103$, $P = 0.001$, $d = 0.97$).

Table 6.3: The weekly average Z-scores of objective and subjective recovery markers and absolute adductor strength scores across the four phases of the season (mean ± *sd*).

	Pre	Early	Mid	Late
Subjective Markers				
Sleep Quality	-0.11±0.34	-0.17±0.36	-0.13±0.27	-0.07±0.28
Sleep Hours	-0.14± 0.65	-0.14±0.57	-0.12±0.5	0.14±0.44
Mood	0.06±0.22	0.03±0.4	-0.03±0.52	0.01±0.25
Fatigue	0.11±0.17	-0.03±0.17[a]	-0.16±0.48[a]	-0.18±0.31[a]
Soreness	0.06±0.34	-0.12±0.44	-0.16±0.43[a]	-0.08±0.32
Wellness	0.05±0.61	-0.04±0.40	-0.13±0.46	-0.14±0.32
Objective Markers				
Adductor Strength				
Right	0.21±0.79	0.41±0.43	0.35±0.51	0.42±0.44
Left	0.27±0.7	0.4±0.38	0.35±0.51	0.42±0.44
Absolute Right (N)	469±77	500±73[a]	523±66[a,b]	526±71[a,b]
Absolute Left (N)	464±81	496±76[a]	517±70[a, b]	521±78[a, b]
S&R	0.11±0.36	-0.12±0.83	0.28±0.61	0.45±0.52[a, b]

[a] significantly different from the pre phase ($p < 0.05$) [b] significantly different from the early phase ($P < 0.05$). S&R – Sit and Reach.

The average weekly external training load across the season.

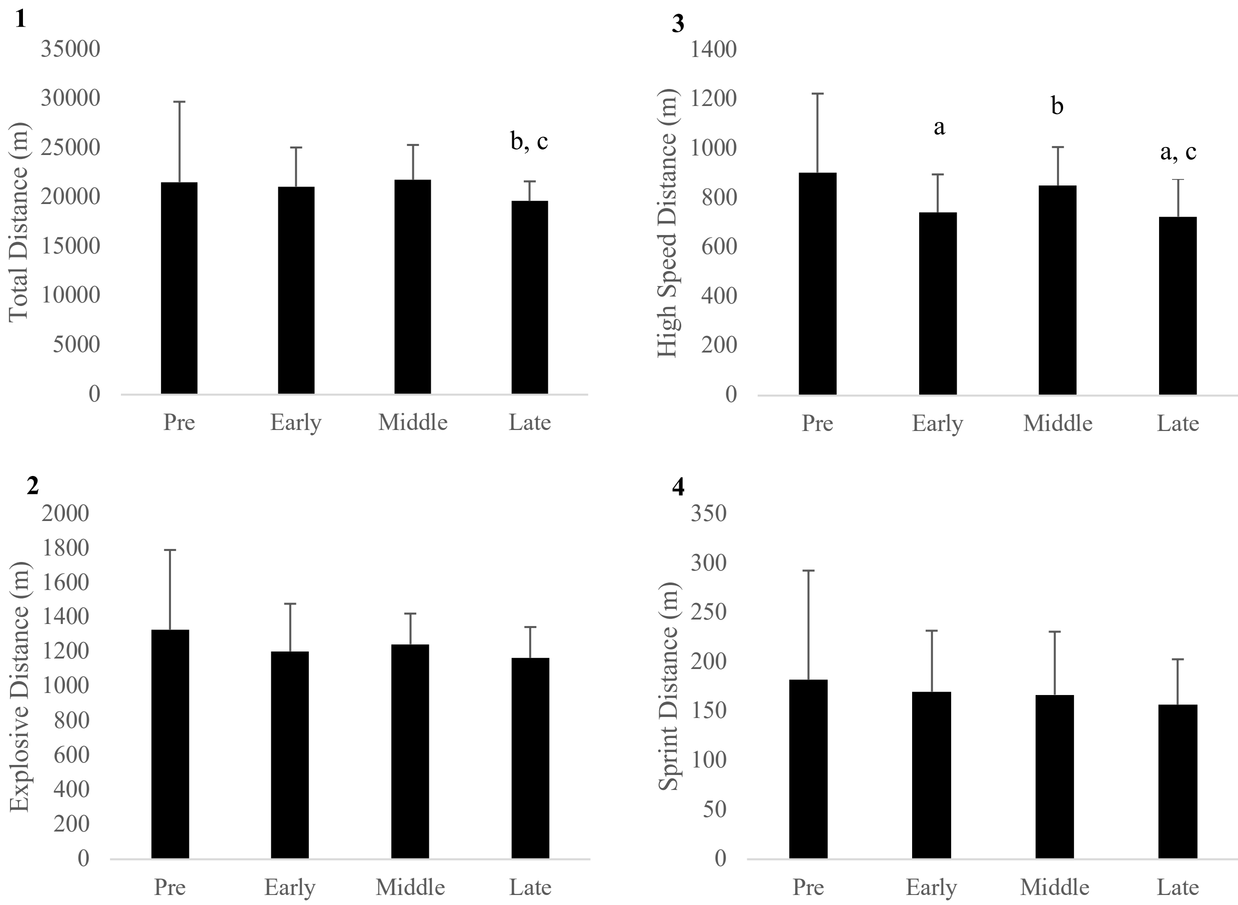

Figure 6.1: Weekly external training load across the season. 1) Total distance (distance covered walking, jogging, fast running, and sprinting) 2) Explosive Distance (distance covered accelerating > $2 m.s^{-2}$ and decelerating > $2 m.s^{-2}$, 3) High Speed Distance ($5\text{-}7 m.s^{-1}$), 4) Sprint Distance (> $7 m.s^{-1}$). *a, significantly different from pre-season, b, significantly different from early phase, c, significantly different from mid-phase. *$P < 0.05$ = significant

The weekly average ETL across the season are demonstrated in Figure 6.1. A one-way repeated measures ANOVA revealed no main effect for time for TD, ED and SD and therefore revealed no seasonal changes ($P > 0.05$). A one-way repeated measures ANOVA revealed a main effect for HSD ($f_{(3,51)} = 3.834$, $P = 0.015$, $\eta^2_{partial} = 0.184$) and was higher during pre-season (906 ± 320) vs. early (743 ± 155) vs. mid (852 ± 157) vs. late (726 ± 154).

The relationship between external training load and subjective and objective recovery markers. The raw tables for each GPS parameter and correlations are displayed in Appendix Table 11.1-11.4. For TD, partial correlations between previous day TL and recovery markers were *trivial to moderate* (r= 0.095 to 0.305, P < 0.05), excluding S&R and mood. Correlations between previous 7-day TL and recovery markers were *trivial to small* (r = 0.060 to 0.167, P <0.05), excluding sleep hours, sleep quality and mood. For SD, correlations between previous day TL and recovery markers were *trivial to small* (r = -0.085 to 0.286, P <0.05), excluding mood and S&R scores. Correlations between previous 7-day TL and fatigue, soreness, and wellness were *trivial* (r = 0.084 to 0.093, P < 0.05).

For HSD, correlations between previous day TL and recovery markers were *trivial to small* (r = 0.095 to 0.330, P < 0.05), excluding mood, right AS and S&R scores. Correlations between previous 7-day TL and mood, soreness, fatigue, and wellness were *trivial to small* (r = 0.043 to 0.141, P < 0.05). For ED, correlations between previous day TL and recovery markers were *trivial to moderate* (r = 0.099 to 0.265, P <0.05), excluding mood and both objective markers. Correlations between previous 7-day TL and fatigue, soreness, and wellness were *trivial to small* (r = 0.139 to 0.177, P < 0.05).

6.5 Discussion

This study is first to examine associations between subjective and objective recovery markers and subsequent associations with ETL in soccer. Current findings revealed a significant *trivial* association between AS and fatigue (r = -0.074 to -0.086) and soreness (r = -0.069 to -0.078). Like the present findings, *moderate* and *weak* associations have been revealed between AS and fatigue (r = -0.335) and soreness (r = -0.277) during a 10-week Rugby pre-season (Tiernan *et al.,* 2019). However, the present associations are much weaker. The present investigation examined the entire season rather than preseason. Preseason is characteristic of high TL to drive adaptations, rather than during the season where TL prescription is focused upon competition freshness. Consequently, time spent performing sport-specific drills vs. strength and conditioning changes throughout the season (Lonie *et al.,* 2020). Therefore, like others, current findings revealed AS increases throughout a season and higher HSD occurs during pre-season (Lonie *et al.,* 2020). Notably, these findings demonstrate the difference in AS between the season phases are only greater than both the smallest worthwhile change (9.10-13.9N) and the error of measurement (20-23N) from pre-season (464-469N) to early-season (496-500N). Therefore, examining the entire season could blunt the present associations revealed, and AS measurements could be more sensitive to subjective recovery during pre-season. Given pre-season is associated with higher injury incidence (Fuller *et al.,* 2019), AS measures may still benefit practitioners, particularly during preseason to quantify subjective recovery.

Present findings also revealed significant but *trivial* associations between S&R scores and wellness, fatigue, mood, and soreness (r = -0.053 to -0.080) suggesting S&R scores could represent subjective recovery. Nevertheless, *trivial* associations imply multiple alternative factors could explain subjective recovery. Mood was related to S&R scores, and attenuated mood has been evident during a EPL season (Grimson *et al.,* 2021). Importantly weak correlations between musculoskeletal tests and subjective wellbeing have been attributed to effort and perceived exertion (Tiernan *et al.,* 2019). Consequently, mood could reduce the effort and confound associations between S&R scores, fatigue, and soreness. Alternatively, mood is related to injury risk (Watson *et al.,* 2016) and instead S&R scores could represent a reduction in psychological recovery. An understanding of factors such as mood may be useful to interpret meaningful changes in S&R scores to represent subjective recovery.

Interestingly, sleep quality and hours were not related to objective recovery. Fatigue accrued through sleep deprivation could influence the physical output on musculoskeletal tests. Given soccer players are exposed to late night fixtures and susceptibility to poor sleep (Nedelec *et al.,* 2019), findings suggest utilising objective markers are ecologically valid. Pertinent, this study utilised individualised Z-scores. Therefore, changes in subjective wellness could reflect changes in objective markers, which adds confidence to adopting flag-based monitoring approaches, to identify poor recovery. Given AS and HF are utilised as a physical performance and preseason screening tests in applied environments to support training and gym-based programs, the frequent monitoring of AS and HF may still be beneficial. Future research however should investigate associations between alternative objective markers and subjective recovery.

Present findings also revealed *trivial* to *moderate* associations between all previous day TL variables, subjective recovery (r = 0.099 to 0.330) and AS (r = 0.71 to 0.119), excluding both S&R and mood, and associations between previous day ED and AS. Additionally, *Trivial* to *Small* associations were revealed between all previous 7-day TL variables and fatigue, soreness, and wellness (r = 0.084 to 0.177) and notably *Trivial* associations between previous 7-day TD and both objective recovery markers (r = 0.052 to 0.060). Previously, wellness surrogates have been related to ITL (r = -0.109 to -0.238) (Clemente *et al.,* 2017; Sekiguchi *et al.,* 2021). Importantly, associations between wellness and TL in the current and previous investigations are only *Trivial* to *Moderate.* This could be rationalised by confounding factors such as social, lifestyle and athlete-coach relationships which can add to the stress experienced by the athlete (Hamlin *et al.,* 2019). Nevertheless, previous authors have referred to this strength of associations as meaningful, and therefore fatigue, soreness, and wellness could reflect changes to previous day and 7-day ETL variables and subsequently inform ETL prescription.

As to which ETL parameters could be utilised by practitioners, all previous day and 7-day TL variables were related to soreness, wellness, and fatigue. Like the current findings, TD were related to soreness in elite soccer (r= -0.51) (Draper *et al.,* 2021) and previous day TD during a collegiate soccer preseason could predict soreness and fatigue (Fields *et al.,* 2021). Noteworthy, novel findings revealed *small* to *moderate* associations between alternative GPS metrics such as previous day, and 7-day ED, fatigue and soreness (r = 0.160 – 0.265) and suggests practitioners could prescribe ED to minimise maladaptation. Notably however, the strongest association between ETL and monitoring markers were HSD and fatigue (r = 0.330, p = 0.0001) in agreement with previous research over a 17-day period (r = -0.51, p < 0.001) in elite soccer (Thorpe *et al.,* 2016). Present findings therefore suggest ETL prescription specifically HSD may be more desirable to reduce fatigue than alternative GPS metrics such as ED. Pertinently, this also indicates subjective markers have a greater sensitivity to ETL than objective. Where both subjective and objective markers cannot be collected, practitioners could utilise subjective markers. The findings that previous 7-day TL (chronic loading) were associated with fatigue and soreness, also advocate practitioners to prescribe daily and weekly TL. Notably however, stronger associations were revealed between previous day TL compared to 7-day. Lastly, wellness was related to all previous day and 7-day TL variables. Previously, wellness has been related to reduced volume and intensity via self-pacing. This could attenuate a player's ability to maintain high intensity actions during training, resulting in under preparation for matches and susceptibility to injury (Fields *et al.,* 2021). Practitioners should therefore prescribe TL to ensure sufficient stimulus for adaptations and prevent detraining.

Findings also revealed *trivial* to *small* associations between previous day TD and SD (r = 0.071 to 0.119) and only previous 7-day TD and AS (r = 0.052 to 0.060). Previously, weak or no relationships have been revealed between AS and ITL (Esmaelli *et al.,* 2018a; Tiernan *et al.,* 2019; Lonie *et al.,* 2020). Moreover, only *trivial* to *small* associations were revealed between rolling 2-3- days previous ETL TD and musculoskeletal tests (r = 0.20) (p<0.0001) (Weaving *et al.,* 2021). Subsequently, utilising alternative GPS metrics to TD, or Strength Testing System may not enhance associations between TL and AS. Yet it should be considered, alternative factors could confound these associations (e.g., age, range of motion, previous injury) (Lovell *et al.,* 2012). Noteworthy, findings revealed more associations between AS and previous day TL than when compared to previous 7-day TL. Subsequently, daily vs. weekly measures of AS and the prescribing TD could aid practitioners to understand a player's acute musculoskeletal recovery from prescribed TL.

Previous no or weak associations between ITL (Esmaelli *et al.,* 2018a) and rolling 2–3-day TD and S&R scores (Weaving *et al.,* 2021) have been revealed. In agreement, current findings reveal only a *trivial* relationship between S&R scores and previous 7-day TD, questioning the efficacy of utilising the S&RT to detect a fatigue response to TL. Given the prevalence of hamstring injuries in elite soccer, future research should investigate alternative objective tests. This study is notwithstanding limitations, for example GPS cannot quantify all football specific movements (e.g., ball striking) which can contribute to physical workloads. Additionally, further GPS metrics available at a practitioners' disposal could be examined. The use of individualised speed thresholds may also provide further information. The applied nature of the study may also have implicated findings, as practitioners would have acted upon the data collected.

6.6 Conclusion

Novel insights into the relationship between ETL and recovery markers for monitoring training responses are revealed. Results suggest objective recovery measures including AS and S&R scores are indicative of some subjective wellness indices, specifically soreness, fatigue, and wellness. Moreover, AS appears more sensitive to ETL than S&R scores. Therefore, multiple monitoring markers should be utilised when understanding the fatigue response to TL. Moreover, it could be TD and previous 7-day ETL is more beneficial. Whilst changes to previous day and 7-day TL might only produce *Trivial* to *Moderate* changes in subjective and objective recovery markers, small changes might still be important for players. The current results may assist practitioners with an understanding of objective monitoring markers (AS and S&R scores) in a monitoring battery (which is easy to administer and cost effective) to identify fatigue. Moreover, monitoring GPS metrics could help inform ETL prescription during periods of high fatigue, soreness, and wellness to allow sufficient recovery and reduce injury and illness risk and enhance performance. Subsequent attention should be focused on TD, and previous 7-day loading to have the biggest influence on recovery markers.

Link to next chapter

The current chapters findings provide an understanding of which ETL parameters, specific to soccer demands could reflect changes to subjective and objective recovery. Specifically, previous day and 7-day TL variables were related to fatigue, soreness, and wellness. Whilst, previous day TD and SD were related to AS, and previous 7-day TD were related to both objective recovery markers. Whilst notably these changes to TL may only produce *Trivial* to *Moderate* changes in recovery markers, these changes may still be important for players. Moreover, the current chapter provides objective measures that can reflect perceived ratings of soreness, fatigue, and wellness. Subsequently, it is concluded that all recovery markers could be useful when predicting injury and illness. However, first, the current chapter focused upon outfield positions and the GK position was excluded. Given that the training demands in GKs may be greater than in outfield positions, and the availability of valid and reliable ETL metrics have increased, the next chapter aimed to examine associations between subjective recovery and GK specific GPS metrics, to enable practitioners to prescribe ETL to a whole football squad rather than just outfield positions.

7.0 Study Four – The relationship between subjective wellness and external training load in elite English Premier league goalkeepers and a comparison with outfield soccer players.

Grimson, S., Brickley, G., Smeeton, N. J., Brett, A & Abbott, W (2022) The relationship between subjective wellness and training load in elite English Premier League Goalkeepers and a comparison with outfield soccer players, *International Journal of Sports Physiology and Performance.* In Press.

7.1 Abstract

Purpose: This study aims to investigate the relationship between TL and subjective wellness in EPL GKs and examine potential positional differences in subjective wellness. **Methods:** Thirty-four players (GK = 7, Outfield = 27) completed a daily subjective wellness questionnaire assessing sleep quality, sleep hours, fatigue, mood, soreness, and total wellness, over two and a half seasons. Ten Hz GPS devices were worn during training to calculate previous day and 7-day TD, PlayerLoad, total dives, total dive load, ATF and high, medium, and low jumps. **Results:** All previous 7-day TL were associated with all wellness markers (r = 0.073 to 0.278, P <0.05). However, associations between previous 7-day dive load and mood, ATF and both sleep quality and quantity, and between low jumps and sleep quality were not significant. For previous day metrics, TD were associated with all wellness markers (r = 0.097 to 0.165, P <0.05). Additionally, PlayerLoad and high jump were associated with fatigue, soreness, and wellness (r = 0.096 to 0.189, P <0.05). Furthermore, total dives and soreness were related (r = 0.098, P <0.05) and between ATF, medium jumps, and all wellness markers, excluding sleep quality (r = 0.114 to 0.185, P <0.05). No positional differences in subjective wellness occurred (P >0.05). Some GK GPS variables are associated with subjective wellness which could inform TL prescription, to maximise recovery and performance. Additionally, GKs are no more vulnerable to poorer subjective wellness when compared to outfield players.

Key Words: *Monitoring, Injury Prevention, Non-locomotive movements, Fatigue, Recovery*

7.2 Introduction

The GK position in soccer is unique and frequently requires executing short and explosive actions including, diving, catching and sharp accelerations and decelerations which could influence match outcome (Ziv *et al.,* 2011; Liu *et al.,* 2015). In contrary to outfield positions during competition, GKs cover less mean TD (5611 vs. 10714m) and SD (61 vs. 905m) and may perform less than two 10-m sprints. (Di Salvo *et al.,* 2008; Bradley *et al.,* 2009; Malone *et al.,* 2018; White *et al.,* 2018). Additionally, high velocity non-locomotive actions could contribute to a GKs physical demands. GKs perform 8-14 kicks, 6.2 ± 2.7 dives, 3.8 ± 2.3 jumps, and 18.7 ± 6 dynamic displacements (De Baranda *et al.,* 2008). Subsequently, GKs engage in position specific training comprising of small and restricted field areas (Malone *et al.,* 2018; Moreno-Perez *et al.,* 2019).

In contrary to outfield positions, during an in-season training microcycle, GKs cover around 50% less TD (4034-6871m vs. 2553-3742m) (Malone *et al.,* 2015; Malone *et al.,* 2018; Moreno-Perez *et al.,* 2019). Moreover, during a training session, GKs perform on average 51 ± 11 dives, 43 ± 15 jumps, 34 ± 12 high speed changes of direction and 70 ± 18 explosive efforts (Stolen *et al.,* 2005). These metrics are higher during a ~79 min training session vs. a 90 min match, indicating higher mechanical and physical workloads during training, consequently indicating the importance of TL monitoring in GKs (White *et al.,* 2020).When compared to outfield positions, GKs report higher subjective perceptions of TL (Clemente *et al.,* 2017). Indeed, GKs undertake more power and high intensity-based activities which could psychologically influence rating of perceived exertion (RPE) reporting and therefore subsequent ITL (Clemente *et al.,* 2017). Moreover, involvement in high stake individual actions e.g., trying to save and block shots, could be psychologically demanding. Alternatively, engagement in explosive, high intensity movements detrimental to strength speed, jumping performance, DOMS and creatine kinase could affect the biomechanics of movement, and motor activity, attenuating regeneration (Paquette *et al.,* 2017). Therefore, DOMS developed post GK training could lead to excessive stretching, tears, and injury risk (Tzatzakis *et al.,* 2019; Muracki *et al.,* 2020). Fatigue monitoring aims to prevent excessive loads and muscle soreness (Clemente *et al.,* 2017; Muracki *et al.,* 2020). Therefore, it is surprising given the high physical demands associated with GK training, there is a paucity of research investigating the dose-response relationships between TL and response. To maximise performance and training adaptations, practitioners modify external TL (ETL) to prescribe an ITL that elicits a suitable fitness/fatigue response (Banister *et al.,* 1975). However, a mismatch between workload and sufficient recovery can attenuate mental and physical health (Buchheit *et al.,* 2013). Therefore, time efficient, non-invasive monitoring tools sensitive to TL are required to quantify fatigue status and guide recovery and TL prescription (Thorpe *et al.,* 2016). Previously, subjective wellness indices have associated with ITL (r = -0.109 – 0.232) (Clemente *et al.,* 2017; Lathlean *et al.,* 2020) and ETL in soccer (Thorpe *et al.,* 2016; Fields *et al.,* 2021). However, there is a paucity of research investigating GK specific ETL metrics and associations with subjective wellbeing (Malone *et al.,* 2018).

GKs physical demands differ to outfield positions and may possess a unique wellness profile and subsequent physiological post-match and training recovery profile, exacerbating susceptibility to overtraining, muscle soreness and fatigue, thereby potentially enhancing injury risk (Carfagno *et al.,* 2014; Muracki *et al.,* 2020). Moreover, the increased demands during training compared to match play specifically for a GK may require a greater emphasis on monitoring responses to training. Previously, one study to date revealed *small* to *moderate* correlations between ETL (duration, TD, high decelerations, and load) and total wellness in one elite GK (Malone *et al.,* 2018). Nevertheless, due to limitations with GPS technology, GK-specific ETL metrics were not investigated (Malone *et al.,* 2018). Additionally, it is unclear if the associations revealed between ETL and total wellness can be generalised to GKs, as only one GK in was previously investigated. Moreover, the previous investigation only investigated 'acute' TL (Malone *et al.,* 2018). Despite these limitations, technological advancements have allowed GPS devices to be validated to measure non-locomotive movements in Rugby and Volleyball (Gageler *et al.,* 2015; Reardon *et al.,* 2017). Knowledge and future research on specific GK-based metrics to elicit a favourable subjective wellness response, may aid practitioners to reflect on training session content, which can help optimise training stimuli more easily than traditional metrics.

Only two studies to date have investigated positional differences in wellness (Clemente *et al.,* 2017; Fernandes *et al.,* 2019). One study identified differences for sleep quality between GK and defenders (Clemente *et al.,* 2017), whilst no positional differences occurred in outfielders (Fernandes *et al.,* 2019). Given the paucity of research that exists, research should investigate the positional differences in subjective wellness.

The current study aims were two-fold: firstly, to examine the relationship between wellness markers and specific ETL GK parameters. Secondly, to examine positional differences in subjective wellness. If such relationships are absent, it questions the ability of GK-based ETL 'dose-response' to suitability inform TL prescription and additionally will prevent the identification of positions that might have higher susceptibility to poor wellbeing and recovery. Based upon the above findings, the authors believe ETL parameters will be related to subjective wellness, and positional differences in wellness responses will exist.

7.3 Methods

Subjects

Thirty-four professional players from an EPL club participated in this study (stature: 184.0 ± 9.4 cm; body mass: 81.9 ± 9.2 kg; age: 27.0 ± 4.30 years), competing for at least a six-month period in the 2019-2020, 2020-2021 and 2021-2022 seasons.

Design

Players took part in routine training, competitive matches, and monitoring procedures. Physical data were collected over two and a half seasons (113 weeks) consisting of 410 training sessions. Training would typically occur on a Monday, Tuesday, Thursday, and Friday, with an occasional alternative training week, comprising of a training session on a Tuesday, Wednesday, Thursday, Friday. Prior to training (~9:00 – 9:30 am), players completed a subjective wellness questionnaire which was supervised by science and medical practitioners. Players were familiar with the subjective wellness questionnaire (> 2 years). Player's data were excluded from the analysis if they were currently injured, resulting in exclusion of 349 outfield and GK observations. An injury was defined as any injury that resulted in time-loss from training or matches (Fuller *et al.,* 2006). Playing positions were coded into a) GKs (n=7), b) CDs (n=5), c) WDs (n=5), d) CMs (n=7), e) WMs (n=5) and FWDs (n=5). At the time of the study, the GK demographic comprised of senior starting (n=2), and non-starting GKs (n=5). Full approval was received from the local ethics review board and participants provided informed written consent.

Methodology

Subjective Wellness Questionnaire Participants completed a custom-based subjective wellness questionnaire via an athlete management system app on a tablet device. Results were subsequently download via an Excel spreadsheet by a sport science practitioner. Based upon previous recommendations, participants rated their perceived fatigue, sleep quality, muscle soreness, mood using a five-point Likert Scale ranging from 1 (best) to 5 (worst). A total wellness score was also calculated by a summation of the 5-item scores, as utilised to previously (Malone *et al.,* 2018). The number of hours sleep they had were also reported. These items have been utilised to examine subjective wellbeing and reported a CV of 7.1% in team sports (Roe *et al.,* 2016).

External training load ETL was calculated by both GK specific and non-GK specific GPS units and 100Hz triaxial accelerometer devices worn during all training sessions. To avoid interunit error, individuals wore the same unit. Devices were turned on a minimum of 15-minutes prior to data collection to allow connection to satellite signals. The mean number of satellites during data collection was 15.3 ± 1.2. ETL parameters included, and definitions are presented in Table 7.1. Session data were subsequently downloaded utilising Catapult Openfield Cloud Software for data analysis (Catapult Cloud Version 2.0.1, Catapult Innovations, Melbourne, Australia).

Statistical Analysis

Data analysis was completed via SPSS (SPSS Version 26.0). Normal distribution was checked and all data were considered normally distributed as the Shapiro-Wilks test was $P > 0.05$. Data were analysed utilising the number of days pre and post a matchday (MD) (MD plus minus method, MD ±), and therefore training sessions were coded 1 day after a match (MD+1), or four days (MD-4), 3 days (MD-3), 2 days (MD-2) and 1 day (MD -1) prior to a match. A one-way analysis of variance (ANOVA) was utilised to assess the difference between the daily session average ETL parameters across the respective MD's (34 data points). A one-way ANOVA was also utilised to assess the differences between playing position (GK; Goalkeeper, FB; Fullback, CD; Central Defender; MF; Midfielder; FWD; Forward) average daily TD and all subjective wellness markers (34 data points). Post-Hoc independent samples T-tests were then utilised to assess differences between each position and wellness markers, and Partial Eta Squared was adopted for effect size calculations. To interpret effect sizes the following criteria were adopted; 0.2 small, 0.5 moderate and >0.8 large. Pearson correlations were utilised to determine the relationship between subjective wellness markers and GK ETL parameters (n=433 player observations). To interpret the magnitude of the correlations (r) between test measures; <0.1 trivial, 0.1 to 0.3 small, 0.3 to

0.5 moderate, 0.5 to 0.7 large, 0.7 to 0.9 very large and 0.9 to 1 almost perfect (Hopkins, 2000). Statistical significance was determined at $P < 0.05$.

7.4 Results

External training load and subjective wellness scores

The daily session average ETL GK GPS parameters across MD's are displayed in Table 7.1. A main effect was revealed between MD and TD ($f_{(4,1032)} = 45.809$, $p = 0.000$, $\eta^2_{\text{partial}} = 0.151$), PL ($f_{(4,1032)} = 41.034$, $p = 0.001$, $\eta^2_{\text{partial}} = 0.137$), total dives ($f_{(4,1032)} = 6.689$, $p = 0.000$, $\eta^2_{\text{partial}} = 0.025$), and low jumps ($f_{(4,1032)} = 5.755$, $p = 0.001$, $\eta^2_{\text{partial}} = 0.022$). Additionally, no main effect was revealed between MD and ATF ($p = 0.324$), high jumps ($p = 0.441$), and medium jumps ($p = 0.287$).

Table 7.1: The average daily GK ETL values for each GPS parameter with respect to MD (Mean ± *sd*) (n= 1371)

	MD+1	MD-4	MD-3	MD-2	MD-1
TD[1]	3667±984[b,c,d]	4142±973[a,d,e]	4060±964[a,e]	3873±951[a,b,e]	3223±859[b,c,d]
Player load[4]	372±84[b,c,e]	423±89[a,e]	426±102[a,e]	401±97[e]	338±84[b,c,d,a]
Player load/min	5.11±0.9[b,c,d,e]	4.66±0.72[a]	4.66±0.76[a]	4.60±1.06[a]	4.50±0.82[a]
Total Dives[2]	36±13	39.9±16	38.27±16.33	36.8±14.11	33.93±11.99[b]
Total dive load	285±114	303±127	300±135	283.87±114.82	270.81±96[b]
ATF	1.35±0.32	1.37±0.37	1.33±0.31	1.39±0.40	1.68±3.62
High Jumps[3]	3.5±4.0	4.18±4.2	4.21±4.93	4.53±5.75	3.97±4.39
Medium Jumps[3]	10.2±10.3	11.18±5.79	11.71±7.85	11.68±7.46	10.76±5.90
Low Jumps[3]	9.6±5.7	11.17±5.72	11.67±5.82	10.90±5.77	9.48±5.37[b,c,d]

a) Significantly different from MD+1, b) Significantly different from MD-4, c) Significantly different from MD-3, d) Significantly different from MD-2, e) Significantly different from MD-1.

[1]Total distance is defined as the distance covered walking, jogging, fast running and sprinting.

[2]Total Dives is defined as the total number of dives completed.

[3]High Jumps are defined as (>0.4m in Height), Medium Jumps are defined as (0.2-0.4m in Height) and Low Jumps are defined as (<0.2m in Height).

[4]Player load is an arbitrary unit (AU) derived from the triaxial accelerometer that measures instantaneous change in acceleration.[33]

Abbreviations: ETL – External training load, GPS – Global Positioning System, MD – Matchday, GK – Goalkeeper, TD – Total Distance, ATF – Average time to feet.

The average daily subjective wellness scores for GKs and their subsequent differences across MD's are displayed in Table 7.2.

Table 7.2: The average daily GK subjective wellness scores in relation to MD. (Mean ± *sd*). (n=1070)

	MD+1(n=107)	MD-4 (n=180)	MD-3 (n=94)	MD-2 (n=325)	MD-1 (n=364)
Wellness	11.00±1.61[e]	10.59±1.55	10.52±1.59	10.53±1.54	10.19±2.21[a]
Soreness	2.15±0.45	2.07±0.47	2.08±0.40	2.07±0.47	2.03±0.45
Fatigue	2.25±0.51[b,e]	2.09±0.43[a]	2.13±0.39	2.12±0.44	2.10±0.46[a]
Sleep Hours	7.57±1.10[d,e]	7.82±0.65	7.70±0.80	7.81±0.76[a]	9.52±32.54[a]
Sleep Quality	2.29±0.61[e]	2.17±0.49	2.16±0.53	2.16±0.48	2.17±0.88[a]
Mood	2.07±0.35	2.08±0.35	2.03±0.37	2.06±0.37	2.14±1.60

a) Significantly different from MD+1, b) Significantly different from MD-4, c) Significantly different from MD-3, d) Significantly different from MD-2, e) Significantly different from MD-1.

*MD – Matchday.

The relationship between wellness markers and ETL.

The partial correlations (95% CI), least regression slope (*b*) and significance for the relationship between previous day and 7-day TL GK-specific GPS metrics and morning measured wellness markers are displayed in Appendix, Table 11.5-11.7. In summary, for TD, correlations between previous day TL and subjective wellness markers were *Trivial* to *Small* (r = 0.097 to 0.165, P = 0.001 – 0.045), excluding mood. Correlations between previous 7-day TL and all subjective wellness markers were *Trivial* to *Small* (r = 0.093 to 0.197, P = 0.000 – 0.004). For PL, correlations between previous day TL and fatigue, soreness, and wellness were *Trivial* (r = 0.107 to 0.189, P = 0.000-0.026). Correlations between previous 7-day TL and all subjective wellness markers were *Trivial* to *Small* (r = 0.080 to 0.192, P = 0.000 – 0.014). For total dives, correlations between previous day TL and soreness were *Trivial* (r = 0.098, P = 0.041). Correlations between previous 7-day TL and all subjective wellness markers were Trivial to *Small* (r = 0.082 to 0.174, P =

0.000 – 0.012). For total dive load, correlations between previous day TL and all subjective wellness markers were *Trivial* (*r* = 0.004 to 0.082, *P* = 0.088-0.928). Correlations between previous 7-day TL and subjective wellness markers were *Trivial* to *Small* (r = 0.073 to 0.135, *P* = 0.000 – 0.075). For ATF, correlations between previous day TL and subjective wellness markers were *Trivial* to *Small* (*r* = 0.114 to 0.172, *P* = 0.001-0.018) excluding sleep quality and soreness. Correlations between previous 7-day TL and subjective wellness markers were *Trivial* to *Small* (*r* = 0.094 to 0.128, *P* = 0.001- 0.005) excluding sleep quality and sleep hours. For high jumps, correlations between previous day TL and fatigue, soreness and wellness were *Trivial* to *Small* (*r* = 0.096 to 0.132, *P* = 0.006 – 0.047). Correlations between previous 7-day TL and all subjective wellness markers were *Trivial* to *Small* (*r* = 0.076 to 0.249, *P* = 0.000-0.019). For medium jumps, correlations between previous day TL and subjective wellness markers were *Trivial* to *Small* (*r* = 0.108 to 0.185, *P* = 0.000 – 0.025) excluding sleep quality. Correlations between previous 7-day TL and all subjective wellness markers were *Small* (*r* = 0.113 to 0.278, *P* = 0.000). For low jumps, correlations between previous day TL and all subjective wellness markers were *Trivial* (*r* = 0.011 to 0.071, *P* = 0.138 – 0.821). Correlations between previous 7-day and all subjective wellness markers were *Trivial* to *Small* (*r*= 0.066 to 0.106, *P* = 0.001- 0.044), excluding sleep quality.

Subjective wellness markers and ETL Positional differences.

The average daily subjective wellness scores and TD for each position are displayed in Table 7.3. No main effect was revealed between position and wellness scores, soreness, sleep quality, sleep hours, mood, fatigue, and TD (*P* > 0.05). Specific P-Values are demonstrated in Table 7.3.

Table 7.3: Descriptive statistics (mean ± *sd*) of subjective wellness markers per playing position.

	GK (n=1371)	CD (n=1388)	FB (n=900)	CM (n=1931)	WM (n=1379)	FWD (n=1222)	*P***
Wellness	10.53±0.84	10.58±0.63	10.08±3.16	11.47±1.49	11.91±2.34	10.81±1.93	0.619
Soreness	2.08±0.25	2.17±0.20	1.93±0.73	2.36±0.41	2.36±0.51	2.19±0.46	0.573
Sleep Quality	2.17±0.15	2.04±0.14	2.11±0.59	2.20±0.26	2.41±0.49	2.25±0.47	0.698
Sleep Hours	7.84±0.38	8.25±0.60	8.03±0.57	7.85±0.28	8.10±0.36	7.82±0.51	0.547
Mood	2.07±0.18	2.05±0.12	2.07±0.59	2.25±0.34	2.40±0.45	2.05±0.26	0.489
Fatigue	2.13±0.20	2.18±0.19	1.92±0.76	2.33±0.39	2.38±0.47	2.16±0.44	0.583
TD*	3664±380	3950±176	4082±283	4118±387	4099±115	4001±287	0.105

*Average TD - Total Distance for all sessions. ** Specific *P*-Value from the ANOVAs. N = Number of Observations, Abbreviations – GK – Goalkeeper, CD – Central Defender, FB – Full Back, CM- Central Midfielder, WM – Wide Midfielder, FWD – Forward.

7.5 Discussion

This novel study aimed to examine the relationship between the subjective wellness markers and GK-specific ETL, and secondly examine whether subjective wellness markers were different based upon playing position. In agreement with the hypothesis, *trivial* to *small* associations were revealed between all previous 7-day TL metrics and subjective wellness markers. However, associations between previous 7-day dive load and mood, ATF and both sleep quality and quantity, and between low jumps and sleep quality were not significant. For previous day metrics, *trivial* to *small* associations were revealed between TD and all wellness markers. Additionally, PlayerLoad and high jumps revealed *trivial* to *small* associations with fatigue, soreness, and wellness. Furthermore, *trivial* to *small* associations were revealed between total dives and soreness, and between ATF, medium jumps, and all wellness markers, excluding sleep quality. In contrary to the hypothesis, no positional differences in subjective wellness occurred.

In agreement with previous research that in one elite GK, TD, decelerations, and load revealed *small* to *moderate* correlations with total wellness (*r* = -0.27 to -0.35) (Malone *et al.,* 2018), current findings revealed *trivial* to *small* correlations between TD and both total wellness and subjective wellness markers (*r* = 0.069 – 0.197). Interestingly in contrary to the previous research, the current investigation revealed weaker associations between TD and wellness markers. Pertinent, the above authors suggested that the small correlations revealed were not sensitive enough to detect changes in TL. Therefore, it should be debated on whether the same conclusion should be made. Elsewhere when examining the relationship between TL and subjective wellbeing, similar strengths of association have been reported and interpreted as meaningful (*r* = -0.109 to -0.238) (Clemente *et al.,* 2017). In general, the relationship between subjective wellbeing and TL can be confounded by alternative factors such as social, lifestyle and athlete coach relationships which can add to the stress experienced by an athlete. However specifically, in contrary to previous research the current study utilised more training sessions (410 vs. 131), and therefore the current findings could be a result of a significant non-meaningful relationship. Consequently, both current and previous results should be interpreted with caution. The previous investigation is limited due to studying one GK, preventing the generalisation of findings to other GKs. In addition, GK specific GPS parameters were not examined and excluded data collection between September and December. Overall current findings demonstrate ETL parameters and subjective wellness markers might be related across multiple seasons and generalised to multiple GKs, however given the strength of such relationships, the practical application of such findings is cautioned.

Building upon previous research, findings revealed stronger associations between wellness and GK-specific ETL in comparison to TD. Current novel findings present non-locomotive GK metrics such as previous 7-day high jumps, medium jumps and total dives were associated with all subjective wellness markers (r = -0.119 to 0.278). Therefore, insights into the GK-specific metrics representing non-locomotive movements, which can indicate how the athlete feels regarding subjective wellness score are provided, and offers practitioners with ETL parameters, specific to GK-training, which can potentially be utilised to elicit a favourable subjective wellness response. It is advantageous GK-metrics such as jump height which are sensitive to subjective wellness have been validated in RU (Gageler *et al.,* 2015) and Volleyball (Reardon *et al.,* 2017). Subsequently, this provides ecological validity and should encourage practitioners to utilise the current findings in practise.

Despite increased strength in associations between subjective wellness and GK-specific ETL metrics, these could still be considered weak and not meaningful, and are lower than those previously reported utilising non-specific GK-ETL metrics (Malone *et al.,* 2018). It could be performance decrements in explosive power which are paramount to executing dives and jumps could confound these relationships. This is because, GKs with a higher explosive power could have an increased ability to tolerate higher loads, which reduces the athlete's perception of subjective wellness markers such as fatigue and soreness. Nevertheless, when comparing the strength of the relationships between ETL and subjective wellness between the current study in GKs and those in outfield positions the strength of associations are similar. For example, it's been reported that HSD was *moderately* associated with fatigue (r = 0.330, P <0.001) (Thorpe *et al.,* 2016). Therefore, instead subjective wellbeing responses could be confounded by practitioners prescribing TLs based upon wellness scores. TL in elite GKs vary across a training cycle, such as a lower duration, TD and playerload being observed on a MD+1 (Malone *et al.,* 2018). Therefore, TLs are often tapered to ensure freshness for a match. From this perspective future research should investigate the relationship between ETL and subjective wellness on each specific MD, to identify the varying strength of relationships. Unfortunately, the current study's, the low sample size prevents this analysis, and pooled TL for all phases of the season together, rather than considering changes of TL and subjective wellness responses at different time points across a season. Moreover, the wide variety in training prescription, allied to a small sample size for the GKs would have led to high *sd*'s around the mean values calculated, impacting on the results.

Interestingly, the tactical nature of competition can influence exposure to GK-specific metrics such as the execution of dives and high jumps (e.g., during attacking play, where the opposition employ high crosses) (White *et al.,* 2020). To further understand subjective wellness responses, practitioners should consider measuring GK-GPS metrics during both competition and training, which would provide a more comprehensive quantification of a GKs TL and therefore enhanced ability to inform practise more accurately. Monitoring GK match outputs could be more relevant for practitioners working with lower leagues, given the possibility that the physical requirement of GKs is influenced by contextual variables of the game (Paul *et al.,* 2015). For example, in 46 Spanish First division GKs a greater number of saves were evident when playing against a high-level team compared to against a low-level team (Liu *et al.,* 2015). Overall, additional insights into the ETL dose-response to subjective wellness are provided and suggest practitioners could assess TL based upon previous 7-day load to enhance wellness responses and positive adaptations to training, rather than the previous day in EPL GKs.

The current study also reveals poorer subjective wellness, specifically sleep hours, fatigue and sleep quality on a MD+1 compared to all other MDs in agreement with previous findings (Malone *et al.,* 2018). Consequently, these results conflict the above suggestion that TL is more important than match loads when monitoring subjective wellness markers. Nevertheless, as situational factors such as opposition quality, match location and outcome can influence subjective wellbeing (Abbott *et al.,* 2018), it could be heightened responses on a MD+1, could be confounded. Therefore, whilst subjective wellness measures are suggested to be superior to objective measures of recovery (Saw *et al.,* 2016), future research should investigate the relationship between ETL and objective markers in elite GKs.

The current study utilises data from both starting and non-starting GKs, in contrast to just one starting GK examined previously (Malone *et al.,* 2018). It is evident, starting GKs accumulate greater TD when compared against non-starting GK (Malone et al., 2018), therefore it was plausible based upon prior research that only starting GKs reported an attenuated subjective wellness on a MD+1. Nevertheless, the current study provides novel insights that non-starting GKs are as vulnerable as starting GKs to attenuated wellbeing on a MD+1. This could be explained by 'pre-match warmups' which include both starting and non-starting GKs and consist of high jumps related to ETL (White *et al.,* 2020). It should also be acknowledged that on a MD+1, subjective perceptions of wellness could be influenced by psychological arousal, sleep disruption, and travel. Nevertheless, to consolidate this theory, future investigation is required between both starting and non-starting GKs to understand the impact TL has on subjective wellness and how this varies upon a training microcycle.

In contrary to previous research in Portuguese Premier League Players (Clemente *et al.,* 2017), current findings revealed no positional differences in subjective wellness markers. Previous research suggests GKs, and midfielders report higher ITL (Clemente *et al.,* 2017), and therefore provides rationale for positional differences to occur. Nevertheless, GKs can train through more power and high intensity-based activities, which may psychologically influence the reporting of RPE and associations with ITL (Clemente *et al.,* 2017). In addition, positional differences, in subjective wellness could have been due to the positional differences in ETL. Nevertheless, in the current study, positional differences in subjective wellness may not have existed due to the ability of players to cope with the training and competition demands preventing the risk of maladaptive responses to training stimulus and subjective wellness markers. This is because, performance coaches typically modulate planned activity in response to players perceived wellness and therefore could confound the identification of poor subjective wellness. Prudent, because current findings revealed no difference in TL across positions, meaning all positions were exposed to the same volume-based load. Finally, small subject samples of 4-5 players may not have been enough to demonstrate positional differences as seen elsewhere. Overall findings suggest GKs, and outfield positions have similar perceptions of subjective wellness over the training week and therefore have similar risks of injury and illness occurrence.

Overall, this study is notwithstanding limitations, and these should be considered when interpreting the results from the current investigation. For example, GPS cannot quantify all football specific movements (e.g., ball striking) which can contribute to physical workloads, and induce fatigue and soreness. Additionally,, given the large number of player observations, there is an increased likelihood to report significant but non-meaningful relationships. Given the *trivial* to *small* correlations revealed, the authors caution the interpretation of findings for practical use.

7.6 Conclusion

The current results may assist coaches and sport science practitioners with an understanding of modifications to planned training activity which could result in positive perceptions of subjective wellbeing, specific to elite GKs. Specific metrics which may be of relevance and sensitive to all next day subjective wellness markers were previous 7-day high jumps, medium jumps, and dive count. Whilst changes to previous day and 7-day TL might only produce *trivial* to *small* changes in subjective wellness, small changes might still be important for players. To enhance this process, it is recommended GK specific metrics are monitored for both competition and TL, given the tactical implication of competition on the GK-specific metrics. As no positional differences were revealed between subjective wellness markers, GK's are at no less or more risk of attenuated subjective wellness, and therefore should be treated as equal as outfield players, when monitoring fatigue responses to TL, and therefore subsequent influence on training adaptations, performance and injury and illness risk.

Link to next chapter

The previous two chapters (six and seven) aimed to examine physical health markers (subjective and objective recovery markers) and their sensitivity to TL. The current chapters findings provide an understanding on some GK specific GPS metrics which could be utilised by practitioners to maintain subjective wellbeing levels. Additionally, findings that no positional differences occur in subjective recovery suggest GKs should be treated the same as outfield positions. Now the previous four chapters have provided insights into monitoring tools that are sensitive to ETL, this has the potential to highlight injury and illness risk. High TLs have previously been associated with injury and illness incidence, and therefore tools sensitive to changes in TL may provide an early identification of an illness or injury. Subsequently the next chapter aimed to examine the role of subjective and objective recovery markers found to be sensitive to TL in the last two chapters on their relationship with injury and illness. Moreover, PWB was included due to being sensitive to chronic load, and the potential that the interaction between PWB and other recovery markers, may assist in predicting injury or illness events.

8.0 Study Five – The predictive ability of subjective wellbeing, musculoskeletal screening, psychological wellbeing, and training load to predict injury and illness in elite Premier League soccer.

8.1 Abstract

This study aims to investigate whether subjective and objective recovery markers, PWB and the ACWR can predict injury or illness in EPL Soccer Players. Nineteen players completed daily objective monitoring tools including AS and S&R, a bi-weekly PWB questionnaire, and a daily subjective wellbeing questionnaire containing five ratings of wellness (fatigue, mood, sleep quality, sleep hours, and soreness) over a 38-week period. Previous day ACWR were calculated from 10Hz GPS devices worn during all training sessions and matches to calculate TD, SD, ED, and HSD. Twenty-One injuries and 74 illnesses were recorded. Compared with non-injury, only PWB was higher the day prior to an injury ($P < 0.05$). Compared with non-illness, mood and AS were lower the day prior to an illness. Injury was predicted by mood (odds ratio [OR], 3.269 [95% CI: 1.310 – 8.155]) ($P < 0.05$). Illness was predicted by left (0.99 [0.99-1.000]) and right AS (0.99 [0.992 – 0.996]), TD ACWR (0.25 [0.09 – 0.70]), ED ACWR (0.33 [0.13 – 0.81]) ($P <0.05$). Results demonstrate mood was the only recovery marker that could predict injury, and AS was the only recovery marker that could predict illness. Nevertheless, the caveats regarding AS and illness are discussed, and practitioners are recommended to utilise alternative monitoring tools when predicting an injury or illness. Practitioners are also recommended to focus upon TD and ED metrics when prescription of TL to reduce injury and illness incidence.

Key words: *Monitoring, Fatigue, Health, Objective, Subjective*

8.2 Introduction

English Premier League soccer players are particularly vulnerable to injury and illness incidences, due to exposure to high physical demands and fixture congestion (both characteristic of the EPL) (Carling *et al.,* 2015; Jones *et al.,* 2019). Injury and illness can impose significant performance, financial and time burdens, due to an inability to sustain high intensity training and missed training sessions and matches (Gleeson, 2007; Hagglund *et al.,* 2013; Eirarle *et al.,* 2013). Therefore, ways to prevent injury and illness occurrences is pertinent.

High and insufficient workloads can increase an athlete's susceptibility to an injury or illness (Nieman, 1994; Gabbett *et al.,* 2016). Previously, TL has been associated with injury in soccer (Malone *et al.,* 2017b; Fanchini *et al.,* 2018; Jaspers *et al.,* 2018; Bowen *et al.,* 2019). Yet, limited research exists surrounding illness and TL. A systematic review across multiple sports revealed significant *moderate* associations between TL and illness (n = 6, 75%) (Drew *et al.,* 2016). Moreover, biomarkers indicative of endocrine and immune status have been related to high intensity exercise, (McLellan *et al.,* 2011). Given associations between TL and injury and illness exist, athlete monitoring is commonly adopted to quantify an athlete's TL response and identify potential injury and illness risk (Taylor *et al.,* 2012; Akenhead *et al.,* 2016). In this regard athlete monitoring should adopt an interdisciplinary approach whereby both objective and subjective measures are monitored to understand both mental and physical health (Purge *et al.,* 2006; Manzi *et al.,* 2009; Gabbett *et al.,* 2016; Thorpe *et al.,* 2016; Colby *et al.,* 2017; Tiernan *et al.,* 2019).

To understand athletes MH, there is increased attention in the routine monitoring of PWB to support the recovery process and potential role within injury and illness risk (Donohue *et al.,* 2018; Purcell *et al.,* 2019; Poucher *et al.,* 2021). Previously, MH status has been associated with TL and injury risk in soccer (Ivarsson *et al.,* 2013; Watson *et al.,* 2016). However, in contrary PWB was no different prior to an injury or illness (Grimson *et al.,* 2022). Pertinent, PWB was isolated, however PWB may be able to better predict injury or illness in combination with other monitoring markers. Given the non-extra time burden upon players and staff, this makes the inclusion of MH status easier, and inviting for applied practitioners to embed into their monitoring practise.

In soccer players, subjective perceptions of wellness are associated with TL (Thorpe *et al.,* 2016; Clemente *et al.,* 2017; Fields *et al.,* 2021; Sekiguchi *et al.,* 2021) and can reflect recovery status (Tiernan *et al.,* 2019) advocating its role in identifying injury risk. Notably, mood, soreness, sleep quality and sleep hours have been related to injury risk across multiple sports (Esmaelli *et al.,* 2018b; Ahmun *et al.,* 2019; Horgan *et al.,* 2020). Yet elsewhere, wellness markers could not predict injury (Colby *et al.,* 2018). It could be multiple antecedents including social bias (Twist *et al.,* 2013), subjective interpretation of the scale utilised, and different physiological training responses could mislead fatigue status and injury risk evaluation. Moreover, TL may be modulated based on subjective perceptions reported by players, which could confound associations between subjective wellness and injury (Twist *et al.,* 2013; Colby *et al.,* 2017). For this reason, obtaining objective fatigue status is important (Mandorino *et al.,* 2022).

Objective musculoskeletal screening tests (e.g., AS and S&R) are often adopted to identify injury risk, given their associations with TL (Esmaelli *et al.,* 2018a; Tiernan *et al.,* 2019; Wearing *et al.,* 2021). Such tests are favourable within soccer as hip and groin injuries account for a third of the injury burden (~5-19 days; time loss per injury) (Ekstrand *et al.,* 2020). Previously, preseason screening has been utilised to predict injury, however obtaining multiple values overtime may better identify injury risk and reflect fatigue (Paul *et al.,* 2014; Whiteley *et al.,* 2016; Thorpe *et al.,* 2017; Esmaelli *et al.,* 2018a). Previously, in AFL players, a >1.5 *sd* vs. > 1 *sd* decline in test score was associated with injury risk (Esmaelli *et* *al.,* 2018b), whilst a 1 *sd* decline could not predict injuries (Colby *et al.,* 2017). Subsequently, the application of weekly screening for injury prevention in EPL soccer does not exist and requires future research. Previously, only one study has revealed a <7.25 AU in subjective wellbeing could predict illness in the presence of increased ITL in team sport athletes (Thornton *et al.,* 2016). Therefore, research is required to identify monitoring tools, practitioners can utilise to predict illness.

Collectively research has modelled load independently and already analysed the association between TL, fatigue markers and injury and illness risk. Nevertheless, these studies have omitted associations specifically in soccer or examined ITL rather than ETL (Mandorino *et al.,* 2022). Pertinent due to sports having different injury risk factors and workload demands . Therefore overall, to appropriately predict injury and illness, the utilisation of monitoring tools sensitive to ETL endured by EPL soccer players and that can predict an injury or illness are required for practitioners to prescribe appropriate TL to reduce injury and illness risk. The study aimed to examine whether TL, musculoskeletal tests, subjective wellness and PWB could be used collectively to predict injury and illness in EPL soccer players. It was hypothesised that TL, musculoskeletal screening, subjective wellness and PWB could predict injury and illness.

8.3 Methods

Participants

Nineteen first team male soccer players from an EPL soccer club participated in this retrospective study (stature: 183.1 ± 8.6cm; body mass: 81.1 ± 8.7kg; Age: 27.2 ± 3.7 years). Participants competed in the 2019-2020 EPL season (July 2019 – March 2020) and completed routine training, matches and monitoring procedures. Player's data were excluded from the analysis if they were currently injured. An injury was defined as any injury that resulted in time loss from training or matches (Fuller *et al.,* 2006). The dates of injury onset and return to full training were recorded along with the injury mechanisms. Both first time and repeat injuries were included if they were felt to represent new injuries based on the resolution of symptoms and return to full participation between time-loss injuries. A self-reported illness was defined as a player self-reporting cold symptoms on the daily wellness questionnaire. Full approval was received from the local ethics review board and participants provided informed written consent.

Experimental Procedure

Physical data was collected over 38-weeks, consisting of 115 training sessions and 35 competitive matches. Training as prescribed by coaching staff, would typically occur on a Monday, Tuesday, Thursday, and Friday. Prior to training, at the training ground, daily monitoring data (subjective wellbeing, S&R scores, and AS scores) were collected between 9:00 ~ 9:30 am and supervised by science and medical practitioners. PWB data was also collected during this time and was completed on a bi-weekly basis on the second day following a match. This day was selected as it was considered the optimum time to reduce the impact of the preceding or following match. The questionnaire was optional and administered by the club doctor to be completed in a confidential manner. Players were familiar with all testing protocols (> 2 years). Additionally, self-reported illnesses and injury occurrence were recorded by the club doctor.

Adductor squeeze strength test

Participants laid beneath the Groin-Bar Strength Testing System (Force Frame, Vald Performance, USA) and adopted a supine position with a hip flexion at 45 degrees, known to be optimal position for maximal adduction strength (Delahunt *et al.,* 2011). Bar height was individualised for each participant and kept consistent. Participants placed the femoral medial condyle of both knees on the fixed pads and push inwards. Participants were given a verbal cue (3,2,1) and instructed to 'squeeze', and verbally encouraged to ensure maximal effort. One warm up repetition (60-80% maximum effort) was followed by two maximal repetitions, each five seconds in length, interspersed by 30 seconds. A maximum force (N) was then obtained for both adductors. Data was uploaded to the 'Vald Hub' cloud, which data from the tests were assessed. The Groin-Bar Hip Strength Testing System has demonstrated excellent test-retest reliability with intraclass correlation coefficients (ICC) for hip adduction (0.97) and acceptable level of CV% (4.65-6.30) (Ryan *et al.,* 2019a). Additionally in the current cohort, the AS test demonstrated good reliability as on the left and right AS a test-retest reliability of ICC 0.95 (95% CI: 0.81-0.99) and 0.88 (95% CI: 0.60-0.97) respectively.

Sit and Reach Test

Participants sat down with their feet placed flat against the S&R box. Then maintaining extension through both knees, stretch their arms with one hand directly on top of the other as far as they can forward and hold for one second. The distance between the toe line and middle finger was visualised by the practitioner and recorded (Gabbe *et al.,* 2004). The testing procedures consisted of two repetitions, interspersed by twenty seconds. The S&RT is reliable and valid to estimate hamstring extensibility with a test-retest reliability of ICC (0.98-0.99) (95% CI: 0.94-1.00) (Gabbe *et al.,* 2004).

Subjective recovery markers

Participants completed a custom-based subjective wellness questionnaire based upon previous recommendations (Hooper *et al.,* 1995). These items included fatigue, sleep quality, muscle soreness, general health, and mood, using a five-point Likert scale ranging from 1 (best) to 5 (worst). A total wellness score was calculated by a summation of the 5-item scores. Higher wellness scores were associated with poorer wellbeing. Sleep hours were also recorded. These items have previously been utilised to examine subjective wellbeing and reported a CV of 7.1% in team sport athletes (Roe *et al.,* 2016).

Psychological Wellbeing Questionnaire

Psychological wellbeing was assessed using the WEMWBS (Stewart-Brown *et al.,* 2009). The WEMWBS has been utilised to monitor MW in athletic populations (Abbott *et al.,* 2019; Nicholls *et al.,* 2020). The WEMWBS had excellent levels of reliability within our sample, with a Cronbach alpha of 0.90. The questionnaire is comprised of a 14-item self-report scale that assesses positive thoughts and feelings. Responses are made relative to the previous two-weeks. Each statement is scored on a 1-5 Likert Scale (1 = 'none of the time', 5 = 'all of the time'). A global score ranging between 14-70 is then calculated by adding up item scores. The higher the score, the higher the level of PWB.

External training load

ETL was calculated by 10Hz GPS units and 100Hz triaxial accelerometer devices (Vector, Catapult Innovations, Melbourne, Australia), worn during all training sessions and matches. Units were worn in manufacturer vests and positioned between the scapulae. To avoid interunit error, individuals wore the same unit. 10Hz units have demonstrated acceptable reliability for acceleration, deceleration and at high speeds (Scott *et al.,* 2016). Devices were turned on a minimum of 15-min prior to data collection to allow connection to satellite signals. The mean number of satellites during data collection was 14±1. ETL parameters included, TD, HSD (distance covered at 5.5-7$m.s^{-1}$), SD (distance covered at >7$m.s^{-1}$) and ED (distance covered accelerating >2$m.s^{-2}$ and decelerating >2$m.s^{-2}$). Session data was subsequently downloaded utilising Catapult Openfield Cloud Software for data analysis (Catapult Cloud Version, 2.0.1, Catapult Innovations, Melbourne, Australia). For each day of the season, the ACWR (previous 7-day TL divided by previous 28-day TL) were calculated individually for each player.

Data Analysis.

Data analysis was completed via SPSS (SPSS Version 26.0). Normal distribution was considered if the Shapiro-Wilks test was ($P > 0.05$). Subjective wellbeing markers (wellness, soreness, fatigue, sleep quality, sleep hours and mood), PWB, objective recovery markers (AS and S&R) and TL were compared between days with and without an injury, and with and without a self-reported illness during the season, utilising independent samples t-tests. Cohen's *d* effect sizes were used to determine the strength of the differences obtained within the t-test (0.1 = small, 0.3 = medium and 0.5 = large) (Cohen, 1988). As seen in previous research conducted by (Haraldsdottir *et al.,* 2021), to evaluate the association between injury and self-reported illness and TL, subjective recovery markers, objective recovery markers, PWB, separate mixed effects logistic regression models were used to evaluate their association with in-season injury by including the variable as a fixed effect and individual repeated measures as a random effect. This tested the relative ability of each variable reported in the morning to predict the likelihood of injury later that same day and self-reported illness the day after, while adjusting for the repeated measures from each individual. Statistical significance was determined at $P<0.05$.

8.4 Results

21 injuries on 20 days and 74 self-reported illnesses on 55 days were recorded among the elite senior soccer players. 1/21 of the injuries was a repeat injury. The breakdown of the injuries such as location and type are outlined in Table 8.1. The average amount of days missed per injury were 21 ± 16, and the subsequent training days missed were 10 ± 8. The distribution of injuries and self-reported illnesses throughout the season are shown in Figure 8.1 and 8.2 respectively.

Table 8.1: In-season injury characteristics among EPL soccer players

Total Injuries	**21**
Injury location	
Ankle	2 (10)
Inguinal	2 (10)
Knee	2 (10)
Upper leg (Thigh)	9 (43)
Shoulder	1 (5)
Trunk	1 (5)
Lower Leg (Calf)	1 (5)
Groin	3 (14)
Injury Type	
Strain	19 (90)
Contusion	1 (5)
Fracture	1 (5)

***Data presented as n (%)**

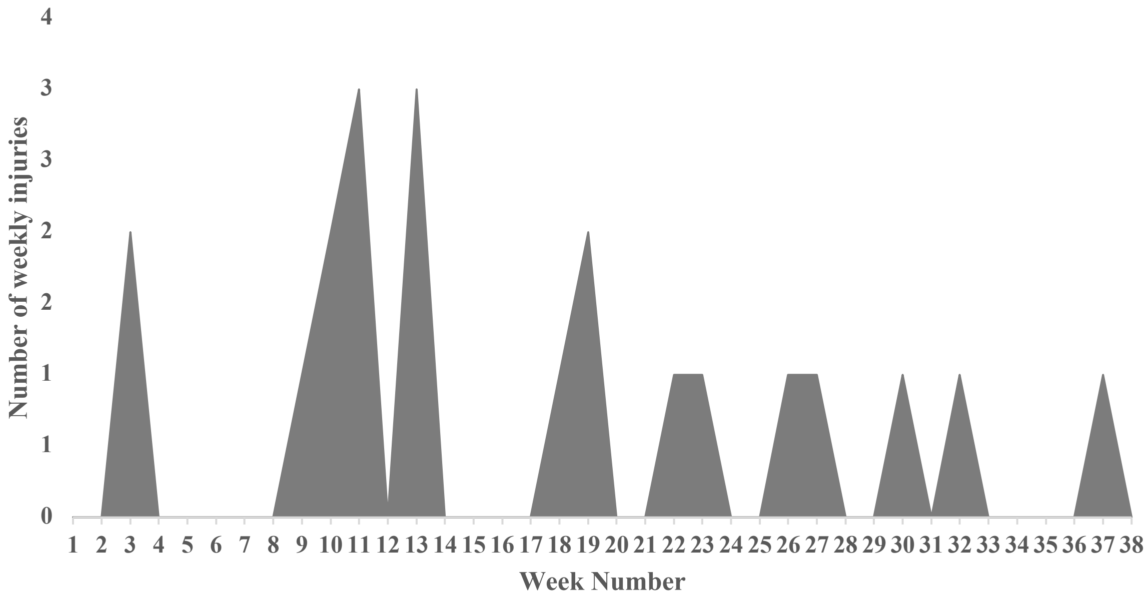

Figure 8.1: Number of weekly injuries during a 38-week season in EPL Players.

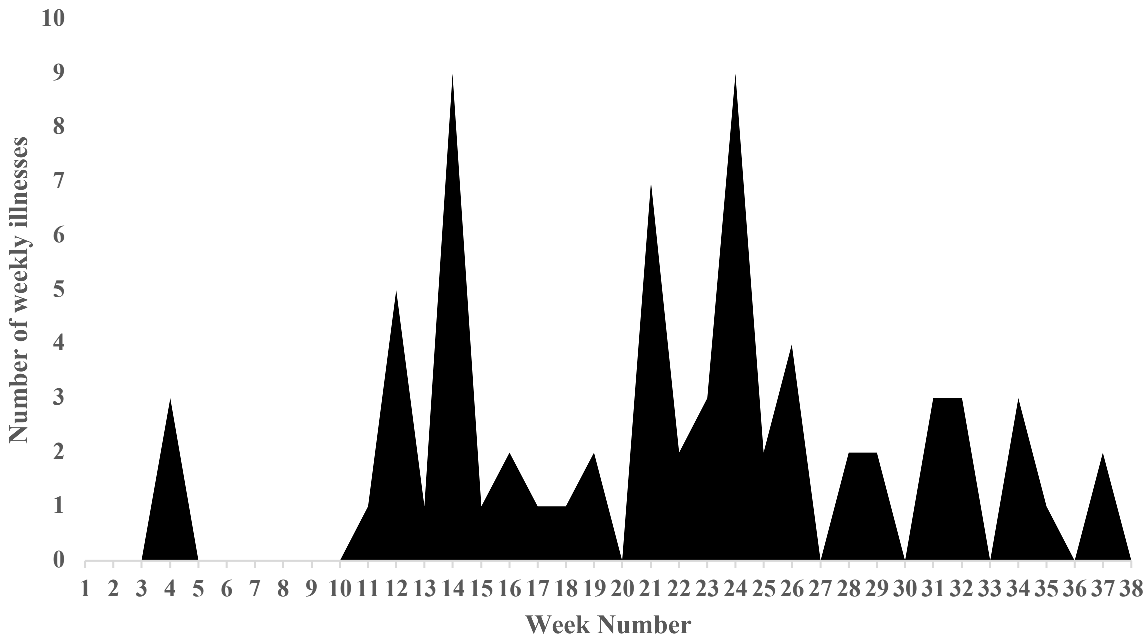

Figure 8.2: Number of weekly self-reported illness during a 38-week season in EPL Players.

The mean daily subjective wellbeing markers and PWB scores the days prior to with and without a subsequent injury or illness are demonstrated in Figure 8.3. Compared with days without an injury, PWB was higher the day before an injury (54.26 ± 8.35 vs. 51.35 ± 6.06) ($P < 0.05$). No differences between all wellness markers were revealed ($P > 0.05$). Compared with days without an illness, worse mood occurred the day before an illness (2.75 ± 0.64 vs. 2.31 ± 0.52) ($P < 0.05$). No differences were revealed for fatigue, soreness, PWB, sleep hours and quality and total wellness ($P > 0.05$).

The mean previous day ACWR, the days prior to with and without a subsequent injury or illness are demonstrated in Table 8.2. Compared with days without an injury or illness, ACWR for all TL parameters (TD, HSD, ED, and SD) no differences were revealed ($P >$ 0.05).

The mean absolute values daily objective markers the days prior to with and without a subsequent injury or illness are demonstrated in Table 8.3. No differences between left and right AS and S&R scores were revealed between days with and without an injury ($P > 0.05$). Compared with days without an illness, left and right AS were lower the day before an illness ($P < 0.05$).

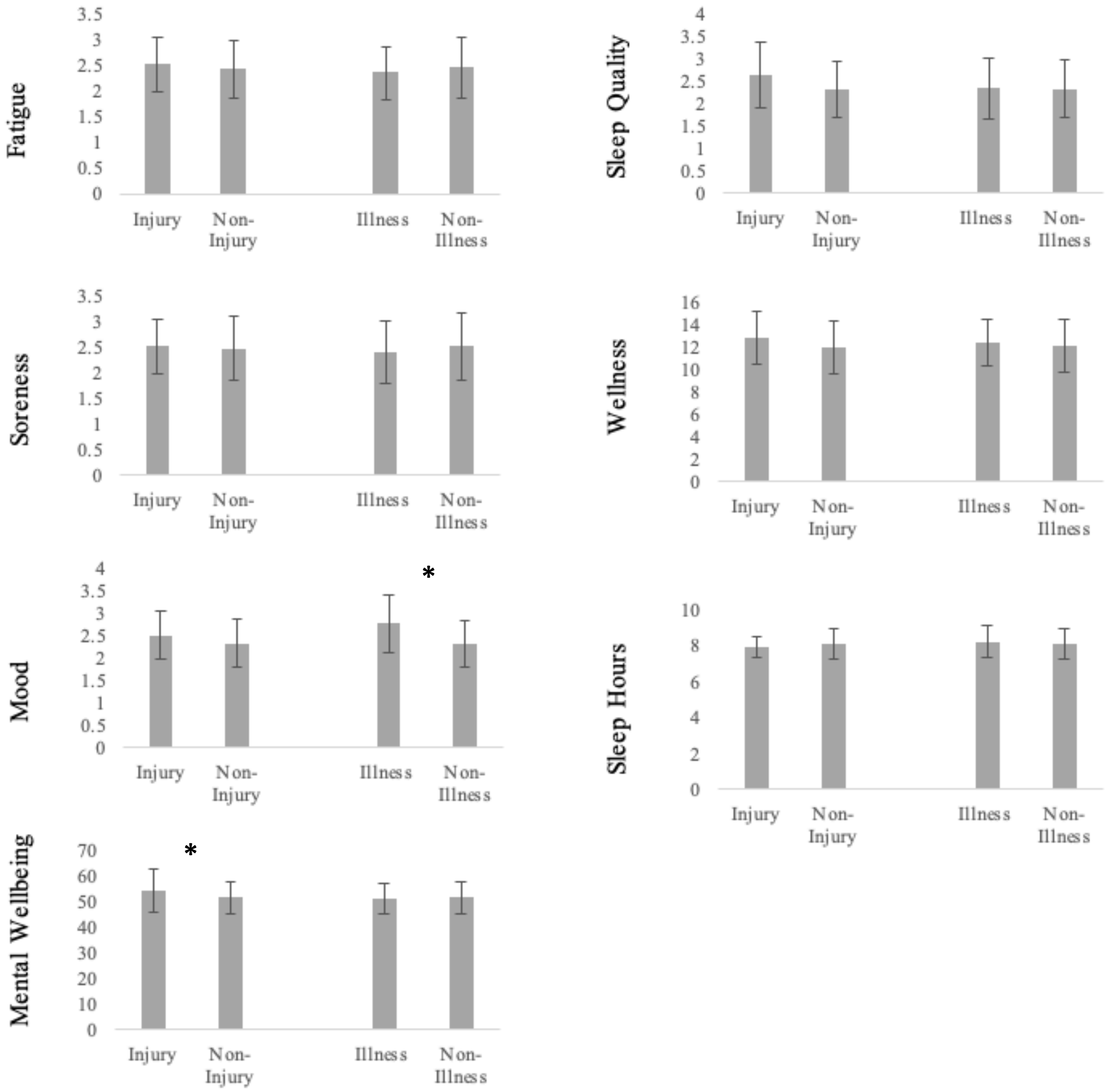

Figure 8.3: The mean daily subjective wellbeing, sleep duration, sleep quality, mood, fatigue, and wellness on the morning prior to self-reported illness or days with and without a subsequent injury.

*Indicates statistical significance ($P < 0.05$).

Table 8.2: Differences in training load parameters on days with and without and injury or illness.

	Injured	Not Injured	*P*	Ill	Not Ill	*P*
ACWR						
TD	1.01 ± 0.56	1.05 ± 0.42	0.638	0.93 ± 0.36	1.06 ± 0.56	0.083
HSD	1.09 ± 0.73	1.03 ± 0.49	0.586	0.97 ± 0.49	1.12 ± 1.08	0.511
SD	1.45 ± 3.20	1.24 ± 1.51	0.071	1.28 ± 2.34	1.24 ± 1.74	0.889
ED	1.04 ± 0.57	1.27 ± 713	0.892	0.91 ± 0.44	1.45 ± 9.11	0.654

***Indicates statistical significance (*P* <0.05). TD – Total Distance, HSD – High Speed Distance, SD - Sprint Distance, ED - Explosive Distance, ACWR – Acute Chronic Workload Ratio.**

Table 8.3: Differences in absolute objective markers of recovery days with and without and injury or illness.

	Injured	Not Injured	*P*	Ill	Not Ill	*P*
Objective Markers						
Left Adductor strength (N)	488 ± 99	514 ± 79	0.344	**497 ± 93**	**517 ± 78**	**0.036***
Right Adductor strength (N)	505 ± 93	517 ± 76	0.616	**499 ± 90**	**521 ± 76**	**0.013***
S&R (cm)	18 ± 9	20 ± 7	0.234	21 ± 6	20 ± 7	0.561

***Indicates statistical significance (*P* < 0.05). S&R – Sit and Reach**

The separate mixed effects logistic regression model results for the subjective and objective recovery markers to identify predictors of injury and illness are displayed in Table 8.4. Only mood could predict injury occurrence ($P < 0.05$). Additionally, left, and right AS and mood were the only markers to predict illness occurrence ($P < 0.05$).

The separate mixed effects logistic regression model results for the AWCR, previous day, 7-day and 28-day TL parameters to identify predictors of injury and illness are displayed in Table 8.5. Only previous day-SD and ED could predict injury occurrence ($P < 0.05$). However, previous day TD and ED ACWR, and previous 7-day TD, HSD and ED, and previous 28-day HSD could predict an illness occurrence ($P < 0.05$).

Table 8.4: Separate mixed-effects logistic regression model to identify objective and subjective predictors of in-season injury and illness.

Univariable	Injured		Self-Reported Illness	
	OR (95% CI)	***P***	**OR (95% CI)**	***P***
Objective Markers				
Left Adductor Strength	0.990 (0.979-1.001)	0.081	**0.996 (0.991 – 1.000)**	**0.044***
Right Adductor Strength	0.994 (0.985 – 1.004)	0.245	**0.996 (0.992-0.996)**	**0.024***
S&R Test	0.923 (0.834- 1.022)	0.111	1.024 (0.971 – 1.079)	0.379
Subjective Markers				
Wellness	1.886 (0.915-3.887)	0.80	1.105 (0.883-1.383)	0.380
Soreness	4.490 (0.098- 206.62)	0.347	0.062 (0.250-1.543)	0.305
Fatigue	9.791 (0.275-349.227)	0.104	0.729 (0.475-1.119)	0.148
Mood	**3.269 (1.310 – 8.155)**	**0.031***	**6.793 (3.195 – 14.443)**	**0.000***
Sleep Hours	0.579 (0.164-2.043)	0.122	0.937 (0.671 – 1.309)	0.703
Sleep Quality	2.364 (0.724-7.719)	0.081	1.475 (0.872-2.492)	0.147
PWB	0.980 (0.868 – 1.107)	0.245	0.984 (0.916 – 1.058)	0.669

***Indicates Statistical Significance (*P* <0.05). PWB – Psychological Wellbeing, S&R – Sit and Reach**

Table 8.5: Separate mixed-effects logistic regression model to identify training load predictors of in-season injury and illness.

Univariable	Injured		Self-Reported Illness	
	OR (95% CI)	***P***	**OR (95% CI)**	***P***
ACWR				
TD	5.261 (0.307 – 90.275)	0.238	**0.245 (0.086-0.704)**	**0.009**
HSD	3.845 (0.471 – 31.014)	0.197	0.660 (0.362-1.202)	0.174
SD	1.130 (0.725 – 1.763)	0.583	1.027 (0.881-1.198)	0.732
ED	2.404 (0.17I9 – 32.313)	0.495	**0.328 (0.133-0.809)**	**0.016**

***Indicates Statistical Significance (*P*<0.05). TD – Total Distance, HSD – High Speed Distance, SD - Sprint Distance, ED - Explosive Distance.**

8.5 Discussion

This novel study aimed to examine whether subjective wellbeing, musculoskeletal screening, PWB, and TL could provide an early insight into an injury or illness occurrence in EPL soccer players. In contrary to the hypothesis, only mood could provide early insights into an injury, and only PWB and previous day AS, mood, TD and ED ACWR could all provide an early insight into an illness. Additionally, significantly lower previous day AS and mood was revealed prior to illness when compared to prior no illness.

Current findings revealed mood could provide an early insight into both an injury (contact and non-contact) and illness incidence. Given injury predictors may be gender and sport specific (Haraldsdottir *et al.,* 2021), only tentative comparisons can be made with previous research containing adolescent athletes and alternative sports. Also important, mood and psychological stress can be dependent upon age and gender (Junge *et al.,* 2016; Kuettel *et al.,* 2021). Previously, mood has predicted injury in volleyball (Haraldsdottir *et al.,* 2021), youth female soccer (Watson *et al.,* 2016), and AFL (Colby *et al.,* 2017b; Esmaeili *et al.,* 2018b; Lathlean *et al.,* 2020). Additionally, has predicted illness in elite and sub elite female athletes (Horgan *et al.,* 2020). Subsequently current findings suggest specifically in senior male EPL soccer players, that mood could provide an early insight into both injury and illness. Such relationships could be evident due to the model proposed by Williams and Andersen (1998), which suggests a heightened psychological stress response could causes changes to increased distractibility, and muscle tension and fatigue which could cause attentional and physical decrements such as, reactions in tackles increasingly likelihood of contact injuries and increased muscle fatigue increasing likelihood of non-contact injuries. Given that only 1/20 injuries in the current study were a contact injury, the authors could speculate the later to be more relevant here. Practitioners should therefore monitor mood daily and implement interventions when declines in mood are identified to reduce injury and illness risk.

In agreement with previous research (Watson *et al.,* 2016; Colby *et al.,* 2017; Esmaeili *et al.,* 2018b), current findings revealed no other wellness markers could provide an early indication of an injury or illness. In contrary, sleep duration, soreness and fatigue have been associated with injury risk (Ahmun *et al.,* 2019; Whitworth-Turner *et al.,* 2019; Lathlean *et al.,* 2020; Horgan *et al.,* 2020; Haraldsdottir *et al.,* 2021). Additionally, reduced wellness and sleep duration when combined with high TL has been associated with illness risk (Hausswirth *et al.,* 2014; Thornton *et al.,* 2016). Null findings have been in elite environments (Colby *et al.,* 2017; Esmaelli *et al.,* 2018b). Yet research revealing associations between subjective wellness, injury and illness have been in collegiate athletes (Haraldsdottir *et al.,* 2021) or adolescents (Ahmun *et al.,* 2019; Whitworth-Turner *et al.,* 2019; Lathlean *et al.,* 2020). More prudent in elite environments, planned training may be modulated based upon subjective data to try and reduce illness and injury, which could help explain discrepancies between current and previous research. Ironically however, the null findings currently identified could reflect the effectiveness of utilising subjective wellness markers to reduce injury and illness, and subsequently advocates its use in injury and illness risk surveillance. This may also help explain associations between mood, injury and illness as TL prescription is likely based upon fatigue and soreness, and therefore less likely to be confounded by practitioner interventions Particularly in elite sporting contexts, subjective scores are also subject to social bias, which could further blunt the effectiveness of subjective wellbeing to predict injury or illness occurrences (Thornton *et al.,* 2016). Disparities may also exist as next day rather than subsequent week injury occurrence was investigated, allowing for a lag period between monitoring markers and an injury or illness occurrence (Lathlean *et al.,* 2020). It should also be considered wellbeing markers may better predict injury and illness, when TL is considered as a moderator variable (Lathlean *et al.,* 2020). Overall current findings suggest only mood and potentially subjective wellbeing markers could provide an early indication of injury and illness in EPL soccer.

In agreement with some previous research conducted by AS and HF did not predict injury (Colby *et al.,* 2017). In contrary, Esmaeili *et al.,* (2018b) reported > 1.5 *sd* v 1 *sd* reductions in AS and HF had effects on injury risk. Discrepancies may exist as Esmaeili *et al.,* (2018) utilised 2-3-days post-match screening scores, with scores generally returning to baseline within this time frame (Dawson *et al.,* 2005; McLellan *et al.,* 2011; Wolin *et al.,* 2017). In contrary, the current study included all training days which may have blunted the ability of screening scores to provide an early indication of an injury occurence. Noteworthy, this study is first to utilise the 'hip-strength based testing system' and suggests enhanced methodological techniques do not increase the ability of AS to provide an early indication injury.

Given musculoskeletal screening can impose significant time burdens on practitioners, dependent upon the rationale for screening (e.g., fatigue or injury), utilising alternative markers particularly for injury prediction may be more beneficial.

Current novel findings revealed adductor strength could be an early indicator of an illness occurrence. Adductor strength deficits can occur because of resultant muscle damage and fatigue, which has been associated with very high intensity running during training and match play (Silva *et al.,* 2018; Hader *et al.,* 2019). Indeed, increased training demands has been reported as a contributor to illness incidence in athletes (Thornton et al., 2016), and therefore it could be measuring AS is an indirect early indicator of an illness incidence. Nevertheless, illness incidences can result in underperformance (Gleeson, 2007; Orhant *et al.,* 2010). Therefore, given previous day AS was measured, reduced AS may reflect illness presence rather than predictive capability. Consequently, future research should investigate illness incidence in the subsequent 7-days, allowing for a lag time for illness development to determine whether AS can truly provide an early indication of an illness. Alternatively, monitoring AS may help detect underperformance in training which inform practitioners of maladaptive training responses and signs of illness allowing appropriate training prescription. Given the caveats surrounding AS and the novel findings that HF could not predict illness or injury, future research should investigate the predictive ability of alternative objective markers to detect injury and illness in EPL soccer. Current findings also revealed PWB could not provide an early indication of injury (Ivarsson *et al.,* 2013). Moreover, higher rates of anger and depression have been revealed in injured athletes (Galambos *et al,* 2009). Discrepancies may exist due to frequency of measures. Mood measures are often obtained 'daily' (Watson *et al.,* 2016) or 'weekly' (Esmaelli *et al.,* 2018b), in contrary to completing the 'WEMWBS' bi-weekly. Subsequently more frequent monitoring PWB may not be applicable in elite environments given the 'stigma' surrounding MH. Also pertinent, the 'WEMWBS' is not a validated measure of PWB in athletic populations. Consequently, their is growing attention in valid scales to assess MH in athletic populations (Rice *et al.,* 2020). Subsequently future research could utilise alternative scales which can be implemented frequently to determine injury risk. Regarding illness, perturbations to MH longitudinally rather than acutely may heighten illness risk (Watson *et al.,* 2016). Null findings may also exist as PWB does not change significantly across a season (Grimson *et al.,* 2021). This could be rationalised by available support and implemented interventions. Different sports and age groups have different psychological support provision. Consequently, future research should associate PWB and injury and illness incidence in alternative sports. Overall findings suggest PWB does not provide an early indication of injury and illness.

Novel current findings revealed previous day ACWR for TD and ED could provide an early indication of illness. Explosive distance represents intensity and TD represents volume and therefore the practitioners are recommended to manipulate both volume and intensity of training sessions. The current study also investigated ETL specific to EPL soccer players, in which individualised responses to different workloads can vary widely (Francis *et al.,* 2005). Future research should therefore investigate alternative GPS metrics and sports when predicting illness. Noteworthy, GPS cannot quantify all football specific movements (e.g., ball striking) which can contribute to physical workloads. Subsequently, it should also be considered the role of non-locomotive movements upon injury and illness risk.

The current study is not without limitations. The predictive ability of monitoring tools could depend upon team characteristics such as age and injury history and therefore limits generalisation of findings to EPL soccer players. Additionally, the current study recorded self-reported illnesses. Self-reported illness can be mis-reported by athletes due to the inability to distinguish between infectious and non-infectious respiratory symptoms (Cox *et al.,* 2008). Further limitations are screening data was considered as raw values rather than Z-scores. Utilising Z-scores may help assist with the monitoring process to increase injury and illness risk. Lastly, multivariate modelling could increase the predictive accuracy allowing for the interaction of common risk factors (Colby *et al.,* 2017b), however due to limited number of injuries, this analysis was not possible.

8.6 Conclusion

In conclusion, mood could best provide an early indication of both injury and illness occurrence and therefore practitioners are encouraged to monitor mood daily to help guide TL prescription but also implement strategies to improve mood. Whilst there may be some value of monitoring AS to detect illness or potentially underperformance instead, practitioners are recommended to utilise alternative monitoring tools when predicting injury or illness. Practitioners are also advised on specific GPS metrics (e.g., TD and ED ACWR) which could provide an early indication of illness. Future research into this area can facilitate identifying an early indication of illness and injury.

9.0 General Discussion

9.1 Introduction

The focus area of the current thesis was utilising an interdisciplinary approach to monitoring player mental and physical health (injury and illness) in EPL soccer players. The studies focused upon aspects of both mental and physical health to help inform TL prescription and assist with guiding the monitoring processes to reduce injury and illness risk and enhance performance. Study One and Two, explored PWB an aspect of MH across a soccer season. These processes involved identifying time periods and contextual factors that may perturb PWB. Study Three and Four focused on examining subjective and objective monitoring tools that are sensitive to ETL in a dose-response related fashion. In addition to identifying positional differences in subjective wellbeing. Study Five, focused on the efficacy of these tools to predict injury and illness. Specifically;

- Study One explored PWB during an EPL season, and during the COVID-19 lockdown. PWB was determined utilising the 'WEMWBS'.
- Study Two, examined the effect of sport related stressors including (match selection, win-rate, and playing status), injury, illness, and TL upon PWB.
- Study Three, analysed the association between subjective and objective recovery markers. The associations between both subjective and objective recovery and ETL were also investigated.
- Study Four, investigated the associations between subjective wellness and GK specific GPS metrics. Positional differences in subjective wellness responses produced were also investigated.
- Study Five, investigated the predictive ability of subjective and objective monitoring tools to predict injury and self-reported illness.

Findings of the current thesis demonstrate the importance of interdisciplinary monitoring procedures to determine and monitor player health (injury and illness) in elite soccer players.

9.2 Experimental Hypothesis Tested

Table 9.1 presents the experimental hypothesis tested within the current thesis, and details whether the individual hypothesis was accepted or rejected.

Table 9.1: Experimental hypothesis tested within the current thesis

Hypothesis Number	Description of Hypothesis	Reject/fail to reject
Study One – Physical activity on psychological wellbeing in senior English Premier League Soccer Players during the COVID-19 pandemic and the lockdown.		
H_1	Psychological Wellbeing will significantly decline during lockdown and improve upon return to sport.	Rejected
H_2	Physical Activity will be reduced during the lockdown.	Fail to reject
Study Two – The effects of injury, contextual match factors and training load upon psychological wellbeing in English Premier League soccer players via season-long tracking		
H_3	Contextual match related factors including injury and match deselection will result in lower psychological wellbeing.	Rejected
H_4	Psychological wellbeing will be lower prior to an injury.	Rejected
Study Three – Musculoskeletal tests and subjective wellness are related to external training loads of English Premier League soccer players: A season long analysis		
H_5	Subjective markers of recovery and objective markers of recovery will be related.	Fail to reject
H_6	Subjective markers of recovery and objective markers of recovery will be related to external training load.	Fail to reject
Study Four – The relationship between subjective wellness and external training load in elite English Premier League goalkeepers and a comparison with outfield soccer players.		
H_7	Subjective wellbeing will be related to external training load (specific goalkeeper metrics).	Fail to reject
H_8	Positional differences in subjective wellbeing responses will occur.	Rejected
Study Five – The predictive ability of subjective wellbeing, musculoskeletal screening, psychological wellbeing, and training load to predict injury and illness in elite Premier League soccer		
H_9	Declines in musculoskeletal screening scores, subjective wellness scores, and psychological wellbeing could predict injury and illness risk.	Rejected

9.3 Understanding psychological wellbeing in senior English Premier League soccer players

Study One monitored PWB across an EPL season, providing novel insights into the psychological demands of the EPL in comparison to period of rest (i.e., lockdown). Previously, numerous psychiatric scales are utilised to measure athlete MH including the anxiety and depression scales (Radloff *et al.,* 1977; Spitzer *et al.,* 2007). These are negatively worded, and valid for clinical populations, rather than athletes, where positive outlooks are more often present. However, the notion that athletes are healthy without a clinical disorder is over simplistic (Henriksen *et al.,* 2019). Subsequently incorporating aspects of positive MH, such as measuring PWB which focus upon the aspects of an individuals functioning and flourishing rather than the presence of MHD are recommended in athletes (Tennant *et al.,* 2007; Schinke *et al.,* 2017; Kuettall *et al.,* 2021b). However, there is a paucity of valid questionnaires to assess PWB. Consequently, the WEMWBS was utilised to assess PWB which encompasses both the hedonic & eudemonic aspect of wellbeing (Keyes, 2007). The WEMWBS is correlated with MH symptoms (e.g., anxiety and depression), is time efficient to deploy, easily accessible and can be utilised in team sport environments (Abbott *et al.,* 2019; Kuettal *et al.,* 2021a). Whilst some exploratory insights into the effects of the COVID-19 pandemic are provided, this novel study was first to examine PWB longitudinally during both a period away from sport 'COVID-19 lockdown' and during the EPL in elite senior soccer players and demonstrated PWB does not change significantly at a group level over the season, however individual differences were identified. For practitioners wanting to measure PWB in their sporting environment, results suggest without accounting for individual PWB levels squads MH would be misrepresented. Individual interventions may be required to prevent declines in athletes PWB. Findings demonstrated a declining trend during the in-season periods in contrary to an upward trend during lockdown. This result suggests elite athletes can maintain PWB during lockdown and may possibly be explained by an increased ability to cope (Pensgaard *et al.,* 2003; di Fronso *et al.,* 2020). This was the first study to monitor PWB in elite senior EPL soccer players and findings therefore compliment previous research, that depression and anxiety symptoms were lower in elite athletes compared to their novice counterparts (Senisk *et al.,* 2020).

Current novel findings also revealed that undertaking above 250 min of PA during lockdown is required to potentially see a positive effect upon PWB specifically in elite athletes, which compliments previous findings that PA is associated with MH benefits (Peluso *et al.,* 2005; Rebar *et al.,* 2015). In student athletes reduced PA during lockdown reduced sleep quality, quantity, and increased depressive symptoms (NCAA, 2020). Therefore, current and previous results suggest PA could impact upon PWB, and specifically above 250 min, which can have practical implications, to load prescription in athletes specifically in periods of isolation or quarantine. Interestingly, PA undertaken during lockdown are similar to the in season (243 ± 23 min), reported in Chapter Four. Therefore, to generalise to the general population perhaps the maintenance of this duration of PA or possibly habitual levels of PA could maintain PWB.

Novel findings suggest EPL sport related stressors imposed upon players are greater than those during the COVID-19 pandemic, highlighting the psychological demand of EPL, and the potential to perturb PWB. Whilst previous research has revealed associations between MHD such as anxiety and depression on sport related stressors (Junge *et al.,* 2016; Junge *et al.,* 2018), currently, no research investigating contextual match related factors (win-rate, match selection and playing status), TL and injury status upon PWB in EPL players exist. Additionally, exploring PWB prior to an injury occurrence. Subsequently, Study Two reveals high chronic 14-day HSD or 21-day SD and two-week win-rate (100 vs. 0%) could explain declines in PWB. Additionally, PWB was no different prior to an injury occurrence. TL is frequently prescribed to elicit a certain 'dose' response; therefore, the prescription of both

HSD and SD could maintain PWB levels resulting in enhanced performance and reduced injury risk despite not being directly different prior to an injury. These findings are disparent with research in academy soccer players where injury and match selection accounted for 50% of the variability of PWB (Abbott *et al.,* 2019), and are likely manifested by the different age groups studied. The findings, PWB prior to an injury occurrence was no different, are disparent from conclusions that worse daily mood, assessed via the subjective wellness questionnaire (Likert Scale 1-5) was an independent predictor of injury (Watson *et al.,* 2016) and daily hassles, trait anxiety and negative life events have accounted for 24% of the variance when predicting injury in both female and male Swedish soccer players (Ivarsson *et al.,* 2013). Discrepancies could exist due to the frequency of MH measure. Overall, the findings that no difference in PWB prior to an injury or illness suggest the efficacy of the WEMWBS to predict injury and illness is unlikely.

Overall, practical implications for monitoring PWB as part of a routine monitoring battery to help provide an interdisciplinary overview of an athlete's ability to monitor player health and subsequent injury and illness risk are provided. PWB fluctuations can occur on an individual level and could decline during an EPL season. These decrements could be explained by win-rate, and chronic high-intensity TL, and guides periodised interventions to maintain PWB. The implementation of a mid-season break may also prevent declines. By applying the correct TL, injury risk and illness may be mitigated and positive PWB maintained. Findings also revealed non clinically meaningful perturbations in PWB, therefore identifying meaningful changes in PWB to inform such interventions may be difficult. Additionally, the weak associations between HSD, SD and PWB could result in *trivial* changes in PWB when HSD and SD are prescribed to augment PWB, therefore interpreting results and practical applications are cautioned.

9.4 Identifying external training load GPS metrics sensitive to subjective and objective recovery markers.

Sports practitioners aim to prescribe ETLs that elicits a suitable fitness and fatigue response (Bannister *et al.,* 1975), which maximises performance and training adaptations. Subsequently, non-invasive, time efficient monitoring tools that are dose-dependent to TL which can inform TL prescription and recovery are required (Gabbett *et al.,* 2016; Thorpe *et al.,* 2016). When investigating associations between monitoring tools and TL, ITL has largely been utilised, omitting utilising ETL. However, for applied practitioners, monitoring tools associated with ETL metrics (e.g., ED), known to exhibit metabolic demands and implications upon muscle damage through eccentric loading, respectively are required (Hewitt *et al.,* 2011; de Hoyo *et al.,* 2016). This is because ETL can be prescribed more readily than ITL, as the quantification of load is not influenced by an individual's perception of load. Additionally, the dose-response relationship has been examined in outfield players and excluded GKs manly due to insufficient sample sizes. Subsequently, Study Three and Four utilised ETL to determine dose response relationships with monitoring tools, with Study Four specifically investigating elite GKs. Associations between objective monitoring tools and ETL have previously been researched in team sport environments, but not in soccer (Roe *et al.,* 2016; Esmaelli *et al.,* 2018a; Weaving *et al.,* 2021). Alongside being feasible to conduct, tests that are reliable and valid and can detect fluctuations to TL could be associated with injury and self-reported illness. Importantly, Study Three, Four and Five utilised objective monitoring (AS and S&R) markers. These two markers reflect AS and HF and are both mediators in workload-injury associations (Windt *et al.,* 2017) specific to elite soccer. Therefore, these findings are imperative for practitioners, working specifically in elite soccer. Study Three was first to suggest a decline in S&R and AS scores were related to increased fatigue, soreness, and a decline in wellness. These agree with the only other previous study that has investigated associations between subjective and objective recovery markers and found AS was related to fatigue and soreness during a 10-week Rugby pre-season (Tiernan *et al.,* 2019). Subsequently these two results support the inclusion of such objective markers to indicate fatigue levels. Notably however both the current and previous studies provide correlational based evidence, rather than causation which limits the current findings. Findings also suggested increased previous-day, and 7-day TL were related to increased fatigue, soreness, and decreased wellness. Moreover, an increase in previous day TL (TD and SD) were related to reduced AS, and an increase in previous 7-day TD were related to a reduction in both objective recovery markers. Noteworthy, all significant associations revealed within the current study were *trivial* and *weak* and should be interpreted with caution. Nevertheless, whilst changes in load might only produce *trivial* to *moderate* changes in subjective and objective recovery markers, small changes might still be important for players. Subsequently, significant implications for practitioners may be provided as they provide novel insights into the potential use of monitoring tools in a battery of tests to detect a fatigue response. Importantly, increased cumulative load specifically previous 7-day TD were also associated with increased AS and HF which may indicate injury risk.

Study Four, was the first to investigate associations between subjective recovery markers and GK-specific ETL within multiple GKS. Findings of the current thesis suggest specific GK-specific metrics which can be utilised by practitioners to augment wellness. When comparing subjective wellness responses between position, no differences across positions (GK, FB, CD, CM, WM & FWD) were reported. Current findings are disparent from previous research that reported GKs and MID reported higher ITL (Clemente *et al.,* 2017). Overall, findings from Study Three and Four, may have significant implications for practitioners, as the associations (albeit weak), allow for insights into ETL that can be prescribed to elicit a dose-response relationship with AS and S&R. Considering both the AS and S&R are easy to administer tools, which can be employed in sporting environments, findings will be of practical interest to practitioners.

9.5 The predictive capacity of an interdisciplinary approach to predicting injury and self-reported illness

An overarching aim of TL monitoring is to mitigate injury and illness occurrence. This requires tools sensitive to changes in TL and should represent the physical and psychological demands that athletes encounter from training and competition, which can highlight maladaptive responses and inform injury and illness risk (Vanrenterghen *et al.,* 2017; Heidari *et al.,* 2019; Draper *et al.,* 2021). Findings from Study Two, suggested that PWB could not predict an injury or illness. However, it could be that a combination of both PWB and alternative markers could together predict injury or illness incidences. Additionally, Study Three revealed associations between ETL and adductor strength, S&R scores and subjective wellness markers which provides provisional evidence that these markers may be a prerequisite for injury and illness events. Subsequently, Study Five utilises these sensitive markers and included PWB to try and provide practitioners with valuable information regarding the role of subjective and objective monitoring tools and their ability to predict injury and self-reported illness.

Findings from the current study suggest that only mood could predict injury and illness and when mood declines, there is a 3.27 and 6.80 higher risk of injury and illness respectively. This agrees with previous research that psychological indicators (e.g., mood and daily life events) could explain 24% of the variance when predicting injury (Ivarsson *et al.,* 2013). Additionally, lower daily mood could predict injury incidence (OR: 0.12) (Watson *et al.,* 2016). Notably however, findings suggest PWB, which reflects more MH status than daily mood which was measured biweekly was not associated with injury. Therefore, current results suggest PWB should be assessed more frequently, or utilise validated psychometric questionnaires which may enhance sensitivity to both TL, injury, and illness occurrence.

Whilst AS, and S&R could not predict injury in elite soccer players, Study Three revealed associations that reductions in objective recovery markers (S&R scores and AS) and increased subjective markers (e.g., fatigue and soreness). Therefore, such monitoring tools could still monitor fatigue status in athletes.

Novel findings suggest TL and AS could provide an early insight into a self-reported illness occurrence. However, previously it was identified that a caveat of this finding was the lag time period, and that an illness could cause a decline in adductor strength. Consequently, suggests with the exclusion of self-reported daily mood, monitoring tools have limited predictive capacity. This has practical implications and if the primary aim of the monitoring battery is to provide an early indication of possible injury and self-reported illness, then practitioners are recommended to not utilise such tests. Due to the limited number of injuries within the current thesis, this prevents the full conclusion of monitoring tools to be made when predicting injury. Additionally, it might be the interaction of such monitoring tests can predict injury or illness occurrence, however, due to the limited number of injuries, prevented such analysis being conducted. Overall findings reject the theme identified by previous studies within the thesis.

9.6 Limitations

Monitoring MH in athletic populations is challenged due to many psychiatric scales being negatively worded and more valid for clinical populations. Despite not yet being a validated measure of PWB, the current thesis assessed PWB via the 'WEMWBS'. The 'WEMWBS' is positively worded and has previously been utilised to assess PWB in athletes (Abbott *et al.,* 2019; Nicholls *et al.,* 2020). Moreover, has demonstrated acceptable reliability within male soccer players (a = 0.94) (Abbott *et al.,* 2019) and in the current cohort in Study One and Two (a= 0.89 and 0.90) respectively.

For all studies, full-time professional soccer players within an EPL squad were recruited, and therefore the extent to which the results of the thesis can be generalised across populations (External Validity) should be considered. PWB may vary upon age and gender (Salk *et al.,* 2017; Kuettal *et al.,* 2021). Subsequently, the elite and homogenous nature of the population studied, limit application to adolescent or female athletes. For Study's Three and Four, physical outputs could vary dependent upon competitive level and age, because of exposure to fixture congestion and high physical loads (Bradley *et al.,* 2010; Mendez-Villanueva *et al.,* 2013). This could affect the 'dose-response' relationships between ETL and recovery markers.

Further limitations are Study Three and Four produced large data sets. External factors which can vary longitudinally, such as athlete motivation can affect objective screening scores, despite being given verbal encouragement. Additionally, overtime the magnitude of physical disturbance can fluctuate because of exposure to chronic load. Prudent as the weak associations observed between recovery markers and ETL in Study Three and Four could be a result of the large data sets utilised. Finally, all studies involved subjective measures, which can be influenced by contextual factors such as match selection (Abbott *et al.,* 2018a).

The instrumentation threat upon internal validity is also important. For example, when assessing adductor strength, a hip strength testing system was utilised. The validity of such measures should always be considered when interpreting findings. For example, preliminary findings revealed the difference in AS between the season's phases are only greater than both the smallest worthwhile change (9.10 and 13.9N) and the error of measurement (20-23N) from the pre-season (464-469N) to early-season (496-500N). Therefore, the daily sensitivity could be questioned. Nevertheless, bar height, verbal encouragement and time of day monitoring procedures were taken place were kept consistent for everyone. The utilisation of 10Hz GPS devices should also be considered. However, 10Hz devices have enhanced accuracy and reliability when compared to 1Hz and 5Hz devices, and athletes wore the same devices to reduce inter unit error (Johnston *et al.,* 2014).

The thesis aimed to provide coaches and sports practitioners with recommendations of monitoring tools that had a dose-response with ETL and their ability to predict injury and illness. To promote ecological validity, all studies were conducted within one professional soccer club. However, this limits the generalisability of the thesis. Additionally due to operating within an applied environment, specific daily objectives to reduce the presence of fatigue, injury, and illness and poor PWB, via load prescription could impact findings. Subjective wellbeing markers can be influenced by match location, match result and opposition quality (Abbott *et al.,* 2018). Moreover, monitoring PWB, can be limited by the stigma surrounding MH and subsequently the reluctance to share information (Bird *et al.,* 2018). Subjective and objective recovery markers were also only collected on training days, due to the agreement of testing players in accordance with their normal training schedule. Daily recovery measures may provide further insight into a player's response to training on their days off. Overall, every effort was made to balance the internal and external validity of the current thesis conducted within applied professional practise.

9.7 Practical Recommendations

The current thesis findings provide applied practitioners with several recommendations for monitoring player health and wellbeing in EPL soccer players.

- To best understand athlete MH, integrating the individual monitoring of PWB, assessed via the 'WEMWBS', will help identify the psychological demands and subsequent fluctuations to PWB evident in EPL soccer players, which can inform interventions to prevent further declines in PWB which can enhance injury risk and attenuate performance.

- Practitioners are recommended to prescribe 250 min or more of PA, when athletes may experience absence from training (e.g., injury) or potential future lockdowns to maintain PWB. Moreover, to maintain PWB, TL prescription, specifically 14 and 21-day high intensity TL and interventions around periods of negative results are recommended.
- To obtain an objective marker of fatigue that reflects subjective recovery, practitioners are recommended to utilise both S&R and AS. Such markers are also sensitive to ETL parameters. Therefore, practitioners are recommended to prescribe specific ETL metrics (e.g., TD) specifically endured by EPL soccer players, which are sensitive to both subjective and objective recovery markers, to provide a desired training responses to ensure freshness before competition. This is particularly advantageous for practitioners, given the availability of real time GPS for select metrics inclusive of TD, which allows for more accurate TL manipulation and prescription in applied practise.
- Practitioners are also recommended to prescribe specific GK-specific metrics relative to the previous 7-days (e.g., high jumps, medium jumps, and dive count) to reduce perceived soreness, fatigue, and wellness, which could help reduce injury and illness risk. Positional differences in subjective recovery markers were not identified and therefore practitioners should pay attention to both GK and outfield position training responses.
- Mood could best predict injury and illness, and therefore practitioners are encouraged to monitor mood daily to inform TL prescription as well as the implementation of strategies to improve mood. Whilst the findings suggest that AS could predict injury or illness, due to previously mentioned caveats, practitioners are recommended to utilise alternative objective monitoring tools to predict injury or illness. Notably,

monitoring AS may have some value in detecting underperformance. With the exclusion of mood, monitoring tools may still be valuable in detecting fatigue status, allowing the provision of a interdisciplinary overview of a player's health, however, not predict injury or illness.

In conclusion, by incorporating current recommendations from the thesis findings, applied practitioners can improve the monitoring of players health and wellbeing to augment performance reduce the risk of subsequent injury.

9.8 Future Directions

In summary the thesis aimed to provide significant contributions to the current body of literature focusing upon an interdisciplinary approach to detecting ill health and wellbeing in elite soccer via understanding PWB and the identification of monitoring tools sensitive to ETL, and therefore their subsequent role in predicting injury and illness. From the findings of the current thesis the following are recommended for future research.

- Given monitoring PWB is recommended, to ensure accurate information regarding ones MH status is obtained, the 'WEMWBS' or alternative measures, which are still practical, cheap, and easy to administer should be validated in athletes.
- The generalisation of the current findings is limited to senior male EPL soccer players. However female athletes could be more vulnerable to poor MH (Rice *et al.,* 2020; Woods *et al.,* 2022). As no research currently exists regarding females, research into female soccer players, PWB levels would be invaluable for practitioners, particularly considering the recent professionalism of the 'Women's Super League' (Clarkson *et al.,* 2022), and the potential increased psychological stressors which may perturbate MH status.
- There is a growing opportunity for practitioners to prescribe ETL, via the use of real time GPS and validated metrics not investigated in the current thesis such as

PlayerLoad, number of sprints and high-intensity efforts. Moreover, individualised speed thresholds can be utilised by practitioners rather than absolute speed thresholds. Consequently, future research could consider alternative metrics and thresholds when assessing relationships between ETL and recovery markers, which may be more sensitive. Moreover, daily screening objective and subjective recovery markers can induce a time burden on practitioners and has the potential to induce fatigue, it is recommended associations between ETL and recovery markers on specific MDs are examined, which could help streamline the monitoring process.

- Given that GK-specific GPS metrics (e.g., high jumps) are sensitive to subjective recovery, and there are an increased number of validated GK GPS metrics available to practitioners, this provides an increased opportunity to prescribe ETL to modify TL responses specifically in GKs. Pertinent, the physical demands and subsequent subjective recovery markers can vary across a week, specifically different for starting vs. non starting GKs (Moreno-Perez *et al.,* 2019; White *et al.,* 2020). Subsequently future research regarding the difference in subjective wellbeing across a week in both starting and non-starting GKs may help provide practitioners with an increased context to appropriately prescribe load.
- Identification of monitoring tools sensitive to ETL are still required to predict injury and illness in elite soccer players given the current thesis concluded AS and S&R scores were weakly associated with TL and could not predict injury or illness. Advancements in both technology and available monitoring tools still maintaining a focus on hamstring strength/ flexibility due to hamstring injuries being most common in soccer. Specifically, the eccentric hamstring strength test is one example of a test which could be more sensitive to TL than the S&RT, and therefore future research should investigate its associations with ETL. Alternative monitoring markers that

have not yet been researched in respect to ETL, injury and illness in elite soccer and could be investigated are neuromuscular function (e.g., CMJ), biochemical markers (e.g., sIgA) and mechanical insights into quantifying hamstring, quadricep and calf function. Increasing the plethora of available tools to detect fatigue status and predict injury and illness are essential to understand a player's full health and performance status.

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11.0 Appendix

11. 1 Appendix One – Study Three, Table 11.1

Table 11.1: Partial Correlations (95% CI), Least Squares Regression slope (b), significance for the relationship between total distance (m) and morning measured wellness markers and objective markers. a) previous day training load b) previous 7-days training load.

		Correlation Coefficient (95% CI)	Magnitude	B	P
Next Day Sleep Quality (Z-score)	*a*	.150 (.056 to .237)	Small	285.762	.000
	b	.028(-.032 to .085)	Trivial	191.94	.252
Next Day Sleep Hours (Z-score)	*a*	-.191 (-.276 to -.104)	Small	-287.08	.000
	b	.031 (-.081 to .021)	Trivial	-174.082	.195
Next Day Mood (Z-score)	*a*	.010 (-.090 to .084)	Trivial	-21.208	.803
	b	.020 (-.072 to .038)	Trivial	-136.658	.417
Next Day Fatigue (Z-score)	*a*	.305 (.217 to .399)	Moderate	510.93	.000
	b	.167 (.122 to .210)	Small	960.019	.000
Next Day Soreness (Z-score)	*a*	.235 (.138 to .326)	Small	469.64	.000
	b	.178 (.129 to .228)	Small	1121.5	.000
Next Day Wellness (Z-score)	*a*	.246 (.145 to .350)	Small	414.90	.000
	b	.133 (.065 to .197)	Small	778.17	.000
Next Day Groin-Bar Left (Z-score)	*a*	.119 (-.201 to -.029)	Small	-256.10	.002
	b	.059 (-.104 to -.013)	Trivial	-364.59	.014
Next Day Groin-Bar Right (Z-Score)	*a*	.095 (-.199 to -.022)	Trivial	-161.80	.014
	b	.052 (-.102 to .004)	Trivial	-348.82	.032
Next Day Sit and Reach (Z-Score)	*a*	.073 (-.141 to -.002)	Trivial	-139.561	.060
	b	.060 (-.102 to -.014)	Trivial	-301.63	.013

11.2 Appendix Two – Study Three, Table 11.2

Table 11.2: Partial Correlations (95% CI), Least Squares Regression slope (b), significance for the relationship between sprint distance (m) and morning measured wellness markers and objective markers. a) previous day training load b) previous 7-days training load.

		Correlation Coefficient (95% CI)	Magnitude	B	P
Next Day Sleep Quality (Z-score)	*a*	.182 (.089 to .260)	Small	8.407	.000
	b	.029 (-.030 to .086)	Trivial	3.854	.233
Next Day Sleep Hours (Z-score)	*a*	.215 (-.309 to -.120)	Small	-7.865	.000
	b	.021 (-.079 to .030)	Trivial	-2.238	.388
Next Day Mood (Z-score)	*a*	.064 (-.026 to .163)	Trivial	3.411	.098
	b	.007 (-.042 to .068)	Trivial	.964	.767
Next Day Fatigue (Z-score)	*a*	.283 (.199 to .372)	Small	11.541	.000
	b	.084 (.032 to .136)	Trivial	9.329	.000
Next Day Soreness (Z-score)	*a*	.286 (.189 to .377)	Small	13.915	.000
	b	.093 (.047 to .140)	Trivial	11.321	.000
Next Day Wellness (Z-score)	*a*	.281 (.184 to .384)	Small	11.537	.000
	b	.083 (.027 to .138)	Trivial	9.411	.001
Next Day Groin-Bar Left (Z-score)	*a*	.105 (-.185 to -.027)	Small	-5.497	.007
	b	.017 (-.061 to .029)	Trivial	-1.999	.486
Next Day Groin-Bar Right (Z-Score)	*a*	.085 (-.017 to -.178)	Trivial	-3.538	.027
	b	.021 (-.068 to .026)	Trivial	-2.762	.379
Next Day Sit and Reach (Z-Score)	*a*	.024 (-.089 to .041)	Trivial	-1.05	.541
	b	.042 (-.087 to .011)	Trivial	-4.053	.083

11.3 Appendix Three – Study Three, Table 11.3

Table 11.3: Partial Correlations (95% CI), Least Squares Regression slope (b), significance for the relationship between high-speed distance (m) and morning measured wellness markers and objective markers. a) previous day training load b) previous 7-days training load.

		Correlation Coefficient (95% CI)	Magnitude	B	P
Next Day Sleep Quality (Z-score)	*a*	.133 (.035 to .234)	Small	18.359	.001
	b	.043 (-.012 to .099)	Trivial	16.204	.075
Next Day Sleep Hours (Z-score)	*a*	.214 (-.116 to -.306)	Small	-23.34	.000
	b	.024 (-.076 to .027)	Trivial	-7.295	.317
Next Day Mood (Z-score)	*a*	.008 (-.060 to .083)	Trivial	1.270	.837
	b	.043 (-.093 to .009)	Small	-16.14	.000
Next Day Fatigue (Z-score)	*a*	.330 (.245 to .414)	Small	40.26	.000
	b	.141 (.093 to .194)	Small	43.93	.000
Next Day Soreness (Z-score)	*a*	.302 (.215 to .383)	Small	43.84	.000
	b	.134 (.087 to .178)	Small	46.03	.000
Next Day Wellness (Z-score)	*a*	.278 (.187 to .373)	Small	34.15	.000
	b	.113 (.053 to .176)	Small	36.14	.000
Next Day Groin-Bar Left (Z-score)	*a*	.095 (-.174 to -.014)	Trivial	-14.85	.014
	b	.020 (-.065 to .027)	Trivial	-6.207	.399
Next Day Groin-Bar Right (Z-Score)	*a*	.071 (-.171 to -.001)	Trivial	-8.764	.067
	b	.024 (-.072 to .029)	Trivial	-8.838	.317
Next Day Sit and Reach (Z-Score)	*a*	.034 (-.101 to .040)	Trivial	-4.728	.381
	b	.016 (-.064 to .038)	Trivial	-4.728	.516

11.4 Appendix Four – Study Three, Table 11.4

Table 11.4: Partial Correlations (95% CI), Least Squares Regression slope (b), significance for the relationship between explosive distance (m) and morning measured wellness markers and objective markers. a) previous day training load b) previous 7-days training load.

		Correlation Coefficient (95% CI)	Magnitude	B	P
Next Day Sleep Quality (Z-score)	*a*	.099 (.004 to .186)	Trivial	15.061	.010
	b	.025 (-.029 to .079)	Trivial	12.098	.293
Next Day Sleep Hours (Z-score)	*a*	.155 (-.236 to -.078)	Small	-18.55	.000
	b	.026 (-.071 to .017)	Trivial	-9.81	.288
Next Day Mood (Z-score)	*a*	.009 (-.097 to .086)	Trivial	-1.547	.819
	b	.025 (-.078 to .027)	Trivial	-11.797	.308
Next Day Fatigue (Z-score)	*a*	.265 (.181 to .360)	Small	35.290	.000
	b	.160 (.112 to .209)	Small	63.265	.000
Next Day Soreness (Z-score)	*a*	.224 (.152 to .292)	Small	35.659	.000
	b	.177 (.132 to .224)	Small	76.881	.000
Next Day Wellness (Z-score)	*a*	.192 (.082 to .298)	Small	25.798	.000
	b	.139 (.079 to .210)	Small	56.217	.000
Next Day Groin-Bar Left (Z-score)	*a*	.069 (-.151 to .009)	Trivial	-11.281	.075
	b	.007 (-.055 to .046)	Trivial	-2.819	.783
Next Day Groin-Bar Right (Z-Score)	*a*	.035 (-.126 to .033)	Trivial	-4.676	.373
	b	.008 (-.037 to .053)	Trivial	3.932	.725
Next Day Sit and Reach (Z-Score)	*a*	.003 (-.071 to .083)	Trivial	.503	.932
	b	.028 (-.074 to .017)	Trivial	-9.660	.247

11.5 Appendix Five – Study Four, Table 11.5

Table 11.5: Partial Correlations (95% CI), Least Squares Regression slope (b), significance for the relationship between total distance, PlayerLoad and morning measured wellness markers (absolute) a) previous day training load b) previous 7-days training load.

		Total Distance (m)			**PlayerLoad (AU)**		
		Correlation Coefficient (95% CI)	B	P	Correlation Coefficient (95% CI)	B	P
Next Day Sleep Quality	*a*	.097 (.004 to .192)	182.970	.045	.034 (-.054 to .118)	6.357	.485
	b	.129 (.060 to .201)	1228.398	.000	.103 (.034 to .171)	99.70	.002
Next Day Sleep Hours	*a*	.098 (-.204 to .010)	-146.06	.041	.063 (-.157 to .037)	-9.400	.188
	b	.111 (-.176 to -.048)	-756.492	.001	.080 (-.141 to -.020)	-55.35	.014
Next Day Mood	*a*	.069 (-.038 to .167)	152.23	.153	.074 (-.032 to .164)	16.283	.125
	b	.093 (.033 to .155)	1035.52	.004	.092 (.031 to .153)	103	.005
Next Day Fatigue	*a*	.145 (.042 to .239)	306.85	.003	.107 (.013 to .203)	22.549	.026
	b	.176 (.112 to .238)	1803.47	.000	.174 (.111 to .242)	181.484	.000
Next Day Soreness	*a*	.142 (.047 to .239)	288.24	.001	.189 (.092 to .282)	38.167	.000
	b	.175 (.110 to .238)	1748.604	.000	.192 (.129 to .257)	195.59	.000
Next Day Wellness	*a*	.165 (.061 to .261)	94.07	.001	.147 (.046 to .249)	8.378	.002
	b	.197 (.134 to .258)	547.64	.000	.189 (.124 to .256)	53.548	.000

11.6 Appendix Six – Study Four, Table 11.6

Table 11.6: Partial Correlations (95% CI), Least Squares Regression slope (b), significance for the relationship between high jumps, medium jumps, low jumps and morning measured wellness markers (absolute) a) previous day training load b) previous 7-days training load.

		High Jumps			**Medium Jumps**			**Low Jumps**		
		Correlation Coefficient (95% CI)	B	P	Correlation Coefficient (95% CI)	B	P	Correlation Coefficient (95% CI)	B	P
Next Day Sleep Quality	*a*	.055 (-.119 to .017)	-.610	.257	.014 (-.078 to .121)	.195	.774	.063 (-.160 to .036)	-.704	.193
	b	.105 (.042 to .168)	2.281	.001	.113 (.045 to .180)	4.189	.000	.049 (-.010 to .105)	1.659	.134
Next Day Sleep Hours	*a*	.041 (-.033 to .120)	.363	.389	.116 (.202 to -.028)	-1.276	.016	.071 (-.176 to .030)	-.629	.138
	b	.076 (-.140 to -.005)	-1.187	.019	.208 (-.267 to .180)	-5.522	.000	.106 (-.164 to -.045)	-2.583	.001
Next Day Mood	*a*	.076 (-.010 to .167)	.998	.112	.108 (.029 to .220)	1.764	.025	.051 (-.031 to .131)	.668	.290
	b	.123 (.061 to .185)	3.121	.000	.182 (.114 to .239)	7.873	.000	.066 (.002 to .126)	2.603	.044
Next Day Fatigue	*a*	.106 (.010 to .207)	1.324	.027	.119 (.027 to .241)	1.861	.013	.023 (-.118 to .066)	-.290	.631
	b	.217 (.153 to .288)	5.057	.000	.216 (.153 to .277)	8.615	.000	.085 (.033 to .140)	3.130	.008
Next Day Soreness	*a*	.132 (.036 to .228)	1.575	.006	.185 (.090 to .293)	2.767	.000	.011 (-.106 to .076)	-.131	.821
	b	.245 (.182 to .302)	5.568	.000	.260 (.192 to .324)	10.113	.000	.096 (.029 to .158)	3.416	.003
Next Day Wellness	*a*	.096 (-.006 to .196)	.323	.047	.137 (.035 to .257)	.582	.004	.029 (-.132 to .074)	-.098	.548
	b	.249 (.193 to .305)	1.582	.000	.278 (.221 to .334)	3.008	.000	.109 (.050 to .172)	1.096	.031

11.7 Appendix Seven – Study Four, Table 11.7

Table 2: Partial Correlations (95% CI), Least Squares Regression slope (b), significance for the relationship between total dive load, average time to feet, number of dives and morning measured wellness markers (absolute) a) previous day training load b) previous 7-days training load.

		Total Dive load			Average Time to Feet			Total Number of Dives		
		Correlation Coefficient (95% CI)	B	P	Correlation Coefficient (95% CI)	B	P	Correlation Coefficient (95% CI)	B	P
Next Day Sleep Quality	*a*	.050 (-.139 to .043)	-11.346	.296	.036 (-.067 to .147)	.026	.455	.032 (-.117 to .051)	-.905	.508
	b	.073 (.005 to .140)	57.00	.025	.003 (-.021 to .070)	.007	.918	.100 (.036 to .164)	10.027	.002
Next Day Sleep Hours	*a*	.058 (-.164 to .040)	-10.242	.229	.172 (-.258 to -.086)	-.099	.000	.086 (-.193 to .030)	-1.904	.075
	b	.079 (-.134 to -.023)	-44.206	.015	.063 (-.102 to -.025)	-.100	.054	.110 (-.173 to -.053)	-7.910	.001
Next Day Mood	*a*	.016 (-.102 to .075)	-4.155	.743	.114 (.020 to .207)	.097	.018	.001 (-.083 to .085)	.019	.991
	b	.058 (.000 to .119)	52.85	.075	.090 (.009 to .158)	.234	.005	.082 (.017 to .148)	9.564	.012
Next Day Fatigue	*a*	.004 (-.097 to .103)	1.102	.928	.161 (.064 to .253)	.132	.001	.038 (-.055 to .136)	1.203	.431
	b	.120 (.053 to .194)	101.14	.000	.094 (.021 to .157)	.225	.004	.155 (.097 to .209)	16.716	.000
Next Day Soreness	*a*	.082 (-.011 to .169)	19.725	.088	.081 (-.020 to .181)	.063	.093	.098 (.009 to .186)	2.970	.041
	b	.135 (.074 to .197)	110.66	.000	.128 (.023 to .232)	.298	.000	.157 (.094 to .223)	16.445	.000
Next Day Wellness	*a*	.023 (-.067 to .114)	1.562	.634	.124 (.029 to .213)	.027	.010	.050 (-.047 to .144)	.425	.304
	b	.133 (.066 to .195)	30.495	.000	.110 (.042 to .171)	.072	.001	.174 (.115 to .235)	5.075	.000

11.8 Appendix Eight - The Warwick Edinburgh Mental Wellbeing Scale

The Warwick–Edinburgh Mental Well-being Scale (WEMWBS)

Below are some statements about feelings and thoughts.

Please tick the box that best describes your experience of each over the last 2 weeks

STATEMENTS	None of the time	Rarely	Some of the time	Often	All of the time
I've been feeling optimistic about the future	1	2	3	4	5
I've been feeling useful	1	2	3	4	5
I've been feeling relaxed	1	2	3	4	5
I've been feeling interested in other people	1	2	3	4	5
I've had energy to spare	1	2	3	4	5
I've been dealing with problems well	1	2	3	4	5
I've been thinking clearly	1	2	3	4	5
I've been feeling good about myself	1	2	3	4	5
I've been feeling close to other people	1	2	3	4	5
I've been feeling confident	1	2	3	4	5
I've been able to make up my own mind about things	1	2	3	4	5
I've been feeling loved	1	2	3	4	5
I've been interested in new things	1	2	3	4	5
I've been feeling cheerful	1	2	3	4	5

11.9 Appendix Nine - Custom subjective wellbeing questionnaire

How are you today?
- Match Ready
- Fresh
- Fine
- Stressed
- Emotional

How many hours of sleep did you get last night?

How well did you sleep last night?
- Great
- Good
- Average
- Below Average
- Extremely Bad

How fatigued are you feeling?
- Not fatigued
- Low
- Average
- Above Average
- Extremely

How would you rate your muscle soreness?
- No soreness
- Low levels
- Average
- Above Average
- Extremely

Are you experiencing cold symptoms?
- No/Yes?

How would you rate your general health now?
- Very Very Healthy
- Very Healthy
- Average
- Poor Awful

Any Soreness?
- No/Yes?

11.10 Appendix Ten - Study One and Two – Participant Information Sheet

University of Brighton

Study Title: A year-long investigation into the physiological and psychological factors on mental wellbeing in professional English Footballers.

Study Invitation
We would like to invite you to take part in our research study. You are requested to read this form carefully. If you have any queries or uncertain about anything, then you should ask one of us prior to signing the consent form. If you are willing to voluntarily participate in the study, then please sign the consent form.

Purpose of the study
Athletes are deemed to be at greater risk than the general population at experiencing poor mental wellbeing. Additionally, poor mental wellbeing appears more prevalent in younger age groups than senior. Unfortunately, poor mental health can have detrimental effects to performance and general wellbeing. Further, poor mental health and impeded wellbeing are likely to fluctuate across time. Therefore, the aim of the current study is to examine the influence of injury, illness, training load, match selection and result on mental wellbeing in a squad of professional senior and U23 premier league players across a year-long period. Additionally, the differences between the U23's and 1st team will be examined.

Why have I been chosen?
You have been chosen because:

- You are an elite English premier league and premier league 2 football player, playing for the U23's or the First Team at Brighton and Hove Albion Football Club.
- You routinely wear Global Positioning Systems (GPS) during training and match play and takes part in a full training macrocycle.
- You routinely complete the Warwick Edinburgh mental wellbeing scale on a two-weekly basis.

Do I have to take part?
It is your choice as to whether you permit access to the use of your routinely collected data. Participation is voluntary. If you change your mind or want to withdraw from the study, then you can do so before January 2021, before the data is anonymously analysed, and form's part of the PhD write up, which could be published in journal articles.

What will happen to me if I take part?
This study will involve the agreement of us utilising your routinely collected data, including, training loads, mental wellbeing screening results. You will not be paid for taking part in the study.

What are the potential advantages and disadvantages of taking part?
Advantages

- Better identification of mental health in elite football

- Associations between mental health, injury and illness and other contextual factors
- A better understanding of levels of wellbeing in football

Disadvantages

- This study is enabling access to routinely collected data, therefore no extra burden is placed on you for participating and therefore there is no additional risked placed on you.
- You are allowing access for the study leader, and research team access sensitive data, however, it is anonymised at this point, and therefore your data will remain strictly confidential within Brighton and Hove Albion football club.

Will my taking part in the study/project be kept confidential?

The raw data will be kept confidential within the medical department staff. From a data analysis perspective, an anonymised copy of the data will be stored on a university one drive, in which my supervisors will have access to this data. The data will then be grouped together. Therefore, your data will not be identifiable in any publication, report, or during data analysis. At the end of the study, the medical department will keep hold of the data indefinitely. The anonymised data utilised in the data analysis will be kept 10 years after completion of the PhD.

Further information on data protection, can be found on the University's Research Privacy Notice:
https://staff.brighton.ac.uk/reg/legal/other/Template%20Privacy%20Notice.docx

What will happen to the results of the project?

Results of the project may be presented or published, with the aim of benefiting others. Will also form part fulfilment of my PhD.

Who is organising and funding the research?

This study is part fulfilment of a PhD Studentship match funded by Brighton and Hove Albion Football Club and the University of Brighton.

Contact for further information

If you would like any further information, please don't hesitate to contact any of the research team.
Sophie Grimson (PhD Student- Study Leader) - S.Grimson@brighton.ac.uk
Will Abbott (Head of academy performance)– Will.Abbott@bhafc.co.uk
Gary Brickley – (PhD supervisor) G.Brickley@brighton.ac.uk

If you have any concerns regarding this study, please do not hesitate to contact the chair of research ethics committee:
Lucy Redhead– L.Redhead@brighton.ac.uk

This study has received ethical and scientific approval to be undertaken, in accordance with current university regulations.

11.11 Appendix Eleven - Study One and Two – Participant informed consent form

Participant Informed Consent Form
(To be completed after the participant information sheet has been read)

Title of project: A year-long investigation into the physiological and psychological factors on mental wellbeing in professional English Footballers.

Name of Researcher: Sophie Grimson – PHD Student, University of Brighton.

	Please **initial** to confirm agreement.
Taking Part	
I have read and understood the information sheet and this consent form for the above study and have had the opportunity to consider the information and ask questions.	_________
I understand that the researcher will be given access to routinely collected GPS training and match data and the 'Warwick- Edinburgh Mental Wellbeing Questionnaire' scores across the 2019-2020 and 2020-2021 seasons, and that some of this information may be sensitive in nature.	_________
I understand that my participation is voluntary and that I am free to withdraw from the study up until January 2021 without giving a reason and without incurring consequences from doing so.	_________
Use of information	
I understand how the data collected will be used, and that any confidential information will only be accessible to medical staff at the club and will not be identifiable to researchers that can access the data.	_________
The information you provide will be anonymised for data analysis and will be used for publications to advance academic knowledge and benefit others.	_________
I give permission for the anonymised data I provide to be stored for 10 years after completion of the PHD thesis.	_________
Consent to participate	
I agree to take part in the above study.	_________

Name of Participant:	Date:	Signature:
………………………	………………………….	………………………
Name of Researcher:	**Date:**	**Signature:**
………………………	………………………….	………………………

11.12 Appendix Twelve - Study Three, Four and Five – Participant information sheet

University of Brighton

Study Title: The sensitivity of training load monitoring responses to external training load, and their subsequent relationship with injury and illness incidences.

Study Invitation
We would like to invite you to take part in our research study. You are requested to read this form carefully. If you have any queries or uncertain about anything, then you should ask one of us prior to signing the consent form. If you are willing to voluntarily participate in the study, then please sign the consent form.

Purpose of the study

English Premier League players are at increased risk of injury and illness as a consequence of congested fixture periods, and insufficient recovery periods. Injury and illness can decrease performance and team success, therefore it is evident that practitioners need to find ways of predicting illness and injury incidences. Therefore, the aim of the current study is to examine the influence of training load on monitoring markers (including adductor squeeze strength, sit and reach, blood parameters, subjective wellness, mental wellbeing and fatigue) and the subsequent relationship with injury and illness.

Why have I been chosen?
You have been chosen because:

- You are an elite English premier league playing in the First Team at Brighton and Hove Albion Football Club.
- You routinely wear Global Positioning Systems (GPS) during training and match play and takes part in a full training macrocycle.
- You routinely complete the Warwick Edinburgh mental wellbeing scale on a two-weekly basis.
- You routinely complete daily monitoring screening (sit and reach test, adductor squeeze test, and subjective wellness and mental fatigue questionnaire) and monthly blood screening.

Do I have to take part?
It is your choice as to whether you permit access to the use of your routinely collected data. Participation is voluntary. If you change your mind or want to withdraw from the study, then you can do so before January 2021, before the data is anonymously analysed, and form's part of the PhD write up, which could be published in journal articles.

What will happen to me if I take part?
This study will involve the agreement of us utilising your routinely collected data, including, training loads, mental wellbeing screening results. You will not be paid for taking part in the study.

What are the potential advantages and disadvantages of taking part?
Advantages

- Better understanding of the monitoring tools currently used within the club, to detect injury risk, and fatigue status.

Disadvantages

- This study is enabling access to routinely collected data, therefore no extra burden is placed on you for participating and therefore there is no additional risked placed on you.
- You are allowing access for the study leader, and research team access sensitive data, however, it is anonymised at this point, and therefore your data will remain strictly confidential within Brighton and Hove Albion football club.

Will my taking part in the study/project be kept confidential?
The raw data will be kept confidential within the medical department staff. From a data analysis perspective, an anonymised copy of the data will be stored on a university one drive, in which my supervisors will have access to this data. The data will then be grouped together. Therefore, your data will not be identifiable in any publication, report, or during data analysis. At the end of the study, the medical department will keep hold of the data indefinitely. The anonymised data utilised in the data analysis will be kept 10 years after completion of the PhD.

Further information on data protection, can be found on the University's Research Privacy Notice:
https://staff.brighton.ac.uk/reg/legal/other/Template%20Privacy%20Notice.docx

What will happen to the results of the project?
Results of the project may be presented or published, with the aim of benefiting others. Will also form part fulfilment of my PhD.

Who is organising and funding the research?
This study is part fulfilment of a PhD Studentship match funded by Brighton and Hove Albion Football Club and the University of Brighton.

Contact for further information
If you would like any further information, please don't hesitate to contact any of the research team.
Sophie Grimson (PhD Student- Study Leader) - S.Grimson@brighton.ac.uk
Will Abbott (Head of academy performance)– Will.Abbott@bhafc.co.uk
Gary Brickley – (PhD supervisor) G.Brickley@brighton.ac.uk

If you have any concerns regarding this study, please do not hesitate to contact the chair of research ethics committee:
Lucy Redhead– L.Redhead@brighton.ac.uk

This study has received ethical and scientific approval to be undertaken, in accordance with current university regulations.

11.13 Appendix Thirteen - Study Three, Four and Five – Participant Informed Consent Form

Participant Informed Consent Form
(To be completed after the participant information sheet has been read)

Title of project: The sensitivity of training load monitoring responses to external training load, and their subsequent relationship with injury and illness incidences.

Name of Researcher: Sophie Grimson - PhD Student, University of Brighton.

<u>Taking Part</u>	Please **<u>initial</u>** to confirm agreement.
I have read and understood the information sheet and this consent form for the above study, and have had the opportunity to consider the information and ask questions.	_________
I understand that my participation is voluntary and that I am free to withdraw from the study at any time without giving a reason and without incurring consequences from doing so.	_________
<u>Use of information</u>	
I understand how the data collected will be used, and that any confidential information will only be accessible to medical staff at the club, and will not be identifiable to researchers that can access the data.	_________
The information I provide will be anonymised for data analysis, and will be used for publications, thus withdrawal from the study can only occur pre data analysis, which will be January 2021.	_________
I give permission for the anonymised data I provide to be stored for 10 years after the completion of the PhD thesis.	_________
<u>Consent to participate</u>	
I agree to take part in the above study.	_________

Name of Participant:	Date:	Signature:
………………………	………………………….	………………………
Name of Researcher:	Date:	Signature:
………………………	………………………….	………………………

11.14 Appendix Fourteen - Generalised Consent Form

Brighton and Hove Albion Football Club – Consent Form

Please **initial** to confirm agreement

I give permission for my medical data, including:

- Training and match load GPS data,
- Monitoring Data (Groin Bar, sit and reach test, wellness data, hydration testing),
- Biochemical markers,
- Mental Wellbeing and Mental Fatigue Questionnaire Data,

Collected across the 2021-2022 season to be utilised for future research projects undertaken by the club. ____________

I understand that routinely collected data will be treated in a confidential manner and will be treated anonymously in any research conducted by the club. ____________

I understand the information utilised in future research projects may be used in academic publications to advance academic knowledge and benefit others. ____________

I understand that the data forming research studies may be stored for a period of 10 years. ____________

I would like to be notified if any studies utilising my data is being conducted, and the option to withdraw from taking part.

Please **tick** to be notified of future studies including my data. ☐

Consent for utilising data

Name of participant:	Date:	Signature:
………………………………	………………………..	…………………

Email Address

……………………………………………

11.15 Appendix Fifteen - Club Permission for Data collection

Dec 2019

To Whom It May Concern:

This letter herby states that Miss Sophie Grimson, has followed appropriate and authorised processes within Brighton & Hove Albion Football Club during the commencement of her PhD study.

I can confirm:

- Informed consent was obtained from all participants
- All data collected (including GPS) was part of routine monitoring at the club, and is a normal daily procedure
- Club permission has been authorised to publish the data collected, due to its anonymity

If any further information is required, please do not hesitate to contact me.

Kind regards,

Adam Brett
Head of Medical Services
Brighton & Hove Albion FC

E-Mail: adam.brett@bhafc.co.uk

Brighton & Hove Albion Football Club
American Express Elite Football
Performance Centre, Lancing, BN15 9FP

General enquiries
01903 875 600*
*Calls cost your normal landline rate

Official club website
BrightonAndHoveAlbion.com