IS ILLNESS IMPORTANT IN PROFESSIONAL SOCCER? AN EVALUATION OF INCIDENCE, RISK FACTORS AND INTERVENTION.

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CONTENTS

LIST OF ABBREVIATIONS

AIS, Australian Institute of Sport

AMP, Antimicrobial protein

AU, Arbitrary unit

CK, Creatine Kinase

CMJ, Countermovement jump

CNS, Central nervous system

CRP, C-reactive protein

CSV, Comma-separated values

CV, Coefficient of variation

ECG, Electrocardiogram

EEG, Electroencephalogram

EFL, English Football League

ELISA, Enzyme-linked immunosorbent assay

EMG, Electromyography

EOG, Electrooculography

EPL, English Premier League

ES, Effect size

FIFA, Fédération Internationale de Football Association

FINA, International Swimming Federation

FOR, Functional overreaching

GI, Gastrointestinal

GPS, Global-positioning systems

HDOP, Horizontal dilution of precision

HPA, Hypothalamic-pituitary-adrenal

HR, Heart rate

HRV, Heart rate variability

IFN-ɣ, Interferon gamma

IL, Interleukin

km, kilometres

LEAF-Q, Low Energy Availability in Females Questionnaire

LFD, Lateral flow device

LFI, Lateral flow immunochromatographic

LJMU, Liverpool John Moores University

m, metres

MEMS, Microelectromechanical system

MHR, Maximal heart rate

ml, millilitres

m/s, metres per second

NFOR, Non-functional overreaching

NKC, Natural killer cell

OSTRC, The Oslo Sports Trauma Research Centre

OTS, Overtraining syndrome

PSG, Polysomnograph

RHR, Resting heart rate

RM-ANOVA, Repeated measures analysis of variance

RMSSD, Root mean square of successive differences

ROS, Reactive oxygen species

RPE, Rating of perceived exertion

SAM, Sympathetic-adrenal-medullary

SIgA, Secretory immunoglobulin-A

SpO2, Peripheral capillary oxygen saturation

SWC, Smallest worthwhile change

TIPS, Total illness prevention strategy

TRIMP, Training impulse

UEFA, Union of European Football Associations

UK, United Kingdom

URS, Upper respiratory symptoms

URTI, Upper respiratory tract infection

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ABSTRACT

Background - Previous research has demonstrated that illness is not a major problem within professional soccer. However, this research did not record illness where performance is restricted or medical attention is given, instead focussing only on illness where time is lost from soccer activities. Therefore, the aim of the present thesis was to establish the importance of illness in professional soccer by evaluating illness incidence, proposed risk factors and an illness prevention intervention.

Methods - Illness incidence was recorded from 1 professional soccer team (59 different players) across 3 seasons (2016-17 - 2018-19), using a system that recorded all illness definitions and a questionnaire to quantify performance-restriction illness. Illnesses were confirmed via physician diagnosis. During the congested fixture period of the 2017-18 season, illness incidence was compared to a recreationally active comparator population from a university institution. Physical load data (via microelectromechanical system and heart rate monitoring) and subjective wellbeing data (via a 1-5 Likert scale assessing fatigue, sleep quality, general muscle soreness, stress, mood and sleep hours) was also collected across this time period. 7 and 28-day average values for physical load and subjective wellbeing variables, prior to illness events, were compared to averages (indicative of normality) across the same time periods, using a paired samples t-test. In the 2018-19 season an illness prevention intervention was developed and implemented across 4 months (November - February). Illness incidence in this season was compared to the 2 previous seasons using a repeated measures analysis of variance (RM-ANOVA). Outcome measures for intervention evaluation assessed the reasons behind intervention effectiveness.

Results - Using 2 seasons worth of data, chapter 3 demonstrated that illness incidence was greater than training injury incidence (91 vs 17 incidences) and greater than values reported in previous research (91 vs 46 incidences). Illness incidence was also greater in the soccer team compared to the recreationally active comparator group (15 vs 10 incidences). Temporal patterns showed that peaks in illness incidence were distributed throughout the 2 seasons, not just in the winter months that coincide with congested fixture scheduling (10 incidences in July, 8 in September, 6 in October, 7 in November and 10 in January). Chapter 4 showed that, prior to illness events, there was an increase in 7-day average values for training impulse per minute (0.4±0.4 vs 0.6±0.5, p=<0.01) and time spent above 85% of maximum heart rate (2.3±1.8 vs 2.8±2.2, p=0.02) (markers of internal physical load), whilst maximum velocity was reduced (4.1±0.3 vs 3.7±1.0, p=0.03) (external load), compared to normality. In the 28 days preceding illness events there also appeared to be a reduction in sleep quality (3.8±0.3 vs 3.7±0.4, p=0.01) compared to normality. Chapter 5 indicates that the intervention did not reduce illness incidence in comparison to previous seasons. A RM-ANOVA determined that there were significant differences in 1 illness incidence variable between seasons (F (2, 11) = 17.581, p = 0.001). Post hoc comparisons showed an increased total illness incidence per 1000 hours in the 2017-18 season (20.2 ± 9.2) compared to the 2016-17 (7.1 ± 9.4, p = 0.004) and 2018-19 seasons (9.2 ± 7.5, p = 0.015). There were no other significant differences between seasons. Evaluation revealed that the intervention appeared to be successful in improving awareness of illness prevention, but did not alter aspects of behaviour.

Conclusions - Illness does appear to be a problem within professional soccer. This has implications towards training and match availability, performance, team success and therefore club finances. Findings suggest that illness is related to physical load and other risk factors within this population. Further exploration of these factors within this environment is required. Changes in the identified markers physical load and subjective wellbeing may identify players who are at risk of illness and allow intervention where appropriate. The illness prevention intervention did not reduce illness in comparison to previous seasons. The limited impact may have been due to increased competition demands during the 2018-19 season, elevated illness reporting due to the intervention itself and a lack of focus on influencing behaviour. Illness surveillance and prevention should be a future focus within professional soccer.

DECLARATION

I declare that no portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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CHAPTER 1 - GENERAL INTRODUCTION

1.1. BACKGROUND

Athlete availability appears to be crucial to team success (Pyne *et al*., 2005; Raysmith and Drew, 2016; Svendsen *et al*., 2016). Indeed, in professional soccer, a higher match availability is associated with greater tournament progress (Hägglund *et al*., 2013). Maintaining a high player availability is therefore a crucial part of the role of sports science and medical practitioners (Gabbett, 2016). The primary cause of player unavailability in soccer is injury (Parry and Drust, 2006), with lower injury rates associated with greater levels of team success (Arnason *et al*., 2004; Eirale *et al*., 2013). In comparison to injury, illness incidence does not seem to be a problem within professional soccer. Illness, in this case, refers to acute upper respiratory tract infections (URTI, such as coughs and colds, influenza, sinusitis, tonsillitis, other throat infections or middle ear infections) and gastroenteritis/diarrhoea (Gleeson *et al.*, 2013b). These are the most common types of illness experienced in professional soccer (Orhant *et al*., 2010; Bjørneboe *et al*., 2016). Despite these illness types being the most common, a low number of illnesses have been reported (46) in comparison with soccer-related injuries (83) across 2 seasons (Parry and Drust, 2006). Illness incidence rates of just 1.5 episodes per 1000 player-days (Bjørneboe *et al*., 2016), and an average of 2.5 complaints per season (Orhant *et al*., 2010), have also been reported. However, research in track and field athletes indicates that, when illness incidence is high, the chances of success in large-scale athletic events are reduced (Raysmith and Drew, 2016).

There is conflict between the aforementioned research completed in other sports and that in professional soccer; this may be due to methodological differences and different definitions of illness. Studies that have assessed illness incidence in professional soccer have either only recorded illness where time is lost from training or match play (Parry and Drust, 2006; Bjørneboe *et al*., 2016) or where 1 or more symptoms were reported on 1 or more consecutive days (Orhant *et al*., 2010). Therefore, illness where players continue to train and compete with symptoms, that may restrict their performance, has been ignored (Palmer-Green *et al*., 2013). It is clear that such situations occur where athletes often choose to ignore illness symptoms. This may be because of a fear of missing training and competition, and a need to suffer adversity on the road to success, often at the detriment of their health (Van Tonder *et al.*, 2016). However, the definitions and recording systems used prevent the incidence of these events being reported. This means that illness incidence in professional soccer may be a greater problem than previously stated. As such, the real impact of illness in professional soccer may be the significant amount of time players are under the influence of minor illness, that decreases performance and reduces the ability to sustain heavy training (Gleeson and Burke, 2007). An illness should, therefore, be defined as "any physical symptom, not related to injury, that requires medical attention, regardless of the consequence with respect to absence from competition or training" (Palmer-Green and Elliott, 2015). Accurate illness surveillance is the first step in illness prevention (Palmer-Green *et al*., 2013). Following this, identification of risk factors, which appear to affect the immune system, is important (Walsh, 2018).

As per descriptions by Gleeson *et al.* (2013b) and Walsh (2018), the human immune system protects us against harmful microorganisms (pathogens) such as bacteria, viruses and parasites. Elements of the immune system can be broadly distributed into innate and acquired components. The innate immune system is the first line of defence against these pathogens; it is fast acting and non-specific. This is comprised of physical (skin and mucosal membranes) and chemical barriers (immunoglobulins found within mucosa and tears) to stop pathogens entering the body, and also phagocytic cells (granulocytes, monocytes, lymphocytes). These cells ingest and kill microorganisms along with other non-specific killing cells such as natural killer cells (NKC). If microorganisms manage to pass the innate immune response then the acquired immune system is activated; this is slower to respond, yet specific to the pathogens in question, with a memory component. This system is comprised of T and B-lymphocytes (cells) and activated upon presentation of specific antigens to T cells. T cells divide into subpopulations of T-helper cells (which co-ordinate the immune response) and cytotoxic T cells (which destroy infected cells). B cells produce antibodies that bind specifically to the antigens on the surface of the foreign pathogens. T and B cells produce memory cells (which can multiply to produce large amounts of antibodies and effector cells) so that a faster, enhanced response can be mounted next time the body is exposed to this specific pathogen. The immune system clearly protects us from harmful pathogens; therefore changes in immune function, via specific risk factors, may lead to an increased risk of illness.

The demands of professional soccer itself may alter these specific risk factors, which in turn impact immune function. For instance, professional soccer is physically demanding, requiring high levels of multiple athletic qualities. The game is made up of short duration, repeated high intensity efforts, which are both linear and multidirectional, interspersed with periods of low intensity activity (Bangsbo *et al*., 2006; Varley and Aughey, 2013). There is also the requirement to repeatedly perform changes of direction, jumps, accelerations and decelerations (Bangsbo *et al*., 2006). An increase in these high intensity demands over recent seasons (Barnes *et al*., 2014), and an ever-increasing congested fixture schedule, including more international fixtures, means competition loads are now greater than ever (Thorpe *et al*., 2017). These factors mean that balancing the time between match play, training to meet match demands and recovery, is an important consideration. Optimal adaptation and preparation are sought, without the debilitating effects of chronic fatigue or maladaptation leading to injury or illness (Nimmo and Ekblom, 2007; Thorpe *et al*., 2015). These debilitating effects may begin to occur when the physical demands of soccer alter immune function. Indeed the immune system does appear sensitive to the specific physical demands of soccer, manifested as an increase in illness events around periods of high physical load (Freitas *et al*., 2014).

There are 2 common concepts used to describe the effects of physical load or heavy exercise on immune function, and the potential subsequent increases in illness risk, in the exercise immunology literature. The first concept, termed the “open window hypothesis” by Pedersen and Ullum (1994), proposes that following strenuous exercise bouts there is a reduction in markers of systemic immune function; this temporary reduction may lead to opportunistic infections. There is evidence of this concept following soccer-specific exercise. Malm *et al.* (2004) reported a reduction in enumerative markers of innate immune function; the number of NK cells, lymphocytes and macrophages was reduced following 2 soccer matches, separated by 20 hours. Bishop *et al.* (2005) reported a reduction in the in vitro function of the acquired immune system; T cell proliferation was reduced when a soccer-specific exercise protocol was repeated twice in 3 days. Further, a marker of mucosal immune function, Secretory Immunoglobulin-A (sIgA), has been reported to fall following professional soccer training (Morgans *et al.*, 2015; Owen *et al.,* 2016). The second concept is a J-shaped curve between the amount or intensity of exercise and illness risk (Nieman, 1994). This concept suggests that a moderate amount or intensity of exercise may lower the risk of a URTI compared to a very high amount or intensity of exercise. Research by Spence *et al.* (2007) provides support for this concept by reporting that recreationally active triathletes experienced a reduced amount of URTI symptoms compared to sedentary individuals and elite triathletes. Seasonal exposure to professional soccer training also appears to impair markers of the innate immune system, such as neutrophil function, and increase URTI incidence in comparison to a student control group (Bury *et al.*, 1998). A decline in acquired immune function (T helper, cytotoxic T, and B cell function) has also been reported following a 5-day training camp in junior soccer players, coupled with an increased URTI incidence post camp (Malm *et al.*, 2004a). This is in addition to reductions in sIgA following intensive soccer fixture scheduling (Morgans *et al.,* 2014) and training, mirroring increases in URTI incidence (Mortatti *et al.,* 2012; Moreira *et al.,* 2014). These longstanding concepts have, however, recently come under review.

Campbell and Turner (2018) suggest that the reductions in systemic markers of immune function following exercise are a reflection of these cells migrating into tissues to perform immune surveillance, and not the opportunity for infection. Walsh (2019) suggests that elite athletes are otherwise healthy individuals, who do not experience any more illness compared to the general population. In actual fact, the training volume required of an elite athlete may be incompatible with a high amount of illness. Indeed, Malm (2006) updated the J-shaped curve to distinguish between “very high” and “elite” exercise demands. As such an S-shaped curve was proposed, where elite athletes exhibit a lower infection risk compared to those who perform a very high amount or intensity of exercise. This may be due to the need to withstand illness to perform at an elite level, the support received and the better lifestyle behaviours adopted from experience and/or education (for example; better hygiene, infection avoidance, diet, sleep and stress management) (Walsh, 2018). Walsh (2019) continues to state that the risk factors elite athletes are exposed to are no different to those experienced by the general population, and exposure to intense exercise alone does not alter immune function enough to increase infection susceptibility. Simpson *et al.* (2020) echoes this, concluding that other illness risk factors, alongside a high physical load, are likely to be just as important (life stress, long-haul travel, sleep disruption, nutritional deficits, genetic polymorphisms, infection/vaccination history, environmental extremes and time of year). As such, immune function may only be altered enough to increase infection susceptibility when changes in these factors are combined, and pathogen exposure increases. Monitoring practices in professional soccer may be able to assess some of these risk factors to determine when players may be at an increased risk of illness.

In order to identify these situations, physical load monitoring practices in professional soccer should assess "spikes" or abrupt changes in physical load, away from normality, which appears to be a risk factor for illness (Foster, 1998; Putlur *et al*., 2004; Piggott, 2008; Thornton *et al*., 2014; Watson *et al*., 2017). Further, consistently high volumes of physical load (Brink *et al*., 2010) and high competition loads (Svendsen *et al*., 2015) are also related to a greater illness incidence. Fatigue monitoring tools may be able to detect the responses to changes in physical load, and also changes in isolated illness risk factors, before an illness event occurs. For example, stress, a subjective fatigue marker used in multiple questionnaires, appears to be related to illness risk (Anderson *et al.,* 2003; Brink *et al.,* 2010; Drew *et al.,* 2017b). Other risk factors that are often highlighted in fatigue monitoring such as; an elevated heart rate (HR) during submaximal exercise (Buchheit *et al*., 2013b), a reduction in heart rate variability (HRV) (Hellard *et al*., 2011), low energy availability and poor hygiene practice (Drew *et al.,* 2017b), international travel (Schwellnus *et al*., 2012), and reduced sleep duration (Prather *et al*., 2015), have also been related to an increased risk of illness. However, few studies have assessed the relationship between objective physical load markers, fatigue variables, and illness risk, in a multiple risk factor model (Jones *et al*., 2017). This model needs to account for the lag time between a change in physical load or a fatigue marker, and an illness event, which may be up to 4 weeks (Drew and Finch, 2016; Jones *et al*., 2017). Identification of these risk factors would provide the basis for targeted illness prevention interventions. However, there is a lack of studies that have looked to implement and assess illness prevention interventions in athletes.

Illness prevention guidelines, built on underpinning evidence, are present within the literature (Schwellnus *et al*., 2016; Walsh, 2018; Castell *et al*., 2019). However, translation of these guidelines into interventions within practice is poor, with only 3 published illness prevention interventions in athletes. Hanstad *et al*. (2011) reported a reduced illness incidence following an illness prevention programme in the Norwegian Olympic team. The illness prevention strategies included; developing and sharing best practice guidelines on illness prevention, screening for illness risk, vaccinations for all staff and athletes, targeting high-risk athletes with isolated rooms when away on tour, indoor air cleaning systems, disinfectant and rigorous cleaning routines. Schwellnus *et al.* (2020) reported a 59% reduction in illness during the Super Rugby tournament, following an illness prevention strategy. The study used 3 years without an intervention as a control period and compared this to a 4-year intervention period. The intervention involved; (1) pre-tournament screening of players at increased risk of illness; (2) during the tournament, sharing of utensils or water bottles was discouraged, whilst ensuring good sleeping habits, regular hand washing and/or use of personal antiseptic hand gel, avoidance of continuous exposure to air-conditioned or polluted environments, considering high-dose vitamin C supplementation (>1000 mg/day), early reporting of symptoms and early isolation of players at the onset of symptom development, was encouraged; (3) additional international travel guidelines such as considering prophylactic local antimicrobial spray, probiotics and antibiotic prophylaxis were also provided. Ranchordas *et al.* (2016) also reported a reduced illness incidence following an intervention with 1 professional soccer player. The nutritional and lifestyle intervention involved increasing energy intake, vitamin-D supplementation, changing hygiene habits and improving sleep quality via education. Despite the success of the interventions there was no attempt made to elicit the key factors responsible for this. Further, despite behavioural change being one of the key factors contributing to the success of health behaviour interventions (Aboud and Singla, 2012; Heijnen and Greenland, 2015), strategies to achieve behavioural change were not included in any of these interventions. Although elements may have been completed successfully, without evaluation it is difficult to see which elements have contributed towards behavioural change. Future illness prevention interventions need to consider that improving knowledge alone may not change behaviour (Heijnen and

Greenland, 2015). The determinants of behavioural change should be key considerations when planning future intervention content (Huis *et al*., 2012).

Clearly this is an important research area from a practical and a theoretical perspective. Illness in professional soccer may be a greater problem than previously reported. As mentioned, the real impact of illness in professional soccer may be the influence of minor illness that decreases performance and reduces the ability to sustain heavy training. This could have implications on training and match availability, training and match performance, team success and therefore club finances. Accurate illness surveillance should be an initial focus to understand the scope of the problem. Following this it is important that the relationships between risk factors and illness be identified in this specific environment, potentially through the use of objective physical load monitoring and fatigue monitoring tools. Once these stages are in place, illness prevention guidelines, in combination with specific surveillance and risk factor data, can be used to develop illness prevention interventions to tackle this problem.

1.2. RESEARCH APPROACH

The research approach within the present thesis has been chosen to produce a series of studies that can impact practice in the ‘real-world’. Therefore there will be a focus on maintaining ecological validity throughout the research project, with a view to using the available information to inform future practice within professional soccer. The research within the present thesis sits within the field of applied sports science, this can be thought of as a scientific process used to guide the practice of sport with the ultimate aim of improving sporting performance (Bishop, 2008). In order to influence performance it is imperative that sports science research can be implemented into everyday practice. However, there is a consensus that the translation of research into practice within the field of sports science is poor (Bishop, 2008; Eisenmann, 2017). Academic researchers have been criticised for not studying problems relevant to real-world practitioners, in favour of publishing findings that are difficult to implement practically (Bishop, 2008).

Bishop (2008) recommended an applied research model to ensure the transfer of sports science research into practice. The model consists of three phases; (1) description; (2) experimentation; (3) implementation (Bishop, 2008). The phases are then divided into eight stages; (1) defining the problem; (2) descriptive research; (3) predictors of performance; (4) experimental testing of predictors; (5) determinants of key performance predictors; (6) efficacy studies; (7) examination of barriers to uptake; (8) implementation studies in a real sporting setting (Bishop, 2008). The 3 phases mentioned above will be followed to ensure transfer into practice. Specifically the thesis will firstly describe the problem of illness in professional soccer, before the experimental assessment of illness risk factors and then finally the development, implementation and evaluation of an illness prevention intervention, guided by the first 2 phases. Within the model, Bishop (2008) also discusses the wealth of data that is present in sports clubs but is never utilised because of the constant drive for original research. It is vital that this data is used, if practice is to be impacted upon.

The structure of scientific enquiries (the way in which research is conducted) may also contribute to the lack of transfer from research into practice (Bishop, 2008). From the very inception of this thesis there was a focus on conducting the research in an approach that would allow application into practice. By using information already utilised within the club, findings have a chance of being implemented practically almost immediately. Further, although a laboratory level of control within the thesis would be favourable, the reality of professional sport is simply not compatible with this. Instead it is important for the recommendations from the thesis be able to operate in the environment in question. Eisenmann (2017) discusses 'translational science'; the goal of which is to remove blocks that impede the translation of science into practice. In order for this to happen there needs to be an understanding of the ecological context in which the research is conducted (Eisenmann, 2017). Therefore, as in the case of the present thesis, active decisions may be made based on the applied environment. If research such as this is to be applied into practice, there needs to be an understanding that data collected and some of the decisions made during the research project may be based on the environment in which the research will be applied.

1.3. AIMS AND OBJECTIVES OF THE THESIS

The overall aim of the present thesis is to establish the importance of illness in professional soccer by evaluating illness incidence, proposed risk factors and an illness prevention intervention. This will be investigated through the fulfilment of the following objectives:

1. To determine the incidence and impact of illness symptoms at a professional soccer club. This will be achieved through completion of Chapter 3.

2. To examine the relationship between physical load, subjective wellbeing, and illness incidence in professional soccer. This will be achieved through completion of Chapter 4.

3. To develop, implement and evaluate the effectiveness of a holistic illness prevention intervention, towards reducing illness incidence, in professional soccer. This will be achieved through completion of Chapter 5.

The successful completion of these aims and objectives will enable a deeper understanding of the importance of illness in professional soccer. As well as greater understanding of illness incidence, proposed risk factors and illness prevention.

CHAPTER 2 - LITERATURE REVIEW

2.1. WHY DO PROFESSIONAL SOCCER PLAYERS MISS TRAINING AND MATCH PLAY?

Player availability appears critical to team success within professional soccer. In a study across 11 seasons, following 24 professional European soccer teams, higher match availability was associated with European tournament progress (Hägglund *et al*., 2013). Despite the clear importance of making players available for match selection, many studies fail to report this simple metric. Instead, injury incidence is mainly reported, this is one of the main causes for player unavailability (Parry and Drust, 2006). Lower injury incidence rates have been correlated with greater team success in 2 previous publications (Arnason *et al*., 2004; Eirale *et al*., 2013). Such research has prompted the emergence of maintaining player availability as one of the key responsibilities for sports science and medical practitioners working within professional soccer (Gabbett, 2016).

Although other factors related to availability such as illness, suspension and personal circumstances may play a part, soccer injuries seem to be the primary reason why players are unavailable to train or compete. In a study assessing player availability across 2 seasons, in 1 professional soccer team, injury accounted for 49% of match unavailability and 60% of training sessions missed (Parry and Drust, 2006). Other factors assessed included illness, social (births, funerals etc.), suspensions, internationals and loans to other clubs. Despite injury being the major factor, it was not the only factor in maximising player availability; suspensions and illness also appeared to be important. Illness accounted for 6% of match unavailability and 6% of training sessions missed in this study. However, to the author's knowledge this is the only paper that has examined factors outside of injury as contributors towards player availability in professional soccer. Instead research within sport, and specifically soccer, has continued to assess the impact and causes of soccer injuries in isolation.

An abundance of research now exists assessing injury incidence within professional soccer. Data from the Union of European Football Associations (UEFA) injury study (Ekstrand *et al*., 2011) was collected from 7 teams across 7 seasons. The study concluded that injury rate remained the same over 7 seasons and that match injuries occur significantly more frequently than training injuries (28 vs 4 injuries per 1000 hours respectively). In addition, the study found that half of the injuries reported per season were minor and caused absences from training and match play for less than 1 week, 8-9 injuries per season were more severe and caused absences of 4 weeks or more. Studies have also assessed some of the risk factors responsible for injuries within professional soccer, citing previous injury, player workload, player wellbeing, communication between the head coach and the medical team, and head coach leadership style as the main factors (Ekstrand *et al*., 2011; Bengtsson *et al*., 2013; Ekstrand *et al*., 2013; Ekstrand, 2013, 2016; McCall *et al*., 2016; Davison *et al*., 2018; Ekstrand *et al*., 2019). Despite an in-depth assessment of the problem of injury to player availability within professional soccer, little research has focussed on illness incidence. Much of the research into illness incidence has been completed in other sporting populations.

2.2. ILLNESS INCIDENCE IN PROFESSIONAL SOCCER

The term "illness", in this thesis, predominantly refers to acute URTI (such as coughs and colds, influenza, sinusitis, tonsillitis, other throat infections or middle ear infections) and gastroenteritis or gastrointestinal (GI) issues leading to vomiting and/or diarrhoea (Gleeson *et al.,* 2013b). Illness surveillance studies completed in others sports, particularly research in the Olympic games, has produced consistent findings regarding illness rates. Across the 17 days of the London 2012 and Rio de Janeiro 2016 summer games, 5-7% of athletes reported an illness (Engebretsen *et al*., 2013; Soligard *et al*., 2017). Although 5-7% may appear trivial, given that 10568 - 11274 participants were involved in these studies, this equates to 528-789 athletes who experienced an illness symptom (651 - 758 illness episodes). The majority of illness reported (41-47%) affected the respiratory system (nose, sinuses, pharynx, larynx, trachea, bronchi or lungs) with 16-21% affecting the GI system (Engebretsen *et al*., 2013; Soligard *et al*., 2017). Across the 18 days of the Sochi 2014 winter games, 8% of athletes reported an illness (222 athletes reported a problem, there were 249 illness episodes) (Soligard *et al*., 2015). In the winter games, a higher percentage appeared to affect the respiratory system (64%), whilst 11% involved the GI system (Soligard *et al*., 2015). Similarly, Steffen *et al.* (2020) reported that 8% of athletes (319) experienced an illness in newer Olympic sports such as futsal, beach handball, karate, roller speed skating, kite surfing, BMX freestyle, climbing and break dancing. Outside of the Olympic games, Svendsen *et al*. (2016) examined the incidence of illness in 37 elite cross-country skiers, across 8 years. The average incidence was 3-4 episodes of illness per year, lasting 5 days in duration. Hellard *et al*. (2015) reported similar findings in elite swimmers; the average incidence was 4 episodes per year, over a 4-year period. Such consistent findings have not been replicated in professional soccer, where the percentage of athletes affected by illness in Olympic sports could have a bigger impact on performance, as there are less team members.

In-season illness incidence studies completed in professional soccer are scarce; with those completed varying in duration and with different approaches employed to record their findings. Illness incidence across 2 seasons (46 incidences) appears to be low in comparison to injury incidence (83 incidences) (Parry and Drust, 2006). Illness incidence also appears low in its own right; an incidence of 1.5 episodes per 1000 player-days has been reported (Bjørneboe *et al*., 2016), with an average of 2.5 complaints per season (Orhant *et al*., 2010). Further to this, the severity of the illness experienced does not seem to be high. Bjørneboe *et al*. (2016) reported that only 3 days were lost per illness episode, whilst Orhant *et al*. (2010) reported that just 0.3% of training days were lost to illness. To give this some context 4.3 days are estimated to be lost per worker, each year, due to sickness in the United Kingdom (UK) (ONS, 2017). Studies completed in soccer also show that the majority of illness occurred in the winter months (November-February) and was either recorded as an URTI (58-75% of total illness) or GI illness (14-38% of total illness) (Orhant *et al*., 2010; Bjørneboe *et al*., 2016). Therefore the current consensus is that, although URTI and GI illness is common across the winter months, illness is not a major contributor towards player unavailability or team success, in the same way as injury, within professional soccer.

Despite in-season research indicating that illness may not be a major problem within professional soccer, tournament research paints a different picture. Theron *et al*. (2013) assessed the incidence of illness during the 2009 Fédération Internationale de Football Association (FIFA) Confederations Cup. This study reported a rate of 16.9 illnesses per 1000 player-days (35 illnesses in 184 players). Similarly, Dvorak *et al*. (2011) assessed illness incidence across the 2010 FIFA World Cup; reporting an illness incidence of 7.7 per 1000 player-days (99 illnesses in 89 players). The differences between in-season and tournament research may be due to a number of factors involved with a tournament. These include a more condensed fixture schedule, long-haul travel and foreign, crowded environments. The comparatively low in-season numbers would indicate that illness does not seem to a problem when these mediating factors are not present. Despite these findings, there are numerous methodological shortcomings that need to be addressed within this body of literature.

One of the biggest issues is the difference in illness definitions and recording systems used between investigations; as such getting any form of consensus is difficult. Olympic-based research has used medical attention only as the cut off point for recording an illness; regardless of whether the illness leads to time lost from training and/or competition (Engebretsen *et al*., 2013; Soligard *et al*., 2015, 2017). These papers also rely on athletes reporting symptoms to one of the medical team; therefore, if not reported, these events may be missed. Svendsen *et al*. (2016) defined illness as when an athlete reported 1 or more symptoms for 1 or more consecutive days in a training diary. Research conducted in professional soccer has also used different definitions. Parry and Drust (2006) and Bjørneboe *et al*. (2016) only recorded time-loss illness reported to members of the medical team. Whilst Orhant *et al*. (2010) recorded an illness when 1 or more symptoms were reported on 1 or more consecutive days. Previous illness or allergy history in these studies is also unknown. When this is combined with the fact that recording is completed via self-report or information given to the medical team, with no assessment of illness origin, the term ‘symptoms indicative of illness’ rather than ‘illness’ itself may be more accurate (Berge and Clarsen, 2016). Further, different studies report different illness outcome measures such as number of illness events, prevalence (the number of athletes affected divided by total number of athletes), incidence (number of illness events divided by the number of exposure hours), severity (number of days affected), burden (the number of affected days divided by the number of exposure hours) and type of illness/affected system or symptoms. The illness definitions and recording system used are the most critical methodological factors that influence the data generated in these studies (Clarsen and Bahr, 2014). As such, the apparent discrepancies between papers make it difficult to compare and contrast findings. More uniformity between studies is needed to accurately assess the problem of illness in sport (Timpka *et al*., 2014). Table 2.1 summarises the current literature on the number of illnesses in professional soccer.

Table 2.1. The current availiable literature on the number of illnesses in professional soccer.

Reference	Illness definition	Participants	Time period	Outcome measures reported	Key findings
Parry and Drust (2006)	Time-loss from training or match play (recorded via physiotherapist)	55 professional soccer players	2 seasons	Number of matches and training sessions missed Number of illness events	22 matches (an average of 6% per season) and 65 training sessions were missed (an average of 6% per season) 46 illness events were reported across 2 seasons (21 and 25 in each season respectively)
Orhant *et al.* (2010)	An athlete presenting with 1 or more symptoms, signs or both on 1 or more consecutive days (diagnosed by a physician)	27 professional soccer players per season	3 seasons	Number of illness events Severity Affected system/illness type	203 illness events were reported over 3 seasons (67 per season) 40 time-loss illness events were reported

	Also recorded time-loss illness			Illness across months of the season	(in total 85 training days and 5 matches were missed due to illness) 98% of the squad were affected by illness with an average of 2.5 complaints per season per player, each complaint had an average duration of 2.9 days 85 days were lost in total due to illness, with an average of 2.1 days lost per episode Upper respiratory illness accounted for 75% of illness and GI complaints accounted for 14% The highest frequency of all illness occurred in February (15.8%)

Dvorak *et al.* (2011)	An illness was defined as 'any physical complaint (unrelated to injury) newly incurred during the world cup Also recorded time-loss illness	736 professional soccer players	12-31 days (2010 FIFA World Cup in South Africa)	Number of illness events Incidence (per 1000 players and per 1000 player-days) Affected system/illness type Severity (number of training sessions and matches missed)	99 illness events were reported in 89 players (12% of all players were affected) Illness incidence was 135 per 1000 players or 7.7 per 1000 player-days The majority of illness affected the respiratory (40%) or the digestive system (26%) 55 (59%) illness events did not result in absence from training or match play, 36 (39%) of illnesses resulted in a 1-3 day absence Time-loss illness incidence was 3.0 per 1000 player-days with an average duration of

					1.8 days missed
Theron *et al.* (2013)	An illness was defined as ‘any physical complaint (unrelated to injury) newly incurred during the tournament Also recorded time-loss illness	184 professional soccer players	6-14 days (2009 FIFA Confederations Cup in South Africa)	Number of illness events Incidence (per 1000 player-days) Affected system/illness type	35 illness events were reported (17 illnesses per 1000 player-days) 0.46 days were lost per illness on average 13 (37%) of illnesses were related to the ear, nose and throat, 7 (20%) of illnesses were related to other respiratory tract symptoms
Bjørneboe *et al.* (2016)	Time-loss from training or match play	73 professional soccer teams (1, 261, 367 player-days)	4 years (2011-2014)	Number of illness events Incidence (per 1000 player-days) Severity (days affected)	1861 illness events were reported over 4 seasons Illness incidence was 1.5 per 1000 player-days (0.4 illnesses per season)

				Burden (days affected per 1000 player-days) Affected system/illness type Illness across months of the season	The most recorded illness type was respiratory illness (58%), followed by GI illness (28%) On average an illness episode led to 3 training days and 0.6 match days missed The highest frequency of illness occurred in the winter months (November - February)

In addition to these methodological differences, in order for a recording system to capture all illness present in a sporting organisation, it must recognize that athletes may experience illness symptoms that do not lead to time lost from training and/or competition. Rather, athletes often continue to train and compete. In this case, they may seek out medical attention and experience no restriction on their performance, or they may continue to train and compete with symptoms that do restrict their performance. Illness may cause a reduction in performance through a decrease in muscle strength, a reduction in maximal oxygen uptake, and alterations in muscle enzyme activity and metabolic function, a fever may also limit the body's ability to regulate temperature, resulting in increased fluid loss, which in turn limits stroke volume and cardiac output (Schwellnus *et al.,* 2016). The nature of professional athletes means they often choose to ignore illness symptoms. This may be because of a fear of missing training and competition, and a need to suffer adversity on the road to success, often at the detriment of their health (Van Tonder *et al*., 2016). Indeed, Mountjoy *et al.* (2019) reported that 27% (121) of aquatic athletes at the International Swimming Federation (FINA) World Championships (Budapest, 2017) competed or trained fully with a health issue, whilst 14% (64 athletes) had to reduce their participation due to a health issue.

However, the majority of illness surveillance research does not record events outside of those that lead to time lost (Palmer-Green *et al*., 2013). Whilst it is clear that such situations occur, the definitions and recording systems used prevent the incidence being reported. Further to this, illness may have an incubation time, unlike injury, where symptoms may at first be minimal and then progress to affecting performance, before causing time loss. Although difficult, it is important that these illnesses are still detected (Berge and Clarsen, 2016). As a consequence, the problem of illness in sport, and in particular within team sports, may have been underestimated (Palmer-Green *et al*., 2013). Palmer-Green *et al*. (2013) recommends a novel recording system for injuries and illnesses. This was employed successfully in a follow-up study around the 2014 winter Olympic games (Palmer-Green and Elliott, 2015). The system aims to accurately quantify illness incidence by recording events that lead to time lost, as well as illness where participation continues and an athlete either experiences performance-restriction or simply receives medical attention. This approach is yet to be adopted longitudinally in a team sport environment.

A more complete quantification of illness in professional soccer will allow the true burden to be determined. As previously stated athlete availability is crucial to team success (Pyne *et al*., 2005; Hägglund *et al*., 2013; Raysmith and Drew, 2016; Svendsen *et al*., 2016) and therefore prevention of time-loss illness is crucial. However, the real impact may be the significant amount of time players are under the influence of minor illness which decreases performance and reduces the ability to sustain heavy training (Gleeson and Burke, 2007). This may hamper training adaptation or effect tactical training for the coach. Further to this, an accurate illness surveillance system is also the first step in putting preventative measures in place (van Mechelen *et al*., 1992; Palmer-Green and Elliott, 2015). Therefore, time should be spent determining the extent of the problem of illness within professional soccer so preventative interventions can be developed, implemented and assessed. Before preventative interventions can be developed it is also important to understand how the demands of professional soccer may alter immune function and risk factors for illness. Infection susceptibility is multifactorial; there are also factors outside of the specific physical and psychological demands of professional soccer that may increase illness risk in this population by directly affecting the immune system (these factors are summarised in figure 2.1). Factors such as additional life stress, pathogen exposure, poor hygiene, sleep disruption, exposure to environmental conditions such as extreme temperatures, long-haul travel, vaccination and infection history, a high gene expression of inflammatory cytokines such as Interleukin 6 (IL-6) and Interferon gamma (IFN-ɣ), low levels of salivary antibodies such as sIgA, time of year, and nutritional deficits, may contribute towards an increased risk of illness in athletes such as professional soccer players (Walsh, 2018; Simpson *et al.,* 2020). It is important that these factors are identified in order for specific, targeted interventions to be implemented to reduce the risk of infection and prevent negative effects on the immune system.

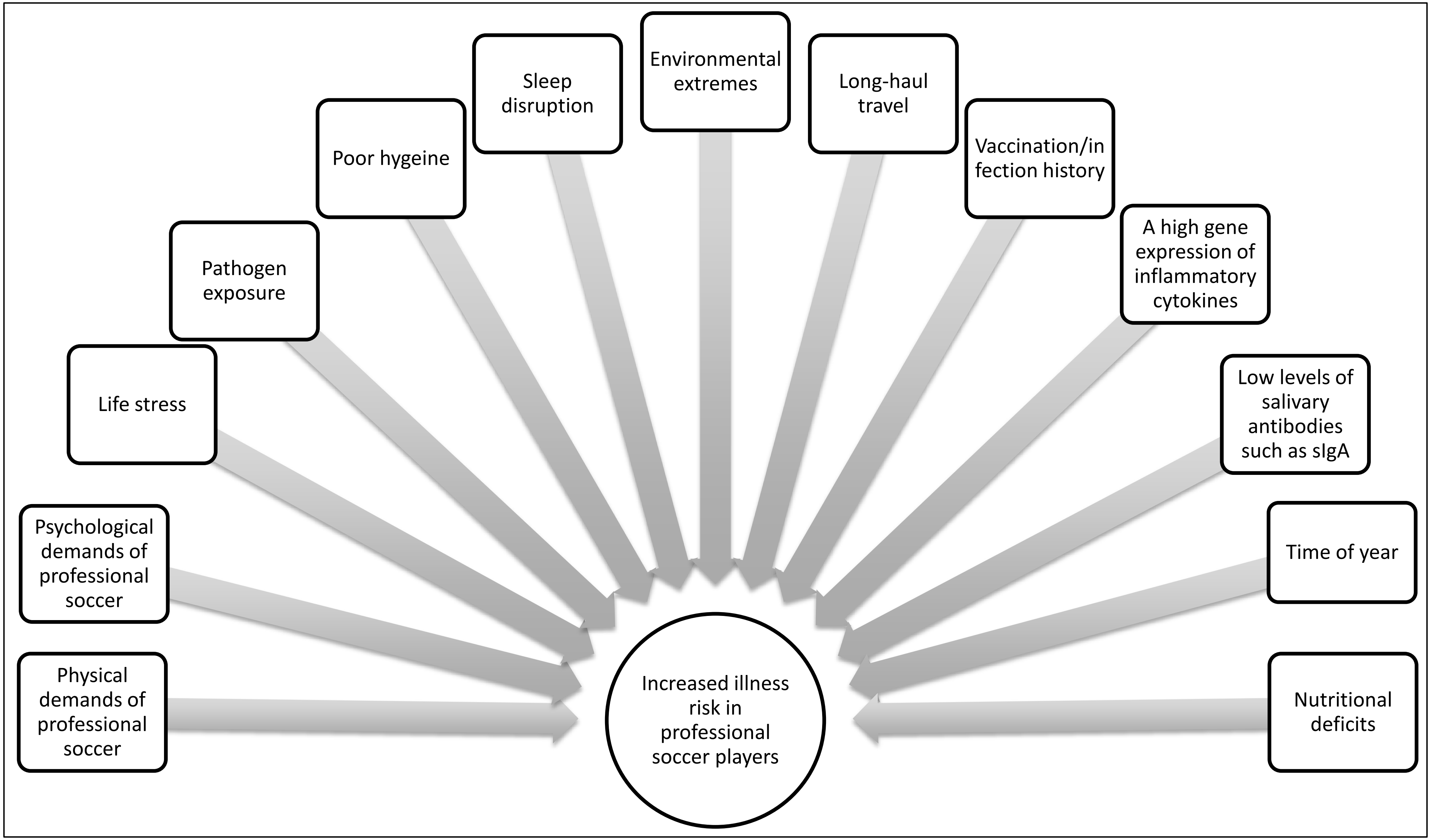

Figure 2.1. A summary of the factors that may increase illness risk in professional soccer players. This diagram was adapted from Walsh (2018) and Simpson *et al.* (2020).

2.3. THE HUMAN IMMUNE SYSTEM

Some of the factors mentioned above may increase illness risk by directly affecting the function of the immune system. As per descriptions by Gleeson *et al.* (2013b) and Walsh (2018), the human immune system protects us against harmful microorganisms (pathogens) such as bacteria, viruses and parasites. Elements of the immune system can be broadly distributed into innate and acquired components (see figures 2.2 and 2.3). The innate immune system is the first line of defence against these pathogens; it is fast acting and non-specific with the main goal of restricting access to the body. The innate immune system is comprised of physical barriers (such as the skin and mucosal membranes which hinder pathogen entry and aid in clearance), chemical factors (such as the low pH of stomach fluids, and numerous antimicrobial peptides and proteins, for example immunoglobulins found within mucosa and tears) and leukocytes (white blood cells). These are phagocytic cells (granulocytes such as neutrophils, eosinophils and basophils, monocytes, macrophages and dendritic cells) that engulf, ingest and digest microorganisms. These cells work alongside other non-specific killing cells such as NKC. NKC destroy host cells that become virally infected to prevent replication. Soluble factors such as complement proteins, lysozymes and cytokines are important in signaling and enhancing the innate response, as well as destroying microorganisms.

Failure of the innate immune response to prevent pathogens entering the body and causing an infection leads to activation of the acquired immune response; this is slower to respond, yet specific to the pathogens in question, with a memory component. The specificity of the acquired immune response means there is a delay until this becomes effective at defending the body, this delay is whilst replication occurs to produce cells specific to the antigen in question. The primary goal of this component is to keep pathogens out of the body and seek out, to destroy, invading microorganisms. This system is comprised of T and B-lymphocytes (cells) and activated upon presentation of specific antigens to T cells. Antigen presenting cells such as monocytes, macrophages and dendritic cells present antigens to naïve (undifferentiated) T cells. T cells then divide into subpopulations of T-helper cells (which co-ordinate the immune response) and cytotoxic T cells (which destroy infected cells). B cells produce antibodies that bind specifically to the antigens on the surface of the foreign pathogens; these antibodies circulate in bodily fluids (humoral). T and B cells produce memory cells (which can multiply to produce large amounts of antibodies and effector cells) so that a faster, augmented response can be mounted next time the body is exposed to this specific pathogen.

Cell-mediated immunity occurs when the immune response does not involve antibodies. Instead T cells and macrophages, in response to an antigen, mediate the response. This response fights pathogens that have already entered cells (intracellular), such as a virus that uses the cell for replication. Humoral immunity involves the production of antibodies and mainly targets extracellular pathogen elimination. The choice of cell mediated or a humoral response depends on the cytokines secreted by T helper cells. Cytokines such as Interleukin 2 (IL-2) and IFN-ɣ lead to a cell-mediated response whilst, Interleukins 4, 5 and 13 (IL-4, IL-5 and IL-13) lead to a humoral response. SIgA is an example of an antibody produced by B cells, this is secreted into the lumen of the upper respiratory tract and provides the first line of defence against pathogens that enter here. Immunoglobulins such as this prevent viral replication via neutralisation, agglutination, complement activation or oponization. The human immune system clearly protects us from harmful pathogens. Therefore changes in immune function, via some of the specific risk factors shown in figure 2.1, may lead to an increased risk of illness. The demands of professional soccer demonstrate some of the factors that may directly impact immune function.

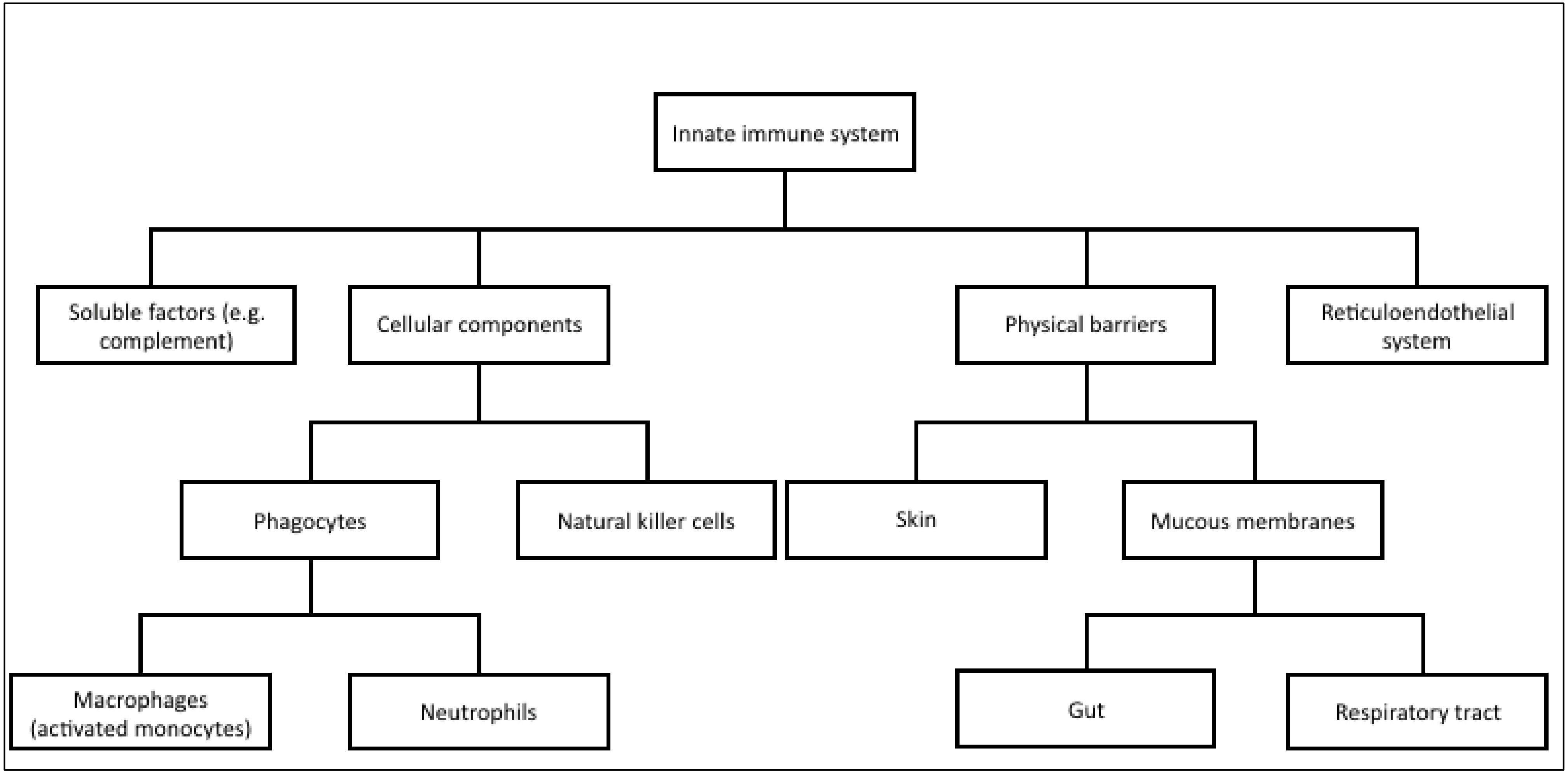

Figure 2.2. Major components of innate immunity (Gleeson *et al.*, 2013b).

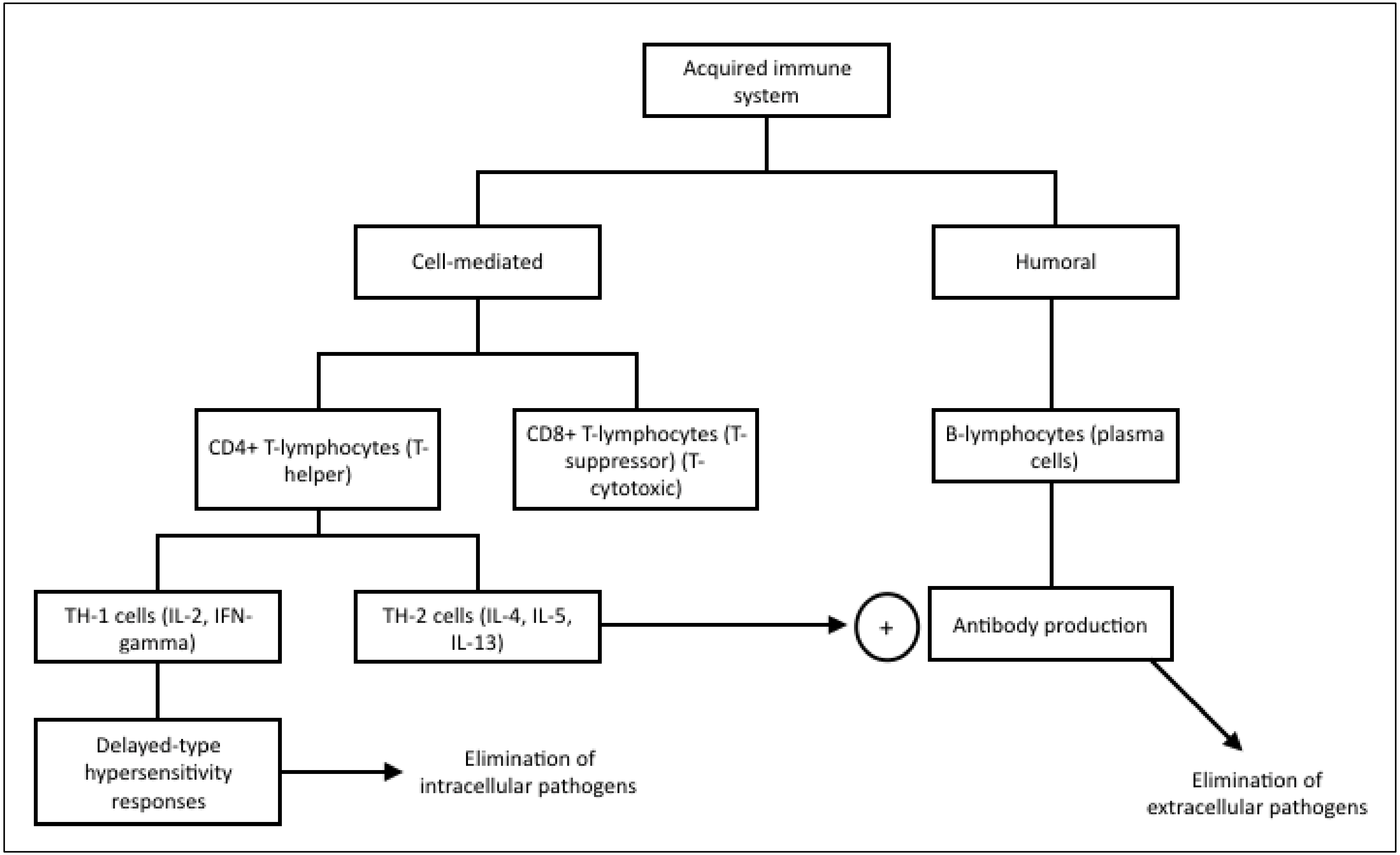

Figure 2.3. Major components of acquired immunity (Gleeson *et al.*, 2013b).

2.4. THE DEMANDS OF PROFESSIONAL SOCCER

Professional soccer is characterised, from a physical perspective, by short duration, repeated high intensity efforts, both linear and multidirectional (Bangsbo *et al*., 2006; Varley and Aughey, 2013). This anaerobic work is interspersed with periods of low-intensity aerobic activity; these periods may reflect opportunities for recovery (Bangsbo *et al*., 2006; Varley and Aughey, 2013). Research using high-speed camera systems indicates that, per match, players cover between 9 and 14 km in total, with around 10% of this distance covered between speeds of 5.5 and 7.0 metres per second (m/s) (high-speed running) (Mohr *et al*., 2003; Di Mascio and Bradley, 2013). Within this intermittent activity profile, players are also required to repeatedly perform movements such as changes of direction, jumps, accelerations and decelerations (Bangsbo *et al*., 2006). As a result there is also a high amount of eccentric muscle contraction and consequently muscle damage (Thorpe and Sunderland, 2012). Evidently, professional soccer players require high levels of multiple athletic qualities to meet such physical match demands.

Match demands have increased over recent seasons, with the English Premier League (EPL) at the forefront of such changes. The EPL is one of the most physically demanding leagues across Europe; demonstrating a greater amount of high intensity activity in comparison to other leagues (Bradley *et al*., 2009; Dellal *et al*., 2011). In addition to an increase in the high intensity demands over recent seasons (Barnes *et al*., 2014), an ever-increasing congested fixture schedule, including more international fixtures, means competition loads are now greater than ever (Thorpe *et al*., 2017). During the winter months, EPL players are exposed to a programme where the same players often complete multiple fixtures, with only 48 hours between consecutive matches (Morgans *et al*., 2014). Games played at such a high frequency over a short period of time may result in residual fatigue, underperformance and even injury due to insufficient recovery (Dupont *et al*., 2010; Bengtsson *et al*., 2013). The ever-increasing physical demands, coupled with such a congested programme is likely to cause problems for practitioners working in professional soccer. Balancing time spent within match play, recovery and training should, therefore, be a key consideration.

Training, to ensure players are physically prepared to meet these competition demands, in repeated succession, would seem paramount. In comparison to match demands, EPL players have been shown to cover between 3170 and 5181 m in total per session, with between 39 and 118 m of high-speed running (Gaudino *et al.*, 2013; Anderson *et al.*, 2015; Malone *et al.*, 2015). Whilst training load will vary greatly between teams based on numerous factors (Akenhead and Nassis, 2016), all practitioners working in professional soccer must ensure players complete enough physical work to be able to repeatedly meet the demands of match play, on a weekly, often bi-weekly basis. However, they must also guard against the accumulative effects of training, on top of match play, leading to fatigue close to the matches themselves. This represents a finite balancing act, where optimal adaptation and preparation are sought without the debilitating effects of chronic fatigue or maladaptation (Nimmo and Ekblom, 2007; Thorpe *et al*., 2015). Therefore, balancing the multiple demands of professional soccer clearly has physiological implications.

2.5. THE PHYSIOLOGICAL CONSEQUENCES OF THE DEMANDS OF PROFESSIONAL SOCCER

The pathway to the effects of chronic fatigue or maladaptation starts with the acute physiological changes caused by soccer. Acute fatigue is evident in physical performance both during and after match play. Players demonstrate a reduction in high intensity activity towards the end of a game (Mohr *et al*., 2003). This is coupled with a post-match, compared to pre-match, impairment in countermovement jump (CMJ) height (Andersson *et al*., 2008; Mohr *et al*., 2010; Silva *et al*., 2013), isokinetic strength (Andersson *et al*., 2008; Krustrup *et al*., 2011), sprint performance (Andersson *et al*., 2008) and repeated sprint performance (Mohr *et al*., 2004; Krustrup *et al*., 2006a). However, the alterations in underpinning physiological mechanisms, which are manifested as acute fatigue, are still unclear.

One mechanistic explanation for the acute fatigue observed during the latter stages of soccer match play, and following the match itself, is the depletion of glycogen from individual muscle fibres (Krustrup *et al*., 2006b). Muscle glycogen level appears to drop below the required values to maintain maximal glycolytic rate (Bangsbo *et al*., 1992) and therefore sustain performance, as a result fatigue may occur. Recovery of performance and restoration of muscle glycogen can take between 48 and 72 hours (Krustrup *et al*., 2011). This impairment in glycogen re-synthesis and recovery may be due to muscle damage from the high number of eccentric contractions (Nédélec *et al*., 2012). Indeed, markers of muscle damage such as creatine kinase (CK), myoglobin and C-reactive protein (CRP) are elevated in blood plasma, coupled with elevated muscle soreness scores, over the same time frame (Andersson *et al*., 2008; Ispirlidis *et al*., 2008; Thorpe and Sunderland, 2012; Silva *et al*., 2013). These changes are indicative of damage to the muscle and subsequent leakage into the bloodstream.

Further to the elevation in markers of muscle damage, high intensity intermittent exercise also leads to an increase in reactive oxygen species (ROS) and antioxidants (Mohr *et al*., 2016). This leads to an increase in oxidative stress that may contribute to fatigue and impair recovery (Andersson *et al*., 2010; Fatouros *et al*., 2010). Antioxidants are increased following a soccer match to prevent oxidation of lipids and proteins. This increase appears to be present for up to 72 hours post match, mirroring the time course of markers of muscle damage and inflammation (Ispirlidis *et al*., 2008; Andersson *et al*., 2010; Fatouros *et al*., 2010; Magalhães *et al*., 2010; Silva *et al*., 2013; Mohr *et al*., 2016). Indeed markers of an inflammatory environment such as leukoytosis, inflammatory cytokines and cortisol appear to peak 24 hours post match (Ispirlidis *et al*., 2008; Fatouros *et al*., 2010; Magalhães *et al*., 2010). Despite this body of research, there is a distinct lack of studies that have attempted to tie together the changes in physical performance tests and biochemical markers with practical outcomes such as injury and illness.

Repeated, acute, physiological changes, when exacerbated by intensive scheduling, may mean players are pre-disposed to reduced performance, and an increased risk of injury and illness (Silva *et al*., 2014). Seasonal research demonstrates evidence of increased levels of muscle damage (plasma myoglobin and CK), oxidative stress and inflammation (increased CRP) mid and end season compared to pre and off-season (Silva *et al*., 2014). Levels of cortisol also seem to increase throughout the season (Filaire *et al*., 2003; Kraemer *et al*., 2004; Handziski *et al*., 2006). These changes may contribute towards the impairment of neuromuscular function; evidenced by reductions in sprint, jump and isokinetic strength performance (Kraemer *et al*., 2004). Objective markers of physiological change are also mirrored by changes in subjective wellbeing. Faude *et al*. (2011) and Noon *et al*. (2015) have reported reductions in psychological wellbeing as the season progresses in soccer players. These changes may be reflective of a congested fixture schedule and the limited recovery time mid-season. Although there are limited tangible links between changes in physiological markers and injury or illness, the immune system itself appears to be sensitive to the chronic load of professional soccer (Freitas *et al*., 2014). This may explain the patterns of illness in professional soccer mentioned in section 2.2.

The demands of professional soccer appear to alter markers of innate and acquired immune function; this may increase illness risk. Following acute bouts of soccer specific exercise, Malm *et al.* (2004b) reported a reduction in enumerative markers of innate immune function; the number of NK cells, lymphocytes and macrophages was reduced following 2 soccer matches, separated by 20 hours. Bishop *et al.* (2005) reported a reduction in the in vitro function of the acquired immune system; T cell proliferation was reduced when a soccer-specific exercise protocol was repeated twice in 3 days. Although these studies use markers of immune function that are not in vivo challenged, but rather taken out of the body where number or function is assessed in an isolated environment, they do show changes following soccer specific exercise. Further, sIgA (measured as a ratio of total protein) appears to fall in response to high intensity soccer training (Fredericks *et al.,* 2012; Morgans *et al.,* 2015; Owen *et al.,* 2016) and in response to match play (Fredericks *et al.,* 2012), when measured within 20 minutes of exercise cessation. This recovered to baseline following 18 hours of rest, however sIgA levels did not recover when 2 consecutive matches were completed, just 52 hours and 45 minutes apart (Fredericks *et al.,* 2012). The acute changes observed following professional soccer exposure might be reflective of the “open window hypothesis” proposed by Pedersen and Ullum (1994). This concept proposes that following strenuous exercise bouts there is a reduction in markers of systemic immune function; this temporary reduction may lead to opportunistic infections. Although illness incidence directly following these acute exposures was not recorded.

Chronic exposure to the demands of professional soccer also appears to alter markers of innate immune function. The number of neutrophils increased, whilst there was a reduction in neutrophil function, and no change in NK cell number or function, across a season in professional soccer players (Bury *et al.*, 1998). Rebelo *et al.* (1998) also reported an increase in neutrophil number across 11 months in professional soccer players. There are also effects on markers of acquired immune function following a soccer season; Bury *et al.* (1998) reported a reduction in T helper cell number and proliferative response, whilst Rebelo *et al.* (1998) reported an increase in the number of cytotoxic T cells. Following a 5-day training camp in junior soccer players, numbers of T helper, cytotoxic T, and B cells have also been reported to decrease (Malm *et al.,* 2004a). Further, reductions in sIgA have been reported following intensive soccer fixture scheduling, where professional players completed 5 matches in 15 days (Morgans *et al.,* 2014) and youth soccer players completed 7 matches in 20 days (Mortatti *et al*., 2012). Similarly, during a 21-week season in youth soccer players, sIgA appeared to increase following a period of lower physical load (Moreira *et al.,* 2014). The changes reported following chronic exposure to professional soccer have been linked to an increased URTI incidence, although the relationship has not been directly tested. An increased URTI incidence was reported in comparison to a student control group (Bury *et al.*, 1998) and post camp compared to pre camp (Malm *et al.,* 2004a). Reductions in sIgA also appear to coincide with an increased URTI incidence following a high level of accumulated fatigue from repetitive match play (Mortatti *et al.,* 2012), whilst increases in sIgA coincided with a reduction in URTI symptoms following a period of reduced training (Moreira *et al.,* 2014). The changes witnessed following chronic exposure to professional soccer support the concept of a J-shaped curve between the amount or intensity of exercise and illness risk (Nieman, 1994). This concept suggests that a moderate amount or intensity of exercise may lower the risk of a URTI compared to a very high amount or intensity of exercise (as is the case in professional soccer).

The longstanding concepts of the open window hypothesis and the J-shaped curve, have, however, recently been disputed. Campbell and Turner (2018) suggest that the reduction in systemic markers of immune function following exercise are a reflection of these cells migrating into tissues to perfrom immune surveillance and not the opportunity for infection. Walsh (2019) suggests that elite athletes are otherwise healthy individuals, who do not experience any more illness compared ot the general population. In actual fact, the training volume required of an elite athlete may be incompatible with a high amount of illness. Indeed, Malm (2006) updated the J-shaped curve to distinguish between "very high" and "elite" exercise demands. As such an S-shaped curve was proposed, where elite athletes exhibit a lower infection risk compared to those who perform a very high amount or intensity of exercise. This may be due to the need to withstand illness to perform at an elite level, the support received and the better lifestyle behaviours adopted from experience and/or education (for example; better hygiene, infection avoidance, diet, sleep and stress management) (Walsh, 2018). More research is needed within professional soccer, where recreationally active control groups are used to test whether the high physical demands of soccer, particularly around congested fixture schedules, are detrimental to immune function. Walsh (2019) continues to state that the risk factors elite athletes are exposed to are not any different to the general population, and exposure to intense exercise alone does not alter immune function enough to increase infection susceptibility. Simpson *et al.* (2020) supports this, concluding that other illness risk factors, alongside a high physical load, are likely to be just as important (life stress, long-haul travel, sleep disruption, nutritional deficits, genetic polymorphisms, infection/vaccination history, environmental extremes and time of year). As such, immune function may only be altered enough to increase infection susceptibility when changes in these factors are combined and pathogen exposure increases. It is unclear whether the specific demands of professional soccer alone can alter immune function enough to increase infection susceptibility or whether these other factors are also involved. Physical load and fatigue monitoring practices in professional soccer may be able to assess some of these risk factors to determine when players may be at an increased risk of illness. These tools may also be able to identify responses to the demands of professional soccer and highlight early warning signs of an increased illness risk.

2.6. THE LINKS BETWEEN PHYSICAL LOAD MONITORING, FATIGUE MONITORING AND ILLNESS RISK

One of the primary goals of sports science and medical practitioners working within professional soccer is to prevent high physical loads and excessive fatigue leading to non-functional overreaching (NFOR), injury and illness (Burgess, 2016; Bourdon *et al*., 2017). Meeusen *et al.* (2013) describes the pathway from short-term fatigue to overtraining syndrome (OTS) where injury and illness may occur. The key distinguishing factor between the stages of adaptation to training is the amount of time needed for performance restoration. Fatigue is defined as "any exercise or non-exercise-induced loss in total performance due to various physiological factors, athlete reported psychological factors, or a combination of the two" (Micklewright *et al.,* 2017). Meeusen *et al.* (2013) suggests that following acute fatigue recovery is rapid, usually within 24-48 hours. Functional overreaching (FOR) occurs in response to a planned intensified training stimulus. In this case there may be a short-term performance decrement whilst fatigue is present, for days to weeks, but athletes recover to an enhanced level of performance, as a result of the higher physical load. When intensified training continues with no regard for recovery, NFOR may occur. At this point there may be signs of psychological disturbance such as decreased vigour and increased fatigue. This is alongside stagnation in performance that will recover, but not for weeks to months. At this point other factors such as inadequate nutrition, frequent URTI's, psychological stressors and sleep disorders may be present. There is a fine line between NFOR and OTS as many of the signs and symptoms are the same. The key distinguishing factor for OTS is a prolonged maladaptation of the athlete through several biological, neurochemical, and hormonal regulation mechanisms. Performance restoration may take months, with the possibility that performance will never fully recover. NFOR and OTS are both characterised by an increased URTI incidence, which may be due to changes in immune function. Physical load and fatigue monitoring practices within professional soccer may be able to identify athletes at risk of NFOR, prior to this occurring, to prevent an increase in injury and illness risk.

Monitoring the physical load experienced by players has now become commonplace in professional soccer. Physical load in professional soccer has been divided into different components, namely the prescribed load (external load) and the response this causes (internal load) (Impellizzeri *et al.*, 2005). External load is the main determinant for internal load, but other factors such as fitness and fatigue will influence the internal load experienced and therefore the adaptation (Impellizzeri *et al.,* 2005). The suggested goals of physical load monitoring are; to make evidence-based decisions on the appropriate loading schemes to reduce injury and illness risk, to maximise performance and to evaluate the training process (Akenhead and Nassis, 2016; Buchheit and Simpson, 2017; Foster *et al*., 2017; Weston, 2018). Monitoring fatigue, to gain an insight into athlete status in response to physical load, has also become important in soccer to aid optimal adaptation, whilst guarding against NFOR, injury and illness (Twist and Highton, 2013; Thorpe *et al*., 2017). Athletes will undoubtedly experience fatigue at some point; it is important to monitor this to understand when fatigue is acute or functional, leading to adaptation, and chronic, which may be an indicator of NFOR (Robson-Ansley *et al*., 2009). See table 2.2 for a summary of physical load and fatigue monitoring tools linked to illness risk in professional soccer players.

There does appear to be a relationship between physical load markers and illness risk as reported by multiple systematic reviews (Drew and Finch, 2016; Schwellnus *et al*., 2016; Jones *et al*., 2017). This relationship appears to be centred on sudden "spikes" or changes in chronic physical load, a change in volume or intensity away from the accustomed load, leading to additional pressure on immune function and a higher risk or incidence of illness (Walsh *et al*., 2011; Schwellnus *et al*., 2016). Multiple studies, conducted within different sports, have observed an increased illness risk in the weeks following an increase in weekly training load above normality (Foster, 1998; Putlur *et al*., 2004; Piggott, 2008). More recently, Thornton *et al*. (2014) assessed the relationship between subjective training load, wellbeing and self-reported illness in professional rugby players, across 29 weeks. The study found that a higher than normal weekly training load, strain and monotony best predicted illness. Similarly, Watson *et al*. (2017) examined the relationships between subjective training load and self-reported illness in female, adolescent soccer players, across a 20-week season. The study reported that an increase in both weekly and monthly training load by 1 z-score was related to an increased illness risk of 50% and 54% respectively. Intensive training blocks have also been linked to a higher illness occurrence compared to other periods in elite swimmers. Hellard *et al*. (2015) found a 0.74 times greater illness risk during intensive training blocks (a mean training volume of greater than or equal to 60% of an individuals maximum) compared to other time periods.

Outside of spikes in physical load, other load-related factors have been suggested which may be related to an increased illness risk. Both Brink *et al.* (2010) and Gleeson *et al.* (2013a) have observed a higher incidence of illness in athletes who have a significantly higher weekly training duration compared to other athletes. Brink *et al*. (2010) reported a 1.12 times greater chance of becoming ill in 53 youth soccer players who had a consistently high training volume, compared to those who trained less. There is clearly a need to periodise training load sensibly to avoid these risks. The highest physical load athletes experience is likely to be during competition. Svendsen *et al*. (2015) assessed self-reported illness in 44 cross-country skiers during the Tour De Ski, using 9 seasons worth of training diaries and HR data. Illness incidence was 3-fold higher in those who completed the race, in the days following, compared to those who did not. Competition clearly involves multiple other factors not experienced by those who did not complete the race. These include increased pathogen exposure, pressure of performance and travel stress. It is these factors that are often assessed by fatigue monitoring tools, which are shown to have some association with illness risk.

Jones *et al*. (2017) completed a systematic review of fatigue marker associations with illness within sport. The review reported that the majority of studies in this area have focussed on using subjective fatigue markers or psychometric questionnaires to model the fatigue and illness relationship. In general, findings are mixed with some of these studies stating that higher subjective fatigue ratings are associated with a lower incidence of URTI's (Hooper and Mackinnon, 1995; Veugelers *et al*., 2016). The review proposes that the higher fatigue ratings may have caused some modification to training where load is reduced, and therefore URTI risk decreases. Another particular subjective fatigue item, used in multiple questionnaires and correlated with illness, appears to be stress. Multiple papers, utilising different tools, have highlighted the relationship between higher stress levels and a higher illness risk (Anderson *et al*., 2003; Brink *et al*., 2010; Drew *et al*., 2017b).

Aside from subjective fatigue markers, there has been a multitude of other fatigue markers linked to an increase in illness risk. An elevated HR during submaximal exercise, in comparison to normal, was predicative of sickness the following day

(Buchheit *et al*., 2013b). A reduction in HRV was linked to a higher infection risk, in the following week, in elite swimmers (Hellard *et al*., 2011). A low energy availability and poor hygiene practices were related to illness in 81 athletes, from a variety of sports, 9 months prior to the Olympic games (Drew *et al*., 2017b). International travel, in particular where there was a time difference of 5 hours or more, was related to an increased risk of illness in elite rugby players (Schwellnus *et al*., 2012). Shorter sleep duration, specifically less than 6 hours, was associated with an increased risk of the common cold in a healthy general population sample (Prather *et al*., 2015). Despite studies assessing a multitude of training load and fatigue markers in isolation, few papers have looked at the load-fatigue interactions and associations with illness. The fatigue status of an individual may determine how much load they can tolerate before illness risk increases (Jones *et al*., 2017). Only Thornton *et al*. (2014) has assessed the relationship between subjective training load, wellbeing and illness. As mentioned above, a higher than normal weekly training load, strain and monotony best predicted illness, whilst typical subjective wellbeing markers such as sleep, general feelings of wellbeing, soreness and diet did not appear to contribute as much.

Despite the comprehensive body of literature described above, there are some discrepancies within this area linking training load and fatigue to illness risk. The majority of studies have not accounted for a lag time between spikes in training load and an increased illness risk. Drew and Finch (2016) reported that a lag of up to 4 weeks might be present between a spike in training load and an illness presenting itself. Instead the majority of studies continue to assess weekly training load that may be lower because of the illness event itself. Jones *et al*. (2017) suggests that, following a spike in load, fatigue markers may change for a period of 7-21 days; it is failure of these markers to return to baseline during this period that increases illness risk. Further to this, few studies have used multivariate modelling to determine the contribution and dose-response relationship between specific factors and illness risk (Schwellnus *et al*., 2016). Selection of these factors is of paramount importance to accurately assess the relationship, although few studies have linked objective physical load or fatigue assessment to illness risk. Finally, the research has not accounted for other potential co-founders of the training load, wellbeing and illness relationship. As Figure 2.1 demonstrates, the physical demands of professional soccer, the psychological demands of professional soccer, life stress, pathogen exposure, poor hygiene, sleep disruption, environmental extremes, long-haul travel, vaccination/infection history, a high gene expression of inflammatory cytokines, low levels of salivary antibodies such as sIgA, time of year and nutritional deficits, may all increase illness risk in professional soccer players. These risk factors need consideration within the relationship. Whilst changes in physical load and fatigue monitoring markers may identify players who are at an increased risk of illness, tools to assess immune function in practice are also available.

Table 2.2. Physical load and fatigue monitoring tools linked to illness risk

Tool	Measurement	Mechanism	Evidence	Limitations
Physical load monitoring	Data collected via microelectromechanical system (MEMS) units (Global positioning system (GPS), accelerometer data), HR monitoring, rating of perceived exertion (RPE) monitoring and training duration.	Abrupt changes in physical load, a change in volume or intensity away from the accustomed load, appears to lead to additional pressure on immune function and a higher risk or incidence of illness.	An increase in weekly RPE load explained 84% of illness, strain explained 89% and monotony explained 52%, in speed skaters (Foster *et al.,* 1998). 55% of illness was explained by an increase in weekly RPE load, 64% was explained by either an increase in monotony or strain, in female youth soccer players (Putlur *et al.,* 2004). 42% of illness was explained by an increase of 10% or more in weekly RPE load, in AFL players (Piggott *et al.,* 2008).	The evidence at present has been collected using subjective markers of physical load (RPE, monotony and strain), there has been no work completed that relates objective physical load measures, which are commonplace in professional soccer, to illness risk.

			Weekly training duration was significantly higher in elite youth soccer players who became ill compared to healthy players (Brink *et al.,* 2010). Weekly RPE load, strain and monotony, greater than normal, predicted illness in professional rugby players (Thornton *et al.,* 2014). A 10% increase in weekly training load (water high-load and dry-land resistance training) increased the odds of becoming ill in professional swimmers, the odds of illness were also 50-70% higher during intensive training periods (Hellard *et al.,* 2015). Increases in weekly and monthly training load, by 1	

			z-score, were related to an increased illness risk of 50% and 54% respectively, in female youth soccer players (Watson *et al.,* 2017).	
HR indices	*HR in response to a sub-maximal test -* HR assessed in response to a standardised sub-maximal test, for example HR over the last minute of a 5-minute running test at 9km/h (Buchheit *et al.,* 2013b) or in response to a 5-minute cycle test (maintain 130 watts or 85 RPM) then sit seated for 5 minutes in silence (Thorpe *et al.,* 2015). *HRV assessment -* HRV (measured as the	*HR in response to a sub-maximal test -* An elevated HR suggests that athletes find the standardized test harder than normal to complete, this may be due to the effects of an underlying illness or fatigue on the nervous system, for example increased sympathetic activity (Buchheit, 2014). *HRV assessment -* HRV is a marker of nervous system function, when this	*HR in response to a sub-maximal test -* Buchheit *et al.* (2013b) reported that a 4% increase in HR response to a sub-maximal test, in response to a moderate increase in TL on the previous day, was predicative of illness on the following day. *HRV assessment -* Hellard *et al.* (2011) reported an increased risk of infection in swimmers following a reduction in	*HR in response to a sub-maximal test -* Although these tests are simple to administer in a team sport environment, there is limited evidence that HR response to submaximal exercise can be used to show illness risk or that this is a clear marker of fitness-fatigue impairment (Buchheit, 2014). *HRV assessment -* Standardisation of testing can be difficult in a team

	variability in the time between R-R intervals) is recorded at rest, for example Hellard *et al.* (2011) recorded this at 09:00 AM weekly, at rest, for 8 minutes in supine/orthostatic positions via a polar HR monitor, whilst Buchheit *et al.* (2013a) measured HRV following a 5-minute shuttle test (during the first and last 3 minutes of recovery).	is high it reflects that sympathetic and parasympathetic arms have equal input, when lower (or extremely higher) than normal this suggests sympathetic dominance due to an underlying condition or fatigue related factor (Buchheit, 2014). Baumert *et al.* (2006) reported an increased resting heart rate (RHR), reduced HRV and reductions in baroreflex sensitivity response following a 2-week intensified training camp in track and field athletes. Buchheit *et al.* (2013a) reported a positive correlation between HRV and high speed running in AFL players during pre-season, the heat may have caused plasma volume	HRV.	sport setting, this is important given how sensitive HRV is to environmental conditions (for example, light, noise and temperature), ideally testing should be conducted at rest to isolate the effects of physical load or fatigue on HRV. To overcome limitations it is recommended that HRV is collected during slow wave sleep episodes, these offer signal stability and a high standardisation of the environmental and respiratory influences on HRV (Buchheit, 2014).

		expansion and therefore a greater stroke volume meaning a greater HR was no longer needed to maintain a high cardiac output.		
Self-report questionnaires	There are a variety of self-report questionnaires availiable for monitoring fatigue, general soreness, sleep, stress, mood and energy availability.	These factors may change in response to a high physical load, the presence of an illness or other lifestyle factors. Many of the factors assessed are independent risk factors for an increased illness risk in athletes. Therefore, questionnaire responses may identify athletes who are at an increased risk of illness.	Multiple papers, utilising different tools, have highlighted the relationship between higher stress levels and a higher illness risk (Anderson *et al*., 2003; Brink *et al*., 2010; Drew *et al*., 2017b). Low energy availability, assessed via the Low Energy Availability in Females Questionnaire (LEAF-Q), was related to sustaining an illness in the previous month, in 81 athletes, from a variety of sports, 9 months prior to the Olympic games (Drew *et al.,* 2017b).	The questionnaire responses are subjective; responses may be influenced by other external factors. Compliance to the questionnaires may be difficult, and can become tedious when assessed frequently, particularly with lengthy questionnaires. The links between fatigue responses and illness are limited at present. Studies often only assess responses in the weekly period around the illness event; fatigue responses

			Poor hygiene (measured via the personal and household hygiene questionnaire for university students) was related to illness. Those who reported washing their hands for less than 10 seconds were 3 times more likely to report missing a training session due to illness in the previous month (Drew *et al.,* 2017b).	may show no change at this point as physical load is often modified to account for the symptoms present (Jones *et al.,* 2017).
Travel demands	Number of hours travelled and number of time zones crossed can be counted (Schwellnus *et al.,* 2012).	The effects of travel on illness risk may be due to the resulting sleep disruption or specific factors such as drying of respiratory epithelium, close contact with fellow travellers, exposure to re-circulated air, or the destination itself (temperature, humidity,	The amount of travel completed by rugby union players was assessed during a 16-week tournament. International travel to a foreign location, with a time zone difference greater than 5 hours from home, was associated with a 2-3 times increased risk of illness when home	Accurate assessment of travel demands can be challenging, practitioners are often reliant on athletes providing accurate information regarding their travel.

		climate, altitude, pollution, pollens, food and foreign pathogens) (Schwellnus *et al.,* 2012).	(Schwellnus *et al.,* 2012).	
Objective sleep monitoring	Sleep laboratory assessment, actigraphy or other commercial wrist-worn devices.	The mechanisms underpinning the effects of sleep disruption on illness risk are unknown at present. However, Haack *et al.* (2007) reported an increase in inflammatory markers following chronic sleep disruption.	Low sleep efficiency and sleeping for less than 6 hours per night appears to increase illness risk (Cohen *et al.,* 2009; Prather *et al.,* 2015).	Athlete buy-in to monitoring sleep can be challenging; they may feel this is an invasion of privacy. Further, accurate assessment can be expensive.

2.7. MEASURING IMMUNE FUNCTION IN THE REAL WORLD

There are a variety of tools available to practitioners working in professional soccer to directly assess immune function; these markers may give an indication of an athlete's susceptibility to infection. Immune function is described in more detail in section 2.3, whilst the response of the immune system to professional soccer training and match play is described in section 2.5. Indeed, the immune system does appear to be responsive to the demands of professional soccer; these responses may reveal information about the presence or risk of infection. Laboratory-assessed blood tests can provide an indication of total leukocyte count, along with differential leukocyte counts (neutrophils, lymphocytes, monocytes etc.) in athletes. Blood samples can also be used in flow cytometric analysis to identify different lymphocyte subsets. Links between these markers and illness risk in athletes, however, are sparse. Cox *et al.* (2008) reported elevated numbers of leukocytes (neutrophils in particular), in elite level athletes at the Australian Institute of Sport (AIS), who had symptoms suggestive of illness. However, in athletes who had infection confirmed via pathogen identification, there were no changes in leukocyte subset counts. Cell counts are often too costly and time consuming to be used to impact practice in the real world. Further, these are enumerative measures of immune function, revealing little information about the function of the cells in question.

Functional immune assays, following fresh blood sample collection, are used to get an insight into immune cell function. These tests determine the response of the immune system to a given form of stimulation. Examples of functional immune assays include, neutrophil phagocytic activity, NKC activity and mitogen-stimulated lymphocyte proliferation. There is evidence of these markers changing in response to chronic soccer exposure. Bury *et al.* (1998) reported a reduction in neutrophil function, NKC function and T-cell proliferation following a soccer season. Although these tests give an insight into immune function, the evidence linking test changes to illness risk in athletes is poor. Further, functional immune assays are in vitro immune tests; these tests are conducted outside of the body and normal systemic function. In vivo immune tests such as blood antibody response to vaccination and skin delayed-type hypersensitivity tests can also be used in practice. These represent the integrated response of the body to immune challenges. However, once more there is little evidence of the links between these tests and infection susceptibility in athletes, possibly due to the invasive nature of these assessments.

Cytokines, which assist in co-ordinating the immune response, may also reveal information regarding immune function and infection susceptibility. Enzyme-linked immunosorbent assay (ELISA) analysis is often used to assess the amount of cytokines present in blood plasma. There is evidence that illness prone athletes have higher levels of plasma inflammatory cytokines. Cox *et al.* (2010a) and Gleeson *et al.* (2017) identified an underlying genetic predisposition to a high expression of IL-6 in athletes prone to frequent upper respiratory symptoms (URS). Cullen *et al.* (2017) also reported higher levels of IL-6 in illness prone athletes compared to those who became ill less often, in highly trained endurance athletes. The symptoms experienced by athletes with high levels of these cytokines may actually be inflammatory symptoms that mimic URTI symptoms, rather than an actual infection. This information may be useful in athletes who are particularly prone to illness symptoms so appropriate interventions can be considered. It is, however, important to consider that blood sampling and analysis (cell counts, cell function, cytokine concentration) are invasive and expensive. In a practical sense this may limit the frequency of assessment needed to impact the fast paced world of professional soccer.

Salivary antimicrobial protein (AMP) assessment has also been used to assess immune function. This relies on saliva samples, which until recently, were collected via passive drooling and analysed using ELISA, to provide the concentration of markers such as sIgA. This marker in particular has received support as a marker that is both sensitive to illness risk factors and reflective of infection risk in athletic populations (Gleeson and Pyne, 2015; Albers *et al.,* 2013; Gleeson *et al.,* 2017). Traditionally salivary AMP assessment has been considered as highly variable, costly and time consuming. However, Coad *et al.* (2015) reported the high validity and reliability of a lateral flow device (LFD) for the measurement of the concentration of sIgA. This procedure is a cost-effective, faster alternative to passive drooling and ELISA assessment. The procedure can be completed within the field using an LFD reader and a small oral fluid collector, requiring only 0.5 ml of saliva. There are, however, considerations that should be observed when collecting saliva samples. Samples should be collected following 38 hours of rest, in a fasted state (Neville *et al.,* 2008; Fredericks *et al.,* 2012). The values obtained should also be compared against individual average values, ideally on a week-to-week basis, to minimize variation (Neville *et al.,* 2008; Fredericks *et al.,* 2012). With these considerations in mind, this analysis may provide practitioners with a real-time, cost effective measure of immune function that is both sensitive to risk factors and reflective of infection susceptibility (Gleeson and Pyne, 2015; Albers *et al.,* 2013; Gleeson *et al.,* 2017). The identification of changes in illness risk factors, through physical load monitoring and fatigue monitoring, or changes in direct markers of immune function, may provide the opportunity for specific, targeted interventions to reduce the risk of illness occurring. However, evidence-based interventions to reduce illness risk in professional soccer players, or athletes in general, are lacking from current literature.

2.8. ILLNESS PREVENTION STRATEGIES

Illness prevention strategies are clearly an integral part of an athletes' health management (Schwellnus *et al*., 2016). These strategies are important to allow uninterrupted training and competition participation (Schwellnus *et al*., 2016). Illness prevention strategies are also important to reduce the impact of any potential illness on performance and the ability to sustain high intensity training (Gleeson and Burke, 2007). Given the importance of such recommendations, guidelines for illness prevention have been reviewed and summarised within the literature (Schwellnus *et al*., 2016; Walsh, 2018; Castell *et al*., 2019). However, translation of these guidelines from research into evidence-based, multifactorial interventions within professional soccer is poor. Walsh (2018) summarises illness prevention strategies into guidelines that target preventing, or limiting the effects of, excessive physical load, life stress, sleep disruption, environmental extremes, travel and nutritional deficits. Schwellnus *et al.* (2016), Gleeson *et al.* (2017) and Castell *et al.* (2019) also consider strategies involving behavioural, lifestyle and medical factors.

The relationship between physical load and illness has been reviewed extensively above and does form part of guidelines for illness prevention in athletes (Schwellnus *et* *al*., 2016; Walsh, 2018; Castell *et al*., 2019). Guidelines are based on the premise that sudden "spikes" in physical load, around 10% above normality, increase illness risk (Foster, 1998; Putlur *et al*., 2004; Piggott, 2008; Thornton *et al*., 2014; Watson *et al*., 2017). Practitioners are advised that physical load and changes in that load should be monitored, both internally and externally, and individualised to particular athletes (Schwellnus *et al*., 2016; Walsh, 2018; Castell *et al*., 2019). Also changes in physical load (volume and intensity) should be in small increments of 5-10% across a week, competition load should be monitored and managed accordingly, shorter, intense sessions may pose less illness risk than longer, volume-based sessions and recovery strategies should be adopted during and after intensive periods of training and competition (Schwellnus *et al*., 2016; Walsh, 2018; Castell *et al*., 2019). Athletes at a heightened risk of illness may also benefit from even further additional recovery periods following intensive training periods or major competitions (Walsh, 2018). Despite these recommendations existing, based on good scientific principles, they are often difficult to implement in practice, particularly in a team sport setting, as they rely very much on coach buy-in. Consequently, in a research setting, there are few interventions which have targeted controlling physical load as a strategy to prevent illness. Psychological load or life stress can also influence immune function and illness risk.

According to Walsh (2018) athletes may experience psychological stress relating to competition, injury, team selection, travel, sleep disruption, jetlag and personal issues. Professional soccer players are regularly exposed to these factors. Walsh (2018) describes how stress influences immune function through similar pathways as exercise. The body reacts to both exercise and stress as challenges, these challenging situations are met by a series of co-ordinated hormonal responses controlled by the central nervous system (CNS). The situation is first appraised cognitively (pleasant or adverse, coping or overloaded). The central control station in the hypothalamus, made up of the HPA (hypothalamic-pituitary-adrenal) and SAM (sympathetic-adrenal-medullary) axes, controls adrenal hormone release (cortisol, epinephrine, norepinephrine). Following appraisal, these hormones are released, directly impacting immune function. Acute stress appears to cause a similar response to moderate volumes or intensities of exercise, increasing markers of immune function (Dhabhar, 2014). However, chronic stress may impair the immune response to a challenge (Dhabhar, 2014). There is evidence of a relationship between stress, and immune function (Dhabhar, 2014), and illness risk in athletes (Anderson *et al*., 2003; Brink *et al*., 2010; Drew *et al*., 2017b). As such it is recommended that; unnecessary life stress is minimised, coping strategies are developed, training and/or competition load is reduced for those who struggle with daily hassles and tools to monitor psychological stress are implemented (Schwellnus *et al*., 2016; Walsh, 2018; Castell *et al*., 2019). The factors mentioned above may pose a significant psychological burden on athletes. However, there is a lack of published literature that has implemented the guidelines mentioned to influence immune parameters or illness risk in athletes. Sleep disruption may affect illness risk directly or by increasing psychological load.

In professional soccer players, sleep may be disrupted as a result of competitive demands (psychological and physical), life stress and excessive travel. Both Cohen *et al.* (2009) and Prather *et al.* (2015) reported an increased risk of the common cold, when sleep duration was reduced, in the general population. Following periods of 7 and 14 days of sleep monitoring respectively, subjects were administered with nasal drops containing rhinovirus and then monitored for symptoms of the common cold. Cohen *et al.* (2009) reported that those who slept less than 7 hours per night were more likely to develop a cold compared to those who slept 8 hours or more, whilst Prather *et al.* (2015) reported that sleeping less than 6 hours increased the risk of developing common cold symptoms compared to 7 hours per night. In an athletic population, Hausswirth *et al.* (2014) reported a reduced sleep quality and an increased incidence of URTI symptoms in FOR triathletes. The mechanisms behind sleep disruption lowering immune function and increasing illness risk are, however, unknown. Chronic sleep disruption, over 28 days, leads to an increase in inflammatory cytokines such as IL-6 (Haack *et al.,* 2007); this has been suggested as a potential mechanism. Adopting strategies that facilitate good sleep quality are recommended to prevent adverse effects on immune function (Walsh, 2018). Guidelines such as, aiming for 7 hours of sleep per night, avoiding restricting and ‘catching-up’ on sleep, considering objective monitoring of sleep duration and efficiency using a wearable device, considering daytime naps, optimising sleep hygiene and ensuring darkness at bedtime have been proposed to maintain immune health in athletes (Walsh, 2018). Indeed, Tuomilehto *et* *al.* (2017) implemented a successful counselling-based sleep hygiene intervention in professional hockey players. This was found to improve subjective sleep quality. Interventions may also be beneficial to prevent environmental conditions, that athletes are often exposed to, influencing immune function.

In English professional soccer, the winter fixture schedule is a key period. It is not uncommon for players to participate in multiple fixtures per week, with just 48 hours of recovery between games, across the Christmas and New Year period *(Morgans et al.,* 2014). Whilst this clearly presents a challenge from a physical perspective, this time of year is characterised by a surge in viral outbreaks (common cold and influenza season) that increase the risk of infection (Hellard *et al.,* 2015; Walsh, 2018). Indeed professional soccer players do seem to experience peaks in illness incidence across the winter months (November - February) (Orhant *et al.,* 2010; Bjørneboe *et al.,* 2016). Whilst the exact mechanisms are unknown, Foxman *et al.* (2015) demonstrated that rhinovirus replicated more robustly in lower ambient temperatures of the nasal cavity, as is the case in winter. Whilst competing during winter in unavoidable for professional soccer players, guidelines state to avoid breathing in large volumes of cold, dry air, and to acclimatise to these conditions where possible (Walsh, 2018). Recent acclimatisation research by Buijze *et al.* (2016) demonstrated how a hot to cold shower for 30 seconds each day reduced sickness days by nearly 30% in the general population. Screening for airway inflammation disturbances such as asthma and allergies, as well as reducing exposure to very cold or dry air, is also advised (Walsh, 2018). Research by Cox *et al.* (2008) concluded that only 57% of URS identified in 70 elite athletes were infectious, instead symptoms were mostly inflammatory in origin. Screening for and controlling inflammatory disturbances such as those mentioned may help reduce the amount of symptoms experienced. In an attempt to do this, Cox *et al.* (2010b) used anti-inflammatory throat spray. The spray reduced symptom severity and markers of local inflammation in half-marathon runners. Consideration of these factors, alongside high levels of physical load, life stress and sleep disruption may be even more important during periods of high amounts of travel.

Professional soccer players are exposed to high amounts of travel throughout the season. It is commonplace for players to travel either by coach or plane, to the destinations of away fixtures, multiple times within a weekly period. This may be further exacerbated when players travel away for international fixtures, for pre-season, and for mid-season training camps. As mentioned above, there appears to be an increase in URS that coincide with long-haul travel (Schwellnus *et al.,* 2012). The effects of travel on illness risk may be due to the resulting fatigue or sleep disruption, as well as specific factors such as drying of respiratory epithelium, close contact with fellow travellers, exposure to re-circulated air, or the destination itself (temperature, humidity, altitude, pollution, pollens, food and foreign pathogens) (Schwellnus *et al.,* 2012). Athletes may also experience high levels of psychological stress due to travel, including fear of flying, delays and being away from their family members for an extended period of time (Walsh, 2018). Therefore, adopting measures to reduce the risk of illness associated with international travel is advised. Walsh (2018) recommends maintaining high levels of personal and sleep hygiene, proper nutrition and reducing unnecessary stress during periods of high amounts of travel to maintain immune health and reduce infection susceptibility. Preventing nutritional deficits may be key during periods of high risk such as before, during and after travel, but also in general to support immune function.

Nutritional deficiencies may impair immune function, for example insufficient energy, macronutrient and micronutrient intake (Walsh, 2018). Nutritional intake can also directly influence the immune response to exercise, for example stress hormones that may suppress immune function, increase during prolonged exercise, when blood glucose levels fall (Walsh, 2018). According to Davison *et al.* (2014), maintaining a balanced diet with sufficient energy, macronutrient and specific micronutrient intake is the best advice provided. A diet high in the macronutrient carbohydrate, fuel for immune cells, is advised for athletes to prevent immune impairment (Burke, 2010). Whilst evidence is lacking around a high carbohydrate diet preventing illness incidence itself (Williams *et al*., 2019), there is evidence that a high carbohydrate diet dampens the stress response observed following exercise, that may contribute towards immune impairment (Bishop *et al*., 2001). Immune function is also seemingly reliant on the macronutrient protein, for the rapid replication of cells (Williams *et al*., 2019). Whilst adopting a diet high in protein has been advised for athletes to prevent illness (Schwellnus *et al*., 2016) and shown to attenuate reductions in circulating immune cells during heavy training (Witard *et al*., 2014), there is no evidence that a higher protein intake reduces illness incidence. Davison *et al*. (2014) concluded that the majority of evidence for nutrition improving immune function is weak as few studies focus on actual illness incidence, rather on the effects of the intervention on specific markers of immune function. A model proposed by Walsh (2019) also suggests that nutritional supplements aimed at reducing illness incidence in athletes are often shown to be ineffective as the athletes are otherwise healthy and not immunosuppressed. Instead, a focus for nutritional interventions should be on improving an athletes tolerance to infection, where the immune system endures and controls infection at a non-damaging level Walsh (2019). This is measured by the amount of time affected, or the duration of illness, rather than illness incidence itself Walsh (2019).

More recent research has focussed on micronutrient intake to prevent illness. The monitoring and subsequent supplementation of vitamin D has been suggested as a guideline to maintain immunity in athletes, with vitamin D believed to influence immune cells through the expression of genes (Bermon *et al*., 2017). There does appear to be a negative association between vitamin D status and illness risk, where lower than optimal status can lead to an increased risk of URS (Cox *et al*., 2008; He *et al*., 2013; Svendsen *et al*., 2016). Vitamin D supplementation has been shown to protect against URTI incidence in the general population (Martineau *et al*., 2019) and reduce URS during the winter, in Taekwondo athletes (Jung *et al*., 2018). Vitamin C supplementation, an antioxidant that works against free radicals, has also been suggested as an illness prevention strategy and does appear to reduce the duration of common cold symptoms (Hemilä and Chalker, 2013). However, there is no effect of supplementation on illness incidence, or benefit to initiating supplementation, following the onset of URS (Hemilä and Chalker, 2013).

Probiotic supplementation is believed to support microbes in the gut and exert effects further up the respiratory tract, to reduce URTI risk (Williams *et al*., 2019). It has been commonly referred to as a strategy to prevent illness in athletes (Schwellnus *et al*., 2016). In a systematic review by Hao *et al*. (2011) it was concluded that, compared to a placebo, probiotic supplementation reduced the number of illness days and resulted in fewer absent days from work or school in non-athletic populations. These findings have also been replicated in athletic populations (Cox *et al*., 2010c; Gleeson *et al*., 2011), where probiotic supplementation has also been used successfully to counteract the increased risk of illness associated with air travel (Svendsen *et al*., 2016). At the onset of cold symptoms zinc lozenge supplementation is advised (Schwellnus *et al*., 2016). There is strong evidence that URS duration, in particular sore throats, can be reduced via the local effects of zinc on the pharyngeal region (Hemilä and Chalker, 2015; Hemilä, 2017). Finally, guidelines for illness prevention also state that athletes should consider consumption of polyphenol supplements such as quercetin (Schwellnus *et al*., 2016), believed to have strong anti-inflammatory properties (Davison *et al*., 2014). Despite the mechanisms being unknown, high doses of quercetin around intensified training periods reduced URTI incidence in trained cyclists (Nieman *et al*., 2007). The aforementioned nutritional countermeasures may, however, have little benefit if some of the strategies regarding behavioural, lifestyle and medical factors are not adopted.

The reviews mentioned above (Schwellnus *et al*., 2016; Walsh, 2018; Castell *et al*., 2019) suggest numerous guidelines to improve behaviour and lifestyle, whilst offering medical advice, for practitioners and athletes, to improve immune function and reduce infection risk. For example, athletes are advised to, minimise contact with infected people and those outside of their team, adopt good hand-washing practices, always carry hand sanitizer, avoid sharing cutlery, ensure good standards of food preparation, become isolated upon symptom onset, and ensure up to date vaccinations. Further to these recommendations, identifying athletes who are at a high risk of illness and those who have consistent complaints leading to illness, is suggested. This should be done based on previously collected illness incidence data, in an appropriate surveillance system, with the relevant precautions taken. Whilst there is undoubted difficulty associated with the implementation of an intervention to address all of the factors mentioned above, given the apparent multi-factorial nature of illness risk (Walsh, 2018), there needs to be some effort made to implement holistic illness prevention interventions in athletes.

Despite practitioners being advised to develop, implement and monitor illness prevention guidelines for athletes and support staff (Schwellnus *et al*., 2016), there have been very few published papers on this. As mentioned continually, illnesses may disrupt preparations and reduce the chance of success in large-scale athletic events such as the Olympic games (Hanstad *et al*., 2011; Raysmith and Drew, 2016). There is, therefore, a need for the development, implementation and monitoring of illness prevention programmes within athletes (Schwellnus *et al*., 2016). There are only 3 papers that have employed evidence-based, multifactorial, interventions in an attempt to reduce illness incidence within athletes (Hanstad *et al.,* 2011; Ranchordas *et al.,* 2016; Schwellnus *et al.,* 2020), with only the latter 2 focussed within a team sport setting.

Hanstad *et al*. (2011) documented the efficacy of an illness prevention programme in the Norwegian Olympic team for the 2010 winter Olympic games. Illnesses, regardless of the need for time-loss, were compared between the 2006 and 2010 winter Olympic games. The common sense illness prevention strategies included; developing and sharing best practice guidelines on illness prevention, screening for illness risk, vaccinations for all staff and athletes, targeting high-risk athletes with isolated rooms when away on tour, indoor air cleaning systems, disinfectant and rigorous cleaning routines. This holistic intervention resulted in the amount of athletes who became ill being reduced from 17.3% in 2006 to 5.1% in 2010. Whilst the study did assess adherence to the programme in terms of vaccinations and high-risk screening, the multifactorial intervention design makes it difficult to see which parts of the intervention were effective and which were not. It is vital that the reasons behind the effectiveness of interventions such as this be determined so future practice can be revised and improved.

Schwellnus *et al.* (2020) implemented a total illness prevention strategy (TIPS), across 4 years, in 6 South African teams participating in the Super Rugby tournament. The paper compared the 4-year intervention period to the previous 3 years, where an intervention was not present. The intervention involved; (1) pre-tournament screening of players at increased risk of illness; (2) during the tournament, sharing of utensils or water bottles was discouraged, whilst ensuring good sleeping habits, regular hand washing and/or use of personal antiseptic hand gel, avoidance of continuous exposure to air-conditioned or polluted environments, considering high-dose vitamin C supplementation (>1000 mg/day), early reporting of symptoms and early isolation of players at the onset of symptom development, were encouraged; (3) additional international travel guidelines such as considering prophylactic local antimicrobial spray, probiotics and antibiotic prophylaxis were also provided. The paper reported a 59% reduction in total illness rate (18 incidence per 1000 player-days to 5 incidences per 1000 player-days). Whilst the study provides evidence that an illness prevention intervention can be implemented across a team, there is no data presented on adherence to illness prevention strategies, or which components were most effective.

To the authors knowledge, Ranchordas *et al.* (2016) is the only available piece of evidence to put in place and test the effectiveness of an intervention to support immune function in professional soccer, albeit in 1 player. The study assessed sIgA as a marker of mucosal immunity, alongside self-reported URTI incidence, before and after a 12-week intervention. The nutritional and lifestyle intervention involved increasing energy intake, vitamin-D supplementation, changing hygiene habits and improving sleep quality via education. In the weeks following the intervention, sIgA concentration increased, alongside a reduction in URS. The study did make some attempt to unpick the mechanisms behind these effects with an increased energy intake, vitamin D concentration and sleep hours per night all recorded. However, the case study nature of this investigation makes it difficult to comprehensively link the intervention, improved mucosal immunity and a reduced illness incidence. Whilst successful in 1 player, the same principles need to be applied across a full squad in professional soccer. Behavioural change may underpin the effectiveness of both interventions, yet is not mentioned in either. It appears to be one of the key factors contributing to the success of interventions targeting health behaviour improvements.

Heijnen and Greenland (2015) conducted a review into the effectiveness that could be expected from a hygiene promotion to improve hand washing. They reported that factors that may have affected the results were the intervention itself, pre-existing habits, knowledge of hygiene behaviours, social norms and underlying theories of behavioural change. The review also reported that improvements in knowledge do not necessarily translate into behavioural changes; in order for this to happen, underlying theories of behavioural change need to be considered. Prior to intervention development and implementation there must be extensive research of the target population, follow up planning, baseline markers and key time points targeted. For strategies to be effective at changing behaviour they need to utilise theories of behavioural change, explore evidence for past success and failure, and have an in-depth understanding of the target audience (Aboud and Singla, 2012).

There also needs to be a process in place when selecting intervention content and delivery method, starting with the selection of appropriate behavioural change techniques (Michie *et al*., 2018). A review completed by Huis *et al*. (2012) assessed frequently used hand hygiene interventions, within medical settings, to understand which were most effective and the reasons behind their effectiveness. The review reported that focussing only on improving knowledge and awareness was not enough to change behaviours or improve compliance. Instead, interventions that addressed combinations of different behavioural change determinants such as social influence, attitude, self-efficacy and intention were far more effective in improving hand hygiene compliance. The review also provides a guided framework to build a successful hand hygiene improvement strategy that may be applicable to illness prevention interventions in athletes. The 7 step framework includes; (1) Description of good practice; (2) Assessment of current compliance; (3) Assessment of barriers and facilitators with compliance; (4) Designing a strategy and linking implementation to these influencing factors; (5) Testing and execution of the strategy; (6) Examination of the cost-effectiveness of the strategy; (7) Evaluation and readjustment of the improvement strategy.

There are a variety of delivery methods to achieve behavioural change, particularly in a modern environment. Both Ujang and Sutan (2018) and Gipson *et al*. (2019) have used text messaging as a medium to implement strategies aimed at improving health behaviours. Ujang and Sutan (2018) sent text messages twice per week, for 2 weeks, aimed at improving sexual health in adolescents. The intervention improved subject knowledge, yet future behaviours were not assessed. In a 6-week intervention to improve sleep, in college students, Gipson *et al*. (2019) sent biweekly text messages regarding sleep hygiene, whilst the control group received messages regarding health behaviours. Subjective sleep quality, hygiene and knowledge improved in both groups suggesting receiving the messages themselves, rather than content, may be the most important factor influencing results. Alternatively, poster-based interventions have also been effective at influencing health behaviours. For example, Thomas *et al*. (2005) used 4 different poster designs to improve hand-washing compliance, over a 12-month period in 1 medical centre. In a step-wise fashion, the study changed poster design every 3 months based on focus group feedback. Whilst a poster itself may be a useful tool, it may be that the consistent feedback guiding the intervention as it progressed was the reason behind effectiveness. Clearly consideration of these factors is vitally important in order for any intervention to be successful. These should be deliberated when planning, implementing and evaluating illness prevention interventions in athletes.

2.9. SUMMARY

In summary, this section describes the important contributor that illness may be, to not just time-loss from training and match play, but also to poor performance within professional soccer. Illness incidence studies within soccer have failed to quantify illness that may not necessarily lead to time-loss from football activities, but affects performance. There is a clear rationale to quantify this performance-restriction illness given the nature of professional athletes to train through illness symptoms and the apparent effects of illness on muscle strength, maximal oxygen uptake, metabolic function and temperature regulation. This may mean illness is a bigger problem within professional soccer than indicated by current research. The physical demands of professional soccer and the implications of these demands are now beginning to be understood. These demands do appear to influence immune function and illness risk. Physical load monitoring and fatigue monitoring practices, which are used to monitor these physical demands and the resultant effects, may also be linked to immune function and illness risk. Indeed some studies have demonstrated that changes in physical load and fatigue monitoring variables may be early warning signs of an increased illness risk. These risk factors should form the basis of specific illness prevention interventions within professional soccer. However, at present, these are lacking from the literature. The present thesis will aim to establish the importance of illness in professional soccer. This will be completed by evaluating illness incidence, proposed risk factors and an illness prevention intervention.

CHAPTER 3 - UNDERSTANDING PLAYER AVAILABILITY IN PROFESSIONAL SOCCER: THE IMPORTANCE OF ILLNESS AS A CONCERN FOR MEDICAL PRACTITIONERS

3.1. INTRODUCTION

During specific congested periods of the competition calendar, the high physical demands of professional soccer are further complicated when players are required to compete in fixtures 48 hours apart (Morgans *et al*., 2014). When combined with training to prepare for these fixtures, players may suffer residual fatigue, underperformance and injury due to insufficient recovery (Dupont *et al*., 2010; Bengtsson *et al*., 2013). Immune function in soccer players also appears sensitive to the effects of such demanding schedules, with this sensitivity manifested as an increase in illness incidence around periods of high physical load (Freitas *et al*., 2014). This may help partially explain the peak illness incidence in soccer players that appears to occur during winter, when fixtures are congested (Orhant *et al.,* 2010; Bjørneboe *et al.,* 2016). Orhant *et al.* (2010) reported that 54% of all illnesses sustained through a professional soccer season were between the winter months of November and February, whilst Bjørneboe *et al.* (2016) reported that 46% of all illnesses occurred during this time. The idea that an increase in physical load explains these findings is, however, based on published data that do not, in the main, include a comparator group (Orhant *et al*., 2010; Bjørneboe *et al*., 2016). It is therefore unclear whether such peaks in illness incidence are a specific consequence of the physical demands of such challenging schedules or merely a reflection of the same factors experienced by the general population (time of year) (Walsh, 2019).

Illness in soccer, most commonly respiratory and GI complaints (Orhant *et al*., 2010; Dvorak *et al*., 2011; Bjørneboe *et al*., 2016), may lead to absence from training and match play. Time lost to such conditions may impact the chances of success (Pyne *et al*., 2005; Hägglund *et al*., 2013; Raysmith and Drew, 2016; Svendsen *et al*., 2016) and cause a significant financial burden (Eirale *et al*., 2017). During tournament soccer, illness incidence values have been reported as 7.7 per 1000 player-days (99 illnesses in 89 players) (Dvorak *et al.,* 2011) and 16.9 per 1000 player-days (35 illnesses in 184 players) (Theron *et al.,* 2013). Research across a competitive season, however, indicates that illness may not be a major contributor towards time loss (Parry and Drust, 2006; Orhant *et al*., 2010; Bjørneboe *et al*., 2016). Higher numbers reported during tournament soccer may be due to a number of contextual factors including;

travel, temporarily residing in foreign countries and crowded environments. The comparatively low in-season numbers appear to indicate that illness is not a problem within professional soccer without these mediating factors.

In-season illness incidence studies in soccer are, however, limited as a consequence of the illness definitions and recording systems used. These are the most critical methodological characteristics that influence the data generated in such studies (Clarsen and Bahr, 2014). Whilst Parry and Drust (2006), Orhant *et al.* (2010) and Bjørneboe *et al.* (2016) use different definitions to record illness, none of these studies recognise that players may continue to train and compete with symptoms that may restrict performance. The nature of professional athletes means they often train and compete through illness symptoms at the detriment of their health (Van Tonder *et al*., 2016). Consequently, the problem of illness is likely underestimated (Palmer-Green *et al*., 2013). Palmer-Green *et al.* (2013) recommends a novel recording system for injuries and illnesses. This approach aims to accurately quantify the impact of illness by recording illness that leads to time loss, where performance is restricted and where medical attention only is given. This methodology has yet to be adopted longitudinally in a team sport environment, despite its apparent usefulness in quantifying illness where no time is lost, but medical attention is sought from physicians or performance is affected (Palmer-Green and Elliott, 2015). Whilst this approach clearly provides a broader evaluation of the incidence of illness, it may be limited by a lack of clear, objective criteria to accurately categorise a performance-restriction illness. In order for the approach to be more robust, this issue would need addressing.

Accurate illness surveillance is the first step in understanding the true nature, extent and impact of the illness problem, before preventative measures can be implemented (van Mechelen *et al*., 1992; Palmer-Green and Elliott, 2015; Eirale *et al*., 2017). Employment of a comparator population would facilitate testing the assumption that professional soccer players are pre-disposed to more illness at times of high physical load to be examined. The aim of this study is therefore to determine the incidence and impact of illness symptoms at a professional male soccer club. This will be achieved by testing 2 hypotheses; (1) the employment of a recording system that encompasses all illness definitions and a questionnaire to objectively quantify performance-restriction illness, will produce higher incidence values compared to more restrictive protocols used in previous research; (2) professional soccer players will experience a greater amount of illness, compared to a recreationally active comparator group, during the congested fixture period.

3.2. METHODS

3.2.1. Experimental approach to the problem

This study aimed to determine the incidence and impact of illness symptoms at a professional soccer club. To accurately record illness data, a prospective study design was used with illness incidence data collected from a male EPL soccer team across 2 seasons. Data was collected using the Palmer-Green *et al.* (2013) methodology. In addition, an adapted version of a questionnaire used to quantify the effects of overuse injuries (Clarsen *et al*., 2013), was used to objectively quantify performance-restriction illness. To examine the assumption that professional soccer players are pre-disposed to more illness, illness incidence data was collected from recreationally active individuals working within an educational institution, in which the environmental factors, such as facility size, were deemed to be similar to those experienced by the players. This was an attempt to evaluate the influence of the exposure to the intense physical demands of soccer training and match play. Data was collected from this population for 3 months (November, December and January), a time that coincided with the congested fixture schedule in the EPL.

3.2.2. Participants

Participants from 1 EPL soccer team were followed across the 2016-17 (age 27 ± 5 years; height 1.86 ± 0.05 m; weight 83.9 ± 7.6 kg) and 2017-18 seasons (age 26 ± 6 years; height 1.87 ± 0.05 m; weight 85.4 ± 6.4 kg). For both seasons, data collection began on the first day of pre-season and continued until the last game of the competitive season. There were a total of 161 training days in 2016-17 and 177 training days in 2017-18. The length of pre-season varied from 40 days in 2016-17 to 41 days in 2017-18. The length of the competitive season varied from 275 days in

2017-18 to 281 days in 2016-17. All players who trained with the first team squad across the 2 seasons were included in analyses (30 players in 2016-17 and 33 in 2017-18). Twenty players were present across both seasons. All participants were provided with a participant information sheet before signing an informed consent document. The Liverpool John Moores University (LJMU) Ethics Committee approved the study.

3.2.3. Data collection

The methodology used recorded all illness events, not just illness which leads to time lost from training or match play. Events where players continue to train and compete but experience restrictions on performance (performance-restriction illness), along with events where athletes simply receive medical attention (medical-attention illness), were included to accurately quantify the problem of illness in soccer. To ensure consistency and qualified medical diagnosis (Timpka *et al*., 2014), the team doctor of 8 seasons, who had previously led the British basketball medical department, was responsible for diagnosing and recording illness, when players reported symptoms (physician diagnosis). Illness was recorded using an adapted definition from Palmer-Green and Elliott (2015); “any physical symptom, not related to injury, that required medical attention, prevented an athlete from taking full part in training and/or competition or restricted an athletes performance where participation in training and/or competition continued.” The definition was adapted for clarity regarding performance-restriction illness. The end of an illness episode was defined as when the player no longer exhibited illness symptoms, in the opinion of the team doctor. Training injuries only were included as a comparative marker to illness because, compared to match injuries, they are considered more preventable (Ekstrand *et al*., 2011; Gabbett, 2016). Training injury was defined as “any physical complaint sustained by a player that results from football training, irrespective of the need for medical attention or time loss from football activities” (Fuller *et al*., 2006, p. 97).

Following recording, illness was classified into 1 of 3 severity categories (Palmer-Green *et al*., 2013; Timpka *et al*., 2014; Palmer-Green and Elliott, 2015); (1) Time-loss illness was defined as an illness that prevented an athlete’s participation in ‘any’ training or competition; (2) Performance-restriction illness was defined as an illness where training and/or competition participation continued but the volume and/or intensity were restricted as a result of the illness (e.g. through pain and/or loss of function); (3) Medical-attention illness was defined as an illness that required medical attention by a qualified medical practitioner but did not cause time loss or performance restriction. Illnesses were then classified into the type of illness/affected system (respiratory, GI, malaise or other) and main symptoms (cold, tonsils, fever, sinus, headache, vomit, diarrhoea, diarrhoea and vomit or other). The team doctor, based on common illness in previous seasons, chose the classification types and symptoms. See table 3.1 for a description of the illness classification system.

Table 3.1. The illness classification system.

Classification	Category	Definition
1. Severity	Time-loss	*An illness that prevented an athlete's participation in 'any' training or competition.*
	Performance-restriction	*An illness where training and/or competition participation continued but the volume and/or intensity were restricted as a result of the illness (e.g. through pain and/or loss of function).*
	Medical-attention	*An illness that required medical attention by a qualified medical practitioner but did not cause time loss or performance restriction.*
2. Type/affected system	Respiratory	*An illness which affected the respiratory system (the nose, sinuses, pharynx, larynx, trachea, bronchi or lungs).*
	GI	*An illness which affected the GI system (the stomach, intestines, rectum or anus).*
	Malaise	*An illness where there were there was purely a general feeling of discomfort or lack of wellbeing.*
3. Main symptoms	Cold	*An illness which exhibited the typical symptoms of a cold (runny nose, cough, sore throat).*
	Tonsils	*An illness which specifically caused pain in the tonsils.*
	Fever	*An illness which caused excessive sweating or chills.*
	Sinus	*An illness causing typical sinus issues such as pain in the face, a blocked or runny nose and headache.*
	Headache	*An illness which led specifically to a headache.*

	Vomit	*An illness which led specifically to vomiting.*
	Diarrhoea	*An illness which led specifically to diarrhoea.*
	Diarrhoea and vomit	*An illness which led specifically to diarrhoea and vomiting.*

To objectively quantify performance-restriction illness, a questionnaire developed and validated by Clarsen *et al*. (2013) for the registration of overuse injuries in sports injury epidemiology (The Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire), was adapted to assess illness. This questionnaire (Appendix 3.1) was given out 1 week following the end of an illness episode, which had not already been classified as time-loss. The questionnaire was only employed during the 2017-18 season.

3.2.4. Recreationally active comparator group

To examine the assumption that professional soccer players are pre-disposed to more illness at times of high physical load, 7 recreationally active, slightly older, male participants (age 34.0 ± 5 years; height 1.81 ± 0.07 m; weight 88.3 ± 15.6 kg), working as staff at an educational institution, were also followed from the 27th November 2017 - 27th January 2018. This time coincided with congested fixture scheduling in the EPL. The average number of matches per month in the EPL is 4 (1 per week). This period is defined as the congested fixture period because during December 2017, 7 matches were played and during January 2018, 6 matches were played (2 matches per week at certain times). These participants were selected as a comparator group because of potential exposure to some of the key environmental factors experienced by the players (life stress, pathogen exposure, poor hygiene, sleep disruption, environmental extremes, long-haul travel, vaccination/infection history, a high gene expression of inflammatory cytokines, low levels of salivary antibodies such as sIgA, time of year and nutritional deficits), but without the associated physical and psychological load of professional soccer. On average participants in the recreationally active comparator group completed 3 hours of moderate intensity exercise per week. In comparison, a regular starter within this professional soccer population completed an average of 5 hours (294 minutes) of combined high-intensity training and match play per week (totalling 25,326 m covered, 3716 m covered above 50% of their maximum velocity and a maximum velocity of 8.86 m/s). The participants worked in a similar sized building to the soccer team's training facility. The building itself also contained similar facilities to the training facility (a shared cooking facility and gymnasium). The assumption was, therefore, that the chance of coming into contact with illness through the environment (touching objects, person to person contact or air droplets) would be similar. The recreationally active participants spent around 9 hours per day, 5 days per week, within the building in question (45 hours per week). In comparison professional soccer players spent around 5 hours per day, 4 days per week, at the training facility (20 hours per week). This sample of staff, at the educational institution, was selected instead of staff at the soccer training facility. This was because illness picked up by the soccer players may have directly influenced the non-playing staff in such close proximity and therefore rendered the comparator group useless. Data collected from these participants was also collected in line with the Palmer-Green *et al.* (2013) methodology, once more using an adapted version of the questionnaire in Clarsen *et al.* (2013), completed weekly. This adaptation involved the addition of questions asking participants to describe illness experienced, duration and the effects on both work and physical activity (Appendix 3.2).

3.2.5. Data analysis

Data was tallied to produce total illness incidence and days spent with illness. Total incidence per 1000 hours, percentage of total illness incidence and percentage of days spent with illness were also calculated. These values were produced for different seasons, severity groups, affected systems and symptoms, to allow comparison across these factors. Mean values (with standard deviation values) were also calculated for illness incidence and days spent with illness. This was again completed for different seasons, severity groups, affected systems and symptoms. Total values were also compared against the comparator population and across months of the season.

Additional statistical analysis was completed to assess the relationship between match exposure and illness events. Initially, a Pearson product-moment correlation coefficient was used to assess the relationship between match minutes and illness events. This was completed using only the 13 players present for both seasons. Goalkeepers were excluded from this analysis as match play represents a relatively small physical load in comparison to a typical training week for their position. An independent-samples t-test was then conducted to compare the amount of illness events between starters and non-starters. Players were excluded from this analysis if they did not have at least 1 full season of data; if a player was present for both seasons then each season was treated as a different case. In total there were 37 player-cases, split into 21 starters and 16 non-starters. Players were classed as non-starters if they fell below the mean number of matches started per season (20 in 2016-17 and 21 in 2017-18). Both statistical tests were conducted using statistical analysis software (SPSS version 26.0, IBM, New York, U.S). P values were 2-tailed and significance was set at $p < 0.05$.

3.3 RESULTS

3.3.1. Total illness incidence data from the EPL soccer team

Ninety-one illnesses (184 days impacted by some form of illness) were recorded in total across 2 seasons, across all definitions (4.1 incidences per 1000 hours). Upon closer examination, 31 time-loss illnesses (1.4 incidences per 1000 hours) causing 58 days missed, 14 performance-restriction illnesses (0.6 incidences per 1000 hours) causing 62 days spent with performance-restriction and 46 medical-attention illnesses (2.1 incidences per 1000 hours) amounting to 64 days, were recorded in total, across 2 seasons. In comparison there were a total of 17 training injuries (0.8 incidences per 1000 hours) causing 614 days missed. Table 3.2 summarises data broken down into each season.

Table 3.2. Total illness impact analysis. Data includes all players that were present in the squad during 2016-17 (30) and 2017-18 (33).

Illness impact	**TL* illness**		**PR* illness**		**MA* illness**		**Total illness**		**TR* injury**	
Season	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***
Days affected	23	35	3	59	37	27	63	121	148	466
Incidence	13	18	3	11	24	22	40	51	8	9
Incidence per 1000 hours	2.6	2.9	0.6	1.8	4.8	3.5	8.1	8.1	1.6	1.4
% Of total days affected	37	29	5	49	59	22	-	-	-	-
% Of total incidence	33	35	8	22	60	43	-	-	-	-

*TL - Time-loss, PR - Performance-restriction, MA - Medical-attention, TR - Training

Respiratory illness was the most frequent illness type, followed by GI illness (Table 3.3). Tonsil and cold symptoms were the most frequent symptoms experienced in 2016-17. Sinus, cold and tonsil symptoms were most frequent in 2017-18 (Table 3.4).

Table 3.3. Total illness type analysis. Data includes all players that were present in the squad during 2016-17 (30) and 2017-18 (33).

Illness type	**Respiratory**		**GI**		**Malaise**	
Season	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***
Days affected	44	101	9	20	10	0
Incidence	23	33	6	13	6	0
Incidence per 1000 hours	4.6	5.3	1.2	2.1	1.2	0
% Of total days affected	70	83	14	17	16	0
% Of total incidence	66	72	17	28	17	0

Table 3.4. Total illness symptom analysis. Data includes all players that were present in the squad during 2016-17 (30) and 2017-18 (33).

Illness symptom	**Cold**		**Tonsils**		**Fever**		**Sinus**		**Headache**		**Vomit**		**Diarrhoea**		**Diarrhoea & Vomit**	
Season	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***
Days affected	14	50	33	10	4	0	0	41	2	0	5	4	4	7	4	9
Incidence	10	10	16	9	1	0	0	14	2	0	3	3	1	4	3	6
Incidence per 1000 hours	2.0	1.6	3.2	1.4	0.2	0	0	2.2	0.4	0	0.6	0.5	0.2	0.6	0.8	1.0
% Of total days affected	22	41	52	8	6	0	0	34	3	0	8	3	6	6	6	7
% Of total incidence	27	22	43	20	3	0	0	30	5	0	8	7	3	9	11	13

3.3.2. Mean illness incidence data from the EPL soccer team

A mean of 1.6 ± 1.2 illnesses (4.0 ± 4.8 days impacted by some form of illness) per season was recorded, across all definitions. This was made up of 0.7 ± 0.8 time-loss illnesses per season causing 1.2 ± 1.6 days missed, 0.3 ± 0.6 performance-restriction illnesses per season causing 1.5 ± 3.7 days spent with performance-restriction and 0.9 ± 1.1 medical-attention illnesses per season amounting to 1.3 ± 2.1 days. In comparison there was a mean of 0.3 ± 0.7 training injuries per season causing 14.2 ± 45.1 days missed. Table 3.5 summarises data broken down into each season.

Table 3.5. Mean illness impact analysis. Data is presented as mean ± standard deviation. Data includes all players that were present for the full season duration 2016-17 (18) and 2017-18 (23).

Illness impact	**TL* illness**		**PR* illness**		**MA* illness**		**Total illness**		**TR* injury**	
Season	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***
Days affected	0.8 ± 1.2	1.5 ± 1.8	0.2 ± 0.4	2.6 ± 4.7	1.6 ± 1.7	1.1 ± 1.4	2.6 ± 3.1	5.2 ± 5.6	6.3 ± 16.8	20.3 ± 58.3
Incidence	0.5 ± 0.7	0.8 ± 0.9	0.2 ± 0.4	0.5 ± 0.7	0.9 ± 1.1	0.9 ± 1.1	1.3 ± 1.4	1.9 ± 1.1	0.3 ± 0.6	0.4 ± 0.8

*TL - Time-loss, PR - Performance-restriction, MA - Medical-attention, TR - Training

Respiratory and GI illness were the most common types of illness across 2 seasons. Players experienced a mean of 1.2 ± 1.0 incidences of respiratory illness (3.2 ± 4.6 days spent with respiratory illness) and 0.4 ± 0.6 incidences of GI illness (0.6 ± 1.0 days spent with GI illness) per season (Table 3.6). Cold, tonsils and sinus symptoms were the most frequent symptoms experienced across 2 seasons. Players experienced a mean of 0.4 ± 0.7 incidences of cold symptoms (1.5 ± 3.3 days spent with cold symptoms), 0.4 ± 0.7 incidences of tonsils symptoms (0.8 ± 1.9 days spent with tonsils symptoms) and 0.3 ± 0.6 incidences of sinus symptoms (1.0 ± 2.0 days spent with sinus symptoms) per season (Table 3.7)

Table 3.6. Mean illness type analysis. Data is presented as mean ± standard deviation. Data includes all players that were present for the full season duration 2016-17 (18) and 2017-18 (23).

Illness type	Respiratory		GI		Malaise	
Season	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***
Days affected	1.8 ± 2.8	4.3 ± 5.4	0.3 ± 0.8	0.9 ± 1.1	0.4 ± 1.0	0
Incidence	0.9 ± 1.1	1.3 ± 1.0	0.2 ± 0.4	0.6 ± 0.7	0.2 ± 0.4	0

Table 3.7. Mean illness symptom analysis. Data is presented as mean ± standard deviation. Data includes all players that were present for the full season duration 2016-17 (18) and 2017-18 (23).

Illness symptom	Cold		Tonsils		Fever		Sinus		Headache		Vomit		Diarrhoea		Diarrhoea & Vomit	
Season	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***	***2016-17***	***2017-18***
Days affected	0.6 ± 1.0	2.2 ± 4.2	1.3 ± 2.7	0.3 ± 0.8	0.2 ± 0.9	0	0	1.8 ± 2.4	0.1 ± 0.2	0	0.3 ± 0.8	0.2 ± 0.5	0.1 ± 0.2	0.3 ± 0.8	0	0.4 ± 0.8
Incidence	0.4 ± 0.7	0.4 ± 0.7	0.6 ± 0.8	0.3 ± 0.6	0.1 ± 0.2	0	0	0.6 ± 0.7	0.1 ± 0.2	0	0.2 ± 0.4	0.1 ± 0.3	0.1 ± 0,2	0.2 ± 0.4	0	0.3 ± 0.5

3.3.3. Recreationally active comparator group

From the 27th November 2017 until the 27th January 2018 there were 15 incidences of illness at the soccer club (0 in November, 5 in December and 10 in January) and 10 incidences of illness at the educational institution (4 in November, 4 in December and 2 in January) (Figure 3.1).

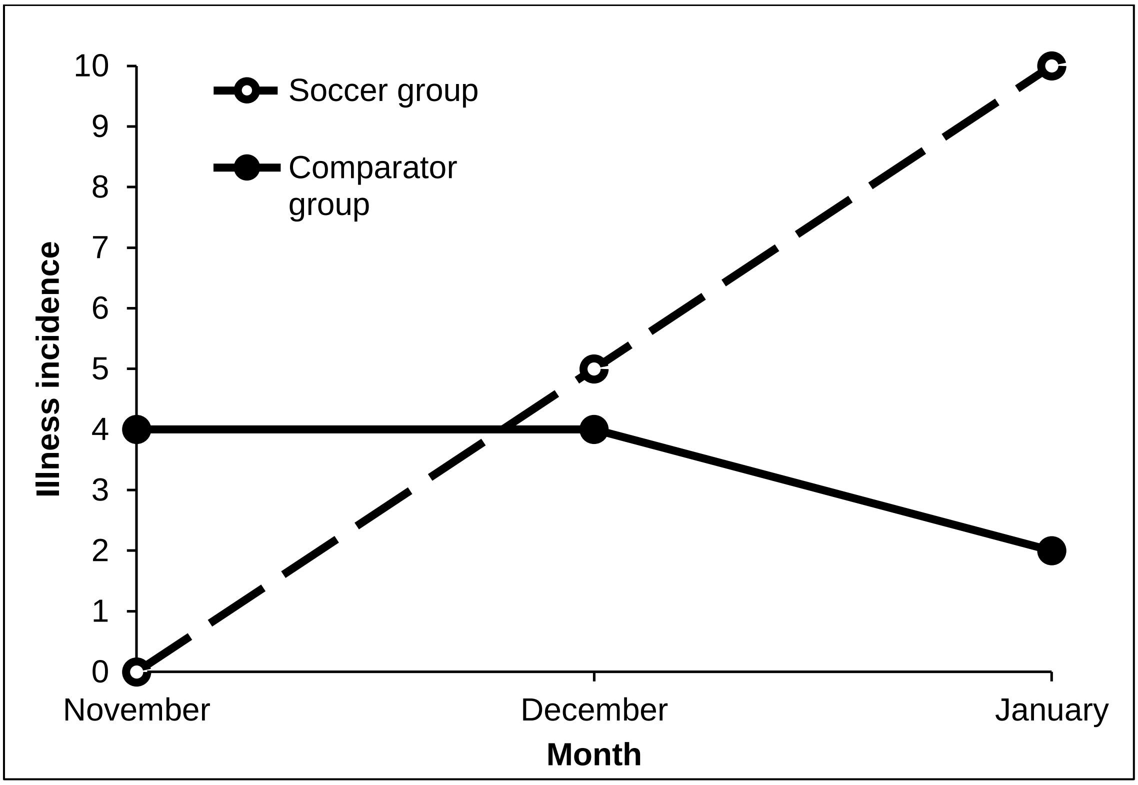

Figure 3.1. Illness incidence from the 27th November 2017 - 27th January 2018 for the soccer team and comparator populations. Data includes all players that were present in the squad during 2017-18 (33) and the 7 subjects from the educational institution acting as the comparator group.

3.3.4. Temporal distribution

During 2016-17 illness occurred most frequently during the months of September (8 incidences), October (6 incidences) and November (7 incidences). During 2017-18 illness occurred most frequently during the months of July (10 incidences) and January (10 incidences) (Figure 3.2).

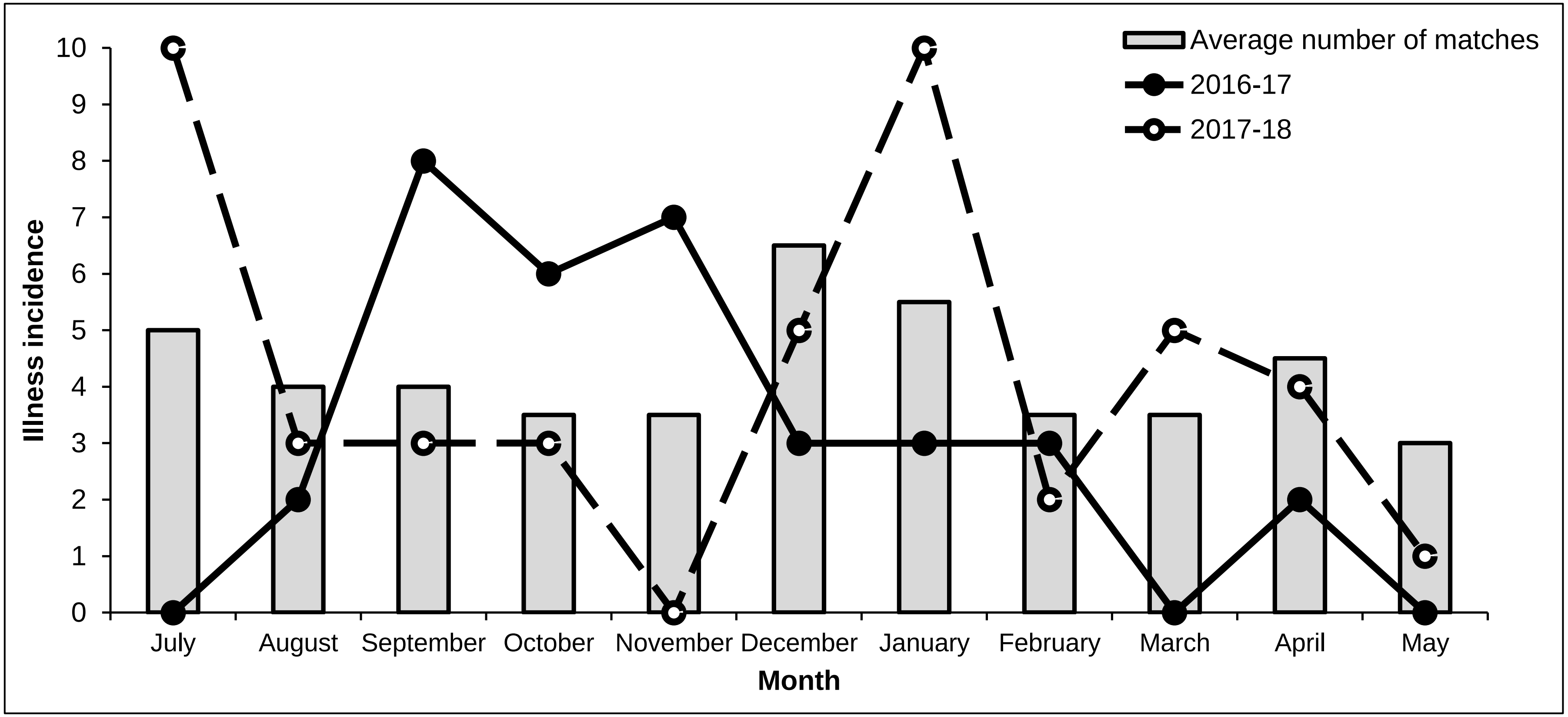

Figure 3.2. Illness incidence across the months coinciding with pre-season and the competitive season for the 2016-17 and 2017-18 seasons. The average number of matches per month across both seasons is also presented. Data includes all players that were present in the squad during 2016-17 (30) and 2017-18 (33).

3.3.5. Match exposure and illness events

There was no correlation between the number of match minutes played and the number of illness events experienced ($r = -0.017$, $n = 13$, $p = 0.957$). Further, there was not a significant difference in the number of illness events experienced between the starter ($M = 1.7$, $SD = 1.3$) and non-starter ($M = 1.7$, $SD = 1.3$) conditions; $t(35)=-0.049$, $p = 0.961$.

3.4. DISCUSSION

The aim of the current study was to determine the incidence and impact of illness symptoms at a professional male soccer club. A recording system, used for the first time within team sports, prompted a more complete quantification of the problem of illness within professional soccer. The main finding of this study was that the incidence of illness was greater than the incidence of training injury, and illness incidence values reported in previous research (Parry and Drust, 2006; Orhant *et al*., 2010; Bjørneboe *et al*., 2016). Secondly, across the congested fixture period, EPL soccer players appeared to experience more illness compared to a recreationally active comparator group. Lastly, temporal patterns of illness incidence show that illness does not just occur over the winter period, but is instead more broadly distributed across months of the year. Peaks occurred during pre-season and in line with international breaks, as well as slightly before and directly after the congested fixture period. Taken together these findings highlight the extent of the problem of illness within professional soccer and the significant burden this may place on resources. Illness should, therefore, be recognised as a key factor in player availability, which has the potential to significantly impact performance. As such, illness prevention strategies may be worthy of consideration and implementation.

3.4.1. Illness incidence

The comparison of training injury to illness highlights the potential extent of the illness problem within soccer. Across 2 seasons, 91 illnesses were recorded compared to 17 training injuries. Although severity (days affected) was much higher for training injury

(614 vs 184), the incidence values show the persistent burden of illness within soccer. Recording of injury can be practically challenging, even using established definitions (Fuller *et al*., 2006) as players are routinely receiving treatment, experiencing soreness and undergoing load modification. Determining what is recognised as an injury can therefore become difficult. The results reported here differ from previous research comparing illness and injury; Parry and Drust (2006) reported 83 incidences of injury over 2 seasons, compared to 46 incidences of illness. This may, however, be due to differences in recording methodologies.

The illness incidence values described in this paper also differ from previous research conducted in professional soccer; in general values reported from this study appear to be higher. Across 2 seasons, Parry and Drust (2006) recorded 46 incidences of illness, whilst 91 incidences were recorded across the same time period in the present study. Bjørneboe *et al*. (2016) reported a prevalence of 0.4 illnesses per season, in the present study a mean of 1.6 illnesses per season was recorded. Orhant *et al.,* (2010), however, reported a prevalence of 2.5 illnesses per season (with a mean of 2.9 days affected), this is higher than the 1.6 illnesses per season recorded in this sample, yet days affected (5.0) is higher in the current study. Research completed in other sports reported that 5-7% of athletes (528-789 athletes) involved at the summer Olympic games reported an illness (Engebretsen *et al.,* 2013; Soligard *et al.,* 2017), whilst 8% of athletes reported an illness (222 athletes) at the winter Olympic games (Soligard *et al.,* 2015). These values once more differ from the 79% of professional soccer players who experienced an illness event across 2 seasons, however the larger samples used within these papers may explain this. The main type of illness reported in athletes, including professional soccer players, is in agreement with the findings of this study. Respiratory and GI illness are consistently the most common illness complaints across studies (Orhant *et al.,* 2010; Engebretsen *et al.,* 2013; Bjørneboe *et al.,* 2016; Soligard *et al.,* 2017). The differences across studies are likely due to the recording systems and illness definitions used; therefore illustrating the importance of methodological differences when collecting this type of data. Prior studies (Parry and Drust, 2006; Orhant *et al*., 2010; Bjørneboe *et al*., 2016) may have been limited by the recording systems used which fail to identify low-level illness that does not cause time-loss, but may affect performance and consequently team success, in the same way as injury. The data presented here supports the hypothesis that this recording system provides a more robust methodology and complete quantification of the problem of illness within professional soccer. It would therefore be logical to allocate adequate resources to illness reduction initiatives as well as those assigned to injury prevention programmes.

Essential to the recording system, was an adapted questionnaire (Clarsen *et al*., 2013) introduced to add objectivity to the quantification of performance-restriction illness (Appendix 3.1). Palmer-Green *et al*. (2013) recommends quantifying performance-restriction illness by asking the medical team to subjectively assess the amount of restriction experienced. This approach is limited as there is no consideration for how the athlete, who may be experiencing the performance restriction, feels. Our approach would seem to address this to produce more ecologically valid data and a better understanding of the performance cost of illness. In reality, performance-restriction illness may be evident because players are under pressure to return to training and match play as fast as possible (Orhant *et al*., 2010). This means they may train or compete still under the influence of illness. The high volume of low-level illness recorded may also have a financial cost. Although only an estimate, when the 184 days spent with some form of illness is multiplied by the average weekly wage of a male EPL soccer player (£50,817) (Global Sports Salaries Survey 2017, 2017), a mean £1,335,840 has the potential to be spent on players who had some form of illness in our sample. The real impact, underestimated and difficult to quantify until now, may be the significant amount of time players are under the influence of this type of illness, which decreases performance, reduces the ability to sustain heavy training (Gleeson and Burke, 2007) and has monetary implications.

3.4.2. The importance of physical load to illness risk

EPL soccer players appeared to experience more incidences of illness compared to the comparator population, over a period that corresponded with the congested fixture calendar (15 vs 10 incidences respectively). The higher physical demands experienced by soccer players during this phase may explain the higher illness incidence. Research completed by Spence *et al*. (2007) supports this notion, reporting that the high physical demands experienced by elite athletes, over and above recreational participation, may alter immune function. However, the link between the demands of soccer during this period and the higher illness incidence in this population is difficult to confirm for methodological reasons. The cross-sectional, minor sample used may not be representative of a full comparator population. Although we attempted to control “environmental” factors such as the facilities, this may not have been as effective as planned, as the two locations included in the investigation are indeed different. Within the soccer training facility the volume of people passing through and sharing equipment in communal areas, where hygiene is of paramount importance, such as the gym, canteen and physiotherapy room, may be higher than within the university building. This may mean the chance of coming into contact with illness through touching objects, person-to-person contact or air droplets was increased at the training facility. In the application of these findings, practitioners should consider that the specific layout of the training facility may have contributed to these findings and therefore results may be reflective of only 1 group of players. Further, adults within the general population appear to experience 2-4 episodes of the common cold per year (Monto, 1994). A mean of 1.6 illnesses per season was reported in this study, this would suggest that professional soccer players may experience an equivalent, if not less, level of illness compared to the general population. This would support the fact that other illness risk factors, outside the physical and psychological load of professional soccer, are important (Walsh, 2019).

The nature of the problem of illness in soccer can also be described by assessing incidence across months of the season. During 2016-17 illness incidence was highest during September, October and November, whereas in 2017-18 illness incidence was highest in July and January. This is in part in agreement with previous research which states that the highest illness incidence occurs during the winter months (November, December, January and February) within professional soccer players (Orhant *et al*., 2010; Bjørneboe *et al*., 2016). The peak in January occurred directly following the congested fixture schedule in the EPL, where there is marked increase in physical demands. At times during this schedule the number of matches per week increased from 1 to 3, with 2 fixtures separated by just 48 hours. As figure 3.2 demonstrates the highest number of matches per month occurs in December (7) and January (6). During the last week of December (the week commencing the 25/12/2017), a regular starter completed 345 minutes of combined training and match play, covering 33130 m, 5394 m above 50% of their maximum velocity (high intensity distance) and reaching a maximum velocity of 9.35 m/s. This is a 17% increase in duration, 31% increase in total distance, 45% increase in high intensity distance and 6% increase in maximum velocity compared to average weekly values cited in section 3.2.4 of the methodology. This suggests that soccer players may be at risk of illness directly following a period of high physical load. Indeed, soccer players experience more illness, in particular URTI symptoms, during or directly following periods of high physical load (Freitas *et al*., 2014). Underlying these symptoms may be changes in immune function. Morgans *et al*. (2014) reported reduced levels of mucosal immunity (sIgA) during the same congested winter fixture schedule within the EPL. Morgans *et al*. (2014) did not report illness incidence, but the study does offer support for mechanistic changes underpinning this data. The findings of the current study suggest that it is naive to assume illness only occurs in the winter; peaks in illness incidence are distributed throughout the season. Therefore, physical load and time of year may not be the only risk factors involved. Walsh (2018) suggests a number of risk factors associated with lower immunity that may explain a high illness incidence during July (pre-season), and September, October and November (the EPL international breaks), such as increased psychological stress, long-haul travel, the resulting poor sleep and/or nutrition, and an increased exposure to foreign pathogens.

3.4.3. Limitations

It is important to consider that the questionnaire to assist in the objective quantification of performance-restriction illness, adapted from Clarsen *et al.* (2013), was only used during the 2017-18 season. This may have meant that the amount of performance-restriction illness in the 2016-17 season was underestimated. Ideally this would have been included from the start of data collection. However quantification of this type of illness was only highlighted as an issue at the end of the 2016-17 season (the first season that the illness recording methodology had been in place). Although physician diagnosis of illness events is gold standard within illness recording systems in practice, Cox *et al.* (2008) reported that only 57% of physician diagnosed viral or bacterial URTI's were associated with an identified pathogen. Therefore, some of the illness symptoms identified may not be reflective of an infection but other factors such as airway inflammation, allergies or asthma (Cox *et al.,* 2008). In a research setting, blood and saliva samples, as well as throat swabs, could be collected and analysed to identify pathogens present. However, in a professional sporting environment, the process of obtaining results is likely to be too slow and expensive to influence decisions. The recreationally active comparator group was not equal, in number of participants, to the professional soccer sample (7 vs 33). This clearly limited comparison of this population to professional soccer players. Ideally, to facilitate a fair comparison, the comparator population would be matched in number, made up of a group of soccer players exposed to similar factors, without the demands of professional soccer. As mentioned, at present results may be limited to 1 professional soccer team, specific environmental factors such as climate, facility size and volume of people using the facility, may have a direct impact on results. As such, it would be valuable to pool data from different clubs, using this recording methodology, to gain an understanding of this problem on a larger scale. Finally, this chapter has not included an objective marker of immune function, such as sIgA. This is important to further try and understand the mechanisms behind some of the patterns in illness incidence witnessed.

3.4.4. Conclusion and practical applications

In conclusion, illness incidence was much greater than training injury incidence, highlighting the potential problems associated with illness in professional soccer. A novel recording system, used in a team sport setting for the first time, recorded performance-restriction and medical-attention illness levels that may suggest previous values are underestimated. An adapted questionnaire facilitated the accurate quantification of performance-restriction illness. Practically, this illness surveillance system could be implemented across professional soccer, for teams to understand the specific nature of illness in their own environment and identify patterns or risk factors that may be important. This methodology clearly has merit as a tool to quantify the otherwise unrecognised effects of illness on performance. Temporal patterns of illness incidence showed that illness does not only occur across winter. This, coupled with the high frequency of illness highlights the need for seasonal illness-prevention interventions. These interventions should be developed, implemented and evaluated until they become a staple part of performance culture in professional soccer, in the same way that injury prevention programmes are now present across the season. Professional soccer players appeared to experience a greater incidence of illness compared to the recreationally active comparator population over the congested fixture period. This, coupled with a particularly high incidence in January compared to other months, may lend further support for the link between a high physical load and illness risk. Further research should look to pool data from different professional soccer clubs, using this recording system, to determine the problem of illness across the sport. Also there is the need to clarify the factors and mechanisms behind the high illness burden within professional soccer players. Tracking a marker of immune function or an illness risk factor alongside illness incidence may reveal the mechanisms that underpin the patterns witnessed in this paper. Finally, the development, implementation and evaluation of interventions targeting these specific risk factors, should be a goal for future studies.

CHAPTER 4 - THE RELATIONSHIP BETWEEN PHYSICAL LOAD, SUBJECTIVE WELLBEING AND ILLNESS INCIDENCE IN PROFESSIONAL SOCCER

4.1. INTRODUCTION

Physical load is monitored in professional soccer to ensure players complete enough training to be able to repeatedly meet and surpass the demands of match play without excessive fatigue, which may lead to NFOR, injury and illness (Akenhead and Nassis, 2016; Burgess, 2016; Bourdon *et al*., 2017). Fatigue is defined as "any exercise or non-exercise-induced loss in total performance due to various physiological factors, athlete reported psychological factors, or a combination of the two" (Micklewright *et al.,* 2017). NFOR occurs when intensified training continues with no regard for recovery. At this point there may be signs of psychological disturbance such as decreased vigour and increased fatigue, alongside stagnation in performance that will recover, but not for weeks to months (Meeusen *et al*., 2013). Other factors such as inadequate nutrition, an increased URTI incidence, psychological stressors and sleep disorders may also be present (Meeusen *et al*., 2013). NFOR has indeed been reported in a sample of male academy soccer players (Williams *et al.,* 2017a). Chapter 1 suggests there may be a relationship between physical load and illness risk in professional soccer. This is indicated by a higher illness incidence in soccer players compared to a recreationally active comparator population. Previous research also supports an increased illness risk when there are sudden "spikes" or changes in chronic physical load. This concept is centred on changes in volume or intensity, away from normality, leading to added pressure on immune function and a higher risk of an illness event (Walsh *et al*., 2011; Drew and Finch, 2016; Schwellnus *et al*., 2016; Jones *et al*., 2017). Research, completed within different sports, has shown that illness risk increases following a 10% increase in weekly subjective training load (RPE) above normality (Foster, 1998; Putlur *et al*., 2004; Piggott, 2008). Similarly, a higher than average weekly (Thornton *et al*., 2014; Watson *et al*., 2017) and monthly subjective training load (Watson *et al*., 2017) was also predicative of illness in team sport athletes. Fatigue monitoring tools may also be useful to detect the effects of changes in physical load before an illness event occurs. Indeed, an illness condition may be preceded by a prodromal period that is characterised by the development of non-specific symptoms such as fatigue in response to acute and chronic exercise (Schwellnus *et al*., 2016). Early warning signs such as this may indicate the onset of illness and could be assessed using fatigue monitoring tools to intervene before the development of the full condition.

Fatigue-monitoring is used to gain an insight into athlete status, in response to physical load, to aid optimal adaptation whilst guarding against NFOR, injury and illness (Twist and Highton, 2013; Thorpe *et al*., 2017). Findings indicate that higher subjective fatigue ratings are often associated with a lower URTI incidence (Hooper and Mackinnon, 1995; Veugelers *et al*., 2016). Whilst this may seem paradoxical, Jones *et al*. (2017) suggests that the higher fatigue ratings may have directly caused some modification to training where physical load has been intentionally reduced and therefore URTI risk is controlled prior to symptom development. Stress, a subjective fatigue item used in multiple questionnaires, has however been correlated with illness. Multiple papers, using different tools, have highlighted the relationship between higher stress levels and a higher illness risk (Anderson *et al*., 2003; Brink *et al*., 2010; Drew *et al*., 2017b). Other factors, indicative of the status of an athlete, such as an elevated HR during submaximal exercise (Buchheit *et al*., 2013a), a reduction in HRV (Hellard *et al*., 2011), low energy availability and poor hygiene practice (Drew *et al*., 2017b), international travel (Schwellnus *et al*., 2012) and reduced sleep duration (Prather *et al*., 2015) have been related to an increased risk of illness. Indeed, Chapter 1 suggests that additional illness risk factors, outside of physical load, may be important in professional soccer players. Temporal patterns of illness in Chapter 1 show an increased illness incidence around international breaks and pre-season, not just in the winter months around congested fixture scheduling. Assessment of these factors during fatigue and physical load monitoring practices, and use of this information to affect practice, is undoubtedly important to reduce illness risk. There are, however, discrepancies within this research area.

Few papers have looked at the physical load-fatigue interactions and associations with illness; the fatigue status of an individual will determine how much load they can tolerate before risk increases (Jones *et al*., 2017). Only Thornton *et al*. (2014) has assessed the relationship between subjective training load, wellbeing and illness. As mentioned above, a higher than normal weekly training load, strain and monotony best predicted illness, whilst typical subjective wellbeing markers such as sleep, general feelings of wellbeing, soreness and diet did not appear to contribute as much. Further, the majority of studies have not accounted for the lag time between spikes in training load and an increased illness risk. Drew and Finch (2016) reported that a lag of up to 4 weeks might be present between a spike in training load and an illness event. Instead the majority of studies continue to assess weekly training load that may be lower because of the illness event itself. Jones *et al*. (2017) suggests that, following a spike in load, fatigue markers may change for a period of 7-21 days; indicative of an elevated illness risk. Finally, few studies have used multivariate modelling to determine the contribution and dose-response relationship between specific factors and illness risk (Schwellnus *et al*., 2016). It is important that these discrepancies are resolved in order for targeted illness prevention interventions to be developed and implemented in professional soccer.

Therefore the aim of the current study is to examine the relationship between training and match load (physical load), subjective wellbeing, and illness incidence in professional soccer. This aim will be achieved by testing 3 hypotheses; (1) there will be a difference in individual physical load variables in the weekly and monthly periods leading up to an illness event, compared to normality; (2) there will be a difference in individual subjective wellbeing variables in the weekly and monthly periods leading up to an illness event, compared to normality; (3) there will be abrupt changes in physical load in the build up to illness events.

4.2. METHODOLOGICAL DEVELOPMENT

Prior to the decision to use subjective wellbeing as a fatigue-monitoring tool within this chapter, the reliability, sensitivity and suitability of 2 other markers were also assessed. A wrist worn device (strap) developed by WHOOP (Boston, USA), to assess sleep and recovery, as well as sIgA assessment via an LFD reader (IPRO, Wallingford, UK), were also considered to monitor the response to physical load.

4.2.1. The WHOOP Strap

The WHOOP Strap is a wrist-worn device that contains an accelerometer, photoplethysmography sensor and temperature sensor. The band uses photoplethysmography to calculate RHR and HRV, whilst a combination of the accelerometer, photoplethysmography sensor and temperature sensor are used in an algorithm to detect sleep and wake time (the sleep auto detection algorithm). RHR and HRV (the root mean square of successive differences between normal heartbeats, RMSSD) are calculated during the last 5 minutes of slow wave sleep, negating some of the difficulties around standardisation of testing, given how sensitive RHR and HRV can be to environmental conditions (Buchheit, 2014). Indeed, Buchheit (2014) recommends that these measurements are collected during slow wave sleep where signal stability is high, environmental factors are standardised and respiratory influence is limited. The WHOOP Strap is worn continuously through day and night, with no user input required. The strap synchronises with the users phone via Bluetooth and information is sent directly to a cloud based storage platform, where performance staff can access this data. There are 3 strands to the WHOOP data output; (1) sleep analysis (hours of sleep, time spent in different stages, number of sleep cycles and number of disturbances); (2) a recovery score (based on RHR, HRV and sleep); (3) strain (based on movement and HR response throughout the day). As mentioned, a low amount of sleep (Cohen *et al.,* 2009; Prather *et al.,* 2015) and a low resting HRV (Hellard *et al.,* 2011) have been linked to an increased illness risk. Therefore the WHOOP Straps were considered as a potentially useful tool to monitor fatigue in professional soccer players.

Internal research completed by WHOOP (Analytics, WHOOP Inc, 2016) validated the band, and algorithm, against a graded polysomnograph (PSG) completed in a laboratory (the gold-standard sleep assessment tool). The PSG assessment contained an electroencephalogram (EEG) sensor to measure brain activity, electromyography (EMG) sensor for muscle movements, electrooculography (EOG) sensor for eye movement, an electrocardiogram (ECG) for HR, and a peripheral capillary oxygen saturation (SpO_2) sensor for blood oxygen saturation. 30 collegiate athletes underwent the PSG assessment whilst wearing a WHOOP Strap at the same time. Results indicated that there was a high level of agreement, and no significant differences, between the WHOOP Strap and the PSG assessment to determine sleep/wake status and hours of sleep recorded. Despite the WHOOP Strap showing validity against gold standard measures of sleep (PSG) and HR (ECG), to determine the use of the band within the thesis and practice, 3 conditions needed to be satisfied. These conditions were that; (1) the data recorded was reliable; (2) the data recorded was sensitive to the demands of professional soccer training; (3) the WHOOP Strap was suitable to be used in this environment.

Reliability assessment

To determine the reliability of the data recorded via the WHOOP Strap, 5 professional soccer players wore bands from the 26/07/2017 until the 01/09/2017 (37 days). The data was analysed to produce a mean, standard deviation and within subject coefficient of variation (CV%) for each player and each WHOOP variable. The majority of WHOOP variables showed high CV% values (above 10%), only RHR was below this with a mean group value of 6%. This data is presented below in tables 4.1 and 4.2.

Table 4.1. Mean values ± standard deviation for each player and WHOOP marker.

Player	RHR (bpm)	HRV (RMSSD)	Hours of sleep	No. dist*	Sleep latency (min)	Sleep cycles	REM sleep (hours)	Deep sleep (hours)	Light sleep (hours)	Time awake (hours)
1	50 ± 6	77 ± 44	7.7 ± 0.9	12 ± 4	1.2 ± 1.4	7.3 ± 1.4	2.3 ± 0.7	0.6 ± 0.5	4.8 ± 0.8	0.7 ± 0.3
2	44 ± 3	98 ± 18	7.9 ± 1.5	13 ± 4	1.5 ± 1.5	6.7 ± 2.2	1.8 ± 0.6	0.6 ± 0.4	5.6 ± 1.1	0.8 ± 0.4
3	49 ± 3	89 ± 52	7.1 ± 1.4	11 ± 3	3.5 ± 5.6	5.5 ± 2.2	1.4 ± 0.5	1.3 ± 0.5	4.4 ± 1.0	0.6 ± 0.3
4	35 ± 2	153 ± 50	6.8 ± 0.8	12 ± 4	2.9 ± 5.8	5.3 ± 1.5	1.1 ± 0.3	0.9 ± 0.6	4.8 ± 0.6	1.4 ± 0.7
5	43 ± 2	131 ± 28	7.9 ± 1.1	13 ± 4	3.7 ± 4.6	3.6 ± 2.4	0.7 ± 0.2	1.0 ± 0.4	6.2 ± 1.0	1.2 ± 0.5
Group mean	**44 ± 6**	**110 ± 31**	**7.5 ± 0.5**	**12 ± 1**	**2.6 ± 1.2**	**5.7 ± 1.4**	**1.5 ± 0.6**	**0.9 ± 0.3**	**5.2 ± 0.7**	**1.0 ± 0.3**

* Dist = disturbances

Table 4.2. Within subject CV% for each player and WHOOP marker.

Player	RHR (bpm)	HRV (RMSSD)	Hours of sleep	No. dist*	Sleep latency (min)	Sleep cycles	REM sleep (hours)	Deep sleep (hours)	Light sleep (hours)	Time awake (hours)
1	11	57	12	32	118	19	31	90	16	46
2	6	19	20	31	99	33	33	68	21	51
3	6	59	20	30	159	39	35	42	23	39
4	5	33	12	32	202	29	28	74	13	51
5	4	21	14	32	123	65	31	42	17	37
Group mean	**6**	**38**	**15**	**32**	**140**	**37**	**32**	**63**	**18**	**45**

* Dist = disturbances

Sensitivity assessment

To determine the sensitivity of the data recorded via the WHOOP Strap, to the demands of professional soccer training, 3 staff members at a professional soccer club wore WHOOP Straps following a soccer specific exercise bout (see figure 4.1). The session was completed following a 10-minute dynamic warm up. Using data collected via a MEMS unit, the session elicited a total distance of 3100 m and a maximum velocity of 7.6 m/s, mirroring the training demands of a typical professional soccer training session (Gaudino *et al.,* 2013).

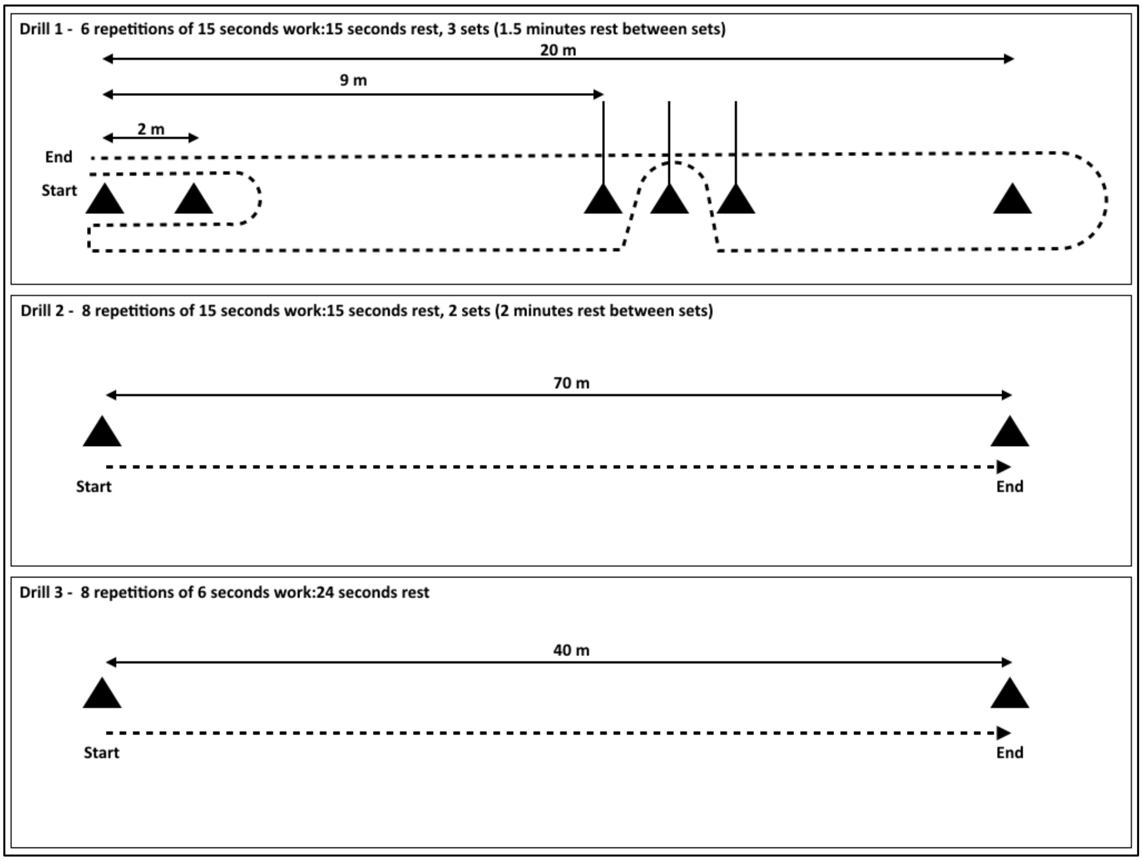

Figure 4.1. The soccer specific exercise bout, all drills were performed at near maximum intensity, with 2 minutes of rest between drills.

In the 5 days following the soccer specific exercise bout (week 1), and the same 5 days, with the absence of a soccer specific exercise bout (week 2), staff members wore the WHOOP Straps. In the days following the exercise bout in week 1, and for the duration of week 2, they completed no exercise. Trends over the 2 weeks, as well as the CV%, were assessed to determine whether the markers (RHR, HRV and sleep hours) were sensitive to this training stimulus. Smallest worthwhile change (SWC) values (0.2 multiplied by the within subject standard deviation) were also calculated for each variable.

The within subject CV% values for RHR, HRV and hours of sleep were 7, 29 and 23 respectively, once more showing that RHR appears to be the only variable with a low CV%. SWC values for RHR, HRV and hours of sleep were 1, 4 and 0.3 respectively. There appeared to be an increase in RHR, above the group mean and outside of the SWC, 2 days following the exercise bout in week 1 (figure 4.2). There was then a decrease in RHR for 2 days before an increase 5 days post exercise. In week 2, a similar pattern was observed in the absence of exercise, RHR was initially lower than week 1 but continued to increase through the week, again peaking on day 5. The lack of a consistent RHR in the absence of exercise would suggest that RHR was not sensitive to the training demands of professional soccer. There appeared to be a reduction in HRV, below the group mean and outside of the SWC, 2 days post exercise in week 1 (figure 4.3). This then appeared to increase 3 days post exercise before decreasing to the lowest value at 5 days post exercise. Whilst the changes in HRV may reflect a response to the exercise bout, the highly variable results in week 2 again suggest that these changes may be reflective of normal variation rather than a response to the training stimulus. Finally, hours of sleep increased through the week in week 1, before a decrease 5 days post exercise. In week 2, there appeared to be a reduction in hours of sleep on Monday, unrelated to exercise. Once more the highly variable nature suggests that the hours of sleep variable was not sensitive enough to show any changes from the exercise bout itself. These results would suggest that data obtained from the WHOOP Strap was not sensitive to the demands of professional soccer training.

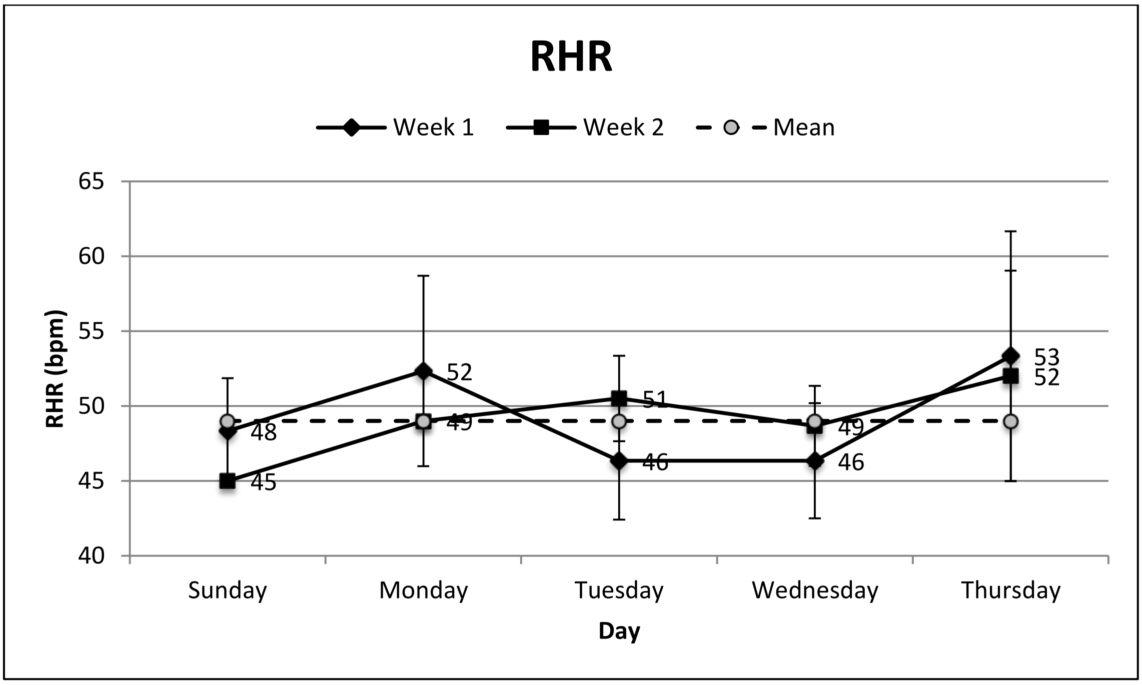

Figure 4.2. Mean values (plus standard error bars) for RHR across week 1 and week 2. Mean values for all participants, across all time periods, have been used to indicate a baseline.

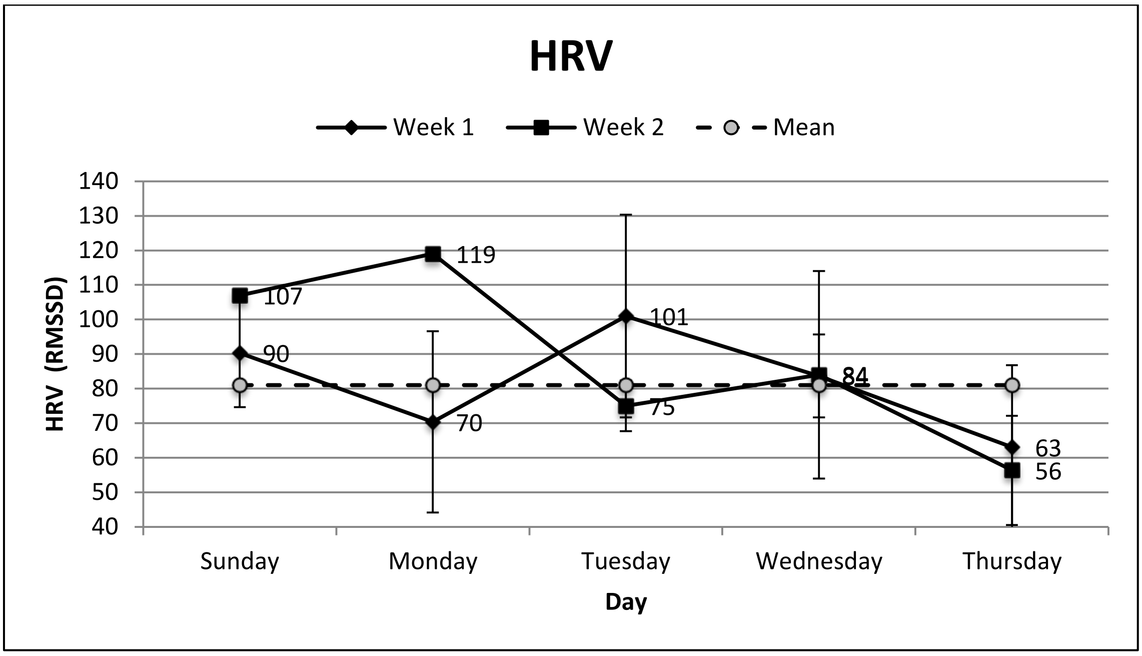

Figure 4.3. Mean values (plus standard error bars) for HRV across week 1 and week 2. Mean values for all participants, across all time periods, have been used to indicate a baseline.

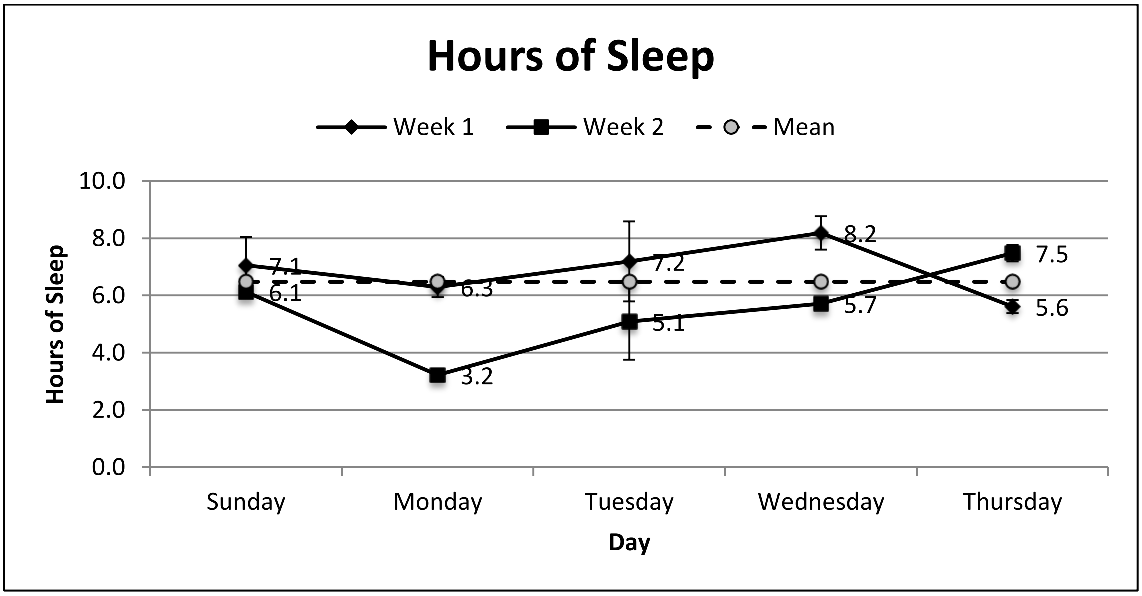

Figure 4.4. Mean values (plus standard error bars) for hours of sleep across week 1 and week 2. Mean values for all participants, across all time periods, have been used to indicate a baseline.

Suitability assessment

Finally, the suitability of the WHOOP Strap to be used in a professional soccer environment was assessed. To do this we asked for feedback from the 5 players who had been wearing the straps, tried to implement wearing the straps across more of the first team squad, and made observations regarding the logistics of implementing this across the full squad, on a daily basis. There were issues highlighted; the WHOOP Strap did not always connect to user phones, this is needed to synchronise the data with their own phones, so players themselves can see their data, but also to synchronise data with the cloud platform for performance staff. In the context of professional soccer, player buy-in can be lost very quickly if technology does not work first time or is inconsistent. Certain players also took straps home but did not wear them; they felt that it was an invasion of privacy to be monitored at home as well as all day at work. Players also felt that straps were bulky, and not aesthetically pleasing, meaning they did not want to wear them all the time. Finally, there were logistical issues around charging the WHOOP straps. Performance staff charged the straps at the training facility during training, before returning the straps back to players before leaving. This was to prevent players forgetting to charge their straps. However, given the already busy environment of a professional soccer club, a more time efficient way of doing this would be needed moving forward.

Conclusion

The WHOOP Strap has the obvious advantage that no user input is required to collect data, once the strap is setup and connected it automatically detects sleep and wake time, and other WHOOP variables. The data collected would have provided an objective fatigue-monitoring tool that may have assisted in the identification of individuals who were in a state of NFOR and potentially at an increased risk of illness. However, evidence supporting the validity behind this device had been conducted by WHOOP themselves, unbiased research is lacking. Further, the work presented above shows that both the reliability (with the exception of RHR) and sensitivity of WHOOP variables was poor. When this was coupled with the fact that there were numerous issues around connection reliability, player feedback and charging the bands, the research team and performance staff felt that this was ultimately not suitable to be used at the soccer club or during this chapter of the thesis.

4.2.2. SIgA measurement

As mentioned, sIgA is an antibody present in saliva that is often used to indicate immune function. This marker appears sensitive to both soccer specific physical load (Fredericks *et al.,* 2012; Mortatti *et al.,* 2012; Moreira *et al.,* 2014; Morgans *et al.*, 2014, 2015; Owen *et al.,* 2016) and indicative of illness risk in athletic populations (Albers *et al.,* 2013; Gleeson and Pyne, 2015; Gleeson *et al.,* 2017). Until recently saliva samples were collected via passive drooling and analysed using ELISA, to provide the concentration of markers such as sIgA. This analysis is often considered too costly and time consuming to be employed practically in professional sport. However, as reported by (Coad *et al.,* 2015), the LFD reader (IPRO, Wallingford, UK) appeared to be valid when measured against ELISA assessment for the measurement of the concentration of sIgA.

This saliva collection procedure involves an oral fluid collector that is held on the top of tongue, with the mouth closed. The collector contains a volume adequacy indicator; this turns blue when the collector is full (0.5 ml of saliva has been collected). Saliva samples are then placed in to a buffer solution, which shaken for 2 minutes, before 2 drops are placed on to a sample pad on the lateral flow immunochromatographic (LFI) test strip. The LFI strip contains anti-sIgA; this captures the presence of sIgA whilst the strip is left for 5 minutes to allow for binding. The strip is then inserted into the LFD reader to measure the colour intensity of the test line; this indicates the amount of anti-sIgA and sIgA complexes formed. The amount of complexes formed is converted into a sIgA concentration based on a standardised curve; this concentration is then displayed on the reader. This procedure is a cost-effective, faster alternative to traditional methods, and was therefore considered as a potentially useful tool to assess the physiological response to the demands of professional soccer, prior to an increase in illness risk. To determine the use of this method to assess sIgA in practice, the same 3 conditions needed to be satisfied. These conditions were that; (1) the data recorded was reliable; (2) the data recorded was sensitive to the demands of professional soccer training; (3) the sIgA assessment method was suitable to be used in this environment.

Reliability assessment

To determine the reliability of the data recorded, 10 staff members at a professional soccer club had 2 saliva samples taken pre breakfast. Staff members provided 2 samples, collected via the method described above, immediately after each other. The CV% between the 2 samples was then calculated to establish reliability. The mean CV% across the group was 29.3%; indicating that this method of calculating sIgA was too unreliable to be used in practice. This data is presented below in table 4.3.

Table 4.3. SIgA concentration values for the 10 staff members tested. Mean values with a standard devation, and CV%, are also presented.

Staff member	SIgA concentration trial 1 (µg/ml)	SIgA concentration trial 2 (µg/ml)	Mean sIgA concentration (µg/ml) ± SD	CV%
1	109.13	20.00	64.57 ± 63.02	97.61
2	116.04	41.23	78.64 ± 52.90	67.27
3	340.69	318.65	329.67 ± 15.58	4.73
4	108.19	142.02	125.11 ± 23.92	19.12
5	118.87	130.26	124.57 ± 8.05	6.47
6	190.56	149.69	170.13 ± 28.90	16.99
7	143.93	75.45	109.69 ± 48.42	44.15
8	131.36	114.79	123.08 ± 11.72	9.52
9	252.16	192.71	222.44 ± 42.04	18.90
10	74.38	83.16	78.77 ± 6.21	7.88
Group mean	**158.53**	**126.80**	**142.66 ± 80.61**	**29.26**

Sensitivity assessment

To determine the sensitivity of the data recorded, to the demands of professional soccer training, 3 staff members at a professional soccer club were sampled (using the same methodology described above) prior to, and for the 4 days following, a soccer specific exercise bout (week 1). The same staff members were then sampled for 5 days across the following week (week 2), without an exercise bout, to assess normal variation. The soccer specific exercise bout was the same bout used in the sensitivity assessment of the WHOOP Straps (figure 4.1). Saliva samples were taken on awakening each day. Trends over the 2 weeks, as well as the CV%, were assessed to determine whether sIgA was sensitive to this training stimulus. The SWC (0.2 multiplied by the within subject standard deviation) was also calculated; this was 36.91 µg/ml.

Patterns identified in figure 4.4 indicate that sIgA concentration appears to increase steadily for 2 days following the exercise bout, before a decrease 3 days post, and a sharp increase 4 days post, in week 1. In the absence of exercise it was expected that there would be little variation in sIgA across week 2, however, there was once more a progressive increase over Sunday and Monday before a sharp increase on Tuesday and a sharp decrease on Wednesday. The average within subject CV% of the 3 staff members was 69.68%, indicating high variability in the samples collected. When this is coupled with the patterns witnessed, it appears that detecting a response to soccer specific exercise, outside of other factors, is difficult. Although the exercise was controlled, it is difficult to control other factors that may influence sIgA, and therefore may account for this variability, such as life stress.

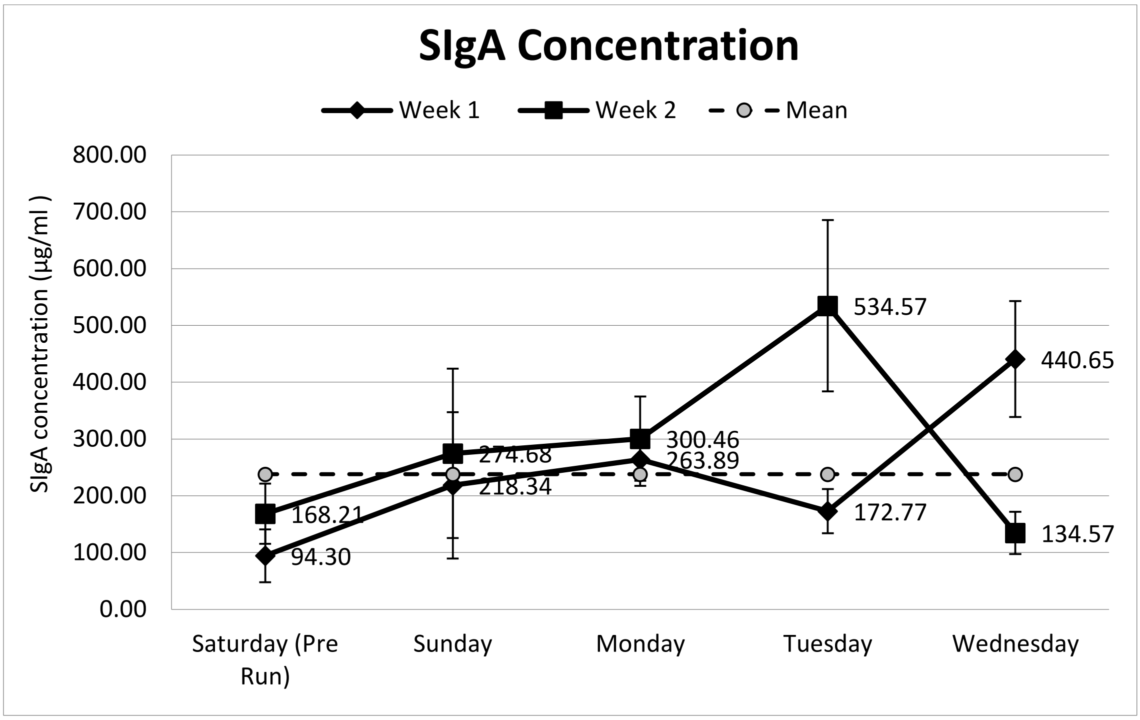

Figure 4.5. Mean values (plus standard error bars) for sIgA concentration across week 1 and week 2. Mean values for all participants across all time periods have been used to indicate a baseline.

Suitability assessment

Finally, the suitability of this sIgA assessment tool to be used in a professional soccer environment was assessed. The methodology described above was implemented, to analyse saliva samples from 3 professional soccer players on a weekly basis, for the last 3 weeks of the 2016-17 competitive season. All samples were taken fasted, pre breakfast, between 08:45 and 09:00 AM. This was done to determine player buy-in, ease of sampling and data turnaround, as well as look at the within subject CV% on a weekly basis. The 3 players that were sampled had no issues with completing the procedure (non-invasive, weekly sampling to avoid tedium) and data turnaround was fast. Performance staff at the soccer club felt that this procedure could easily have been adopted as part of a weekly fatigue monitoring screening. Results from the 3 players are presented in figure 4.5; once more this marker shows a high CV% of 35.90%, indicating high variability.

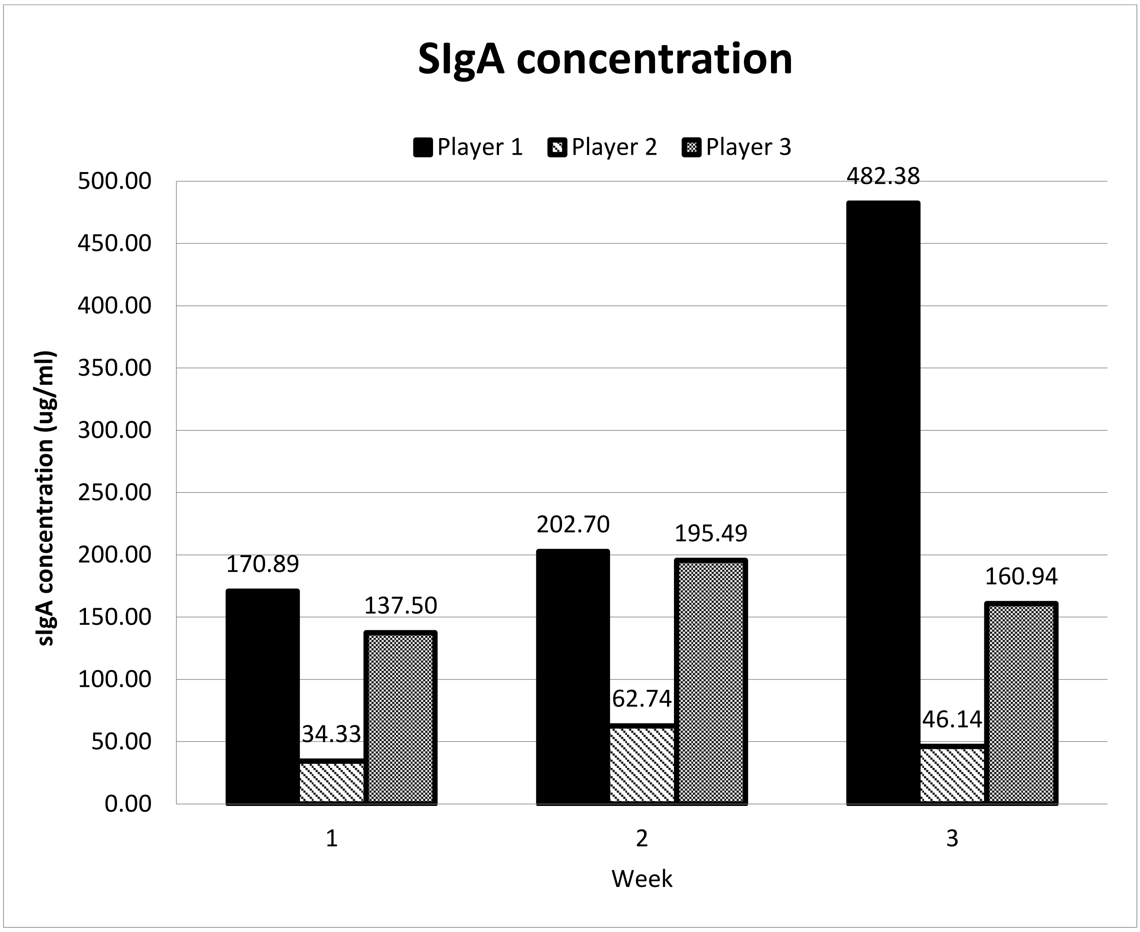

Figure 4.6. Weekly sIgA concentration in 3 professional soccer players across the last 3 weeks of the 2016-17 competitive season.

Conclusion

There is a strong body of evidence supporting the use of sIgA as a practical tool to assess immune function within athletes; it appears to be both reflective of illness risk and responsive to changes in physical load. Further, recent developments regarding the validity of the LFD reader to measure sIgA concentration, and the ease of sampling, are positive towards the incorporation of this method into professional sporting environments. However, our results appear to indicate that, although the testing procedure may be suitable for the environment, the data obtained suggests that the measurement of sIgA using this device is too unreliable to be incorporated into practice and be used within this thesis. Also results indicate that sIgA is not sensitive to the demands of professional soccer training. Therefore the research team and performance staff at the soccer club felt that this was not suitable to be used at the soccer club or within the thesis as an indicator of immune function.

4.3. METHODS

4.3.1. Experimental approach to the problem

This study aimed to examine the relationship between physical load, subjective wellbeing, and illness incidence in professional soccer players. Training and match load, subjective wellbeing and illness incidence data was collected from a male professional soccer team across 3 seasons (2016-17, 2017-18 and 2018-19). Training load data was made up of information that was collected via MEMS, HR and RPE monitoring. Match load data was collected via a high-speed camera tracking system and imported into the MEMS system. The chosen physical load variables were selected to provide an indication of internal, external, objective and subjective load components (Bourdon *et al*., 2017). In order to be able to easily interpret results, physical load variables were divided into locomotive external (distance, velocity), mechanical external (change of direction and accelerometry) and internal (HR, RPE) categories. Subjective wellbeing data was collected using a questionnaire (McLean *et al*., 2010) assessing fatigue, general muscle soreness, sleep quality, stress and mood. Although not part of the published questionnaire, number of hours of sleep was also added in the 2018-19 season. This particular subjective questionnaire was employed as a fatigue-monitoring tool because it was deemed simple, easy to administer and sensitive to changes in physical load (McLean *et al*., 2010). Illness incidence data was collected using the same methodology used in Chapter 3, for the full 3 seasons, to ensure that all illness definitions were considered.

4.3.2. Participants

A total of 51 participants from 1 English Football League (EFL) Championship soccer team were included in the analysis (age 26 ± 5 years; height 1.85 ± 0.06 m; weight 82.4 ± 7.6 kg). The soccer team competed in the EPL during the 2016-17 and 2017-18 seasons, prior to the EFL Championship in 2018-19. For all seasons, data collection began on the first day of pre-season and continued until the last game of the competitive season. All outfield first-team players present at the club during the 2016-

17, 2017-18 and 2018-19 were included. Goalkeepers were excluded from the analysis because of incomplete training load information. Further goalkeeper specific training, and therefore the physical load variables assessed, would have made them distinct cases and difficult to integrate into the analysis. Clearly 51 participants were not present at all times across 3 seasons, players changed each season, and within each season, due to both permanent transfers and loan players coming into and leaving the club. Only when a player was present at the club was their data included in the analysis. A total of 9532 individual training observations were collected with a mean of 187 sessions per player. A total of 2291 individual match observations were collected with a mean of 45 matches per player. All participants were provided with a participant information sheet before signing an informed consent document. The LJMU Ethics Committee approved the study.

4.3.3. Data collection

Training data collection

Training observation data included all team training sessions, on-field rehabilitation sessions, individual training sessions and post-match conditioning sessions. Data for post-match conditioning sessions through out each season was replicated from data collected from a sample of 5 players at the start of each season. This was because GPS devices were not taken to each match and therefore data for these sessions was not availiable. All MEMS data was collected using 10-Hz portable GPS devices containing an accelerometer, gyroscope and magnetometer (OptimEye S5, Firmware Version 7.18; Catapult Innovations, Melbourne, Australia), whilst all HR data was collected using T31 belts (Polar, Kempele, Finland). GPS units were turned on outside, 30 minutes prior to training, to lock on to the appropriate satellites, as per the manufacturer's guidelines. The GPS units were then placed into custom-designed vest garments, where units are positioned between the players' scapulae to minimise movement artefacts (Varley *et al*., 2017). The vests, along with HR belts, were hung on individual pegs for players to take before leaving the building for training. Where possible, to avoid potential inter-unit variation, players wore the same GPS unit for each training session (Malone *et al*., 2017). To ensure data collection, sports science staff checked the pegs prior to training to make sure each player was wearing a GPS unit and HR belt. Following training GPS units were collected and downloaded into OpenField (version 1.12.0, Catapult Sports, Melbourne, Australia) for data processing. Following this, the full training session was broken down into individual drills. Therefore data outside of the working drills was not included in analysis. As per recommendations by Malone *et al*. (2017), data was checked to ensure the GPS had been connected to at least 6 satellites and that the horizontal dilution of precision (HDOP) was less than 1. Individual HR traces were checked for accuracy. After these procedures the session data was exported in a Microsoft Excel (Microsoft, Washington, US) document under the comma-separated values (CSV) format, containing certain variables, where specific thresholds were applied. This data was then input into a longitudinal training load database within Microsoft Excel. Where GPS or HR data was missing, or deemed inaccurate, group average values for that particular session were input into the database.

RPE was collected as a subjective assessment of training load, not match play, during the 2017-18 season only. Immediately following the end of each training session players were asked to provide an RPE rating using a laminated scale for guidance. The scale used was a modified 1-10 Borg scale (Foster *et al*., 2001). Specifically, players were asked, "how hard did you find the training session?" Players were then prompted to select a specific 1-10 RPE rating individually by touching the respective score on the laminated scale. This score was recorded on a sheet under the scale to ensure scores were not visible to other players. The RPE score was collected within 15 minutes of the end of each training session. In order to familiarise players with the scale, during the last 4 weeks of the 2016-17 season, players followed the described RPE collection procedure. However, data recorded during this time was not used in the analysis. Following data collection, the RPE scores were input into the same longitudinal training load database as the GPS and HR data described above.

Match data collection

Match data was collected using an optical tracking system, using 6 semi-automated HD cameras sampling at a frequency of 25 Hz (TRACAB, ChyronHego, New York, USA).

Following each match, raw TRACAB files were imported into OpenField. TRACAB provides 2 files; a raw data file with x-y positions collected at 25 Hz and a basic summary file with summary metrics. The importer within OpenField processes the raw data with Catapult filters to generate data in the same thresholds as training data.

To assess the accuracy of this process, data was recorded by TRACAB and Catapult GPS for 2 pre-season matches. This data was then imported into OpenField using the same process described above. The data for all players present in the 2 matches (34 in total) was compared between systems using R^2 values. This analysis was completed for total distance, high intensity distance, very high intensity distance, sprint distance, number of high intensity runs, number of sprints and maximum velocity (see Table 4.4 for an explanation of these variables). The agreement between the 2 systems appeared to be moderate to strong, with the following R^2 values reported; total distance (0.84), high intensity distance (0.83), very high intensity distance (0.95), sprint distance (0.94), number of high intensity runs (0.89), number of sprints (0.61) and maximum velocity (0.87).

Further, there also appears to be strong agreement between raw data collected by TRACAB, and the same data imported through OpenField (R^2 values from 0.91 to 0.96) (Durussel, 2015). The variables assessed were total distance, maximum velocity, sprint distance (> 7 m/s) and number of high intensity runs (> 5.5 m/s). Differences here are likely due to the different filtering processes used by the 2 platforms. There was also moderate to good correlations between raw data collected by TRACAB and raw data collected via Catapult 10 Hz GPS units (R^2 values of 0.96 for maximum velocity, 0.97 for sprint distance, 0.88 for number of high intensity runs and 0.78 for total distance were reported) (Durussel, 2015). The larger differences observed here are due to the differences in data-collection technology (video vs. GPS-based).

Therefore importing data through OpenField to collect longitudinal data appears justified from an accuracy perspective. Only locomotive external variables (total distance, high intensity distance, very high intensity distance, sprint distance, number of high intensity runs, number of sprints and maximum velocity) could be obtained from the TRACAB system (Table 4.4). Mechanical external (Table 4.5) and internal data

(Table 4.6) is therefore absent from each match entry. Following the match data import process, the data was input into the same longitudinal physical load database as the GPS, HR and RPE data described above. Tables 4.4-4.6 explain all physical load variables collected.

Table 4.4. Locomotive external physical load variables.

Variable	**Explanation**
Duration (minutes)	Total working time of the session.
Total distance (m)	Total distance covered within the session.
Metres per minute	Total distance covered divided by duration.
High intensity distance (m)	Distance covered above 49% of an individual's maximum velocity.
Number of high intensity runs	Number of efforts above 49% of an individual's maximum velocity, lasting for 0.2 seconds or more.
Very high intensity distance (m)	Distance covered above 60% of an individual's maximum velocity.
Sprint distance (m)	Distance covered above 80% of an individual's maximum velocity.
Number of sprints	Number of efforts above 80% of an individual's maximum velocity, lasting for 0.2 seconds or more.
Maximum velocity (m/s)	Maximum recorded velocity within the session.

Table 4.5. Mechanical external physical load variables.

Variable	**Explanation**
Player load (AU)	A modified vector magnitude that uses accelerometer data to combine movements from all 3 planes. It is expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (X, Y and Z axis) and divided by 100 (Boyd *et al*., 2011). The equation is described below; $$\text{Player load} = \sqrt{\frac{(a_{y1} - a_{y-1})^2 + (a_{x1} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2}{100}}$$ In the equation ay = Forward accelerometer, ax = Sideways accelerometer and az = Vertical accelerometer.
Player load per minute	Player load divided by duration.
Number of accelerations (> 2 m/s/s)	Number of efforts where velocity increases by 2 m/s/s or more, lasting for 0.4 seconds or more.
Number of accelerations (> 3 m/s/s)	Number of efforts where velocity increases by 3 m/s/s or more, lasting for 0.4 seconds or more.
Number of decelerations (< - 2 m/s/s)	Number of efforts where velocity decreases by 2 m/s/s or more, lasting for 0.4 seconds or more.
Number of decelerations (< - 3 m/s/s)	Number of efforts where velocity decreases by 3 m/s/s or more, lasting for 0.4 seconds or more.

Table 4.6. Internal physical load variables.

Variable	**Explanation**
Training impulse (TRIMP) (AU)	The sum of the duration spent in all HR zones (1-6) that are each multiplied by given a weighting factor. HR zones - 1 - 0-50% of maximal heart rate (MHR) 2 - 50-65% of MHR 3 - 65-75% of MHR 4 - 75-85% of MHR 5 - 85-92% of MHR 6 - 92-105% of MHR Weighting factors - 1 - 0 2 - 1.2 3 - 1.5 4 - 2.2 5 - 4.5 6 - 9.0
TRIMP per minute	TRIMP divided by duration.
Time spent above 85% MHR (minutes)	Duration spent above 85% of an individual’s MHR.
RPE (AU)	1-10 rating of perceived exertion score given using the modified Borg scale (Foster *et al.*, 2001).
Session (s) RPE (AU)	RPE score multiplied by duration.

Subjective wellbeing data collection

Subjective wellbeing data was collected using a custom-made questionnaire based on recommendations by Hooper and Mackinnon (1995) and originally employed in McLean *et al*. (2010). The questionnaire assessed fatigue, sleep quality, general muscle soreness, stress levels and mood on a 1-5 Likert scale to produce a total wellbeing score ranging from 5-25. The original questionnaire was shown to be simple, easy to administer and sensitive to changes in physical load (McLean *et al*., 2010). However, due to a change in the fatigue monitoring philosophy of the sports science and medicine department, number of hours of sleep was also added into the questionnaire during the 2018-19 season (Appendix 4.1). The questionnaire was completed before training (between 8:30 and 10:00 AM).

During the 2016-17 and 2017-18 seasons a member of staff asked each individual player to complete the questionnaire as they entered the first team changing room, this was completed as privately as possible to ensure honesty. However, given the small nature of the training ground facility, this was difficult. Specifically, a staff member asked players the following individual questions; how tired do you feel, how was your sleep last night, how sore do you feel, how stressed do you feel, what is your current mood and how many hours of sleep did you have. Players were then prompted to select a specific 1-5 rating by either touching or saying the respective score using a laminated copy of the questionnaire. This score was immediately recorded within a database on a password-protected laptop. This was, therefore, not visible to other players or staff members without permission.

During the 2018-19 season, a link to the questionnaire (on Google sheets) was sent out daily to a player WhatsApp group. Players then clicked on the link and filled out the same questions as above on their phones prior to training. Following completion of the questionnaire, individual responses were sent directly to a Microsoft Excel spreadsheet. The spreadsheet was then used to record scores in a longitudinal database on a password-protected laptop. Once more, after completing the questionnaire results were not visible to any other players or staff without permission. If a player did not complete the questionnaire they were initially asked the questions in person, as above. If a player did then not answer the questions, for whatever reason, no subjective wellbeing data was recorded for that particular player on that day.

Subjective wellbeing data collection ranged from daily to every 2 weeks across the 3 seasons. Alterations in the fatigue monitoring philosophy within the sports science and medicine department dictated the changes in frequency of data collection. Unfortunately this may have impacted the results seen below. At times where subjective wellbeing information was collected daily, alterations in fatigue status that may or may not have led to an illness would have been picked up. However, the sensitivity to pick up on these changes may have been lost when the frequency of data collection was reduced to every 2 weeks.

Illness incidence

Illness incidence data was recorded across all 3 seasons using the same methodology described in Chapter 3. To ensure both consistency and accurate diagnosis by qualified medical personnel (Timpka *et al*., 2014), the research team tried to ensure the same medical practitioner was responsible for diagnosing and recording illness throughout the investigation. The same team doctor, who had been with the club for 8 seasons, and prior to this had worked in Olympic sports and as an emergency medical consultant, was present for the 2016-17 and 2017-18 seasons. However the responsibility of diagnosing and recording illness was passed to the head of medical during the 2018-19 season following the previous doctor’s departure. The head of medical had worked closely with the team doctor for the previous 5 seasons, including assisting in the recording injury and illness surveillance data. This ensured data quality was maintained over the transfer in staff. Illness incidence information was passed from the team doctor/head of medical to the lead researcher to record in a database specific to this project.

4.3.4. Data analysis

To evaluate hypotheses 1 and 2, median acute (7-day) rolling averages for physical load, and subjective wellbeing variables, as well as number of training sessions and matches per week, were calculated per player. The median was used, instead of the mean, as this is not affected by outlier values and was therefore deemed a better indicator of an average reference value. The choice of the median is justified in this case as there were many outlier values on preliminary assessment of the data due to weeks or months containing rest days where a physical load value of "0" would be present. The mean rolling averages for these variables in the acute (7-day) period preceding illness events were also calculated. Mean values for the whole sample were compared between the 7 days preceding an illness event, and the general 7-day averages for each variable using a parametric paired-samples t-test. This process was repeated for the chronic (28-day) time periods. The parametric paired-samples t-test was chosen because of the need to compare 2 conditions. This test was used following confirmation of the assumption of a normal distribution of differences with the Kolmogorov-Smirnov test. For each variable assessed, the effect size (ES) was calculated as the absolute difference between the general and illness averages divided by the between-subject standard deviation. This was completed to show the magnitude of differences between general and illness averages. ES values were classified as follows: 0 to 0.2, trivial; 0.2 to 0.6, small; 0.6 to 1.2, moderate; 1.2 to 2.0 large; 2.0 to 4.0 very large; >4.0, extremely large (Hopkins *et al.,* 2009). The smallest worthwhile change (SWC) was then calculated as 0.2 times the between-subjects standard deviation of the general condition (corresponding to the threshold value for a small effect) (Hopkins *et al.,* 2009). This was calculated to show whether differences between general and illness averages were practically meaningful.

To evaluate hypotheses 3, the daily mean acute (7-day) to chronic (28-day) ratios for physical load, and subjective wellbeing variables, every day from 1-15 days before an illness event, were compared to a fixed value of 1 (indicating no change in physical load or wellbeing). The comparison for each variable was completed using a 1-samples t-test, this was chosen as ratios were compared to a fixed value. All data analysis was completed with 37 players. 12 players were excluded as they did not experience an illness event and therefore comparison was impossible. A further 2 players were excluded as they had too short of a time period to conduct a proper monthly analysis

(48 and 28 days respectively). P-values for all analyses were set at $p<0.05$. All analyses were completed in the statistical software R (R Core Team, 2019).

4.3.5. Theoretical rationale for data analysis

The initial comparison of physical load and subjective wellbeing variables in the 7 and 28-day periods around an illness event to normality was selected as a way of distinguishing which variables were most important around illness events. Also this was used to highlight some of the key preliminary relationships between physical load, subjective wellbeing, and illness risk. 7 and 28-day periods around illness events were selected in this analysis as it had previously been completed in female youth soccer players, using purely subjective training load data (Watson *et al*., 2017). The study reported an increased average monthly training load preceding an illness event, compared to normality. Watson *et al*. (2017) also found an increased weekly training load, compared to normality, was predicative of illness. Further, work completed by Williams *et al.* (2017b) attempted to decipher the most important training load measures, using subjective training load data from rugby union players. The component that explained the most variance in injury risk, and therefore was deemed most important, was a 1-4 week cumulative load. Although this work was completed using injury, and not illness as an outcome measure, the principles referred to in section 4 of Chapter 2 show that the demands of soccer and the accumulation of fatigue over these periods are important. A weekly increase in physical load has been related to illness risk (Foster, 1998; Putlur *et al*., 2004; Piggott, 2008; Thornton *et al*., 2015), whilst a lag of up to 4 weeks can be present between a change in physical load and illness risk (Drew and Finch, 2016). As such, weekly and monthly periods were selected for analysis.

The comparison of daily mean acute to chronic ratios for physical load, and subjective wellbeing variables, to a fixed value of 1, was chosen as an analysis to explore the contribution of individual physical load and subjective wellbeing variables towards illness risk. This was used as a way to determine how much specific physical load and subjective wellbeing variables would need to change to alter illness risk. A change in physical load, specifically the acute to chronic ratio, was the component that explained the second most amount of variance in injury risk (Williams *et al*., 2017b). Further, spikes in physical load are related to an increased risk of illness (Walsh *et al*., 2011; Drew and Finch, 2016; Schwellnus *et al*., 2016; Jones *et al*., 2017). In a practical sense it is important that these abrupt increases in physical load are detectable on a daily basis to impact the fast paced decision making involved in professional soccer. Despite the recent published discussions around the acute to chronic workload ratio (Drew *et al*., 2017a; Menaspà, 2017; Murray *et al*., 2017; Williams *et al*., 2017c; Fanchini *et al*., 2018; Hulin and Gabbett, 2019; Impellizzeri *et al*., 2019; Lolli *et al*., 2019a, 2019b; Windt and Gabbett, 2019), this was selected as a descriptor of changes in physical load and subjective wellbeing over time. Whilst there are clearly justified criticisms around the ratio, it was chosen as one simple way of modelling spikes in physical load and subjective wellbeing. As mentioned above it is clear that these spikes are associated with an increased illness risk.

4.4. RESULTS

The mean and median values displayed in the results section may look lower than expected. This is because the averages contained days off within the weekly and monthly time periods. Despite being accurate, a day off would equate to a load of “0”, regardless of the variable, and therefore bring the average down. Further, data on RPE and sRPE was removed from the results presented below as this data was only collected during the 2017-18 season. Therefore any results presented may not have been truly representative of the physical load-illness relationship, as missing data may have influenced the results.

4.4.1. Physical load and subjective wellbeing in the 7 and 28-day periods preceding an illness compared to normality

Due to the large amount of physical load and subjective wellbeing variables analysed, only variables that showed significant differences between normality and periods prior to illness events have been included in the results section of this chapter. The analysis for all variables is presented in appendix 4.2. In the 7 days preceding an illness event, maximum velocity was significantly lower than general 7-day values (4.1 ± 0.3 m/s vs.

3.7 ± 1.0 m/s, p=0.03); this was a large effect size (ES = 1.3). TRIMP per minute was significantly higher in the 7 days preceding an illness event compared to general 7-day values (0.4 ± 0.4 vs. 0.6 ± 0.5, p=<0.01); this was a small ES (ES = 0.5). Similarly, time spent above 85% MHR was significantly higher in the 7 days preceding an illness event compared to general 7-day values (2.3 ± 1.8 minutes vs. 2.8 ± 2.2 minutes, p=0.02); this was a small effect size (ES = 0.3). These results are presented in table 4.7.

Table 4.7. Comparison of general 7-day physical load and subjective wellbeing variables to the 7 days preceding an illness event. Values presented are a 7-day average and therefore reflect values per day. Data is presented as mean values ± standard devation. P-values, ES and SWC values are also presented. Data analysis was completed with 37 players.

Variable	General 7-day average	7 days before illness	P-value	ES	SWC
Maximum velocity (m/s)	4.1 ± 0.3	3.7 ± 1.0	0.03*	1.3	0.1
No. of accelerations (> 3 m/s/s)	0 ± 1	1 ± 1	<0.01*	0.4	0.1
TRIMP per minute	0.4 ± 0.4	0.6 ± 0.5	<0.01*	0.5	0.1
Time spent above 85% MHR (minutes)	2.3 ± 1.8	2.8 ± 2.2	0.02*	0.3	0.4

* Denotes statistical significance (p<0.05).

In the 7 days preceding an illness event, there were no significant differences in the amount of training sessions completed or matches played, compared to general 7-day values (Table 4.8).

Table 4.8. Comparison of the general 7-day number of matches and number of training sessions per week to the 7 days preceding an illness event. Data is presented as mean values ± standard devation. P-values, ES and SWC values are also presented. Data analysis was completed with 37 players.

Variable	General 7-day average	7 days before illness	P-value	ES	SWC
Number of matches per week	1 ± 0	1 ± 0	0.22	0.3	0
Number of training sessions per week	3 ± 0	3 ± 1	0.16	0.5	0.1

* Denotes statistical significance (p<0.05).

In the 28 days preceding an illness event, high intensity distance was significantly lower than general 28-day values (284.7 ± 63.7 m vs. 268.0 ± 84.1 m, p=0.03); this was a small effect size (ES = 0.3). Sleep quality was also significantly lower than general 28-day values (3.8 ± 0.3 AU vs. 3.7 ± 0.4 AU, p=0.01); this was a small effect size (ES = 0.3). These results are presented in table 4.9.

Table 4.9. Comparison of general 28-day physical load and subjective wellbeing variables to the 28 days preceding an illness event. Values presented are a 28-day average and therefore reflect values per day. Data is presented as mean values ± standard devation. P-values, ES and SWC values are also presented. Data analysis was completed with 37 players.

Variable	General 28-day average	28 days before illness	P-value	ES	SWC
High intensity distance (m)	284.7 ± 63.7	268.0 ± 84.1	0.03*	0.3	12.7
Sleep quality (1-5)	3.8 ± 0.3	3.7 ± 0.4	0.01*	0.3	0.1

* Denotes statistical significance (p<0.05).

In the 28 days preceding an illness event, there were no differences in the amount of training sessions completed or matches played, compared to general 28-day values (Table 4.10).

Table 4.10. Comparison of the general 28-day number of matches and number of training sessions per week to the 28 days preceding an illness event. Data is presented as mean values ± standard devation. P-values, ES and SWC values are also presented. Data analysis was completed with 37 players.

Variable	General 28-day average	28 days before illness	P-value	ES	SWC
Number of matches per week	1 ± 0	1 ± 0	0.29	0.2	0
Number of training sessions per week	3 ± 0	3 ± 1	0.39	0.3	0.1

* Denotes statistical significance (p<0.05).

4.4.2. Changes in physical load and subjective wellbeing in the build up to illness events

Further, comparison of daily mean acute to chronic ratios to 1 (indicating the same acute and chronic load or wellbeing) for physical load, and subjective wellbeing variables, every day from 1-15 days before an illness event, showed significant results. Many physical load and subjective wellbeing variables show a significant increase in daily acute to chronic ratios in the 15 days leading up to an illness event. These results are described in tables 4.11 - 4.14. Specifically it appears that a daily acute to chronic ratio of 1.1, in physical load variables, may precede illness events by 6 days.

Table 4.11. Comparison of daily mean acute to chronic ratios to 1 (indicating no change) for locomotive external physical load variables, every day from 1-15 days before an illness event. Data is presented as mean daily acute to chronic ratios. Data analysis was completed with 37 players.

Variable	ID-1	ID-2	ID-3	ID-4	ID-5	ID-6	ID-7	ID-8	ID-9	ID-10	ID-11	ID-12	ID-13	ID-14	ID-15
Duration (minutes)	1.05	1.09*	1.03	1.02	1.06	1.11*	1.10*	1.04	1.04	1.04	1.03	1.04	1.00	0.96	0.98
Total distance (m)	1.05	1.08*	1.02	1.01	1.04	1.11*	1.07	1.02	1.01	1.02	1,00	1.01	0.98	0.96	0.99
Metres per minute	1.09*	1.11*	1.05	1.03	1.06	1.11*	1.08*	1.03	1.03	1.04	1.05	1.05	1.01	1.00	1.03
HID (m)	1.05	1.09	1.03	0.99	1.00	1.11*	1.04	1.00	1.00	0.99	0.97	0.98	0.98	0.98	1.01
No. HI runs	1.03	1.06	0.99	0.99	1.01	1.12*	1.06	1.03	1.04	1.05	1.02	1.03	0.98	0.97	1.02
VHID (m)	0.99	1.04	0.98	1.04	1.09	1.20*	1.13*	1.12*	1.12*	1.08	1.04	1.05	1.02	1.06	1.06
Sprint distance (m)	1.02	1.06	1.05	1.14*	1.11	1.19*	1.15*	1.17*	1.17*	1.19*	1.13	1.24*	1.21*	1.11	1.22*
Number of sprints	1.24*	1.25*	1.16*	1.19*	1.12	1.19*	1.16*	1.13*	1.11	1.16*	1.12	1.24*	1.20*	1.11	1.20*
MV (m/s)	1.07	1.09*	1.04	1.04	1.08*	1.13*	1.12*	1.04	1.04	1.05	1.06	1.05	1.02	0.99	1.01

* Denotes a statistically signifcant difference from 1, this is also highlighted using grey ($p<0.05$), ID = illness day, HID = High intensity distance, No. HI runs = Number of high intensity runs, VHID = Very high intensity distance and MV = Maximum velocity.

Table 4.12. Comparison of daily mean acute to chronic ratios to 1 (indicating no change) for mechanical external physical load variables, every day from 1-15 days before an illness event. Data is presented as mean daily acute to chronic ratios. Data analysis was completed with 37 players.

Variable	ID-1	ID-2	ID-3	ID-4	ID-5	ID-6	ID-7	ID-8	ID-9	ID-10	ID-11	ID-12	ID-13	ID-14	ID-15
Player load (AU)	1.07	1.10*	1.09*	1.01	1.06	1.13*	1.10*	1.07	1.09	1.11	1.10	1.12*	1.09	1.04	1.02
PL/min	1.09*	1.09*	1.09*	1.01	1.06	1.12*	1.09*	1.06	1.07	1.10*	1.11*	1.11*	1.09	1.05	1.03
No. acc (> 2 m/s/s)	1.10*	1.12*	1.10*	1.01	1.05	1.13*	1.11*	1.09	1.11*	1.12*	1.12*	1.17*	1.14*	1.10	1.07
No. acc (> 3 m/s/s)	1.28*	1.34*	1.30*	1.43*	1.48*	1.53*	1.59*	1.49*	1.50*	1.59*	1.43*	1.52*	1.62*	1.55*	1.48*
No. dec (< -2 m/s/s)	1.04	1.04	1.02	0.97	1.01	1.09	1.06	1.06	1.09	1.13	1.11	1.14*	1.13	1.09	1.04
No. dec (< -3 m/s/s)	1.17*	1.16*	1.15*	1.09	1.22*	1.26*	1.26*	1.37*	1.47*	1.48*	1.56*	1.51*	1.49*	1.42*	1.37*

* Denotes a statistically signifcant difference from 1, this is also highlighted using grey ($p<0.05$), ID = illness day, PL/min = Player load per minute, No. acc = Number of accelerations, No. dec = Number of decelerations.

Table 4.13. Comparison of daily mean acute to chronic ratios to 1 (indicating no change) for internal physical load variables, every day from 1-15 days before an illness event. Data is presented as mean daily acute to chronic ratios. Data analysis was completed with 37 players.

Variable	ID-1	ID-2	ID-3	ID-4	ID-5	ID-6	ID-7	ID-8	ID-9	ID-10	ID-11	ID-12	ID-13	ID-14	ID-15
TRIMP (AU)	1.10*	1.11*	1.09*	1.02	1.07	1.13*	1.10*	1.07	1.10	1.10	1.09	1.12*	1.07	1.00	0.98
TRIMP per minute	1.31*	1.28*	1.27*	1.15*	1.19*	1.31*	1.27*	1.24*	1.25*	1.21*	1.16*	1.19*	1.05	1.02	0.96
> 85% MHR (minutes)	1.21*	1.18*	1.16*	1.14*	1.16*	1.26*	1.25*	1.27*	1.26*	1.28*	1.30*	1.32*	1.24*	1.15	1.06

* Denotes a statistically signifcant difference from 1, this is also highlighted using grey ($p<0.05$), ID = illness day, > 85% MHR (minutes) = Time spent above 85% MHR (minutes).

Table 4.14. Comparison of daily mean acute to chronic ratios to 1 (indicating no change) for subjective wellbeing variables, every day from 1-15 days before an illness event. Data is presented as mean daily acute to chronic ratios. Data analysis was completed with 37 players.

Variable	ID-1	ID-2	ID-3	ID-4	ID-5	ID-6	ID-7	ID-8	ID-9	ID-10	ID-11	ID-12	ID-13	ID-14	ID-15
Fatigue (1-5)	0.99	0.97*	0.98	0.98	0.99	1.01	1.00	1.02	1.03	1.02	1.02	1.01	1.00	1.01	1.00
GMS (1-5)	1.00	0.99	1.00	0.99	0.98	1.00	1.01	1.02	1.03*	1.03*	1.03	1.02	1.02	1.01	0.99
Sleep quality (1-5)	1.01	1.00	1.01	1.01	0.99	1.00	1.01	1.02	1.01	1.01	1.01	1.01	1.01	1.00	0.99
Hours of sleep (1-5)	0.98	0.98	0.98	1.02	1.00	1.02	1.03*	1.04*	1.04*	1.02	1.02	0.99	0.99	1.00	1.01
Stress (1-5)	0.99	0.98	0.98	1.00	1.01	1.02*	1.01	1.02*	1.02*	1.02	1.02	1.01	1.01	0.98	0.98
Mood (1-5)	1.01	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.98	0.97*
TWS (5-25/30)	1.00	0.99	0.99	1.00	0.99	1.01	1.01	1.02	1.02*	1.01	1.01	1.01	1.00	0.99	0.98

* Denotes a statistically signifcant difference from 1, this is also highlighted using grey ($p<0.05$), ID = illness day, GMS = General muscle soreness, TWS = Total wellbeing score.

4.5. DISCUSSION

The aim of the current study was to examine the relationship between physical load, subjective wellbeing, and illness incidence in professional soccer players. In relation to hypotheses 1 and 2, differences exist between physical load and subjective wellbeing during the 7 and 28-day periods leading to an illness, compared with the average values across the same time periods. Specifically there appears to be a reduction in maximum velocity, whilst an increase in TRIMP/min and time spent above 85% MHR, in the 7 days prior to an illness event. In the 28 days preceding an illness event, high intensity distance is reduced compared to normal values. These findings are coupled with a reduction in sleep quality over the 28 days preceding an illness event. In relation to hypothesis 3, there appears to be increases in the daily acute to chronic ratio of physical load variables in the 15 days prior to an illness event. Taken together findings provide warning flags for practitioners to identify and intervene appropriately. Reductions in weekly external physical load variables (such as maximum velocity and high intensity distance) at the same time as increases in internal physical load variables (such as TRIMP and time spent above 85% MHR) may indicate that, at the onset of symptoms, a player finds it harder than usual to produce their usual external output and is therefore at risk of developing an illness. A reduced sleep quality should also be highlighted, as this may be present in the month preceding an illness. Further, spikes in physical load should be guarded against; these may increase illness risk in the days that follow.

4.5.1. Physical load and subjective wellbeing in the 7 and 28-day periods preceding an illness compared to normality

In support of hypothesis 1, there are significant differences in physical load variables in the 7 and 28-day periods prior to illness compared to averages of the same time periods. Identification of an increase in internal physical load variables (TRIMP/min and time spent above 85% MHR) in the 7 days before an illness event, compared to normality, is comparable with previous research. Previously published literature suggests that increases in weekly physical load, above normality, are related to an increased risk of illness (Brink *et al*., 2010; Thornton *et al*., 2014; Hellard *et al*., 2015;

Watson *et al*., 2017). These studies differ from the current study in both the specific variables used to model the physical load-illness relationship and the illness recording system used. In this study, weekly increases in internal physical load, described as the response to prescribed or external physical load (Impellizzeri *et al.,* 2005), may be related to an increased risk of illness. RPE is a subjective internal physical load marker indicating the perceived response to a prescribed external load; this was used to model the physical load-illness relationship in Thornton *et al* (2014) and Watson *et al* (2017). Therefore increased internal physical load variables around illness events may be related to illness risk. This supports the idea of a relationship between physical load and illness risk described in Chapter 3. However, average data from the whole team, was used in the longitudinal database, when internal physical load (HR) data was not present for a player in a particular session. Similarly, match data was only available for locomotive external physical load variables; unfortunately it was impossible to collect mechanical external or internal physical load variables for match play. Such discrepancies in data collection may have contributed towards these results. Further, effect sizes are relatively small for these variables (0.5 for TRIMP/min and 0.3 for time spent above 85% MHR).

In any case, increases in markers of internal physical load were coupled with decreases in maximum velocity (a marker of locomotive external load) in the 7 days preceding an illness, compared to average values, with a strong effect size of 1.3. This has not been reported in previous research, which may be due to the methodological differences described above. In this study maximum velocity was defined as the "maximum recorded velocity within the session" and is often used as marker of session intensity. Over the 7-day period prior to an illness it seems that a reduction in external or prescribed load is coupled with an increase in internal load. This finding would suggest that players are finding the external physical demands harder to cope with in comparison to normal and are therefore producing a greater response (an elevated cost for a reduced output). A key symptom of NFOR is a reduced ability to perform high intensity exercise (Mackinnon, 2000), whilst athletes may differ in their internal load outputs based on factors such as fatigue, emotion, recent training history and illness risk (Bourdon *et al*., 2017). Elevated internal demands and a reduced external output may therefore be present when symptoms first present, prior to an illness developing. In accordance with this, practitioners should look to highlight these incidences using tools such as the internal to external physical load ratios described by Akubat *et al*. (2014), so appropriate interventions can be implemented. Assessment of the relationship between specific internal to external physical load ratios and illness risk may provide an avenue for future research.

A reduction in high intensity distance (a further marker of locomotive external load) was observed in the 28 days preceding an illness event compared to average values, albeit with a small effect size of 0.3. Increases in markers of internal physical load over a 28-day period were not observed in this study and therefore these findings differ from previous research. Indeed, Watson *et al*. (2017) reported that the average monthly physical load was significantly higher preceding an illness, compared to normality. However, once more this study used RPE as the physical load marker. Without an increase in internal physical load over this period, findings from the current thesis may suggest that players are choosing to reduce their external output rather than doing so at an elevated internal cost, to prevent symptoms becoming worse. Also, at the onset of illness symptoms, players may undergo some form of load modification, following guidance from the performance team, where their external physical load is reduced to prevent symptoms developing into an illness. However, given the nature of the statistical approach it is also possible that this finding, along with an increased number of accelerations (> 3 m/s/s) over a 7-day period, may be a type 2 error or a statistical artefact. Further, the perturbations in external markers of physical load, observed in this study, may be the direct result of changes in coach instruction. These considerations should be noted when interpreting results.

In comparison to physical load, few studies have modelled the relationship between subjective wellbeing and illness risk. In accordance with hypothesis 2, over a 28-day period, sleep quality was found to be significantly lower preceding an illness event, compared to normality, once more with a small effect size of 0.3. Sleep disruption is continually cited as a risk factor for illness within prevention guidelines (Schwellnus *et al*., 2016; Walsh, 2018; Castell *et al*., 2019). This is built on underpinning evidence that suggests that low sleep efficiency and low amount of sleep (less than 6 hours) increases the risk of developing the common cold (Cohen *et al.*, 2009; Prather *et al*., 2015). Chronic sleep disruption, as evident over a 28-day period here, leads to increases in inflammatory markers (Haack *et al*., 2007) that may influence illness risk. These findings may also have implications for the variables used, and the frequency of assessment, of subjective wellbeing questionnaires within professional soccer. These tools often contain a multitude of questions and are often utilised on a daily basis; this may lead to a lack of adherence and inaccurate responses (Saw *et al*., 2014). Instead, if using tools such as this to identify players at risk of illness, attaining a monthly sleep quality score using data collected at various time points throughout the month, may be the most effective use of time and resources. Whilst a reduction in sleep quality may be related to an increased illness risk, it is important to consider that the amount of subjective wellbeing data collection would have varied throughout the 3 seasons. This varied based on changes in the fatigue monitoring philosophy of the sports science and medicine department, and may have influenced results.

4.5.2. Changes in physical load and subjective wellbeing in the build up to illness events

As demonstrated in tables 4.12-4.14, all physical load variables show significant increases in the daily acute to chronic ratio, compared to 1, at some point during the 15 days before an illness event, thus supporting hypothesis 3. The theoretical rationale underpinning this analysis was to use the daily acute to chronic ratio as a marker of change in physical load. By comparing this to 1, indicating no change, it was evident when a change in physical load occurred. Although these findings can be interpreted in different ways, they are supported by previous research which suggests that a sudden increase in weekly physical load, above normality, appears to increase illness risk in the week following (Foster, 1998; Putlur *et al*., 2004; Piggott, 2008; Thornton *et al*., 2014; Watson *et al*., 2017). Findings from these studies are based on the premise that, when exposed to increased physical demands that are different to normality, immune function may be compromised and therefore provide the opportunity for infection (Pedersen and Ullum, 1994). Some research has identified a 10% increase in weekly physical load above normality as a risk factor for illness (Foster, 1998; Putlur *et al*., 2004; Piggott, 2008). Whilst other papers have reported that an increase in weekly physical load, by 1 z-score away from normality, increases illness risk by 50% (Watson *et al*., 2017). Regardless of the threshold used, spikes in physical load appear to be important in the build up to illness events.

In comparison to indices of physical load, subjective wellbeing variables show few changes in daily acute to chronic ratios in the 15 days before an illness event. This is in agreement with previous research which demonstrates that changes in subjective wellbeing variables (sleep, general feelings of wellbeing, soreness and diet) are not related to changes in the risk of illness (Thornton *et al*., 2014). Although stress has been related to illness risk (Anderson *et al*., 2003; Brink *et al*., 2010; Drew *et al*., 2017b), multiple different subjective stress assessment tools have been used. These tools may mean comparing previous work to current findings is useless. The subjective questionnaire used here may not have been sensitive enough, or collected frequently enough to highlight changes in stress in the build up to an illness. Instead, the sustained lower monthly sleep quality in the build up to an illness, observed above, may be more important. Further, it is possible that subjective fatigue variables important to illness, such as an elevated HR during submaximal exercise (Buchheit *et al*., 2013a), a reduction in HRV (Hellard *et al*., 2011), low energy availability and poor hygiene practice (Drew *et al*., 2017b) and international travel (Schwellnus *et al*., 2012) are related to illness risk in this population, yet were not measured. These factors should be included in future research.

4.5.3. Limitations

Subjective wellbeing data collection varied throughout the 3 seasons used in this chapter. Data collection varied in terms of frequency within a week, how the data was actually collected (phone based application or a member of staff) and the addition of hours of sleep as a question in the 2018-19 season. This variation may have limited results and ideally would have been controlled over all 3 seasons. However, in a practical setting, alterations in performance staff and training philosophies may alter the way in which data is collected. Similarly, the physical load data collected may be limited by various factors. As mentioned, the club did not advocate wearing MEMS units in match play; therefore match data was integrated with training data by importing TRACAB data into the Openfield system. Although there was strong agreement between systems, as reported above, the datasets are ultimately collected using different tools (MEMS units and high-speed camera tracking). This may have influenced the final dataset analysed. Further, RPE data was only collected during the 2017-18 season and average data was used, where a player's data was incorrect or missing. In a research setting these factors are more easily mitigated, however, in a practical environment they are much harder to control. The data analysis section of this chapter is fairly exploratory in nature; the section aims to determine whether a relatively small sample of physical load and fatigue monitoring markers may be related to an increased illness risk. A multivariate analysis, looking to assess the strength and direction of relationships between the risk factors mentioned in figure 2.1 and illness risk, would be beneficial. The methodological development section explains the reasons behind the exclusion of 2 objective fatigue-monitoring variables, hence the reason to use subjective wellbeing monitoring only within this chapter. However, other objective fatigue monitoring tools such as an elevated HR during submaximal exercise (Buchheit *et al*., 2013a), low energy availability and poor hygiene practice (Drew *et al*., 2017b) and international travel (Schwellnus *et al*., 2012) may have warranted assessment and inclusion In an illness risk model. The physical load and subjective wellbeing markers assessed and described only form a small part of this model, other factors, including those mentioned in figure 2.1, will impact immune function and illness risk. It is important to consider this when interpreting results. One practical way to implement submaximal exercise assessment in professional soccer would be to complete a standardised submaximal exercise test, potentially as part of a warm up, every 6 weeks throughout the season. This would allow objective assessment of the response to physical load, and other factors, as well as the isolation of specific physical load variables in future studies.

4.5.4. Conclusion and practical applications

In conclusion, there appears to be differences in physical load and subjective wellbeing variables in the 7 and 28-day periods that precede an illness event, compared to normality. Specifically, reductions in weekly external physical load variables at a similar time as increases in internal physical load variables may indicate that a player is at risk of developing an illness. Sleep quality also appears reduced over the 28 days preceding an illness event. Chronic disturbances in sleep should be guarded against, and where present, targeted with appropriate interventions. There also appears to be abrupt increases in physical load in the 15 days prior to an illness event. Therefore, in a practical sense, the findings above have provided practitioners with specific monitoring strategies that may inform interventions to reduce the incidence of illness in professional soccer. Highlighting players at risk of illness, using these strategies, may provide the opportunity for appropriate intervention, which may involve physical load modification and use of additional recovery modalities. SWC values have been provided for practitioners to highlight where changes may be practically significant and where opportunities to intervene may exist. Future research should clarify whether the differences in physical load and subjective wellbeing between illness events and normality are translated into relationships. It is important that the strength and direction of these relationships, as well as the dose-response relationships between physical load and subjective wellbeing markers, and illness risk, be assessed. Specifically, a multivariate regression analysis could be used to do so. Inclusion of the internal to external load ratios described above, in this analysis, may provide a greater insight into the practicality of these variables to highlight players at risk of illness. Further, factors outside of the scope of this study need to be added into this risk factor model to identify their contributions towards illness. Markers of pathogen exposure, hygiene, objective sleep quality, environmental extreme exposure, long-haul travel, vaccination/infection history, inflammatory cytokine gene expression, salivary antibody concentration, time of year and nutritional deficits should be considered. Finally, holistic interventions targeting these factors, alongside the changes in physical load and subjective wellbeing, require development and implementation in team sports.

CHAPTER 5 - THE DESIGN, IMPLEMENTATION AND EVALUATION OF A HOLISTIC ILLNESS PREVENTION INTERVENTION IN PROFESSIONAL SOCCER

5.1. INTRODUCTION

Chapter 3 suggests that illness occurs more frequently than training injury, and more frequently than reported in previous research in professional soccer. Therefore illness may be a bigger problem in professional soccer than previously reported. A more comprehensive illness quantification was completed where there was evidence of performance-restriction and medical attention only illness alongside the traditionally measured time-loss illness. Practitioners should therefore recognise the effects that illness may have on player availability, and the chances of team success (Pyne *et al*., 2005; Hägglund *et al*., 2013; Raysmith and Drew, 2016; Svendsen *et al*., 2016), as well as performance and the ability to sustain heavy training (Gleeson and Burke, 2007). Given the apparent importance of illness, prevention guidelines should be used to determine appropriate interventions.

Extensive illness prevention guidelines, built on underpinning evidence, have been developed (Schwellnus *et al.,* 2016; Gleeson *et al.,* 2017; Walsh, 2018; Castell *et al.,* 2019). Walsh (2018) summarises illness prevention strategies into guidelines that target preventing, or limiting the effects of, excessive physical load, life stress, sleep disruption, environmental extremes, travel and nutritional deficits. Schwellnus *et al.* (2016), Gleeson *et al.* (2017), Castell *et al.* (2019) also consider strategies involving behavioural, lifestyle and medical factors. These guidelines are in agreement with findings from Chapter 4 that suggest physical load and sleep quality may be related to illness risk. Whilst guidelines clearly exist, highlighting the multifactorial nature of illness prevention in athletes, translation of these strategies from research into practice is poor. Despite practitioners being advised to develop, implement and monitor illness prevention guidelines for athletes and support staff (Schwellnus *et al*., 2016), there appears to be only 3 published, holistic, illness prevention interventions in athletes.

Following a multi-factorial intervention in Norwegian winter Olympic athletes, the amount of athletes who became ill during the competition period was reduced by 12.2% (Hanstad *et al*., 2011). The intervention included; developing and sharing guidelines on illness prevention, screening for illness risk, vaccinations for all staff and athletes, targeting high-risk athletes with isolated rooms, indoor air cleaning systems, disinfectant and rigorous cleaning routines. Unfortunately, the specific factors contributing to the success of the intervention were not determined. The reasons behind the effectiveness of an intervention are important so this can be refined when repeated in future practice. Schwellnus *et al.* (2020) reported a 59% reduction in illness during the Super Rugby tournament following an illness prevention strategy. The strategy involved; (1) pre-tournament screening of players at increased risk of illness; (2) during the tournament sharing of utensils or water bottles was discouraged, whilst ensuring good sleeping habits, regular hand washing and/or use of personal antiseptic hand gel, avoidance of continuous exposure to air-conditioned or polluted environments, considering high-dose vitamin C supplementation (>1000 mg/day), early reporting of symptoms and early isolation of players at the onset of symptom development, was encouraged; (3) additional international travel guidelines such as considering prophylactic local antimicrobial spray, probiotics and antibiotic prophylaxis were also provided. However, there was no data provided on adherence to intervention content, or an evaluation of specific intervention components. Similarly, following a nutritional and lifestyle intervention in 1 professional soccer player, self-reported URTI incidence was reduced alongside an increased sIgA concentration (Ranchordas *et al.,* 2016). The intervention involved; increasing energy intake, vitamin-D supplementation, changing hygiene habits and improving sleep quality via education. The study did make some attempt to assess the mechanisms behind these effects with an increased energy intake, vitamin D concentration and sleep hours per night all recorded. However, the case study nature of this investigation makes it difficult to comprehensively link the intervention, improved mucosal immunity and reduced URS. Whilst successful in 1 player, the same principles need to be applied across a full squad of professional soccer players. Clearly these interventions rely on changing behaviour to be successful, however behavioural change theory has not been considered in any of the aforementioned studies.

Behavioural change appears to be one of the key factors contributing to the success of interventions targeting health behaviour improvements (Aboud and Singla, 2012; Heijnen and Greenland, 2015). Although elements may have been done successfully in the studies above, without evaluation it is difficult to see which specific elements of the interventions may have contributed towards behavioural change. The Ranchordas *et al.* (2016) case study did assess energy intake, vitamin D concentration and sleep hours per night as mechanisms that may underpin the intervention results. However, the study did not evaluate which intervention aspects contributed to changes in these mechanisms. Therefore future illness prevention interventions need to consider that improving knowledge alone may not change behaviour (Heijnen and Greenland, 2015). Instead, during the development of illness prevention interventions, a focus should be placed on affecting behavioural change determinants such as social influence, attitude, self-efficacy and intention; this appears to be effective at altering health behaviours (Huis *et al*., 2012). There are a variety of delivery methods that have achieved behavioural change in healthcare. Both Ujang and Sutan (2018) and Gipson *et al*. (2019) have used text messaging as a medium to improve sexual health and sleep hygiene respectively. Whilst Thomas *et al*. (2005) used different poster designs, with constant feedback, to improve hand-washing compliance. Determinants of behavioural change and selection of delivery method should, therefore, be key considerations when planning an illness prevention intervention.

Illness prevention content, coupled with key information on how to influence behaviour, is present in the literature. However, this has not been combined to develop, implement and evaluate illness prevention interventions in athletes. Therefore, the aim of the current study is to develop, implement and evaluate the effectiveness of a holistic illness prevention intervention, towards reducing illness incidence in professional soccer. This aim will be achieved by completing 1 objective and testing 2 hypotheses. The first objective is to document the intervention development and implementation, including the rationale, evidence-base and logistical considerations. The 2 hypotheses are; (1) the illness prevention intervention will reduce illness incidence in comparison to previous seasons; (2) the outcome measures for intervention evaluation will reflect an improved awareness of illness prevention and key changes in behaviour that will contribute to a reduction in illness incidence.

5.2. METHODS

5.2.1. Experimental approach to the problem

This study aimed to develop, implement and evaluate the effectiveness of a holistic illness prevention intervention in professional soccer. The intervention consisted of 3 strands; (1) education, (2) refined hygiene practice and (3) refined nutritional practice. Previous illness prevention interventions in athletes (Hanstad *et al*., 2011; Ranchordas *et al*., 2016; Schwellnus *et al.,* 2020) and recently published guidelines for illness prevention in athletes (Schwellnus *et al.,* 2016; Gleeson *et al.,* 2017; Walsh, 2018; Castell *et al.,* 2019) were used to guide intervention development. The intervention was implemented and delivered across 4 in-season months during the 2018-19 season (November, December, January and February). These months were selected based on previous research that has indicated the occurrence of peak illness incidence in professional soccer (Orhant *et al*., 2010; Bjørneboe *et al*., 2016). To evaluate effectiveness, illness incidence data was collected using the same methodology used in Chapters 3 and 4, across the 2018-19 season. This was compared with data collected using the same approach from the 2 previous seasons, where there was no illness prevention intervention in place. Two seasons worth of comparative data was selected to keep data consistent, as the recording methodology mentioned above had only been in place at the soccer club for the previous 2 seasons. Measures related to knowledge, adherence, behaviour and intervention feedback were used to evaluate the reasons behind the effectiveness of the intervention.

5.2.2. Participants

Thirty-five participants from 1 EFL Championship soccer team were followed across the 2018-19 season (age 26 ± 5 years; height 1.86 ± 0.07 m; weight 84.1 ± 7.3 kg). Illness incidence data collected from these participants was compared to data from the same soccer team across the previous 2 seasons (2016-17 and 2017-18) when the club competed in the EPL. Illness incidence data collection began on the first day of pre-season and continued until the last game of the competitive season, where all players who trained with the first team squad across the respective seasons were included. There were 30 players present in 2016-17 (age 27 ± 5 years; height 1.86 ± 0.05 m; weight 83.9 ± 7.6 kg) and 33 in 2017-18 (age 26 ± 6 years; height 1.87 ± 0.05 m; weight 85.4 ± 6.4 kg). Training and match hours were higher during the 2018-19 season, compared to the previous 2 seasons. This is because of the division the club competed in. There were a total of 271 training and match hours in the 2018-19 season compared to 234 and 263 in 2016-17 and 2017-18 respectively. Despite illness incidence data being recorded from 35 participants across the 2018-19 season, there were only 24 who were present for the full duration of intervention delivery. This was due to both permanent transfers, and loan players, coming into and leaving the club, at certain points during the season. There were 59 different players used across the 3 seasons of data collection. The amount of seasons that each individual player was present for, were added up. There were 34 of these players present for 1 season, 12 for 2 seasons and 13 for the full 3 seasons of data collection. All participants were provided with a participant information sheet before signing an informed consent document. The LJMU Ethics Committee approved the study.

5.2.3. Theoretical and conceptual overview for intervention design

As described in Chapter 2, no study has attempted to translate evidence-based illness prevention guidelines (Schwellnus *et al.,* 2016; Gleeson *et al.,* 2017; Walsh, 2018; Castell *et al.,* 2019) into practical interventions embedded within professional sport. The guidelines in these papers clearly indicate that illness prevention is multi-factorial. This intervention was developed to fulfil the apparent holistic nature of illness prevention, instead of an isolated intervention that may only affect certain illness risk factors. Illness prevention guidelines can be summarised into strategies that target preventing, or limiting the effects of, excessive physical load, life stress, sleep disruption, environmental extremes, travel, nutritional deficits, and behavioural, lifestyle and medical factors (Schwellnus *et al.,* 2016; Gleeson *et al.,* 2017; Walsh, 2018; Castell *et al.,* 2019). These categories guided the development of a 3-strand approach when designing the current intervention. Components of illness prevention guidelines were divided into; (1) education regarding illness prevention and immediate response strategy guidelines; (2) hygiene improvement strategies at the training ground; (3) nutritional support to improve immune function and immediately reduce the effects of symptoms. Table 5.1 is a framework that guided specific intervention content. Content was developed using the rationale and evidence-base behind individual intervention components.

Table 5.1. A framework that guided intervention content; including the rationale and evidence-base behind individual intervention components.

Strand	Intervention component	Rationale	Evidence-base
Education	Educational messages	To improve knowledge of illness prevention in players and staff via a combination of subtle background (posters) and individual directive (WhatsApp, coach guidelines) messages. Animated videos were used as a more interactive educational tool.	Guidelines provided within the educational content were used and adapted from Schwellnus *et al.* (2016), Gleeson *et al.* (2017), Walsh, 2018 and Castell *et al.* (2019). In terms of the delivery methods; Ujang and Sutan (2018) and Gipson *et al*. (2019) have used text messaging to improve sexual health and sleep quality respectively. Whilst Thomas *et al*. (2005) used posters to improve hand-washing compliance.
Education	Targeted consultations	To improve knowledge of illness prevention in selected players. These players were chosen based on previous history showing they were highly susceptible to illness.	Guidelines provided within the consultations were used and adapted from Schwellnus *et al.* (2016), Gleeson *et al.* (2017), Walsh, 2018 and Castell *et al.* (2019).
Hygiene	Air cleaning disinfectant	To clean key communal areas	"Use of special indoor air cleaning systems" was used as

	machine (Pro-Disin, Netherlands).	around the training ground.	a strategy in Hanstad *et al*. (2011).
Hygiene	Hand sanitizer	To encourage players and staff to use hand sanitizer as a strategy to prevent illness.	Guidelines by Schwellnus *et al*. (2016), Walsh (2018) and Castell *et al*. (2019) identify carrying hand sanitizer as an illness prevention strategy.
Hygiene	Zero-tolerance policy towards illness at the training ground	To prevent the spread of illness through the training ground.	Guidelines by Schwellnus *et al*. (2016), Walsh (2018) and Castell *et al*. (2019) identify minimising contact with infected people and isolation upon symptom onset as illness prevention strategies.
Nutrition	Daily supplementation containing a multivitamin and probiotic, with 1 vitamin D capsule (4000 IU) 2 times per week	To support immune function and reduce illness risk.	Davison *et al*. (2014) describes the importance of avoiding nutrient deficiencies as these may impact immune function. Multivitamin supplementation was included as a safeguard against micronutrient deficiencies within the diet. Probiotic supplementation is believed to support microbes in the gut and exert effects further up the respiratory tract, to reduce URS risk (Williams *et al*., 2019). Supplementation has been consistently shown to

			reduce illness in athletic and non-athletic populations (Cox *et al*., 2010c; Gleeson *et al*., 2011; Hao *et al*., 2011). Vitamin D is believed to influence immune cells through the expression of genes (Bermon *et al*., 2017). Lower than optimal levels, which may be encountered by UK-based athletes in autumn and winter months, have been linked with an increased risk of illness (Cox *et al*., 2008; He *et al*., 2013; Svendsen *et al*., 2016). The recommended dose of vitamin D is 1,500- 2,000 IU per day, for individuals not getting adequate sun exposure, to maintain a sufficient concentration (Holick *et al.,* 2011).
Nutrition	Immunity "boosting" packs containing 9 zinc acetate lozenges (10 mg of ionic zinc in each), 3 quercetin with green tea capsules (333 mg of quercetin and 40 mg of green tea in each) and 2 vitamin C tablets (500 mg each) were	To prevent symptoms becoming worse and as an immediate response strategy at symptom onset.	At the onset of cold symptoms zinc lozenge supplementation is advised (Schwellnus *et al.,* 2016). There is strong evidence that URS duration, in particular sore throats, can be reduced via local effects on the pharyngeal region (Hemilä and Chalker, 2015; Hemilä, 2017). The recommended dose of ionic zinc to relieve these symptoms is 75 mg per day (Hemila, 2017).

	given out upon symptom onset		Guidelines for illness prevention also state that athletes should consider consumption of polyphenol supplements such as quercetin (Schwellnus *et al*., 2016), believed to have strong anti-inflammatory properties (Davison *et al*., 2014). Despite mechanisms being unknown, high doses of quercetin around intensified training periods reduced URTI incidence in trained cyclists (Nieman *et al*., 2007). The recommended dose of quercetin to reduce URTI incidence is 1000 mg per day (Nieman *et al*., 2007). Vitamin C supplementation appears to reduce the duration of common cold symptoms (Hemilä and Chalker, 2013). Peters *et al*. (1993) also demonstrated that marathon runners who took vitamin C supplementation were less likely to experience a URTI compared to those who did not. The recommended dose to reduce the duration of common cold symptoms is 0.25 - 1 g per day (Hemilä and Chalker, 2013).

5.2.4. Intervention development

The intervention started on the 01/11/2018 and continued until the 28/02/2019 (17 weeks). The intervention was delivered primarily towards first-team players at the club in question. The specific content of the intervention, guided using the framework above, is presented below. This is divided into education-based, hygiene-based and nutrition-based content:

Education-based content

a) Educational messages: Infographics (Appendix 5.1) displaying illness prevention and immediate response strategy guidelines were placed around key areas of the training ground for the duration of the intervention. The infographics were also delivered directly to first-team players via WhatsApp messenger (California, USA), alongside animated videos (Appendix 5.2) on the same topic. These were sent out every 2-3 weeks during the intervention period, with a focus on a different topic each time. The topics for this content were; general illness prevention guidelines, recovery strategies to prevent illness, immediate response strategies to illness symptoms, hand hygiene to reduce illness risk, nutrition tips to reduce illness risk and sleep tips to reduce illness risk. First team coaching staff members were also provided with an infographic (Appendix 5.3) detailing training load guidelines to minimize illness risk at the start of the intervention period.

b) Targeted consultations: One-on-one consultations were completed, using a script (Appendix 5.4), with 7 first-team players to discuss illness prevention and immediate response strategy guidelines. The consultations also acted as interviews as part of the outcome measures for intervention evaluation. Consultations were completed from the 28/11/2018 until the 15/03/2019, similarly every 2-3 weeks. These 7 players were chosen, as they appeared to experience more illness in comparison to the rest of the group, based on data from previous seasons.

Hygiene-based content

a) An air-cleaning, disinfectant machine: The machine (Pro-Disin, Netherlands) was used weekly to clean key communal areas around the training ground. At the start of the intervention period, a weekly list of certain rooms to be disinfected was given to maintenance staff. Key rooms (the first-team changing room, gymnasium, canteen and physio room) were prioritized more than other areas based on the volume and relative importance of the people using them.

b) Hand sanitizer: At the start of the intervention period additional hand sanitizers were positioned around key areas of the training ground (outside the first-team changing room and physio room) to compliment the ones already in place. This was done to encourage first-team players, as well as anyone else in the training ground, to use hand sanitizer to prevent the spread of illness. Individual, smaller, hand sanitizers were also given out monthly during the intervention period to first-team players, this was done to ensure constant access.

c) A zero-tolerance policy towards illness at the training ground: This was implemented at the start of the intervention period. At the discretion of the Head of Medical or Team Doctor, players were either sent home immediately or not allowed in to the building if they presented with symptoms.

Nutrition-based content

a) Daily supplementation: From the start of the 2018-19 season first-team players were provided with a daily supplementation pack to support immune function. All "Elite" supplements were from Healthspan, UK and Informed-Sport certified to reduce the risk of contamination with prohibited ingredients. One multivitamin was supplemented daily (Elite Gold A-Z Multivitamin) containing *800 µg of Vitamin A, 1.1 mg of Vitamin B1, 1.4 mg of Vitamin B2, 16 mg NE of Vitamin B3, 6 mg of Vitamin B5, 1.4 mg of Vitamin B6, 2.5 µg of Vitamin B12, 80 mg of Vitamin C, 5 µg of Vitamin D, 12 mg a-TE of Vitamin E, 37.5 µg of Vitamin K1, 50 µg of Biotin, 200 µg of Folic Acid, 150 µg of Boron, 200 mg of Calcium, 36 mg of Chloride, 20 µg of Chromium, 1000 µg of Copper, 50 µg of Iodine, 14 mg of Iron, 75 mg of Magnesium, 2 mg of Manganese, 50 µg of Molybdenum, 40 mg of Phosphorus, 40 mg of Potassium, 55 µg of Selenium and*

10 mg of Zinc. Multivitamin supplementation was included as a safeguard against micronutrient deficiencies within the diet; these may impair immune function (Davison *et al.,* 2014). One probiotic was also supplemented daily (Elite Pro20 Biotic) containing *Lactobacillus acidophilus NCFM, Bifidobacterium lactis Bi-07, Lactobacillus paracasei Lpc-37, Bifidobacterium lactis BI-04 and Bifidobacterium bifidum Bb-02*. Probiotics were used as there is evidence that probiotic supplementation, containing a daily dose of 10^{10} live bacteria, reduces the number days missed from work or school, due to illness, in the general population (Hao *et al.*, 2011). Probiotic supplementation increases the number of beneficial bacteria in the gut and exerts effects further up the respiratory tract (Hao *et al.*, 2011). There is also evidence that supplementation reduces illness risk in athletes (Cox *et al.,* 2010c; Gleeson *et al.,* 2011), particularly around periods of high amounts of travel (Svendsen *et al.,* 2016). At the start of the intervention period, 1 Vitamin D capsule was also supplemented 2 times per week (Elite Vitamin D3) containing *100 µg, equivalent to 4,000 IU, of Vitamin D3*. Vitamin D supplementation was included as this is believed to influence the production of immune cells by altering gene expression (Bermon *et al.,* 2017). Lower than optimal levels (25(OH) D<50nmol/L), which may be encountered by UK-based athletes in the autumn and winter months, have been linked with an increased risk of illness (Cox *et al.,* 2008; He *et al.,* 2013; Svendsen *et al.,* 2016). Holick *et al.* (2011) recommends 1,500- 2,000 IU per day for individuals who receive inadequate sun exposure.

b) Immunity "boosting" packs: These were distributed to players on the first sign of symptoms, as an immediate response strategy to illness, from the start of the intervention period. Players were advised to dissolve 9 zinc acetate lozenges (Elite Zinc Defence 45 Lozenges) containing *34 mg of Zinc Acetate/10 mg of Ionic Zinc,* slowly in the mouth every 2-3 hours as required, a maximum of 9 lozenges could be taken during 1 day. These lozenges were included as zinc ions (75 mg per day of ionic zinc) appear to exert local effects on the pharyngeal region to reduce sore throat symptoms and may also limit the replication of rhinovirus to alleviate other common cold symptoms (Hemilä and Chalker, 2015; Hemilä, 2017). Three quercetin with green tea capsules (Elite Quercetin and Green Tea 90) containing *333 mg of Quercetin and 40 mg of Green Tea Extract* were prescribed. These were used because 1000 mg per day of quercetin has been shown to reduce URTI incidence (Nieman *et al.,* 2007; Somerville *et* *al.,* 2016). Although the direct mechanism is unknown, quercetin appears to exert anti-inflammatory effects (Somerville *et al.,* 2016). Two chewable vitamin C tablets (Elite Vitamin C), containing *500 mg of Vitamin C,* were also prescribed. Vitamin C was used as an antioxidant to work against the free radicals and ROS produced which may impair immune function (Hemilä and Chalker, 2013). There is evidence that 0.25-1.0 g per day of vitamin C reduces the duration of common cold symptoms (Hemilä and Chalker, 2013).

5.2.5. Assessment of intervention impact

In order to assess the impact of the intervention, illness incidence data from the current season was compared to data collected from the 2 previous seasons, where there was no illness prevention intervention in place. To ensure consistency, data was recorded across all 3 seasons using the same methodology described in Chapters 3 and 4.

5.2.6. Outcome measures for intervention evaluation

Whilst it was not only important to develop and assess the intervention, the literature was also lacking in research that had evaluated the reasons behind the success of previous interventions. Clearly, consideration of the factors that may impact success is vitally important; these should be deliberated when planning, implementing and evaluating illness prevention interventions in athletes. Therefore, as the intervention was developed, implemented and carried out, multiple outcome measures were put in place to determine the reasons behind the resulting effectiveness and to evaluate the intervention (Table 5.2). The rationale for these particular outcome measures is also provided in Table 5.2. The intervention components are likely going to act through these outcome measures, aiming to influence them to improve illness incidence. It is important that these outcome measures are assessed to evaluate the different areas in which the intervention was or was not successful. The outcome measures assessed were also divided into education-based, hygiene-based and nutrition-based content, they were:

Education-based content

Read receipts: WhatsApp messenger read receipts were used as a proxy for adherence to the educational infographics and animated videos sent to players. After sending a message the 2 ticks next to the sent message turn blue to inform the user that the recipient has at least opened their message. These ticks were monitored following sending the message. Although this process did not guarantee that players had taken in or studied the information it did mean they had opened the content in question. The number of read receipts per piece of content sent was tallied, before being divided by the total number of players who had received the message to get an adherence percentage.

A pre and post-intervention questionnaire: A questionnaire (Appendix 5.5) was used to assess current knowledge and practice on the subject of illness prevention in the players. Questions were selected based on the content of the intervention to evaluate the transfer of knowledge. Initially, shortly following the start of the intervention (12/11/2018), the questionnaire was sent to all first-team players via survey monkey. Data collected at this time point was used to gain some baseline information on current knowledge and practice. The questionnaire was then completed 1-month post intervention (25/03/2019), and compared to responses collected pre-intervention, to assess whether knowledge and practice had changed.

Interviews: The one-on-one educational consultations with 7 players, as part of the educational intervention content, also acted as interviews. The same 7 players, who were identified as experiencing a greater amount of illness in comparison to the rest of the players, were interviewed. The interviews were conducted in a semi-structured format (Appendix 5.4). Semi-structured interviews were used to ensure only important elements, relating specifically to the aims and objectives of thesis, were discussed. However, they were also selected to provide the opportunity for players to discuss and clarify items in greater depth, adding to the data collected objectively. Interview questions were designed to assess past experiences of illness and illness prevention, perceptions of the intervention and thoughts on specific illness risk factors. These particular topics were chosen, as they were deemed important to evaluate the reasons behind the intervention effectiveness.

Hygiene-based content

Hand sanitizer refills and the number of rooms disinfected: Maintenance staff at the training facility recorded each time a hand sanitizer dispenser was refilled and a room was disinfected using the air-cleaning device. Maintenance staff recorded the date, week, month and location of these events. Maintenance staff were given targets for the amount of times key rooms were to be disinfected across the intervention period. The 4 key rooms (1^{st} team changing room, gym, canteen and physio room) were to be disinfected weekly (17 procedures in total) based on the volume of people and the relative importance of people using these areas.

Nutrition-based content

Supplementation adherence and immunity packs distributed: The number of players who had taken their daily supplements was tallied, before being divided by the total number of first-team players who were present in the training facility, on that day, to get an adherence percentage. The amount of immunity packs distributed was recorded in a log by the lead researcher, where date, week and month of the season were also recorded.

Table 5.2. A framework that guided the development of the outcome measures for intervention evaluation including the rationale behind individual outcome markers.

Strand	**Outcome marker**	**Rationale**
Education	Read receipts	Read receipts were used as a proxy for adherence to educational content. Specifically this covered infographics and animated videos on different illness prevention topics that were sent to players.
Education	A pre and post-intervention questionnaire	The questionnaire was used to assess whether the intervention impacted on illness prevention knowledge and behaviours.
Education	Interviews	The interviews were also used to assess whether the intervention impacted on illness prevention knowledge and behaviours in a less structured format. This allowed certain individuals to express what they may not have been able to via the questionnaire.
Hygiene	Hand sanitizer refills and the number of rooms disinfected	These markers were used as indicators of the changes in hygiene practice at the training ground.
Nutrition	Supplementation adherence and immunity packs distributed	These markers were used as indicators of adherence to the nutrition-based strand of the intervention.

5.2.7. Data analysis

The effects of the intervention on illness incidence

Data was tallied to produce total illness incidence and days spent with illness. Incidence per 1000 hours of training and match play was also calculated. These values were produced for different seasons, severity groups and affected systems to allow comparison across these factors. To evaluate the effectiveness of the intervention, a repeated measures analysis of variance (RM-ANOVA) was completed to compare illness incidence variables between the 3 seasons (2016-17 and 2017-18 where the intervention was not present, and 2018-19 where the intervention was present). Only players who were present for 3 seasons were included in this analysis (13 players). Data from 13 players was used for all variables apart from illness per 1000 hours. For this variable, data from 6 players was used. Goalkeepers and outfield players not present for the full season duration were removed from the illness per 1000 hours analysis, as training and match duration information was incomplete. A RM-ANOVA was conducted for each of the dependent illness variables (total illness, days affected, total illness per 1000 hours, time-loss illness, performance-restriction illness, medical-attention illness, respiratory illness and GI illness). This was because the aim was to determine differences between the 3 seasons, whilst there was 1 within subject factor (season), with 3 time points. The sphericity assumption (Mauchly's test of sphericity) was met. Post hoc pairwise comparisons, using the Bonferroni correction, were completed to see where differences were. This was conducted using statistical analysis software (SPSS version 26.0, IBM, New York, U.S). P values were 2-tailed and significance was set at $p<0.05$.

Data from each season was also compared to the mean of all seasons combined. Only players that were present for the duration of 1 full season were included in this analysis (18 in 2016-17, 23 in 2017-18 and 22 in 2018-19). Goalkeepers were removed from the number of illness per 1000 hours of training and match play analysis due to incomplete training data (this was completed with 16 players in 2016-17, 20 players in 2017-18 and 18 in 2018-19). Where a player was present for more than 1 season, in each season they were classed as a new case. As such, over 3 seasons, there were 63 player cases for all variables other than illness per 1000 hours, where there were 54.

The mean values from each season were compared to the 3-season mean using an independent t-test for each illness variable and each season within that variable. The independent t-tests were conducted using statistical analysis software (SPSS version 26.0, IBM, New York, U.S). P values were 2-tailed and significance was set at $p<0.05$.

Outcome measures for intervention evaluation

In terms of the outcome measures for intervention evaluation, the number of players who opened educational content was calculated as a percentage for each topic and then averaged to give an average adherence value. Data included in this analysis was based on the 24 players present for the full duration of intervention delivery. The percentage of players who selected each questionnaire response was compared pre and post intervention. This was completed using a Chi-Square test for each individual questionnaire response pre vs post intervention. The test was completed in Microsoft Excel. A Chi-Square test was chosen to test the association between 2 categorical variables, the dependent variable (response) and the independent variable (time point). The variables assessed are classed as binary (the number participants who did vs did not select the relevant response pre vs post-intervention) and there was 2 time points (pre and post-intervention). P-values were set at <0.05 for these analyses. The 18 players who provided pre and post questionnaire responses were included in this analysis.

Thematic analysis was used to analyse transcripts from the one-on-one interviews completed with 7 players. Initially all interviews were recorded and transcribed by the lead researcher. Following transcription, the stages of coding and analysis provided by Braun and Clarke (2013) were followed. The transcripts were read for familiarisation, taking note of items of potential interest. Following this, all transcripts were coded completely using researcher-derived codes and then searched for themes. Themes were then reviewed where a thematic map was produced. Finally themes were defined and named.

The incidences of hand sanitizer refilling and room disinfection were tallied to produce number of sanitizer refills and rooms disinfected in different areas of the training facility. These were summed to provide monthly incidence values per area of the training ground. Daily adherence to supplementation was averaged across a month to provide monthly adherence values. The number of immunity packs distributed was tallied across a month to get monthly values. Data included in this analysis was based on the 24 players present for the full duration of intervention delivery.

5.3. RESULTS

5.3.1. The effects of the intervention on illness incidence

A RM-ANOVA determined that there were significant differences in 1 illness incidence variable between seasons ($F(2, 11) = 17.581$, $p = 0.001$). A post hoc pairwise comparison, using the Bonferroni correction, showed an increased total illness incidence per 1000 hours in the 2017-18 season (20.2 ± 9.2) compared to the 2016-17 (7.1 ± 9.4, $p = 0.004$) and 2018-19 seasons (9.2 ± 7.5, $p = 0.015$). There were no other significant differences between seasons. These results are presented in table 5.3.

Table 5.3. Results from the RM-ANOVA comparing illness incidence variables between seasons. Data is presented as mean ± standard deviation. Data includes the 13 players who have data present for 3 seasons for all variables, apart from incidence per 1000 hours, where 6 players are included.

Illness variable	2016-17	2017-18	2018-19
Total illness	1.4 ± 1.5	1.9 ± 1.2	1.4 ± 1.3
Days affected	2.8 ± 3.5	4.8 ± 6.1	5.0 ± 5.3
Incidence/1000 h	7.1 ± 9.4	20.2 ± 9.2*¥	9.2 ± 7.5
TL* illness	0.4 ± 0.7	0.6 ± 0.9	0.5 ± 0.7
PR* illness	0.2 ± 0.4	0.2 ± 0.6	0.1 ± 0.3
MA* illness	1.2 ± 1.1	1.2 ± 1.3	0.8 ± 1.0
Respiratory illness	1.0 ± 1.2	1.3 ± 1.2	1.1 ± 1.2
GI illness	0.2 ± 0.4	0.6 ± 0.5	0.4 ± 0.5

*TL - Time-loss, PR - Performance-restriction, MA - Medical-attention**.** * Denotes statistical significance from 2016-17. ¥ Denotes statistical significance from 2018-19. Significance was set at $p<0.05$.

5.3.2. Comparison of individual seasons to the 3-season mean

An independent t-test determined that there were significant differences in 1 illness incidence variable (number of GI illnesses), between the 3-season mean (0.4 ± 0.6) and the 2016-17 season (0.2 ± 0.4), $t(42)=-2.109$, $p = 0.041$. The Levene's test for Equality of Variances was violated and therefore values from the "*equal variances not assumed*" row were used. There no other significant differences between seasons and the 3-season mean. These results are presented in table 5.4.

Table 5.4. A comparison of mean values for each individual season to a 3-season mean. Data is presented as mean ± standard deviation. Players that were present for the duration of 1 full season were included in this analysis (18 in 2016-17, 23 in 2017-18 and 22 in 2018-19). Goalkeepers were removed from the number of illness/1000h (this was completed with 16 players in 2016-17, 20 players in 2017-18 and 18 in 2018-19). Where a player was present for more than 1 season, in each season they were classed as a new case. As such, over 3 seasons, there were 63 player cases for all variables other than illness per 1000 hours, where there were 54.

Variable	3-season mean	2016-17	2017-18	2018-19
Total illness	1.7 ± 1.2	1.3 ± 1.4	1.9 ± 1.1	1.9 ± 1.2
Days affected	5.0 ± 5.7	2.6 ± 3.1	5.2 ± 5.6	7.0 ± 6.6
Incidence/1000h	11.7 ± 9.0	8.9 ± 9.0	13.6 ± 8.5	12.2 ± 9.1
TL* illness	0.7 ± 0.7	0.5 ± 0.7	0.8 ± 0.9	0.6 ± 0.6
PR* illness	0.3 ± 0.6	0.2 ± 0.4	0.5 ± 0.7	0.2 ± 0.4
MA* illness	1.0 ± 1.1	0.9 ± 1.1	0.9 ± 1.1	1.2 ± 1.1
Respiratory illness	1.3 ± 1.1	0.9 ± 1.1	1.3 ± 1.0	1.5 ± 1.1
GI illness	0.4 ± 0.6	0.2 ± 0.4*	0.6 ± 0.7	0.5 ± 0.5

*TL - Time-loss, PR - Performance-restriction, MA - Medical-attention. ***** Denotes statistical significance, this was set at $p<0.05$.

5.3.3. Illness patterns across 3 seasons

Figure 5.1 shows patterns of illness incidence across the months of the 3 seasons measured. Whist 2016-17 (September, October, November) and 2017-18 (July, August, January) show peaks in illness incidence, in 2018-19 this is more broadly distributed over the season.

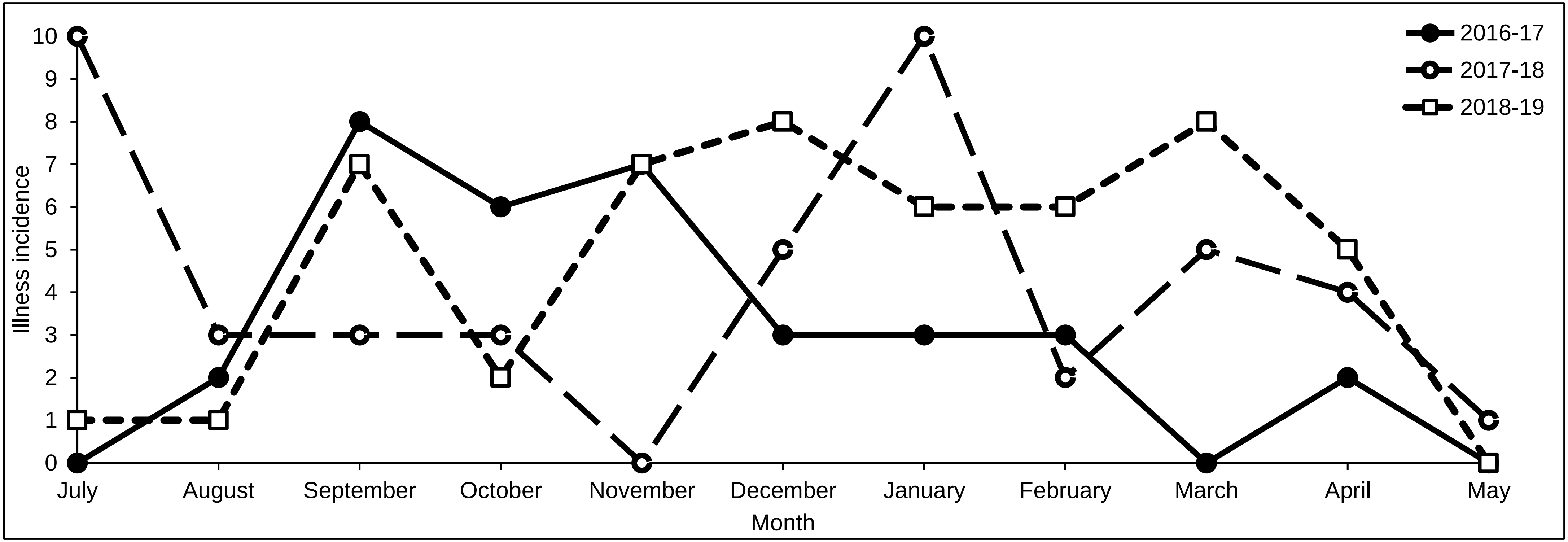

Figure 5.1. Illness incidence across the months coinciding with pre-season and the competitive season for the 2016-17, 2017-18 and 2018-19 seasons. Data includes all players that were present in the squad during 2016-17 (30), 2017-18 (33) and 2018-19 (35).

5.3.4. Outcome measures for intervention evaluation

Read receipts

Adherence to the educational message infographics and animated videos sent to first-team players via WhatsApp messenger (Appendix 5.1-5.2) was assessed via read receipts. The average percentage of players who opened the messages containing the infographics and videos was 93%. This is broken down into the respective topics in table 5.5.

Table 5.5. The average percentage of players who opened messages containing infographics and videos. Data includes the 24 players who were present for the full duration of intervention delivery.

Video and infographic topic (order)	Percentage of read receipts
General illness prevention guidelines (1)	100
Recovery strategies to prevent illness and injury (2)	100
Immediate response strategies to illness symptoms (3)	96
Hand hygiene to reduce illness risk (4)	83
Nutrition tips to reduce illness risk (5)	88
Sleep tips to reduce illness risk (6)	88
Average	93

Pre and post-intervention questionnaire

Significant changes in questionnaire responses from pre to post intervention are shown in Figures 5.2-5.8. Given the large amount of analysis completed, all pre and post intervention questionnaire responses are presented in appendix 5.6. The number of participants who selected “January”, as when they thought they were most vulnerable to illness, increased significantly from 44% to 78% (Figure 5.2).

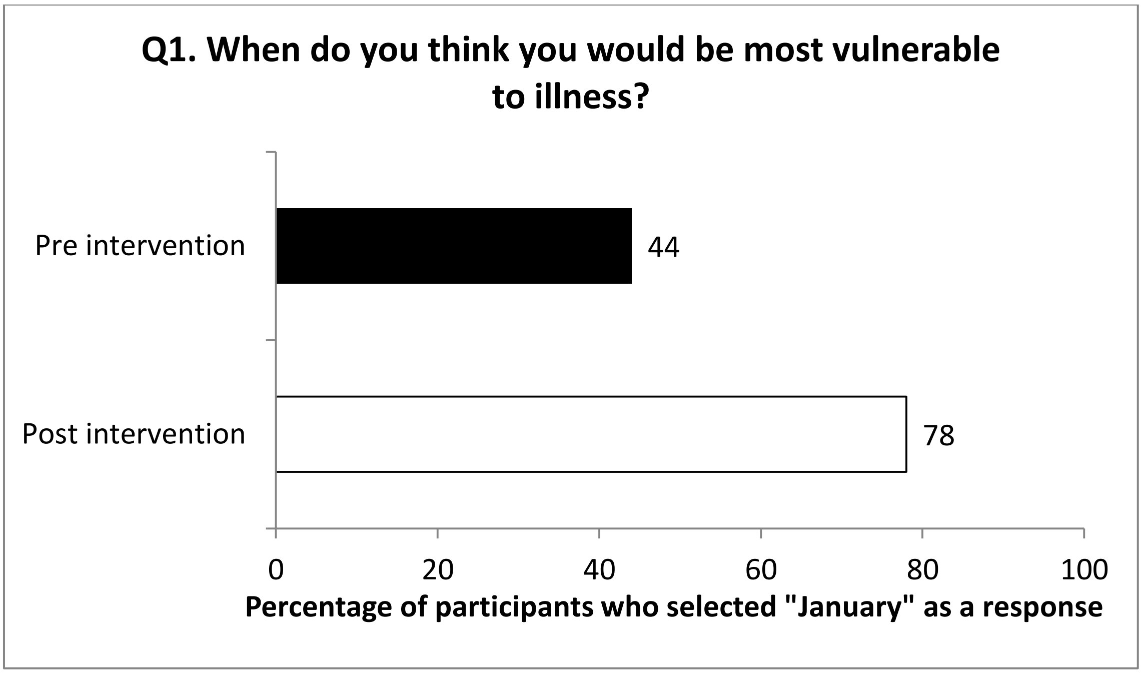

Figure 5.2. The percentage of participants who selected “January” as a response to Q1. When do you think you would be most vulnerable to illness? Data includes the 18 players who provided pre and post questionnaire responses.

The number of participants who selected “after blowing your nose”, as when they currently washed their hands with soap and water, increased significantly from 22% to 67% (Figure 5.3).

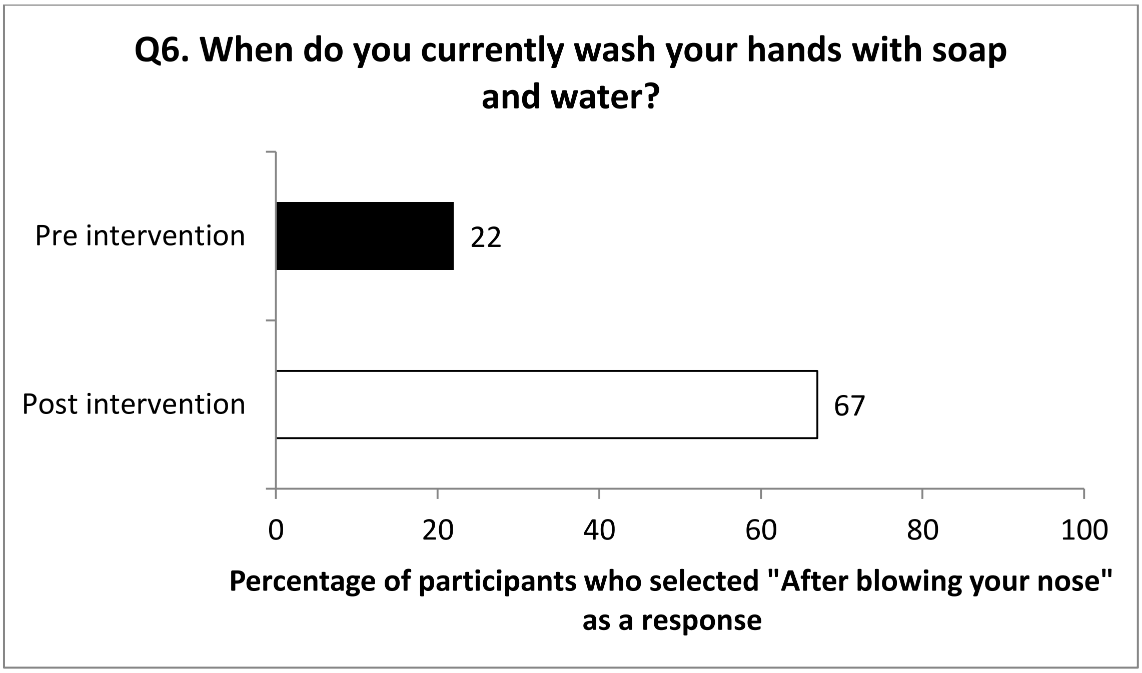

Figure 5.3. The percentage of participants who selected “After blowing your nose” as a response to Q6. When do you currently wash your hands with soap and water? Data includes the 18 players who provided pre and post questionnaire responses.

The number of participants who selected “ask for an immunity pack at the first sign of illness symptoms”, as a nutritional strategy that could help reduce the risk of illness, increased significantly from 39% to 89% (Figure 5.4).

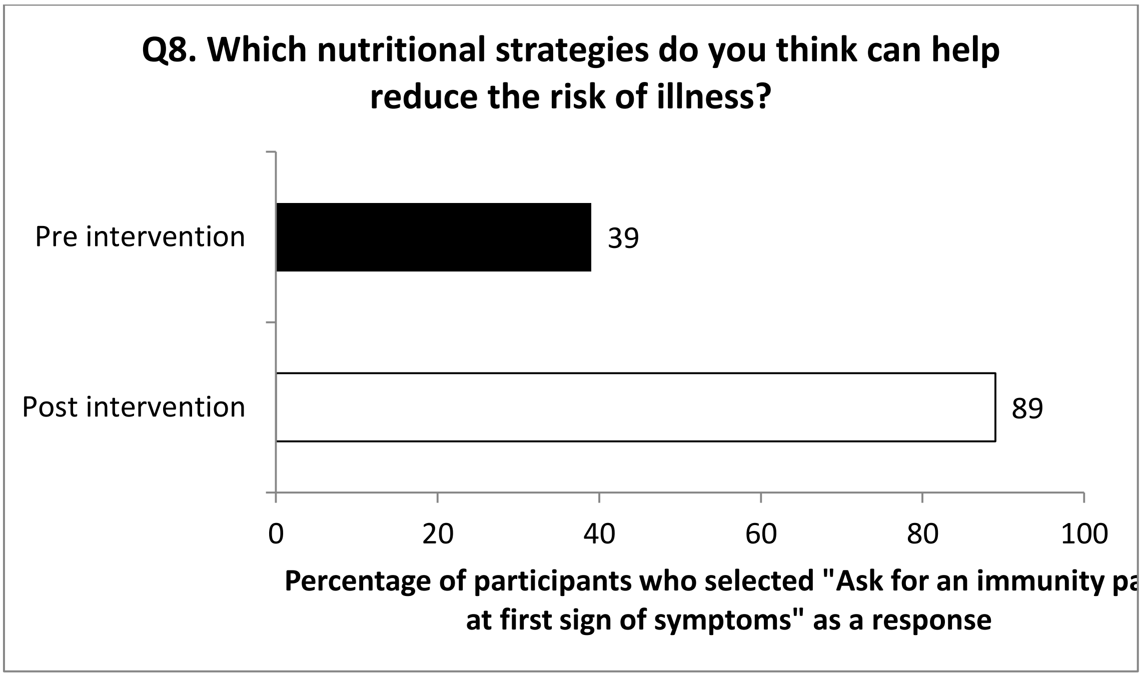

Figure 5.4. The percentage of participants who selected "Ask for an immunity pack at the first sign of symptoms" as a response to Q8. Which nutritional strategies do you think can help reduce the risk of illness? Data includes the 18 players who provided pre and post questionnaire responses.

The number of participants who selected "avoid low energy availability", as a nutritional strategy that could help reduce the risk of illness, increased significantly from 0% to 22% (Figure 5.5).

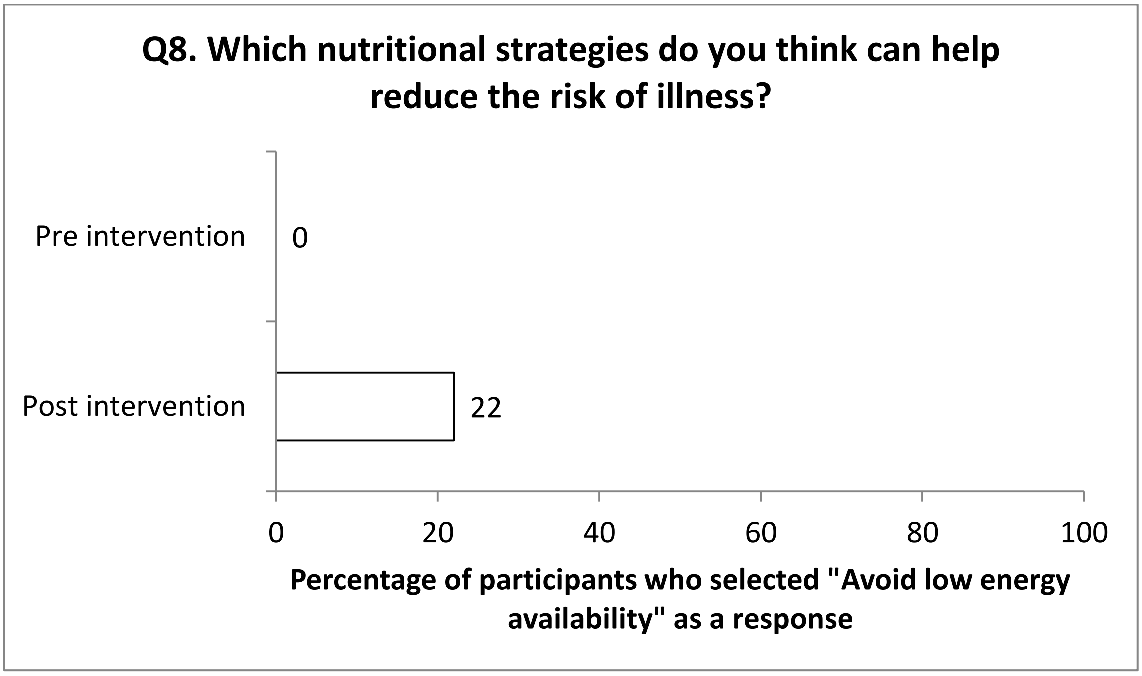

Figure 5.5. The percentage of participants who selected “Avoid low energy availability” as a response to Q8. Which nutritional strategies do you think can help reduce the risk of illness? Data includes the 18 players who provided pre and post questionnaire responses.

The number of participants who selected “8 hours”, as how many hours of sleep the evidence suggests that you need, to reduce the risk of illness, increased significantly from 78% to 100% (Figure 5.6).

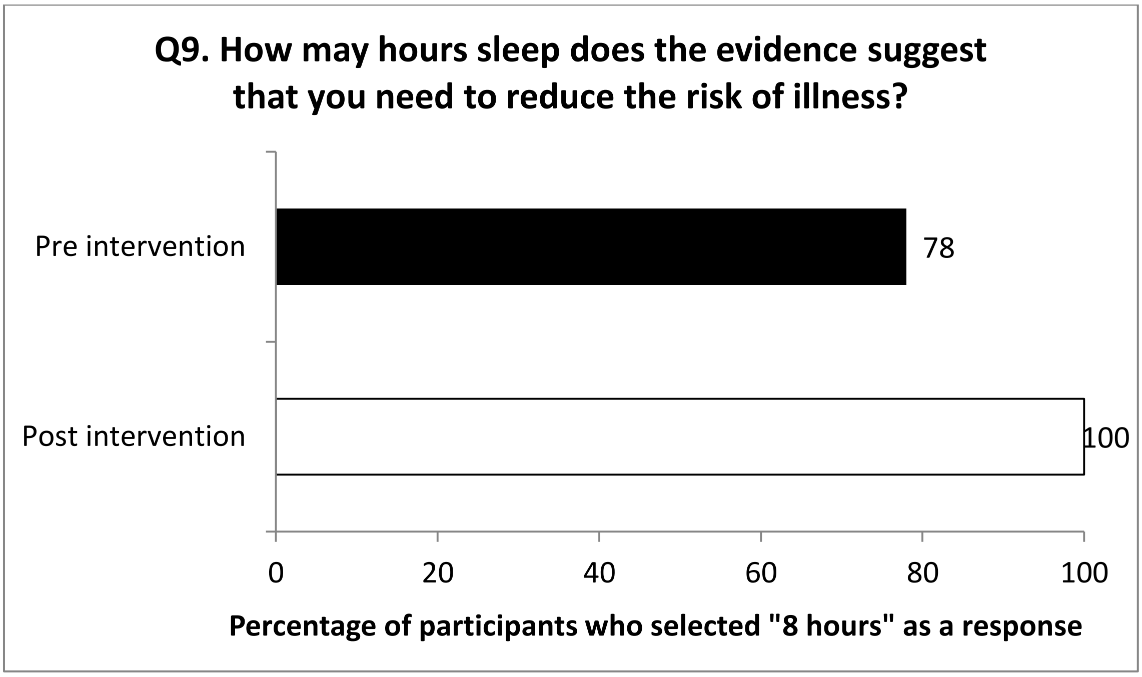

Figure 5.6. The percentage of participants who selected "8 hours" as a response to Q9. How many hours sleep does the evidence suggest that you need to reduce the risk of illness? Data includes the 18 players who provided pre and post questionnaire responses.

The number of participants who selected "ensure a cool room", as a strategy to improve sleep, increased significantly from 50% to 83% (Figure 5.7).

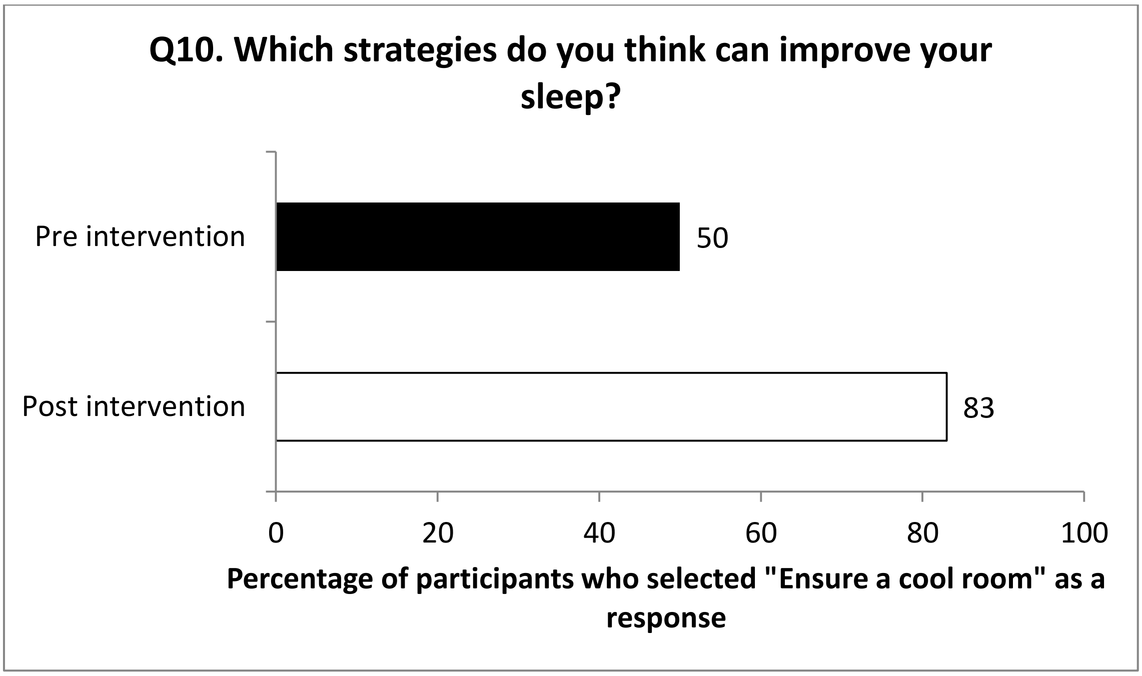

Figure 5.7. The percentage of participants who selected “Ensure a cool room” as a response to Q10. Which strategies do you think can improve your sleep? Data includes the 18 players who provided pre and post questionnaire responses.

The number of participants who selected “nap no later than mid-afternoon”, as a strategy to improve sleep, increased significantly from 39% to 72% (Figure 5.8).

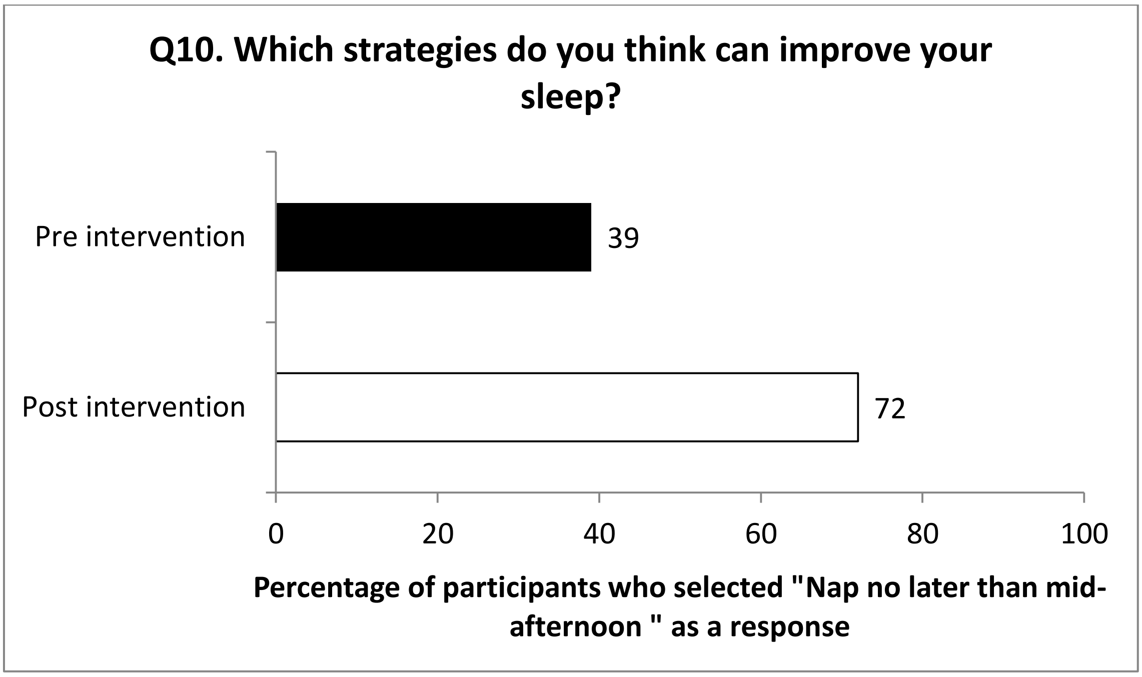

Figure 5.8. The percentage of participants who selected "Nap no later than mid-afternoon" as a response to Q10. Which strategies do you think can improve your sleep? Data includes the 18 players who provided pre and post questionnaire responses.

Interviews

Overarching themes were identified from the interview transcripts (appendix 5.7) using the thematic analysis described in the data analysis section of the methods. As mentioned, interviews were transcribed and read for familiarisation (taking note of items of potential interest). Transcripts were then coded completely using researcher-derived codes and searched for themes. Themes were then reviewed where a thematic map was produced. Finally themes were defined and named. An overview of the overarching themes identified is provided as table 5.6. The contributing factors to the identification of each theme are discussed below. Overarching themes identified were; (1) The importance of hygiene; (2) Players can identify risk factors for illness; (3) The illness prevention intervention is valued; (4) Intervention considerations; (5) Intervention impact.

Table 5.6. An overview of the overarching themes identified with definitions. 7 players were included in this analysis.

Overarching theme	**Definition**
The importance of hygiene	The value that professional soccer players place on hygiene as a risk factor for illness.
Players can identify risk factors for illness	The ability of professional soccer players to identify illness risk factors through their own career and life experiences.
The illness prevention intervention is valued	The appreciation of this set of professional soccer players towards the intervention. It also highlights the value they place on specific intervention content.
Intervention considerations	Professional soccer players understand what works and what does not work in this environment and the underpinning reasons why.
Intervention impact	The impact professional soccer players feel the intervention has had on their current practices. The subtheme “illness prevention” highlights how the intervention has impacted on what players do to prevent being ill. The subtheme “immediate response strategies” highlights how the intervention has impacted on what players do when they become ill.

The importance of hygiene: Players appeared to place a big emphasis on hygiene as a risk factor for illness. The need to stay away from the training facility with symptoms such as sickness, diarrhoea and flu, to prevent symptoms spreading through the squad was mentioned. Not only was hygiene identified as a key risk factor for illness, but players also highlighted the importance of maintaining personal hand hygiene when signing autographs and when imbedded in a hand-shaking culture. Further, players also stated the importance of hygiene given the small size of the training ground where large volumes of people pass through a small space and multiple teams use the same facilities.

Players can identify risk factors for illness: Players were able to identify a host of illness risk factors, presumably through their own career and life experiences. Heavy exercise (the high levels of training and match load experienced in the EFL Championship), mental stress, sleep disruption, nutritional deficits (including low energy availability) and travel were all identified as risk factors for illness. Time of year and the presence of children in the household were also identified.

The illness prevention intervention is valued: This set of players appears to appreciate and value this intervention. Numerous players felt that the intervention was working and cited a specific style of intervention delivery that they valued. Certain players identified with the infographic posters around the training ground that acted as subtle background reminders, whilst others valued the more forthright animated videos and messages sent via WhatsApp messenger. Players also valued the importance of placing educational messages in places of impact, for example hand washing guidelines on toilet doors.

Intervention considerations: In terms of trying to implement an intervention, players appear to clearly understand what works and what does not work in this environment, and the underpinning reasons why. They highlighted the difficulty in satisfying the needs of each individual player and the importance of getting the balance right between subtle and forthright educational messages. Players felt it was important that key messages were refreshed frequently. Certain players stated that it was their own responsibility to utilise the intervention content in order to improve their own practice. Finally, players identified the difference between noticing information and actually taking it in.

Intervention impact: Players felt the intervention had impacted on their current practice and made them more aware of what to do. In terms of improving illness prevention strategies, players identified that their time around a busy training facility was reduced, they had increased the use of hand sanitizer, altered hand washing behaviours, adopted to take their daily supplements each day and put more of an emphasis on fuelling to avoid low energy availability. In terms of immediate response strategies to illness, players stated that they now reported symptoms straight away and asked for an immunity pack.

Counts of hand sanitizer refills and number of rooms disinfected

The hand sanitizer stations in reception and in the canteen were refilled the most during the intervention period (6 and 7 times respectively). Other stations (1st team changing room, gym and physio room) were refilled between 1 and 3 times (table 5.7).

Table 5.7. The number of times hand sanitizer in key areas of the training ground was refilled across the months of the intervention period.

Area	Total	Nov	Dec	Jan	Feb
1st team changing room	1	0	1	0	0
Gym	3	1	1	0	1
Canteen	7	2	2	2	1
Physio room	1	0	1	0	0

Reception entrance	6	2	2	1	1

The total number of times key rooms were disinfected by maintenance staff did not meet targets set at the start of the intervention period. The 1st team changing room was disinfected the most times (13), however the target for each of these key communal areas was 17 (Table 5.8).

Table 5.8. The number of times key rooms were disinfected across the months of the intervention period. The target set at the start of the intervention period is also provided.

Room	Target	Total	Nov	Dec	Jan	Feb
1st team changing room	17	13	4	3	4	2
Gym	17	9	2	2	4	1
Canteen	17	9	3	2	3	1
Physio room	17	6	3	0	2	1

Counts of supplementation adherence and immunity packs distributed

On average the monthly adherence to daily supplementation was 63%, including only the 24 players who were present for the full duration of intervention delivery. The total number of immunity packs distributed during this period was 35.

5.4. DISCUSSION

The aim of the current study was to develop, implement and evaluate the effectiveness of a holistic illness prevention intervention, towards reducing illness incidence in professional soccer players. A holistic illness prevention intervention was developed and implemented across 4 months at a professional soccer club competing in the EFL Championship. The development and implementation of this intervention is described above, including the rationale, evidence-base and logistical considerations. The intervention effectiveness was evaluated using illness incidence variables compared to the 2 previous seasons. The main finding of the study was that there was no significant difference in the mean values of the majority of illness incidence variables between the 2016-17, 2017-18 and 2018-19 seasons. The only variable that did differ was total illness incidence per 1000 hours; this was significantly higher in the 2017-18 season compared to both the 2016-17 and 2018-19 seasons. Therefore, the intervention did not appear to be effective at reducing illness incidence in comparison to previous seasons. However, it may be that the increased fixture demands during the 2018-19 season, along with players being encouraged to report symptoms immediately, counteracted any effects of the intervention. To assess the reasons behind intervention effectiveness, outcome measures for intervention evaluation were implemented. These measures revealed that the intervention appeared to be positive in terms of knowledge transfer and improvements in awareness, yet did not influence behaviour. Adherence to the educational content, improvements in the educational questionnaire knowledge and positive interview feedback would suggest improvements in player awareness around illness prevention. However, measures collected on hand sanitizer use, disinfectant use, daily supplementation adherence and immunity pack uptake would suggest these changes in awareness did not change behaviour. This may also explain why there was no improvement in illness incidence during the 2018-19 season. Taken together, these findings highlight the importance of focussing on techniques to impact behavioural change, rather than purely improving knowledge, to impact health-related outcome measures such as illness incidence.

5.4.1. The effects of the intervention on illness incidence

The first hypothesis was that the illness prevention intervention would reduce illness incidence in comparison to previous seasons. The intervention did not appear to be effective at reducing illness incidence in the 2018-19 season, compared to the 2016-17 and 2017-18 seasons. There were no significant differences in the mean values of the majority of illness incidence variables between these seasons. Therefore data appears to reject the hypothesis that the intervention would reduce illness incidence. Walsh

(2019) suggests that days affected or duration of illness may be a better marker of the success of nutrition-based illness prevention interventions, compared to illness incidence, in athletes. This is based on the premise that athletes may not be immunosuppressed and are otherwise healthy, often choosing to train through illness symptoms (as identified by Chapter 3). However, this intervention was also ineffective at improving the days affected by illness in the 2018-19 season. The small amount of comparable research makes the appraisal of these findings, within the literature, difficult. This research differs from other interventions (Hanstad *et al.,* 2011; Ranchordas *et al.,* 2016; Schwellnus *et al.,* 2020) in terms of illness incidence definitions used, variables reported, length of intervention, number of participants involved and specific intervention content. Although comparison between this intervention and previous work is difficult due to numerous methodological differences, it does seem that this intervention was less effective at reducing illness incidence.

However, there may be a number of factors not assessed that could have contributed towards the ineffectiveness of the illness prevention intervention. The soccer team was relegated from the EPL into the EFL Championship at the end of the 2017-18 season; resulting in both increased physical and mental demands in the 2018-19 season. Specifically, there were a total of 271 training and match hours in the 2018-19 season compared with 234 and 263 in 2016-17 and 2017-18 respectively. A greater training and match load, meaning increased travel demands and therefore a potential reduction in sleep, coupled with an increased time spent together as a group during 2018-19, may have contributed to the inability of the intervention to reduce illness incidence. Indeed, increases in physical load and reductions in sleep quality have been linked to illness risk in both Chapters 3 and 4 of the present thesis. Furthermore, peak periods of fixture scheduling may contribute to an impairment in immune function (Morgans *et al*., 2014). Figure 5.1 shows different patterns of illness incidence across the 3 seasons measured. Whist 2016-17 and 2017-18 show peaks in illness incidence, in 2018-19 this is more broadly distributed over the season. This may also reflect the high physical load sustained across the full season in the EFL Championship.

In addition to the effects of a change in league, a big emphasis was placed on this intervention within the club, with much of the intervention content stating to "report symptoms straight away." This guideline was used in order for players to flag symptoms immediately so everything could be done to prevent symptoms becoming worse and this affecting performance or leading to time lost from training or match play. Although every effort was made to ensure data collection consistency, players may have reported more illness across this season due to an increased awareness of the intervention itself. Employment of a control group, who were not exposed to the intervention, would have been beneficial to test the effects of the intervention on illness reporting. However, given the environment, it was not possible to withdraw the intervention from a select group of players. Therefore both the increased number of fixtures and the potential increase in illness-reporting rate may have influenced results.

5.4.2. Outcome measures for intervention evaluation

The second hypothesis was that the outcome measures for intervention evaluation would reflect an improved awareness of illness prevention and key changes in behaviour that would contribute towards a reduction in illness incidence. The hypothesis is in part supported by outcome measures that assessed adherence to educational content and awareness of illness prevention strategies. WhatsApp messenger read receipts were used as a proxy for adherence to educational content. Adherence to the 6 infographics and animated videos appeared high; the average number of players who opened the messages was 93%. Clearly opening the WhatsApp messages does not guarantee that players have taken on board and put into practice illness prevention guidelines. This was identified by the "Intervention considerations" theme in Table 5.6. The opening of messages does, however, mean that players have at least received and looked at the relevant message. Indeed, an intervention by Gipson *et al*. (2019) involved sending biweekly text messages regarding sleep hygiene, whilst a control group received messages about general health behaviours. Subjective sleep quality, hygiene and knowledge improved in both groups, suggesting receiving the messages themselves, rather than the specific content, may be the most important factor influencing results.

An improved awareness of illness prevention strategies was also reflected in the outcome measures for intervention evaluation, in particular the importance of hygiene. This was identified as an overarching theme from interviews, with players stating the need to avoid spreading illness through the training facility, the importance of hand hygiene around fans and within a hand-shaking culture, and the large volume of people using the same, small, training facilities. For example, one player commented, "when shaking hands with fans, holding their pens, anything where I come in contact with those who I don't know. They may have been waiting outside for hours and hours and that pen may have touched God knows how many other players hands who perhaps don't take hygiene as seriously as myself. I do tend to, when coming in contact with fans, to try and wash my hands and sanitize them as much as I can." This is also supported by a post-intervention improvement in hygiene knowledge, with players identifying "following blowing your nose" as a key time to wash hands with soap and water (Figure 5.3). Hygiene guidelines are mentioned multiple times as a strategy to reduce illness risk (Schwellnus *et al*., 2016; Walsh, 2018; Castell *et al*., 2019) and formed a key message displayed throughout the educational content. Further, thematic analysis of the interviews identified "the illness prevention intervention is valued" as an overarching theme. The players appeared to value the intervention and believe it was working to reduce illness incidence. In particular players valued that the illness prevention infographics, displaying key educational messages, were located in places of impact, such as hand washing guidelines on the toilet doors. One player stated, "to always have little signs around the sink or in the bathrooms, in the gym, and you know just little things to remind us." This highlights the importance of placing educational content in places of impact; as identified by Thomas *et al*. (2005) when implementing a poster-based hand washing intervention in hospitals.

The increased awareness was also reflected in players being able to identify illness risk factors and implement strategies to tackle these factors. Indeed, an overarching theme from the interviews was that "players can identify risk factors for illness." These included heavy exercise (the high levels of training and match load experienced in the EFL Championship), mental stress, sleep disruption, nutritional deficits (including low energy availability), travel, time of year and the presence of children in the household. A statement from one player read, "I think the sleep, I think the travel as well, you know you can be on a plane travelling or be on a coach for hours, and you can feel yourself getting run down a little bit after a game" with another stating, "I think obviously if you're tired, your run down, you've had a lot of games, you've had hard training - it's important to refuel and if you've got any little illness, any little infection is going to get you. It's important to keep on top of everything, diet is obviously important, sleep is very important, and just the basic hygiene bits really." This was coupled with a post-intervention change, where more players selected January as the most vulnerable period for illness (Figure 5.2); indicating players are aware of the time of year as a factor. This time of year is where peak illness incidence appears to occur in other research within professional soccer (Orhant *et al*., 2010; Bjørneboe *et al*., 2016). Also there were a greater number of responses selecting "8 hours of sleep" as the amount of sleep that the evidence suggests is beneficial to reduce the risk of illness (Figure 5.6). When this is coupled with the identification of sleep as a key illness risk factor in the quotes above, this may mean players have paid attention to this risk factor and the supporting evidence (Prather *et al*., 2015). Finally, there were more responses selecting "ensuring a cool room" and "napping no later than mid-afternoon" as strategies to improve sleep post-intervention. These were continually provided as guidelines within intervention content, grounded in the literature (Nédélec *et al*., 2015; Simpson *et al*., 2017). However, despite the apparent awareness of illness risk factors and strategies to impact these risk factors, there is no objective evidence that players actually implemented this knowledge into their daily practice.

"Intervention impact" was also identified as an overarching theme from the interviews. Players commented on the impact they felt the intervention had made on their current practice and behaviours to reduce illness risk. Indeed, within interviews, players identified that they had; reduced their time around a busy training facility, increased their use of hand sanitizer, altered hand washing behaviours, adopted to take their daily supplements each day and put more of an emphasis on fuelling to avoid low energy availability. In terms of immediate response strategies to illness, players stated that they now reported symptoms straight away. This may confirm the idea that a higher illness-reporting rate contributed to the ineffectiveness of the intervention towards reducing illness incidence during this season. Players also stated that they now asked for an immunity pack upon symptom onset. For example one player stated, “Hand sanitizer - I’m doing it all the time, I’m doing it as we speak now, always trying to keep my hands clean. And then trying to reduce my contact time with youngsters as well, just anything can spread around, so the less amount of time I spend with them the less likely I am to get something. So, at the minute, touch-wood, its seemed to work pretty well, so I just need to stay on top of that and also vitamins and minerals and supplements when you’re ill. So you give them out everyday - I’ve always had them and then if I do become ill, or have a little bit of a sore throat coming on I go in and ask for zinc tablets and stuff like that to help me and I think it has done.” Similarly, there appeared to be a post-intervention change in the key nutritional strategies identified to reduce illness risk, with more players selecting “an immunity pack at the first sign of symptoms”, and “avoiding low energy availability” as responses (Figures 5.4-5.5).

However, although these results suggest that adherence was high, and that awareness had improved, this may not always translate into improved behaviours (Heijnen and Greenland, 2015) and therefore a reduced illness incidence. Indeed, the outcome measures that were put in place to evaluate hygiene and nutritional changes suggest that behaviour was not altered. A count of the number of times hand sanitizer was refilled around different areas of the training ground was completed as a representation of hygiene compliance at this facility (Table 5.7). This showed that the most used hand sanitizer stations were in reception and in the canteen. These areas would experience the highest volume of people and visitors from outside the training ground. The dispensers used around the training ground held 1 litre of hand sanitizer fluid; each use is around 1 ml, meaning 1000 uses can be completed before a refill is required. 24 players were present throughout the duration of the intervention. Players would have entered and left each of these rooms at least once during a day at the training ground (48 uses per station). During this 4-month period there were a total of 73 training days meaning each station should have been used at least an estimated 3504 times. As such each station should have experienced 3.5 refills. In comparison, the dispensers in the first team dressing room and physio room were only refilled once. This would seem to go against comments identified above where players cited the importance of hand hygiene and their increased use of hand sanitizer. Further, counts of the air-cleaning device use, again as a proxy for hygiene alterations at the training ground, were completed. Unfortunately maintenance staff did not complete the targets set at the start of the intervention process (Table 5.8). The changing room, physio room and gym are where players spend the majority of their time. The chance of coming into contact with illness through touching objects, person-to-person contact or air droplets will be increased in these areas. Therefore it is vital that a high level of hygiene is maintained to reduce the chance of illness in first team players.

Similarly, supplementation adherence was used as a proxy for adherence to the nutritional strand of the intervention. On average, 63% of players, per month, took their daily supplement pack consisting of multivitamin, probiotic, and vitamin-D supplements. The supplementation packs were designed to give nutritional support to lessen the risk of illness, the evidence-base for which is described above. Unfortunately not all of the squad adhered to this, highlighting that the nutritional education and changes in knowledge might not have carried over into behaviour. Despite the educational information provided regarding daily supplementation, it is often difficult to influence a whole squad of players. This was identified by the “intervention considerations” theme from player interviews where players highlighted the difficulty in satisfying the needs of each individual player. Players may not have understood the reasons behind daily supplementation, believed in the benefits of this, or opted to take their own supplements not provided by the club. Further, the transfer of educational information into behaviour may have been limited by other key concepts identified within this theme such as; getting the balance right between subtle and forthright educational content, players taking responsibility for their own illness prevention strategies and the difference between noticing information and actually taking it in. Walsh (2019) also suggests that nutritional supplements designed to prevent illness may not be effective in otherwise healthy athletes. Instead, nutritional supplements designed to improve tolerance to infection when symptoms first present, allowing the athlete to continue and manage illness at a non-damaging level, may show better effects. These effects may be best highlighted using markers such as days affected by illness, rather than illness incidence itself.

The immunity packs, provided upon symptom onset, are an example of nutritional supplementation used to improve tolerance to infection. Only 35 immunity packs were distributed over a 4-month period. During this period there were 74 days affected by illness, however, using these figures immunity packs were only distributed for 47% of the days affected. In any case, the mean number of days affected by illness was not lower across the 2018-19 season in comparison to previous seasons (5.0 days compared to 2.8 days in 2016-17 and 4.8 days in 2017-18). Despite players identifying immunity packs as an important immediate response strategy to illness symptoms, this did not transfer into behaviour. Players may not have been competent enough at recognizing symptoms and when to ask for these packs to have an impact. Once more these findings seem to go against comments made by players regarding daily supplementation and immunity packs in interviews, and the improved selection of an immunity pack as an immediate response strategy to illness post-intervention. The players selected for interview may not have been fully representative of the full population and the outcome measures for intervention evaluation may not have been appropriate to identify certain behaviours. However, it is also possible that the awareness gained from the intervention did not transfer into an improved illness incidence because of a lack of behavioural change.

5.4.3. The importance of behavioural change to intervention effectiveness

Behavioural change appears to be one of the key factors supporting the success of interventions regarding health behaviours. Reviews into interventions to improve health behaviours (Huis *et al*., 2012; Heijnen and Greenland, 2015) have stated that improvements in knowledge and awareness do not necessarily translate into behavioural change. Heijnen and Greenland (2015) reported that the intervention itself, pre-existing habits, knowledge of hygiene behaviours, social norms and underlying theories of behavioural change impacted on the success of a hand washing promotion. Huis *et al*. (2012) suggests that focusing on determinants of behavioural change such as social influence, attitude, self-efficacy and intention were far more effective in improving hand hygiene, compared to simply targeting improvements in knowledge. Whilst adherence and awareness towards illness prevention appears to have changed, it is possible that there was no impact on behaviour because these determinants were not considered during the development and implementation of the current intervention. Instead, the main focus was on the intervention content itself. Whilst it is clear that future interventions need to consider determinants of behavioural change during the planning and implementation stages of an intervention, players also identified some additional considerations relating to intervention evaluation. Each factor stated within the “intervention considerations” theme may have had a bearing on the transfer of educational information into behavioural change and an improved illness incidence. The fact that maintenance staff did not complete targets set in regards to air cleaning disinfectant use also highlights the need to g*et al*l key stakeholders on board with an intervention such as this. These factors also need consideration, alongside behavioural change determinants, when planning and implementing future interventions.

5.4.4. Limitations

During the 2016-17 and 2017-18 seasons, 40 and 43 matches were played respectively (whilst the club competed in the EPL), however during the 2018-19 season 54 matches were played (when the club was relegated to the EFL Championship). The change in division, and resulting increased demands, may have affected results. Ideally the control population for the intervention would be another professional soccer team, competing in the same division, with a similar facility size and training schedule, who do not receive the intervention arm. However, in this case, this was not possible and therefore previous seasons were used as a comparison to the intervention season. As well as a change in league, soccer players present at a club change each season, primarily due to transfers in and out of clubs. The high player turnover, that is impossible to control, also limits the number of participants that can be used for an accurate comparison. Further, a focus on the intervention itself may have meant players were more sensitive to reporting symptoms during the 2018-19 season. Players were encouraged to report illness symptoms immediately, to limit the effects of a potential illness as fast as possible, this may have led to an over reporting of illnesses. A control condition, similar to that mentioned above, may control for this. The intervention was only present for 4 months (November - February). Culturally, asking soccer players to focus on illness prevention for a full season, when they had received no previous support in this area, would have been challenging. Especially given some of the considerations around delivering a large-scale intervention such as this (cost, logistics, time and facilities). Despite 4 months being a good starting point, illness appears to occur through out the professional soccer season, not just in the winter months, as demonstrated repeatedly through the thesis. This may mean the ability of the intervention to influence illness was limited. Future studies should look to develop, implement and evaluate seasonal illness prevention interventions. Finally, outcome measures for intervention evaluation may not have accurately represented the pathway between the intervention and main outcome measure. Future studies may look to include markers such as focus groups, observations, objective hand hygiene tests, objective sleep monitoring, energy intake assessment, and objective markers of immune function to understand the reasons behind intervention effectiveness.

5.4.5. Conclusion and practical applications

The design and implementation of an illness prevention intervention in professional soccer, along with a rationale, evidence-base and logistical considerations, has now been documented. The intervention did not appear to impact on illness incidence, however this is difficult to confirm given certain limitations. The change in league, and therefore enhanced demands across the 2018-19 season, coupled with a larger emphasis placed on players reporting illness symptoms immediately, may have influenced these findings. Although the outcome measures for intervention evaluation revealed that the intervention appeared to be positive in terms of awareness and knowledge transfer in certain players, this did not influence behaviour across the whole sample of players assessed. As such, future illness prevention programmes and research studies should target the behavioural change determinants and considerations identified above that underpin the impact of health-related outcomes such as illness incidence. When the factors that may have influenced results are considered, this intervention may have merit as a tool to aid illness prevention, if applied practically, within professional soccer. Given the underestimated importance of illness as a contributor to availability and performance (Chapter 3), practitioners working in professional soccer should consider the development and implementation of such interventions within their own practice. Future research evaluating the effects of illness prevention interventions should look to ensure that the periods against which the intervention is evaluated are matched in every factor other than the intervention itself. Indeed, the increased amount of fixtures and a higher illness reporting rate during the 2018-19 season may have limited this intervention.

CHAPTER 6 - SYNTHESIS OF FINDINGS

6.1. THE PURPOSE OF THE SYNTHESIS OF FINDINGS

The purpose of the following chapter is to provide a conceptual and theoretical interpretation of the results obtained from the present thesis. An evaluation of the original aims and objectives will be conducted prior to reviewing the outcomes of the experimental studies. Specifically the ability of these outcomes to influence practice within professional soccer will be assessed.

6.2. EVALUATION OF AIMS AND OBJECTIVES

The overall purpose of the present thesis was to establish the importance of illness in professional soccer by evaluating illness incidence, proposed risk factors and an illness prevention intervention. The individual studies conducted resulted in the fulfilment of the original aims and objectives stated in Chapter 1. These objectives were met through 3 separate studies (Chapters 3, 4 and 5).

Chapter 3: To determine the incidence and impact of illness symptoms at a professional soccer club

The incidence and impact of illness symptoms at a professional male soccer club was assessed using a recording system that encompassed all illness definitions, and a questionnaire to objectively quantify performance-restriction illness. Illness incidence was also compared to a recreationally active comparator group, during the congested fixture period. Total illness, including medical-attention, performance-restriction and time-loss illness, occurred more frequently than training injury across 2 seasons (91 incidences of illness vs. 17 incidences of training injury). This, therefore, appears to be a problem in professional soccer, greater than identified by previous research. Professional soccer players also experienced more illness compared to a recreationally active comparator group, during the months that coincide with congested fixture scheduling in the EPL (15 incidences in professional soccer players vs 10 incidences in the recreationally active comparator group). Peaks in illness incidence occurred in July, September, October, November and January, not just in the winter months. Therefore illness does appear to be a problem within professional soccer. This may impact player availability, performance, the chances of team success and have financial implications.

Chapter 4: To examine the relationship between physical load, subjective wellbeing, and illness incidence in professional soccer

Differences in individual physical load, and subjective wellbeing variables, in the weekly and monthly periods leading up to an illness event, compared to the median rolling average for the same respective time period (indicative of normality), were assessed. Changes in physical load and subjective wellbeing variables in the build up to illness events were also analysed. From the analysis it was clear that significant differences exist between physical load and subjective wellbeing variables during the 7 and 28-day periods leading to an illness, compared with the average values. Internal physical load variables appear to be elevated in the build up to illness events, whereas external physical load variables are reduced. Sleep quality also appears significantly lower in the 28 days preceding an illness compared to normality. Further, there appears to be increases in the daily acute to chronic ratio of physical load variables in the 15 days prior to an illness event. Therefore, an elevated internal to external load ratio over a weekly time period, and a reduced sleep quality over a monthly time period may influence illness risk. Spikes in physical load variables may also precede illness events.

Chapter 5: To develop, implement and evaluate the effectiveness of a holistic illness prevention intervention, towards reducing illness incidence, in professional soccer

A holistic illness prevention intervention, aimed at reducing illness incidence in professional soccer, was developed, implemented and evaluated. This was achieved by documenting the intervention development and implementation, including the rationale, evidence-base and logistical considerations. Further, effectiveness was evaluated by comparing illness incidence variables to previous seasons (the intervention took place in the 2018-19 season and was compared to the 2016-17 and 2017-18 seasons). The outcome measures for intervention evaluation were used to assess the reasons behind the effectiveness of the intervention. These were compared pre and post intervention. The intervention did not appear to be effective at reducing illness incidence in comparison to previous seasons. There were no significant differences in illness incidence variables between seasons, apart from an increased total illness incidence per 1000 hours in the 2017-18 season, compared to the 2016-17 and 2018-19 seasons. Whilst adherence to educational content was high (93%), illness prevention knowledge increased post intervention and there was positive intervention feedback, this was not translated into the behaviours assessed. Low levels of hand sanitizer use, air cleaning, immunity packs distributed and adherence to daily supplementation, indicate that the intervention was not effective at changing the behaviour of players, or key stakeholders involved in illness prevention at the training facility. Therefore, despite documenting the development and implementation of an illness prevention intervention in high detail, the intervention was not effective at reducing illness incidence. Following evaluation, this may be due to a lack of changes in the assessed behaviours, and the limitations of an increased amount of fixtures and a potentially higher illness-reporting rate.

The following section aims to describe and discuss the key findings of the present thesis. The practical implications of illness incidence findings, a novel recording methodology, proposed illness risk factors and an illness prevention intervention will be discussed. The research approach used within the present thesis will also be evident through the following section. The approach was to maintain ecological validity throughout, in order to produce a series of studies that could impact practice in the 'real-world'. This will be considered within the discussion, where section 6.4 discusses the challenges of completing applied research in professional soccer.

6.3. GENERAL DISCUSSION OF FINDINGS

Findings from Chapter 3 suggest that illness is a major problem within professional soccer that has been underestimated by previous research (Parry and Drust, 2006; Orhant *et al.*, 2010; Bjørneboe *et al.*, 2016). This chapter showed that illness occurred more frequently than training injury across 2 seasons. Whilst training injury may often be more severe, in terms of days lost or time to recover, the consistent burden of illness may impact team performance and success. The effects of these factors are often measured in the time lost from training or match play, indeed athlete availability has been consistently related to team success (Pyne *et al*., 2005; Hägglund *et al*., 2013; Raysmith and Drew, 2016; Svendsen *et al*., 2016) and the broader financial implications of this success (Eirale *et al*., 2017). However, Chapter 3 indicates that the true importance of illness in professional soccer may be the effects on performance. The higher incidence reported encompasses all types of illness. This not only includes illness where time is lost from training or match play, but also illness where performance is affected and illness where medical attention is sought (Figure 6.1). Poor performance during competition, due to illness, will directly impact the chances of success on during that event. However, when athletes cannot train and compete to the best of their abilities consistently due to illness, long-term performance and ultimately success will suffer. These findings may impact team selection in professional soccer, where the stereotypical mentality of playing through illness, believing performance will be unscathed, must be challenged. Players often carry on regardless, causing a significant detriment to their future health, as well as their performance (Van Tonder *et al*., 2016; Walsh, 2019). Injury surveillance, risk factor assessment and prevention work have become commonplace within professional soccer. The sheer frequency of illness, and clear performance effects, present a challenge to practitioners working in professional soccer, which needs addressing. Evidently, a focus on accurate recording, assessment of risk factors and development of interventions, to reduce the problem of illness in this population, is essential in future research and practice.

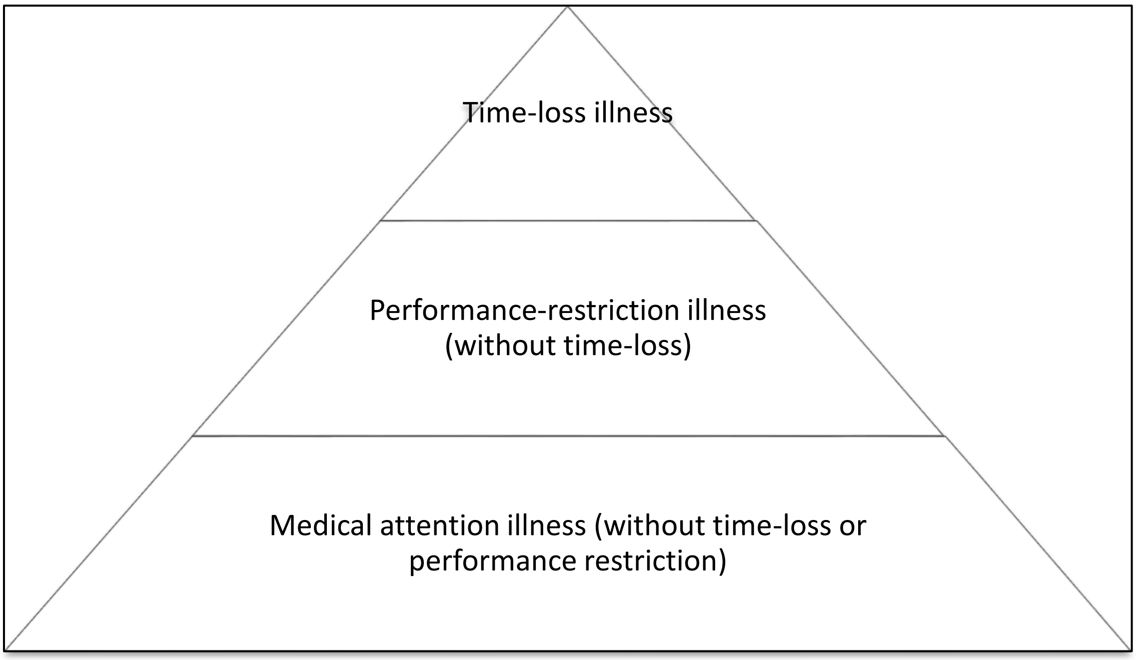

Figure 6.1. An adapted version of the model proposed by Palmer-Green *et al*. (2013) to accurately record illness.

The recording system used (Figure 6.1) was employed throughout the present thesis as a vehicle to improve illness surveillance within professional soccer and determine the true extent of this problem. This was used in conjunction with an adapted questionnaire to objectively quantify performance-restriction illness (Appendix 3.1) following the 2016-17 season. The questionnaire was not employed for the full 3 seasons as the challenges associated with accurately quantifying performance-restriction illness were only evident following the data collected across the 2016-17 season. Following this, the decision was made to implement the questionnaire in order for a more objective quantification of performance-restriction illness. The first step in tackling the problem of illness within professional soccer is accurate illness surveillance. Whilst Chapter 3 went some way to addressing this, findings are at present limited to 1 professional soccer team. Chapter 3 provides a strong rationale and a clear recording methodology that could be adopted throughout professional soccer, not just at this particular club. UEFA has employed such surveillance systems to monitor injury rates over a consistent period of time (Ekstrand *et al*., 2011). Such systematic recording would enhance illness surveillance and further improve the understanding of illness in professional soccer. Chapter 3 also demonstrated that illness incidence is more broadly distributed across the months of the year, rather than confined to winter alone. The high frequency and year-round temporal pattern of illness means that a significant amount of time and resources should be allocated to tackle this problem. Year-round injury prevention programmes are now a staple part of professional soccer with substantial provisions allocated to their development and implementation. Professional soccer teams need to develop and implement year-round illness prevention protocols to combat periods such as pre-season and international fixtures, not just winter. From a business perspective, the investment of resources in this problem may be cost-effective as, at present, professional soccer teams are paying players when they may not be able to train or compete at the best of their ability due to illness.

Chapter 3 also highlighted physical load as a risk factor for illness in professional soccer. Across the congested fixture period professional soccer players appeared to experience more illness compared to a recreationally active comparator group. This would suggest that the high physical load experienced by professional soccer players, in comparison to a recreational level of exercise, contributes to an increased amount of illness. In a model proposed by Walsh (2018) heavy exercise is described as one of the risk factors for lowered immune function in athletes, which may in turn lead to illness (Figure 6.2). This relationship is based on the idea that an elevated physical load, away from normality, lowers immune function and therefore provides the opportunity for illness (the “open window” hypothesis) (Pedersen and Ullum, 1994). Periods of NFOR, in response to intensified training, inadequate recovery and the resulting fatigue, have also been proposed to reduce immune function (Walsh *et al.,* 2011; Meeusen *et al.,* 2013). Findings here would support that a very high amount or intensity of exercise contributes to an increased illness risk, whilst moderate, recreational, levels would lower the risk of illness, as proposed by Nieman (1994) as the J-shaped curve. Malm (2006) updated this model and attempted to distinguish between “very high” and “elite” exercise demands. As such an S-shaped curve was proposed, where elite athletes exhibit a lower infection risk compared to those who perform a very high amount or intensity of exercise. This may be due to the need to withstand illness to perform at an elite level, the support received and better lifestyle behaviours from experience and/or education (better hygiene, infection avoidance, diet, sleep and stress management) (Walsh, 2018). The professional soccer players here are not likely to be part of the “elite” category given their league position over the 3 seasons in which this thesis was completed. Instead the players would likely fall into the “very high” exercise demand, rather than “elite” category, and therefore fit this theoretical model. Recent reviews have, however, argued against high levels of physical load alone leading to a compromised immune function and an elevated risk of illness (Campbell and Turner, 2018; Walsh, 2019; Simpson *et al.,* 2020). It is likely that physical load, in combination with other illness risk factors experienced by the general population, is related to illness risk in professional soccer players.

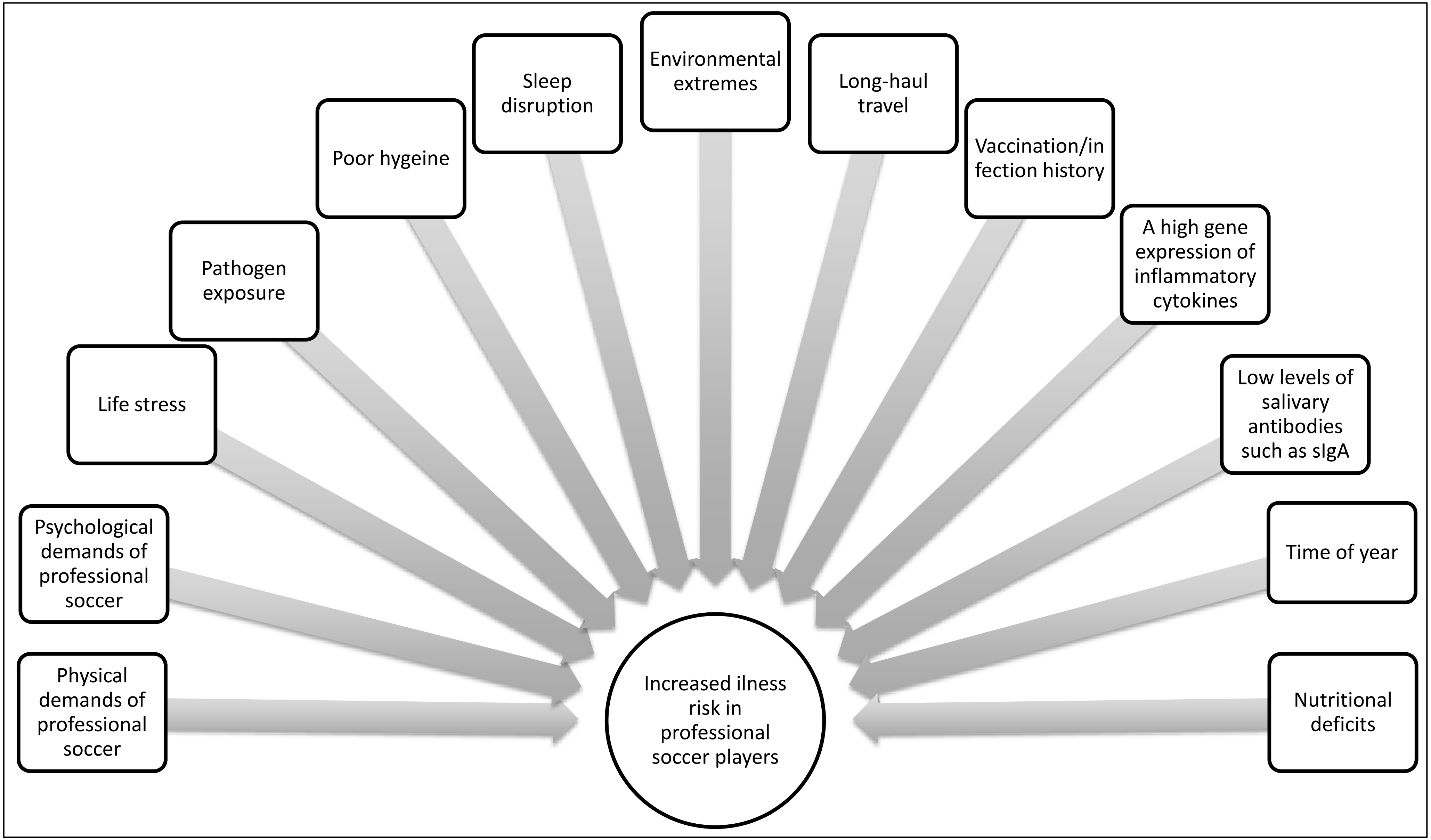

Figure 6.2. A summary of the factors that may increase illness risk in professional soccer players. This diagram was adapted from Walsh (2018) and Simpson *et al.* (2020).

The relationship between physical load and illness was explored in more detail in Chapter 4. This analysis revealed that elevated markers of internal load, coupled with reductions in markers of external physical load were present in the weeks preceding illness events. This finding may be related to the NFOR stage of fatigue, where illness is often common (Meeusen *et al.,* 2013). A further key indicator of NFOR is a reduced ability to perform high intensity exercise (Mackinnon, 2000). The reduced levels of external load variables such as maximum velocity and high intensity distance may reflect this. Bourdon *et al.* (2017) reports that athletes will experience different levels of internal loading based on their state of fatigue, emotion, recent training history and illness risk. The high internal load (HR) when coupled with a lower external output, may suggest players are finding physical demands harder than normal and therefore cannot reach the same external intensities. Practitioners should look to include variations of the internal to external load ratios proposed by Akubat *et al.* (2014) as methods to monitor the status of their athletes. The inclusion of these simple ratios within monitoring systems may help in the identification of players within the NFOR stage, and at risk of illness, and therefore maintain higher levels of player availability and performance. This would also assist in conversations with coaches who may highlight when players are producing a lower external output than normal. This common situation often ends up with players completing additional work that would be at the detriment of the illness. This finding should also be incorporated in future illness prevention guidelines within athletes.

Chapter 4 also suggests that spikes in physical load are important; this is comparable with ideas from previous research (Walsh *et al*., 2011; Drew and Finch, 2016; Schwellnus *et al*., 2016; Jones *et al*., 2017). Changes in the daily acute to chronic ratio, in the 15 days prior to an illness event, were evident. As such the daily acute to chronic monitoring process may also be an important tool in the monitoring systems of professional soccer teams, and in illness prevention guidelines, to identify a higher illness risk and intervene appropriately. Both findings here support the concept described in Figure 6.2, where an increased physical load, away from normality, impairs immune function and increases illness risk. The exclusion of RPE data from results and the fact that mechanical external and internal physical load data could not be obtained from match play are representative of the environment in which the research was conducted. RPE data collection was introduced at the end of the 2016-17 season, collected throughout the 2017-18 season and then stopped during the 2018-19 season due to a change in the philosophy of the sports science and medicine department. The club philosophy did not involve players wearing GPS units and HR belts in matches and therefore mechanical external and internal physical load data was unavailable. The research approach was to maintain the ecological validity of the data collected; therefore the decision was made to accept these changes and continue to collect data where possible. These considerations are reflective of both applied research and what actually happens in practice. If research is to be translated into practice then these considerations must be accepted (Bishop, 2008; Eisenmann, 2017).

Whilst physical load may be important to illness risk in professional soccer, the fact that Chapter 3 reported peaks in illness incidence at other key times during the season suggests that other risk factors may also be involved. Peaks in illness incidence were reported during pre-season and in-line with international breaks. Additional life stress, sleep disruption, long-haul travel, environmental extremes and nutritional deficits (Walsh, 2018) may all be related to pre-season and international breaks. Players may experience an increased level of stress from being away from family members, sleep disruption from the travel or foreign surroundings, long-haul travel to other countries, differing climates and changes in nutrition habits due to the foreign environments. A spike in physical load during pre-season and international breaks, due to a lack of training or match play at club level, may have also been present. Chapter 4 supports the idea that other risk factors are involved. Indeed, significantly lower values of sleep quality were reported in the month preceding an illness event compared to normal. Sleep disruption forms part of the Walsh (2018) model and this particular sleep quality marker may have merit as a tool to monitor the changes in the sleep disruption risk factor. Data suggestive of a relationship between sleep quality and illness incidence may assist in the allocation of resources to monitor sleep more objectively and provide education on sleep hygiene to professional soccer players in order to maintain performance. These findings support recent reviews (Campbell and Turner, 2018; Walsh, 2019; Simpson *et al.*, 2020) which suggest that the physical load associated with professional sport is unlikely to directly cause an illness alone. As shown in figure

6.2, there are a multitude of factors likely to be involved in a professional soccer player contracting an illness, including exposure to a pathogen. Whilst much of the exercise immunology literature has focused on the relationship between exercise and the immune system, the contribution of these other risk factors has been ignored. Future research needs to assess the contribution of these risk factors to illness in professional soccer players; whilst in practice these factors need to be considered to reduce illness risk.

These findings may also challenge the use of multiple-item questionnaires administered daily within professional soccer; where players may often not answer accurately given the time needed and frequency of when these tools are administered (Saw *et al.*, 2014). Instead, based on these findings, it may be more effective to attain a monthly sleep quality value, based on data collected at various points across the month, as a specific marker of illness risk. There were changes to the subjective wellbeing data collection across the thesis. Number of hours of sleep was only implemented as part of the subjective wellbeing questionnaire during the 2018-19 season, subjective wellbeing data collection ranged from daily to every 2 weeks across the duration of the thesis and data collection changed from selecting a score on a laminated to scale to an application filled in on player phones. Changes in the fatigue monitoring philosophy within to the sports science and medicine department during this time period will have contributed to these alterations. As mentioned previously, the research approach was to maintain the ecological validity of the data collected; therefore the decision was made to accept these changes to monitoring practice and continue data collection. Once more these changes are clearly reflective of both applied research and what actually happens in practice. From a broader perspective it is clear that the factors mentioned, alongside physical load, need assessment as part of a monitoring process within professional soccer, if illness risk is to be minimized. This is particularly pertinent within English professional soccer given the intensive winter fixture period, 4 international breaks and importance of a good pre-season campaign. The subjective wellbeing markers employed in Chapter 4 are often used as a tool to assess the responses to the risk factors proposed by Walsh (2018), prior to a change in immune function. It is important to understand the specific relationships that these factors may have with illness in order to design specific, targeted, interventions.

Chapter 5 successfully documented the design and implementation of an illness prevention intervention in professional soccer. However, the intervention was unsuccessful at reducing the problem of illness incidence, described in chapter 3, in comparison to previous seasons. It is important to consider the change in league, and therefore the enhanced demands across the intervention season may have contributed towards these findings. Employment of a control group across the same period as the intervention itself may have been a better comparison on which to base the success of the intervention. Further, despite data from Chapter 3 emphasizing that illness appears to be a year-round problem within professional soccer, and therefore year-round illness prevention programmes are needed, the intervention was only completed over the 4 winter months. The decision was made to employ the intervention over this time period, where peak illness incidence occurred in previous research (Orhant *et al*., 2010; Bjørneboe *et al*., 2016). This was to test the effectiveness at a key time, gradually implement an illness prevention philosophy within the professional soccer club and assess the potential sustainability over a longer period of time. With changes this intervention may have merit as an intervention to be implemented in other soccer teams or sports. It is clear from Chapter 3 that illness is a problem within professional soccer and more needs to be done to prevent the adverse effects on performance and success. Therefore practitioners are encouraged to implement illness prevention programmes in professional soccer, baring in mind the considerations below. The outcome measures for intervention evaluation, implemented to determine the reasons behind the intervention effectiveness, suggested that whilst knowledge and awareness improved, and feedback was positive, there were no effects on behaviour (Figure 6.3). Changing behaviours such as hygiene and nutritional habits would have been central to the success of an intervention such as this. A lack of published illness prevention interventions in athletes meant that content was adapted from illness prevention guidelines (Schwellnus *et al*., 2016; Walsh, 2018; Castell *et al*., 2019) and just 3 interventions (Hanstad *et al.,* 2011; Ranchordas *et al.,* 2016; Schwellnus *et al.,* 2020). Unfortunately these papers did not consider the impact or importance of focussing on key behavioural change determinants to alter health behaviours (Huis *et al*., 2012).

Combinations of different behavioural change determinants such as social influence, attitude, self-efficacy and intention (Huis *et al*., 2012) have been suggested as key factors to assist in changing health-related behaviours. Using the example of this intervention, and advice from Huis *et al.* (2012) these factors may be targeted in the following ways. “Social influence” may be targeted by; (1) providing information about peer behaviour by providing information on peers’ opinions of correct illness prevention behaviour; (2) providing opportunities for social comparison via group sessions with peers in which discussion and social comparison of illness prevention practices can occur. “Attitude” may be targeted using; (1) persuasive communication, for example showing the positive consequences of illness prevention; (2) reinforcement of behavioural progress via praise, encouragement or material rewards. “Self-efficacy” may be altered by; (1) modelling by use of a role model to demonstrate proper illness prevention behaviour in a team environment; (2) verbal persuasion via use of messages designed to strengthen beliefs about illness prevention; (3) guided practice, for example teaching skills, providing feedback and providing specific instructions for correct illness prevention behaviours; (4) planning of coping responses by identification of potential barriers and how to cope with them; (5) setting of graded tasks and goal setting, for example desired illness prevention behaviours and how to achieve them, in a stepwise model. Finally, “intention” may be impacted by; (1) general intention information by explaining the goals and targets concerning illness prevention; (2) agreement to behavioural content via a contract or commitment with formulated goals of illness prevention behaviours. As mentioned, it is vitally important that practitioners implement illness prevention interventions in professional soccer to tackle the problem of illness. When developing and implementing these interventions, focus should be directed towards factors that could impact behavioural change. The Huis *et al.* (2012) review also provides a guided framework to build a successful hand hygiene improvement strategy that may be applicable to illness prevention interventions in athletes. The 7 step framework includes; (1) Description of good practice; (2) Assessment of current compliance; (3) Assessment of barriers and facilitators with compliance; (4) Designing a strategy and linking implementation to these influencing factors; (5) Testing and execution of the strategy; (6) Examination of the cost-effectiveness of the strategy; (7) Evaluation and readjustment of the improvement strategy. It may be useful for practitioners to follow these steps when implementing future illness prevention interventions in athletes.

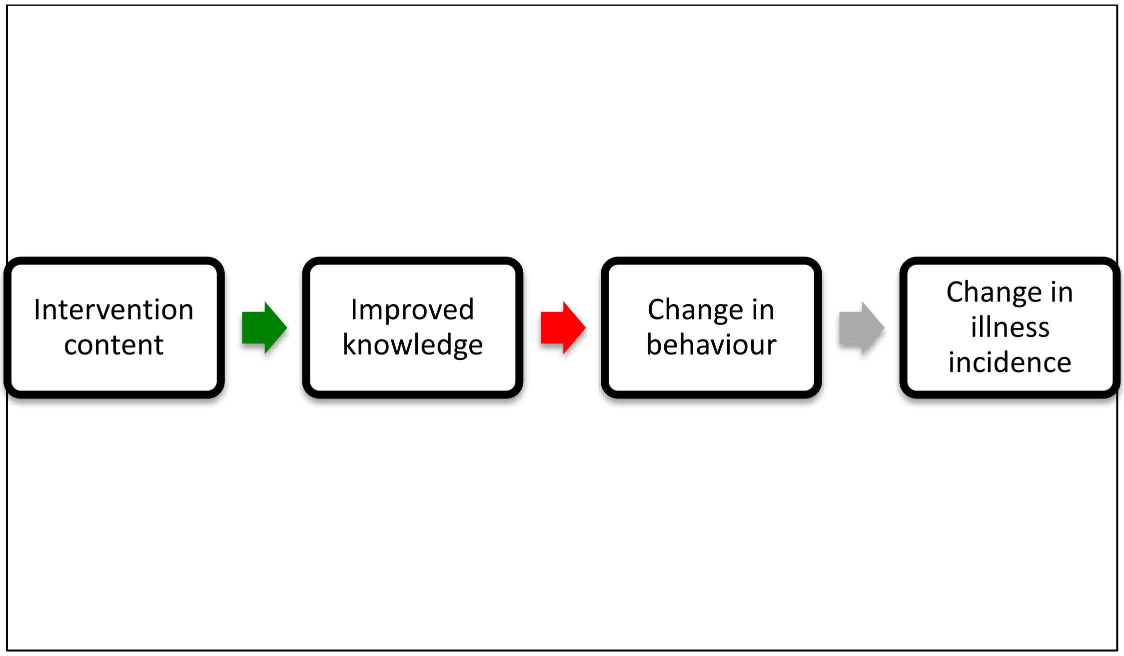

Figure 6.3. A schematic to show the successful knowledge improvement following delivery of intervention content; this did not translate into behavioural change or a change in illness incidence.

6.4. THE CHALLENGES OF APPLIED RESEARCH IN PROFESSIONAL SOCCER

The aim of thesis was to establish the importance of illness in professional soccer by evaluating illness incidence, proposed risk factors and an illness prevention intervention. Inherently, attempting to complete this aim leads to a variety of challenges, many due to the real-world context in which the research has been conducted. This section aims to discuss these challenges and how the research team has tried to overcome them to produce a piece of research that can affect practice.

Initially, implementing an illness surveillance system within a professional soccer club can be challenging, particularly if there has not been a system in place before. This was evident when 1 of the limitations of the system was exposed, 1 season into the thesis. Unfortunately, data was only collected via the OSTRC questionnaire (Clarsen *et al.,* 2013) for the 2017-18 and 2018-19 seasons, not for 2016-17. After initial data assessment and discussion of the recording system with the team doctor, at the end of the 2016-17 season, we found that quantification of performance-restriction illness was difficult compared to medical-attention or time-loss illness (which had more objective diagnosis criteria). At this point performance-restriction illness was diagnosed based on whether the team doctor (head of performance at the time) felt there had been a reduction in volume or intensity of training or match play. This limited the doctor's ability to diagnose this type of illness and therefore we felt a more objective set of criteria was needed. However, as mentioned, this problem was only identified following 1 season of the system being in place in a practical environment. Time constraints meant that a period of pilot testing was not possible; this is one of the challenges of collecting novel data in an applied setting.

As mentioned, the team doctor diagnosed illness. In the fast-paced world of professional soccer this may be gold standard, as decisions need to be made on player health and availability almost immediately. However, as Cox *et al.* (2008) demonstrated, physician assessment alone may falsely diagnose illness where there are no associated pathogens present. Instead symptoms may be the consequence of airway inflammation or allergies, and not infective illness. Cox *et al.* (2008) used nasopharyngeal swabs, taken from athletes on the presence of symptoms, which were then sent away to a lab for analysis. In a research setting, where there may be fewer time pressures and less financial concerns, this is possible. However, in a professional soccer setting, there would not be time or money allocated for these tests to take place. As such, we chose to use physician diagnosis in the present thesis, with a robust set of illness criteria, to record illness events. This would mirror the situations experienced at the majority of professional soccer clubs, should an illness recording system be adopted, and therefore practitioners may be able to directly implement findings.

In any research setting it is difficult to recruit participants, in Chapter 3 the decision was made to recruit participants from a university institution as a comparator group to the professional soccer team. Unfortunately there were more participants in the soccer group than the comparator group, due to difficulties in recruitment; this meant comparison between groups was limited. An ideal comparator group in this case would be participants from a lower-level football team, who trained at a similar sized facility, with a similar amount of players and staff, without the exposure to the intense physical demands of EPL soccer. This would ensure that the comparator group was matched in number. However, the nature of professional soccer means many teams would be hesitant to share data outside of their club. Without an adequate comparator condition, determining the importance of physical load to illness risk in this population is difficult. Pooling data from different teams would also allow the problem of illness in professional soccer to be better understood. At present results are limited to 1 team, yet as mentioned it is challenging to gain access to data from multiple clubs given the competitive nature of the sport.

In an ideal world, throughout the thesis, an objective marker of immune function or an objective fatigue-monitoring tool would have been tracked alongside illness incidence to understand some of the physiological the mechanisms behind the patterns witnessed. As mentioned in chapter 5, WHOOP Straps and sIgA assessment were tested for their reliability, sensitivity and suitability in this environment. Unfortunately neither marker passed all of these tests, and therefore they were not included. Implementing these markers in an applied setting requires a high level of justification, and an often stringent testing process, as described. Although this would have generated a good dataset for the thesis, without passing these tests it would have been difficult to justify regular monitoring at the soccer club to both players and performance staff. Further, professional players already undergo high amounts of monitoring to ensure they are able to train and compete. Adding additional tools into this monitoring system may mean players become frustrated and this dilutes the quality of some of the more robust procedures already in place. As mentioned, utilising other objective fatigue monitoring tools such as HR during submaximal exercise (Buchheit *et al*., 2013a), assessment of energy availability and hygiene practice (Drew *et al*., 2017b) and recording the amount of travel (Schwellnus *et al*., 2012) would likely add value to an illness risk model. However, implementing and sustaining all of these monitoring tools would be practically challenging.

Given the nature of professional soccer, staff members and philosophies change frequently; this presents a challenge to any piece of applied research that takes 3 years to complete. Staff turnover, on a coaching level, and within the sports science and medical department, meant the club philosophy altered throughout the completion of the thesis. For instance, the frequency of data collection, how the data was collected and the specific questions, of the subjective wellbeing questionnaire, varied throughout the thesis based on changes at the soccer club. Similarly, the perceived value and therefore collection of RPE data varied. This limited the ability to collect a consistent data set and therefore may have affected results. It is also common in professional soccer to merge data from different systems to collect a longitudinal dataset. For example, match data was collected via a high-speed camera tracking system and training data collected via MEMS units, as the decision was made not to wear MEMS units during match play. This is further complicated when players go away on international duty where there may be a completely different system used once more. Although every effort is made to ensure data consistency, ultimately the integration of different technologies may affect the quality of data collected in professional soccer. Mean group data is often used in these longitudinal datasets where individual data is not available, for example where a player has not worn a MEMS unit or the data quality is deemed inadequate. Although this is commonplace, this may limit the strength of the final dataset collected.

As mentioned above, recruiting participants for an intervention condition can be challenging. In the case of the intervention utilised in Chapter 5, this became even more apparent. In an ideal world the control condition for the intervention would be a group of players at the same football club who were not exposed to the intervention content. However, for ethical and performance reasons this could not be done. Therefore the decision was made to compare across the 2 previous seasons where the intervention was not in place. This approach is limited by the high player turnover that occurs in professional soccer; this limits the amount of players that can be used in this analysis. Clearly, comparing different players limits the strength of the analysis and may not answer the research question. A different approach may be to compare players at this soccer club to another club in the same league, who follow a similar training schedule and train at a similar sized facility. However, this is once more limited by the willingness of professional soccer teams to participate in studies where data may be shared across teams who are competing against each other.

Finally, implementing a successful intervention within professional soccer is challenging. Players had received little previous support regarding illness prevention and therefore some of the guidelines presented would have been novel to them. In a laboratory setting it may have been much easier to ensure adherence and for participants to buy in to the intervention. However, in this specialist population changing habits and altering behaviour is far more difficult. Further, the intervention content may have been limited by the applied context; player and coach buy-in, money, staff and time available, and training ground layout, dictated certain aspects of the intervention. When introducing novel concepts in this population it is important to implement them slowly, otherwise players will not buy in to what you are trying to do. With this in mind, the intervention itself only lasted 4 months as the research team felt it was important to gradually integrate the intervention to ensure adherence and to test the effectiveness on a smaller scale. Ideally, as mentioned, seasonal illness prevention interventions should be developed and implemented in professional soccer, however these interventions should be gradually developed to ensure players adhere to the intervention content.

6.5. CONCLUSIONS

The current thesis suggests that illness incidence appears to be a greater problem in professional soccer than training injury incidence, and is a bigger issue than identified by previous research. It appears that peaks in illness incidence do not just occur through the winter months but rather throughout the season, including around international breaks and following pre-season. The frequency and nature of this problem means that adequate resources should be allocated to illness surveillance and prevention programmes. Illness incidence may share a relationship with physical load and other risk factors in this population. Indeed, a higher illness incidence was observed compared to a recreationally active comparator population. Closer examination of this relationship reveals key concepts that should be incorporated into physical load and fatigue monitoring practices in professional soccer. Increases in internal physical load markers, in combination with a reduction in external outputs across a week may be related to an increased risk of illness. Spikes in physical load variables within a 15-day period may also precede an illness event. Further, a reduced monthly sleep quality may be related to illness risk. A holistic illness prevention intervention designed to tackle these risk factors was not successful at reducing illness incidence. The intervention may have merit in professional soccer if there was more of a focus on influencing the determinants of behavioural change. Further, limitations exist where increased fixture demands and a potentially higher illness-reporting rate may have influenced results. In conclusion, the thesis suggests that Illness is a bigger problem within professional soccer than previously recognised; this may be related to the high physical load and other illness risk factors that players are continually exposed to. As such, more of a focus should be placed on illness prevention programmes in professional soccer.

6.6. RECOMMENDATIONS FOR FUTURE RESEARCH

The studies completed within this thesis have provided novel information related to the importance of illness in professional soccer. This has been achieved by evaluation of illness incidence, proposed risk factors and an illness prevention intervention. In achieving the aims of the thesis, several issues and subsequent findings have prompted the formulation of recommendations for future research. This section details those recommendations in relation to each specific chapter of the thesis.

6.6.1. Suggestions arising from Chapter 3:

Whilst every effort was made to ensure good scientific practice, ultimately Chapter 3 does need replicating with a recreationally active comparator group that is matched in number of participants. This would allow a more accurate comparison and assessment of the influence of physical load on illness risk. The novel recording system may have merit as a tool to be used for illness surveillance within professional soccer and in future research. However, it is important that the questionnaire used to quantify performance-restriction illness be used from the start of data collection. Consistency in methodology across teams and across research would allow pooling of data and an even better understanding of this problem to ensure results are not isolated to 1 team. Each professional team should have an understanding of this issue within their specific environment so resources can be allocated appropriately and specific risk factors targeted. Clearly, further research is needed to clarify the risk factors and mechanisms behind the high illness burden, and temporal pattern of illness, observed within soccer players. Assessment of objective markers of immune function or physiological function, alongside illness incidence, may help answer this question. Finally, given the frequency of the problem of illness in professional soccer, more illness prevention interventions designed to reduce illness incidence should be developed, implemented and evaluated.

6.6.2. Suggestions arising from Chapter 4:

Further research is needed to clarify whether the observed differences in physical load and subjective wellbeing between illness events and normality is translated into relationships. Assessment of the strength and direction of these relationships via specific data analysis (such as a multivariate regression analysis) would add to the findings observed in this thesis. Inclusion of the internal to external load ratios (Akubat *et al.,* 2014), in this analysis, may provide a greater insight into the ability of these ratios to pinpoint players who may be at an increased risk of illness. Consistency in RPE and subjective wellbeing data collection would improve the data generated in future studies. Further, the collection of mechanical external and internal physical load data from match play would facilitate a more complete indication of the relationship between physical load and illness incidence in professional soccer. Factors identified in figure 6.2, outside of the scope of this study, need to be added into this risk factor model to identify their contributions towards illness. Factors identified by previous research such as an elevated HR during submaximal exercise, a reduction in HRV, low energy availability, poor hygiene practice and international travel, should be considered, as well as objective markers of immune function. A case study approach to assess the contribution of other risk factors may be first beneficial before trying to do this on a larger scale. Holistic interventions targeting these factors, alongside the changes in physical load and subjective wellbeing, also require development and implementation in team sports.

6.6.3. Suggestions arising from Chapter 5:

The intervention framework provided in Chapter 5 should be used to develop, implement and evaluate future illness prevention interventions. Although illness incidence per 1000 hours was greater in the 2017-18 season compared to the 2016-17 and 2018-19 (intervention) seasons, there was a limited effect of the intervention on illness incidence variables in comparison to the previous 2 seasons. These findings, reported in Chapter 5, may be due to the increased amount of fixtures during the 2018-19 season. The increased amount of fixtures may have contributed towards increased travel and time spent together as a group, as well as reduced sleep. These factors may all be important and should be assessed over the intervention and control periods in future research. As a marker of intervention effectiveness illness incidence was compared to the previous 2 seasons, however the intervention was only present for 4 months. Ideally, in future research, control periods should be as close to the intervention periods as possible in all aspects other than the intervention itself, to allow accurate comparison. Specifically in relation to this thesis, the control period should be one that mirrors the intervention period in terms of number of fixtures to ensure similar physical and mental demands. Processes should be put in place to prevent intervention content having a direct effect on results. For example, encouraging players to report symptoms straight away may have contributed to a greater reporting rate in comparison to previous seasons. Utilising a team present in the same league, with a similar training schedule and facility size, yet who are not exposed to the intervention, may control some of these factors. Further, as based on suggestions from Chapter 3, future illness prevention interventions should be implemented year round. This may have more of an effect on reducing illness incidence. The competition demands in the season of intervention development differed substantially, this factor should be kept similar across control and intervention periods in future research. Behavioural change may have had an impact on the intervention outcome; future work should also try and use behavioural change determinants to develop and implement intervention content. Finally, it may be prudent to introduce different variables as the outcome measures for intervention evaluation in future research. Focus groups, observations, objective hand hygiene testing, objective sleep monitoring, energy intake assessment, blood sampling and objective immune function monitoring could be included in future studies. It is possible that the variables used did not capture the true reasons behind effectiveness.

6.7. PRACTICAL RECOMMENDATIONS

In order to impact and improve soccer practice, it is important that practitioners are able to derive useful information from the present thesis that can be used in the applied setting. The following is a summary of key practical recommendations/findings that have been identified through completion of the present thesis:

I. All professional soccer teams should record illness incidence. Based on this thesis not only time-loss illness events, but also performance-restriction and medical-attention illness events, occur frequently in professional soccer. Employment of the recording system and performance-restriction questionnaire used in this thesis may assist in accurate quantification.

II. Based on the specific temporal patterns of illness incidence seasonal illness prevention interventions may be needed, in the same way that injury prevention programmes are in place.

III. Physical load monitoring and fatigue monitoring systems within professional soccer should look to include a flagging system which identifies; (1) an increased internal to external load ratio over weekly time periods, specifically a significant reduction in maximum velocity by 0.4 m/s (SWC = 0.1 m/s), increase in TRIMP per minute by 0.2 (SWC = 0.1) and increase in time spent above 85% MHR by 0.5 minutes (SWC = 0.4 minutes) was noted in this thesis; (2) reduced sleep quality and external load over a monthly period, specifically a significant reduction in high intensity distance by 16.7 m (SWC = 12.7 m) and sleep quality by 0.1 AU (SWC = 0.1 AU) was noted in this thesis; (3) an increase in the daily acute to chronic ratio of physical load variables, specifically a daily acute to chronic ratio of 1.1 seems to precede illness events by around 6 days. These factors may identify when players are at an increased risk of illness so appropriate action can be taken.

IV. Chapter 5 provides a framework for professional soccer clubs to develop, implement and evaluate future illness prevention interventions. Whilst this framework appears to improve awareness and knowledge around illness prevention, in future clubs may wish to include strategies specifically to change behaviour.

CHAPTER 7 - REFERENCES

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APPENDICES

Appendix 3.1. The adapted OSTRC Overuse Injury Questionnaire given to players to quantify performance-restriction illness.

<u>Illness Problem Questionnaire</u>

Please answer all questions regardless of whether or not you have had an illness problem. Select the alternative that is most appropriate for you, and in the case that you are unsure, try to give an answer as best you can anyway. The term "illness problem" refers to a cold, tonsil problems, a fever, sinus problems, headaches, vomiting, diarrhoea, stomach cramps, dizziness or drowsiness.

Question 1

Have you had any difficulties participating in normal training and competition due to illness problems during the past week?

❒ Full participation without illness problems

❒ Full participation, but with illness problems

❒ Reduced participation due to illness problems

❒ Cannot participate due to illness problems

Question 2

To what extent have you reduced your training volume due to illness problems during the past week?

❒ No reduction

- ❒ To a minor extent
- ❒ To a moderate extent
- ❒ To a major extent
- ❒ Cannot participate at all

Question 3

To what extent have illness problems affected your performance during the past week?

- ❒ No effect
- ❒ To a minor extent
- ❒ To a moderate extent
- ❒ To a major extent
- ❒ Cannot participate at all

Question 4

To what extent have you experienced illness problems related to your sport during the past week?

- ❒ No problem
- ❒ A mild problem
- ❒ A moderate problem

- ❒ A severe problem

Appendix 3.2. The adapted OSTRC Overuse Injury Questionnaire given to the recreationally active comparator group.

Illness Prevalence Questionnaire

Question 1

What is your name?

[Insert name]

Question 2

Have you been ill over the past week, and if so, what type of illness have you experienced?

- ❒ Yes, respiratory illness
- ❒ Yes, gastrointestinal illness
- ❒ Yes, malaise illness
- ❒ Yes, UTI/STD illness
- ❒ No
- ❒ Yes, other illness (please specify)

Question 3

When did the illness start?

[Insert date]

Question 4

How long did the illness last?

[Insert number of days]

Question 5

What were the illness symptoms? (Choose whichever best represents the illness)

- ❒ Cold
- ❒ Sore throat/tonsils
- ❒ Fever
- ❒ Sinus
- ❒ Headache
- ❒ Vomit
- ❒ Diarrhoea
- ❒ D&V
- ❒ Stomach cramps
- ❒ UTI
- ❒ Vertigo/vestibular
- ❒ Other (please specify)

Question 6

Has this resulted in time loss from work, time loss from physical activity/sport, you taking medication, or visiting a doctor?

- ❒ Time loss from work
- ❒ Time loss from physical activity/sport
- ❒ Time loss from work and physical activity/sport
- ❒ Took medication
- ❒ Visited a doctor

Question 7

Have you had any difficulties participating in your normal work or physical activity/sport due to illness problems during the past week?

- ❒ Full participation without illness problems
- ❒ Full participation, but with illness problems
- ❒ Reduced participation due to illness problems
- ❒ Could not participate due to illness problems

Question 8

To what extent have you reduced your normal work or physical activity/sport volume due to illness problems during the past week?

- ❒ No reduction
- ❒ To a minor extent
- ❒ To a moderate extent
- ❒ To a major extent
- ❒ Could not participate at all

Question 9

To what extent have illness problems affected your work or physical activity/sport performance during the last week?

- ❒ No reduction
- ❒ To a minor extent
- ❒ To a moderate extent
- ❒ To a major extent
- ❒ Could not participate at all

Question 10

To what extent have you experienced illness problems related to your work or physical activity/sport during the past week?

- ❒ No problem
- ❒ A mild problem
- ❒ A moderate problem
- ❒ A severe problem

Appendix 4.1. The subjective wellbeing questionnaire format.

Score	5	4	3	2	1
Fatigue (How tired do you feel?)	Very fresh	Fresh	Normal	More tired than normal	Always tired
Sleep quality (How was your sleep last night?)	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia
General muscle soreness (How sore do you feel?)	Feeling great	Feeling good	Normal	Increase in soreness/ tightness	Very sore

Stress levels (How stressed do you feel?)	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed
Mood (What is your current mood?)	Very positive mood	A generally good mood	Less interested in others and/or activities than usual	Snappiness at team-mates, family and co-workers	Highly annoyed/ irritable/do wn
Sleep hours (How many hours of sleep did you have?)	9 or more	8	7	6	5 or less

Appendix 4.2. Analysis of all physical load and subjective wellbeing variables in the 7 and 28-day periods preceding an illness compared to normality.

Table 4.2.1. Comparison of general 7-day locomotive external physical load variables to the 7-days preceding an illness event. Values presented are a 7-day average and therefore reflect values per day. Data is presented as mean values ± standard devation. P-values, effect sizes (ES) and smallest worthwhile change (SWC) values are also presented. Data analysis was completed with 37 players.

Variable	General 7-day average	7 days before illness	P-value	ES	SWC
Duration (minutes)	29.9 ± 4.2	27.6 ± 8.5	0.05	0.6	0.8

Total distance (m)	2459.8 ± 395.8	2247.9 ± 787.6	0.06	0.5	79.2
Metres per minute	44.6 ± 4.3	41.6 ± 12.9	0.17	0.7	0.9
High intensity distance (m)	285.2 ± 61.5	256.0 ± 124.7	0.09	0.5	12.3
Number of high intensity runs	26 ± 7	24 ± 12	0.36	0.2	1.5
Very high intensity distance (m)	89.3 ± 49.8	93.3 ± 62.2	0.44	0.1	10.0
Sprint distance (m)	8.0 ± 5.4	7.7 ± 7.7	0.77	0.1	1.1
Number of sprints	1 ± 0	1 ± 1	0.76	0.0	0.1
Maximum velocity (m/s)	4.1 ± 0.3	3.7 ± 1.0	0.03*	1.3	0.1

* Denotes statistical significance (p<0.05).

Table 4.2.2. Comparison of general 7-day mechanical external physical load variables to the 7-days preceding an illness event. Values presented are a 7-day average and therefore reflect values per day. Data is presented as mean values ± standard devation. P-values, effect sizes (ES) and smallest worthwhile change (SWC) values are also presented. Data analysis was completed with 37 players.

Variable	General 7-day average	7 days before illness	P-value	ES	SWC
Player load (AU)	174.8 ± 39.6	167.5 ± 69.2	0.48	0.2	7.9
Player load per minute	3.6 ± 0.7	3.4 ± 1.2	0.21	0.3	0.1
No. of accelerations (> 2 m/s/s)	10 ± 3	9 ± 4	0.48	0.2	0.6
No. of accelerations (> 3 m/s/s)	0 ± 1	1 ± 1	<0.01*	0.4	0.1
No. of decelerations (< -2 m/s/s)	5 ± 2	5 ± 2	0.45	0.1	0.4
No. of decelerations (< -3 m/s/s)	0 ± 0	0 ± 0	0.16	0.0	0.1

* Denotes statistical significance (p<0.05).

Table 4.2.3. Comparison of general 7-day internal physical load variables to the 7-days preceding an illness event. Values presented are a 7-day average and therefore reflect values per day. Data is presented as mean values ± standard devation. P-values, effect sizes (ES) and smallest worthwhile change (SWC) values are also presented. Data analysis was completed with 37 players.

Variable	General 7-day average	7 days before illness	P-value	ES	SWC
TRIMP (AU)	42.0 ± 13.8	43.0 ± 21.1	0.68	0.1	2.8
TRIMP per minute	0.4 ± 0.4	0.6 ± 0.5	<0.01*	0.5	0.1
Time spent above 85% MHR (minutes)	2.3 ± 1.8	2.8 ± 2.2	0.02*	0.3	0.4

* Denotes statistical significance (p<0.05).

Table 4.2.4. Comparison of general 7-day subjective wellbeing variables to the 7-days preceding an illness event. Values presented are a 7-day average and therefore reflect values per day. Data is presented as mean values ± standard devation. P-values, effect sizes (ES) and smallest worthwhile change (SWC) values are also presented. Data analysis was completed with 37 players.

Variable	General 7-day average	7 days before illness	P-value	ES	SWC
Fatigue (1-5)	3.6 ± 0.4	3.6 ± 0.7	0.84	0.0	0.1
General muscle soreness (1-5)	3.5 ± 0.4	3.6 ± 0.6	0.79	0.3	0.1
Sleep quality (1-5)	3.8 ± 0.3	3.7 ± 0.5	0.32	0.3	0.1
Hours of sleep (1-5)	3.7 ± 0.5	3.4 ± 0.8	0.25	0.6	0.1
Stress (1-5)	3.7 ± 0.4	3.6 ± 0.6	0.41	0.3	0.1
Mood (1-5)	3.9 ± 0.3	3.9 ± 0.4	0.20	0.0	0.1
Total wellbeing score (5-25/30)	19.9 ± 2.2	20.0 ± 2.8	0.66	0.0	0.4

* Denotes statistical significance (p<0.05).

Table 4.2.5. Comparison of general 28-day locomotive external physical load variables to the 28 days preceding an illness event. Values presented are a 28-day average and therefore reflect values per day. Data is presented as mean values ± standard devation. P-values, effect sizes (ES) and smallest worthwhile change (SWC) values are also presented. Data analysis was completed with 37 players.

Variable	General 28-day average	28 days before illness	P-value	ES	SWC
Duration (minutes)	28.4 ± 3.5	27.8 ± 5.5	0.27	0.2	0.7
Total distance (m)	2381.9 ± 336.0	2295.4 ± 473.7	0.09	0.3	67.2
Metres per minute	42.9 ± 4.5	41.4 ± 7.1	0.10	0.3	0.9
High intensity distance (m)	284.7 ± 63.7	268.0 ± 84.1	0.03*	0.3	12.7
Number of high intensity runs	26 ± 8	25 ± 9	0.37	0.1	1.5
Very high intensity distance (m)	89.1 ± 52.1	92.9 ± 51.2	0.11	0.1	10.4
Sprint distance (m)	10.6 ± 6.2	9.6 ± 6.2	0.18	0.2	1.2
Number of sprints	1 ± 0	1 ± 0	0.14	0.3	0.1
Maximum velocity (m/s)	3.8 ± 0.3	3.7 ± 0.6	0.09	0.3	0.1

* Denotes statistical significance ($p<0.05$).

Table 4.2.6. Comparison of general 28-day mechanical external physical load variables to the 28 days preceding an illness event. Values presented are a 28-day average and therefore reflect values per day. Data is presented as mean values ± standard devation. P-values, effect sizes (ES) and smallest worthwhile change (SWC) values are also presented. Data analysis was completed with 37 players.

Variable	General 28-day average	28 days before illness	P-value	ES	SWC
Player load (AU)	166.8 ± 38.8	164.4 ± 46.9	0.56	0.1	7.8
Player load per minute	3.4 ± 0.7	3.3 ± 0.8	0.16	0.1	0.1
No. of accelerations (> 2 m/s/s)	10 ± 3	10 ± 3	0.43	0.1	0.6
No. of accelerations (> 3 m/s/s)	1 ± 1	1 ± 1	0.13	0.1	0.1
No. of decelerations (< -2 m/s/s)	5 ± 2	5 ± 2	0.78	0.2	0.4
No. of decelerations (< -3 m/s/s)	1 ± 0	1 ± 1	0.14	0.0	0.1

* Denotes statistical significance (p<0.05).

Table 4.2.7. Comparison of general 28-day internal physical load variables to the 28 days preceding an illness event. Values presented are a 28-day average and therefore reflect values per day. Data is presented as mean values ± standard devation. P-values, effect sizes (ES) and smallest worthwhile change (SWC) values are also presented. Data analysis was completed with 37 players.

Variable	General 28-day average	28 days before illness	P-value	ES	SWC
TRIMP (AU)	40.7 ± 13.6	38.9 ± 12.6	0.25	0.1	2.7
TRIMP per minute	0.5 ± 0.4	0.5 ± 0.3	0.86	0.0	0.1
Time spent above 85% MHR (minutes)	2.4 ± 1.7	2.3 ± 1.3	0.59	0.1	0.3

* Denotes statistical significance (p<0.05).

Table 4.2.8. Comparison of general 28-day subjective wellbeing variables to the 28 days preceding an illness event. Values presented are a 28-day average and therefore reflect values per day. Data is presented as mean values ± standard devation. P-values, effect sizes (ES) and smallest worthwhile change (SWC) values are also presented. Data analysis was completed with 37 players.

Variable	General 28-day average	28 days before illness	P-value	ES	SWC
Fatigue (1-5)	3.6 ± 0.4	3.6 ± 0.5	0.80	0.0	0.1
General muscle soreness (1-5)	3.5 ± 0.5	3.5 ± 0.5	0.62	0.0	0.1
Sleep quality (1-5)	3.8 ± 0.3	3.7 ± 0.4	0.01*	0.3	0.1
Hours of sleep (1-5)	3.6 ± 0.4	3.5 ± 0.5	0.36	0.3	0.1
Stress (1-5)	3.7 ± 0.4	3.6 ± 0.5	0.05	0.3	0.1
Mood (1-5)	3.9 ± 0.3	3.8 ± 0.4	0.93	0.3	0.1
Total wellbeing score (5-25/30)	19.9 ± 2.2	20.0 ± 2.6	0.78	0.0	0.4

* Denotes statistical significance (p<0.05).

Appendix 5.1. Link to infographics placed around the training ground.

https://drive.google.com/open?id=1hhc7wpvbXKpkukw7HJVX3GkW4DqLvVe9

Appendix 5.2. Link to infographics and animated videos sent via what's app messenger.

https://drive.google.com/open?id=1_aOo8LYT0UMPqisq0OMiOmHGpRbwAul4

Appendix 5.3. Link to training load infographic given to first-team coaching staff.

https://drive.google.com/open?id=1hwbYgJDCuxsxPgoJdx41aNqPrFwxZrou

Appendix 5.4. The script used for targeted consultations and player interviews.

Interview script

To give you some context, the aim of my PhD is to develop an understanding of the relationships between immunity, health and wellness in football players. I have completed 2 studies so far; (1) looking at illness incidence (when it occurs, what type and the severity) and (2) looking at the associations between training, wellness information (questionnaire) and illness.

I am now starting my third study which is an intervention designed to reduce illness incidence using the information gathered from the first 2 studies. The intervention will run from November-February (to coincide with the peak illness incidence times over the past 2 seasons). I want the intervention to be adaptable and almost change based on feedback as we go - hence the interview.

Prior to the start of the intervention pre-markers (including the questionnaire you filled in) were assessed. The intervention is made up of multiple components, the first being education - posters around the training ground, videos and information sent via what's app, consultations, coaches guidelines and objective sleep monitoring offered. The other components are refined nutrition and hygiene practice - disinfectant machine, individual and additional hand sanitizer, zero-tolerance policy to illness, daily supplementation, immunity pack distribution and flu vaccinations offered. Post checks will be completed following this period including a post-intervention questionnaire and a comparison of illness incidence vs the past 2 seasons.

**Definition of illness (if needed) - any physical symptom, not related to injury, which requires medical attention, affects performance or causes time loss from training or matches. It is likely that the illness you have experienced has either affected the respiratory (nose, sinuses, throat or chest) and/or gastrointestinal (stomach) systems.

You may have experienced illness symptoms such as a sore throat, cough, runny or congested nose, headache, body aches, fever, vomiting and/or diarrhea.

Questions -

Describe your experience of illness in football and what you've done in the past to stop being ill.

Do you feel like you've had a lot of illness over the past few seasons? Looking back at the data you would be high on the list of people who frequently become ill.

Is there any specific factor in particular you would put this down to?

What are your perceptions of how much illness we've had this season and in previous seasons?

Can you tell me about your experience of this intervention so far?

Do you feel the intervention has been effective so far?

What are your perceptions of buy-in and compliance with some of the strategies we've put in place?

Do you feel the intervention has impacted on your current practice?

What sort of things have you changed and why?

Why do you think it hasn't impacted practice?

Which aspects of the intervention do you think work well?

Which aspects of the intervention do you think need to change or improve?

Research has shown biggest risk factors for illness in sport are - hygiene, poor nutrition, long-haul travel, poor sleep, life stress and training stress. What are your experiences of these factors and illness?

Do you feel like any of these factors have had a specific impact on your illness incidence?

Is there anything that you think we're missing or you think would work really well or that has impacted up on you?

Do you feel like you need more support in any of these areas? I'm happy to discuss them or put something together to help you work on the areas in question.

Appendix 5.5. The pre and post-intervention questionnaire, with choices, used as a process to evaluate the reasons behind intervention effectiveness.

1. When do you think you would be most vulnerable to illness? (Multiple options availiable)

- ❒ June (off-season)
- ❒ July (pre-season)
- ❒ August (season starts)
- ❒ September
- ❒ October
- ❒ November
- ❒ December
- ❒ January
- ❒ February
- ❒ March
- ❒ April
- ❒ May (season ends)
- ❒ All of the above
- ❒ I don't know

2. Which strategies do you think can reduce the risk of illness? (Multiple options availiable)

- ❒ Minimise contact with infected people
- ❒ Keep unnecessary life stress to a minimum
- ❒ Carry alcohol-based hand-washing gel
- ❒ Report symptoms straight away
- ❒ Avoid crowded areas and hand-shaking outside of the team
- ❒ Keep at distance to those who are coughing, sneezing or have a 'runny nose'
- ❒ Ensure good hand hygiene
- ❒ Avoid self-infection by touching the eyes, nose and mouth
- ❒ Pay close attention to recovery following tough sessions and matches
- ❒ Cough or sneeze on elbow, not the hands - always clean hands after
- ❒ Avoid low energy availability
- ❒ Eat a well balanced diet
- ❒ Take your daily supplements (multivitamin, probiotic, and vitamin D)
- ❒ Aim for 8 hours of sleep per night
- ❒ I don't know
- ❒ Other (please specify)

3. What is your current strategy when you first get illness symptoms? (Multiple options availiable)

- ❒ Immediately report symptoms to one of the physios
- ❒ Immediately report symptoms to the doctor
- ❒ Ask for an immunity pack
- ❒ Other (please specify)
- ❒ I don't currently have a strategy

4. How do you think illness is spread? (Multiple options availiable)

- ❒ Hand-to-hand contact (passed on to eyes, nose or mouth)

- ❐ Droplets in the air (coughs and sneezes)
- ❐ I don't know
- ❐ Other (please specify)

5. What do you currently use to wash your hands? (Multiple options availiable)

- ❐ Soap and water
- ❐ Hand sanitizer
- ❐ I don't wash my hands
- ❐ Other (please specify)

6. When do you currently wash your hands with soap and water? (Multiple options availiable)

- ❐ Before eating or handling food
- ❐ After contact with potentially contagious people
- ❐ After contact with animals
- ❐ After contact with blood
- ❐ After contact with secretions
- ❐ After using the toilet
- ❐ After blowing your nose
- ❐ After coughing
- ❐ After sneezing
- ❐ I don't wash my hands with soap and water
- ❐ Other (please specify)

7. Which food types and/or supplements do you think are most important to reduce the risk of illness? (Multiple options availiable)

- ❐ Vitamin D
- ❐ Vitamin C
- ❐ Probiotic
- ❐ Zinc lozenges

- ❒ Multivitamin
- ❒ Carbohydrate
- ❒ Protein
- ❒ I don’t know
- ❒ Other (please specify)

8. Which nutritional strategies do you think can help reduce the risk of illness? (Multiple options availiable)

- ❒ Eat a well-balanced diet with 7 portions of fruit and vegetables per day
- ❒ Choose beverages from sealed bottles
- ❒ Consume a high protein diet (1.2-1.6 g per kg of weight)
- ❒ Take your daily supplements (multivitamin, probiotic and vitamin D)
- ❒ Ask for an immunity pack at the first sign of symptoms
- ❒ Avoid low energy availability
- ❒ Do not share cutlery
- ❒ Wash and peel fruit before eating
- ❒ Consume at least 50% of your daily intake as carbohydrate for energy
- ❒ Avoid excessive alcohol consumption
- ❒ I don’t know
- ❒ Other (please specify)

9. How many hours of sleep do you think you need to reduce the risk of illness?

- ❒ 5 hours or less
- ❒ 6 hours
- ❒ 7 hours
- ❒ 8 hours
- ❒ 9 hours
- ❒ 10 hours or more
- ❒ I don’t know

10. Which strategies do you think can improve your sleep? (Multiple options availiable)

- ❒ Avoid caffeine before sleep
- ❒ Avoid alcohol before sleep
- ❒ Avoid fatty meals before sleep
- ❒ Ensure a cool room
- ❒ Ensure a quiet room
- ❒ Ensure a dark room
- ❒ Ensure a comfortable room
- ❒ Create a consistent bed time routine - same sleep and wake time daily
- ❒ Create a relaxing bed time routine
- ❒ No electronic device exposure at least 1 hour before sleep
- ❒ Nap no later than mid afternoon
- ❒ Nap for no longer than 30 minutes
- ❒ Consider monitoring sleep patterns
- ❒ Avoid restricting sleep and catching up
- ❒ Aim for 8 hours of sleep per night
- ❒ I don't know
- ❒ Other (please specify)

Appendix 5.6. The pre and post-intervention questionnaire results.

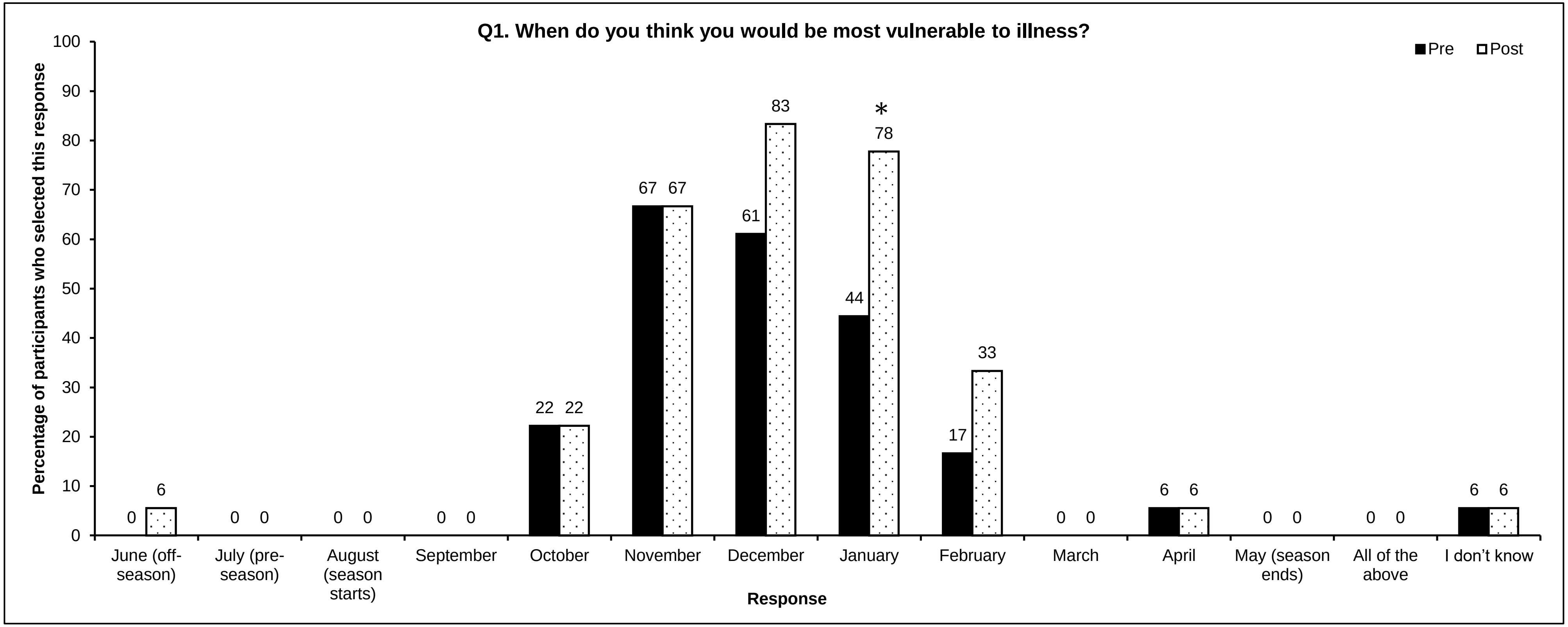

Figure 5.6.1. Pre and post-intervention questionnaire responses to "Q1. When do you think you would be most vulnerable to illness?" * Denotes a significant difference in the distribution of participants who did vs did not select the relevant response pre vs post-intervention. Significance was set at $p<0.05$. Data includes the 18 players who provided pre and post questionnaire responses.

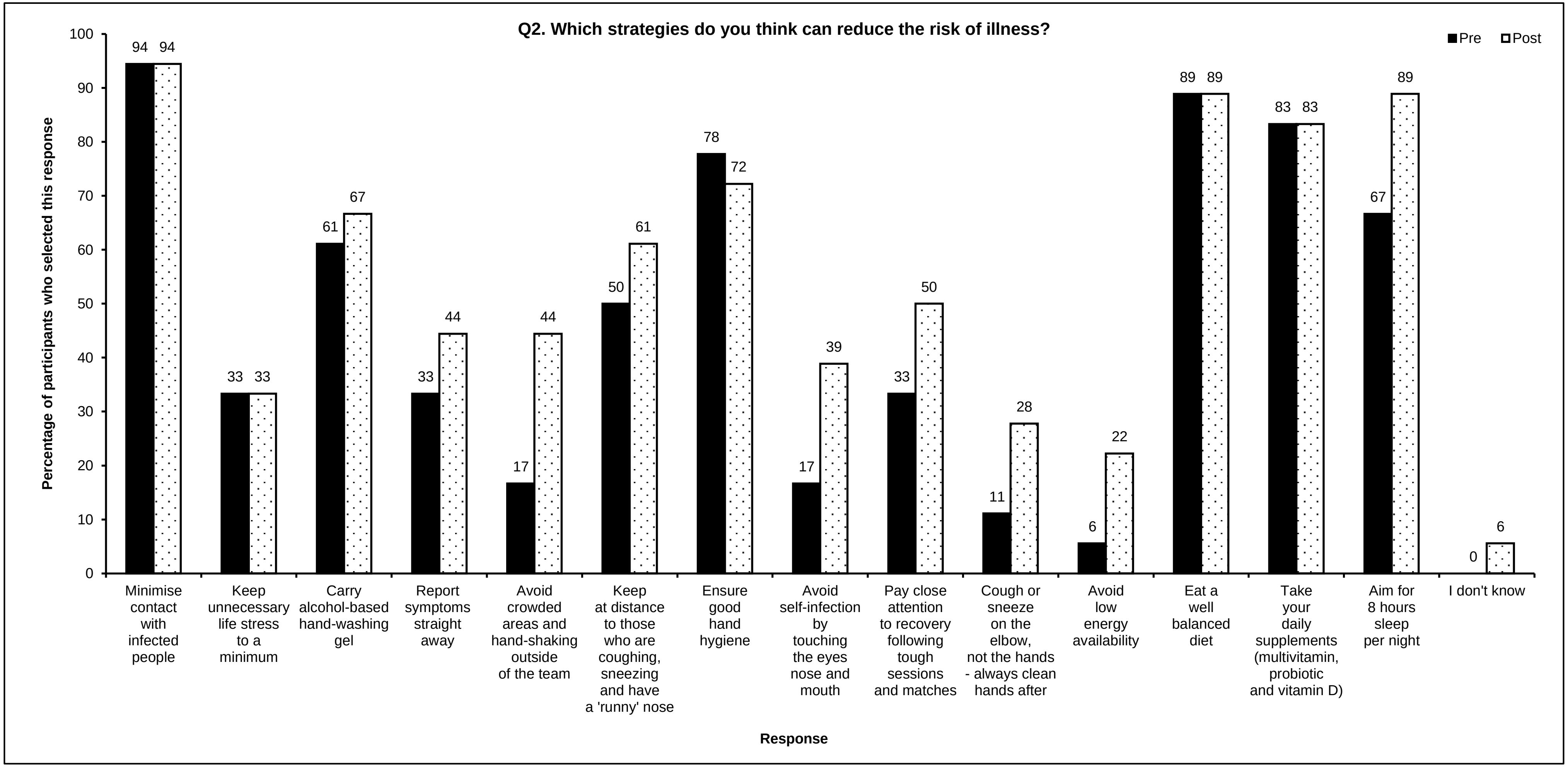

Figure 5.6.2. Pre and post-intervention questionnaire responses to “Q2. Which strategies do you think can reduce the risk of illness?” * Denotes a significant difference in the distribution of participants who did vs did not select the relevant response pre vs post-intervention. Significance was set at p<0.05. Data includes the 18 players who provided pre and post questionnaire responses.

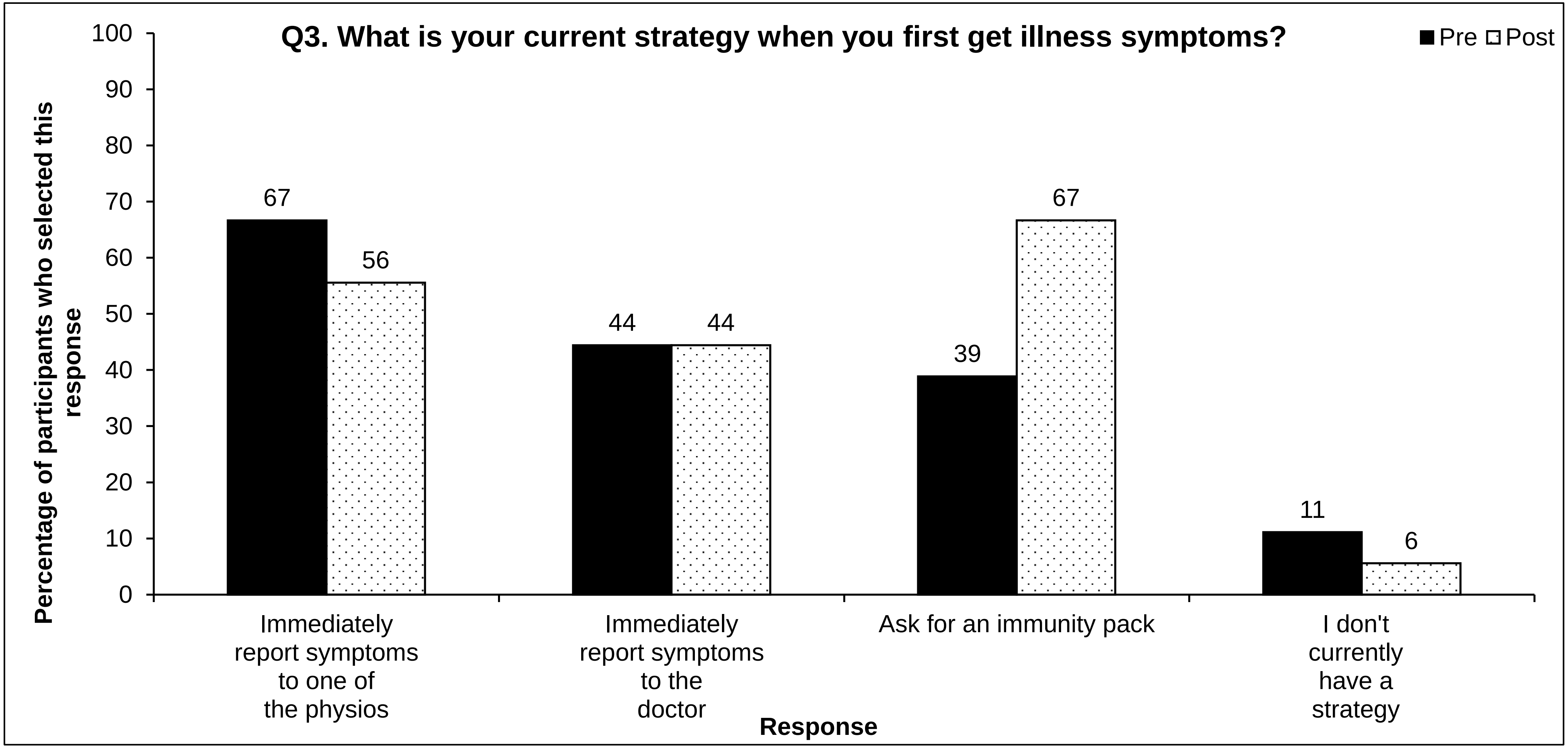

Figure 5.6.3. Pre and post-intervention questionnaire responses to "Q3. What is your current strategy when you first get illness symptoms?" * Denotes a significant difference in the distribution of participants who did vs did not select the relevant response pre vs post-intervention. Significance was set at $p<0.05$. Data includes the 18 players who provided pre and post questionnaire responses.

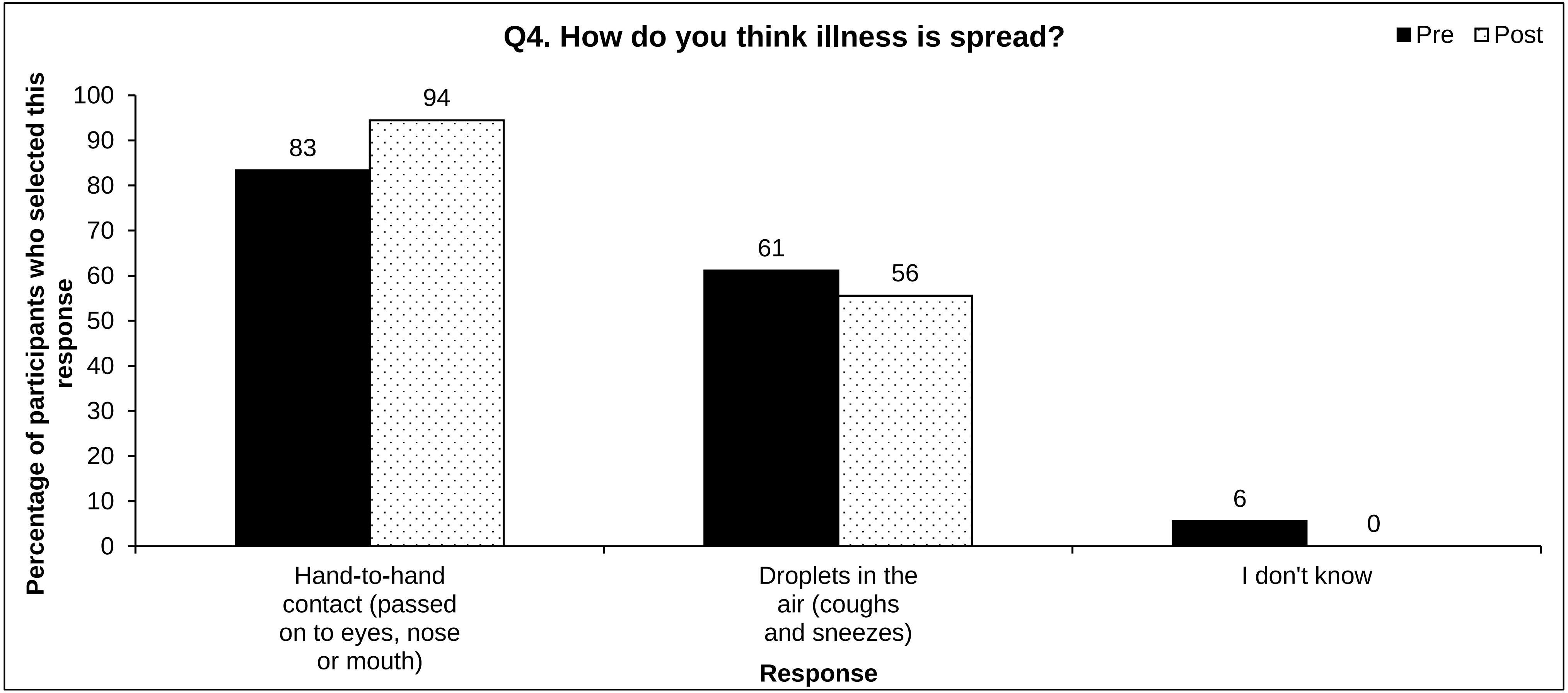

Figure 5.6.4. Pre and post-intervention questionnaire responses to "Q4. How do you think illness is spread?" * Denotes a significant difference in the distribution of participants who did vs did not select the relevant response pre vs post-intervention. Significance was set at p<0.05. Data includes the 18 players who provided pre and post questionnaire responses.

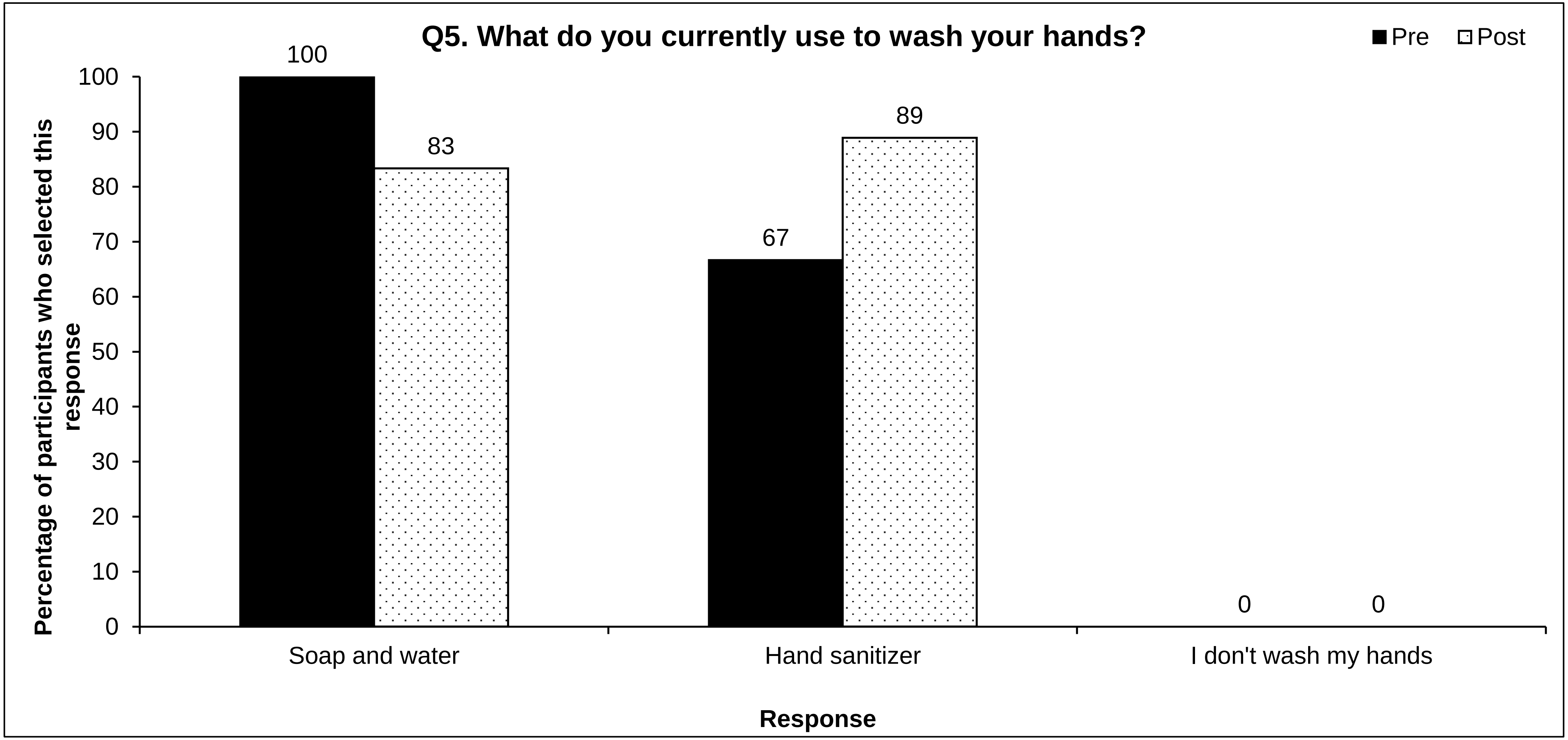

Figure 5.6.5 Pre and post-intervention questionnaire responses to “Q5. What do you currently use to wash your hands?” * Denotes a significant difference in the distribution of participants who did vs did not select the relevant response pre vs post-intervention. Significance was set at $p<0.05$. Data includes the 18 players who provided pre and post questionnaire responses.

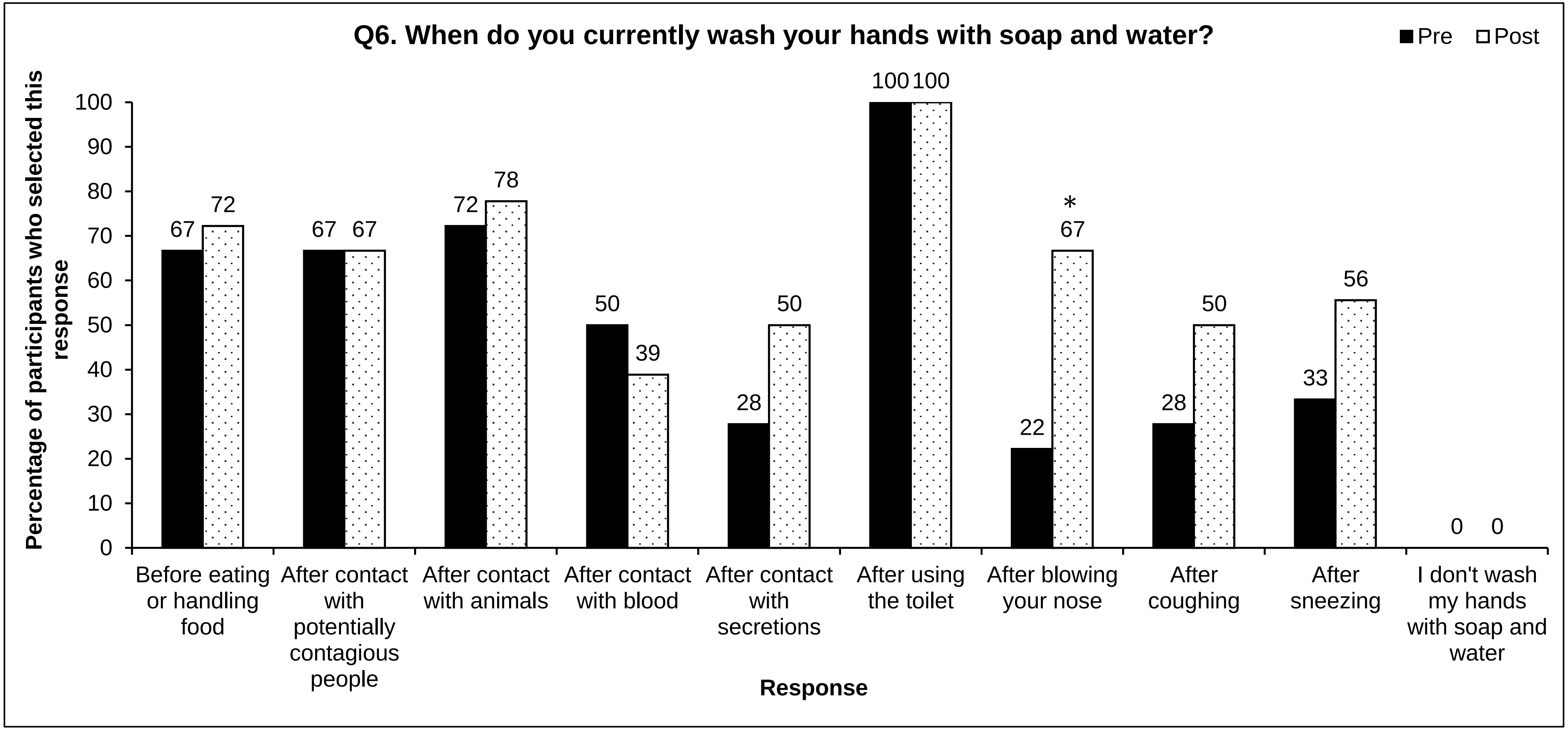

Figure 5.6.6. Pre and post-intervention questionnaire responses to "Q6. When do you currently wash your hands with soap and water?" * Denotes a significant difference in the distribution of participants who did vs did not select the relevant response pre vs post-intervention. Significance was set at p<0.05. Data includes the 18 players who provided pre and post questionnaire responses.

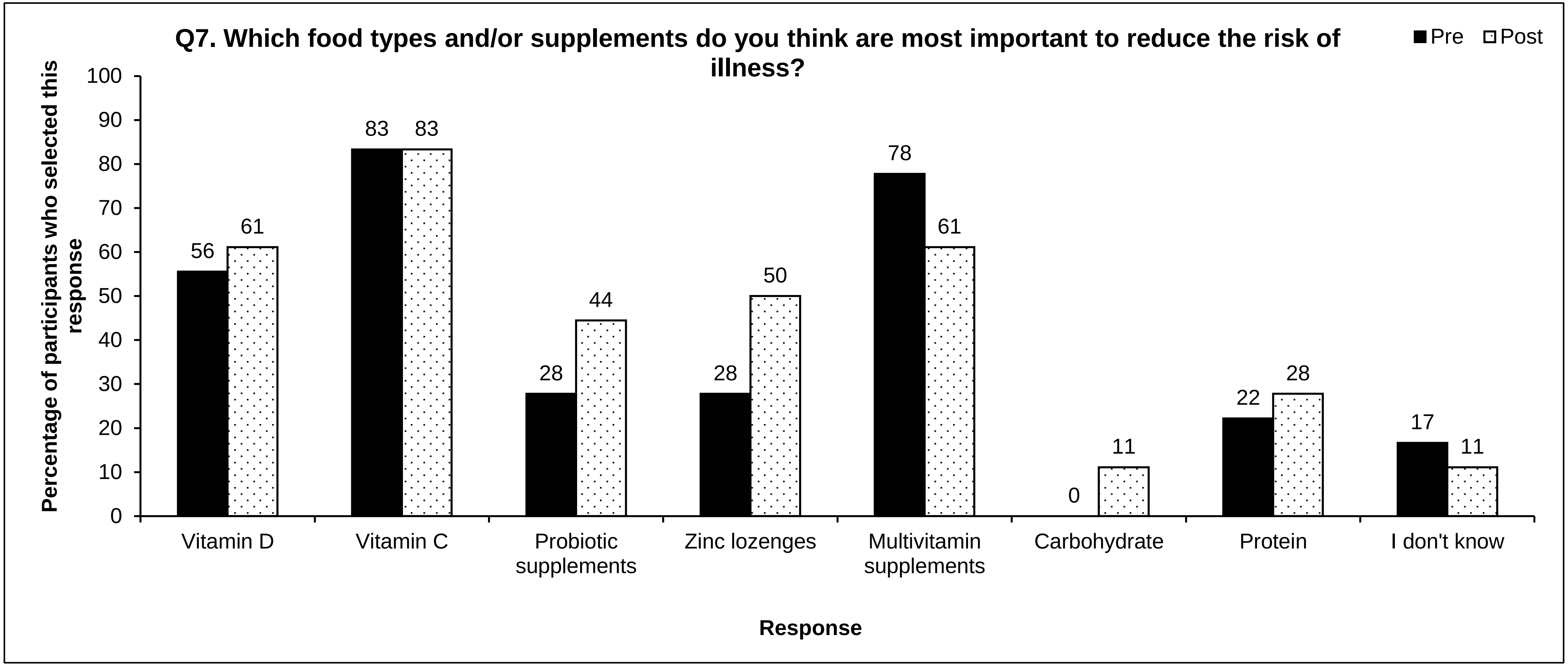

Figure 5.6.7. Pre and post-intervention questionnaire responses to "Q7. Which food types and/or supplements do you think are most important to reduce the risk of illness?" * Denotes a significant difference in the distribution of participants who did vs did not select the relevant response pre vs post-intervention. Significance was set at $p<0.05$. Data includes the 18 players who provided pre and post questionnaire responses.

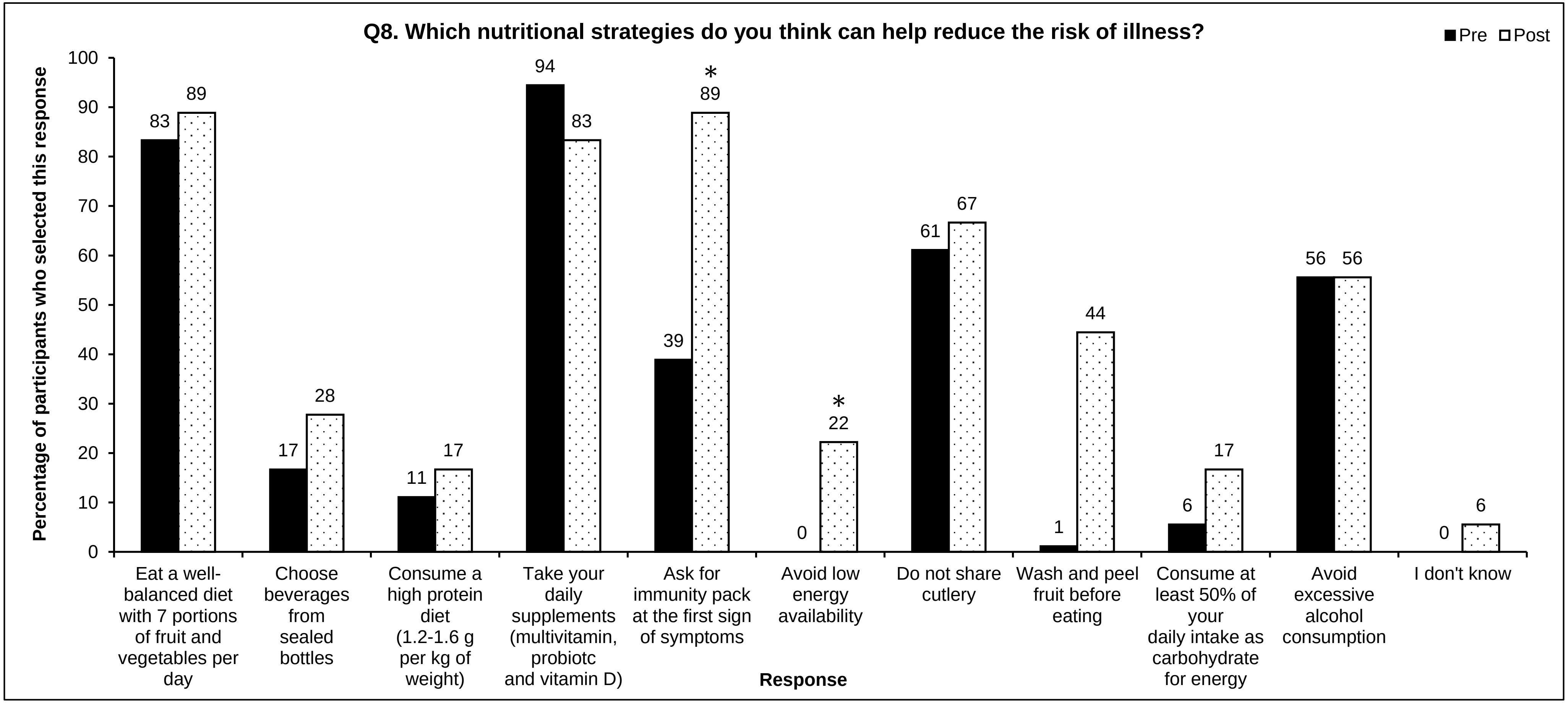

Figure 5.6.8. Pre and post-intervention questionnaire responses to "Q8. Which nutritional strategies do you think can help reduce the risk of illness?" * Denotes a significant difference in the distribution of participants who did vs did not select the relevant response pre vs post-intervention. Significance was set at p<0.05. Data includes the 18 players who provided pre and post questionnaire responses.

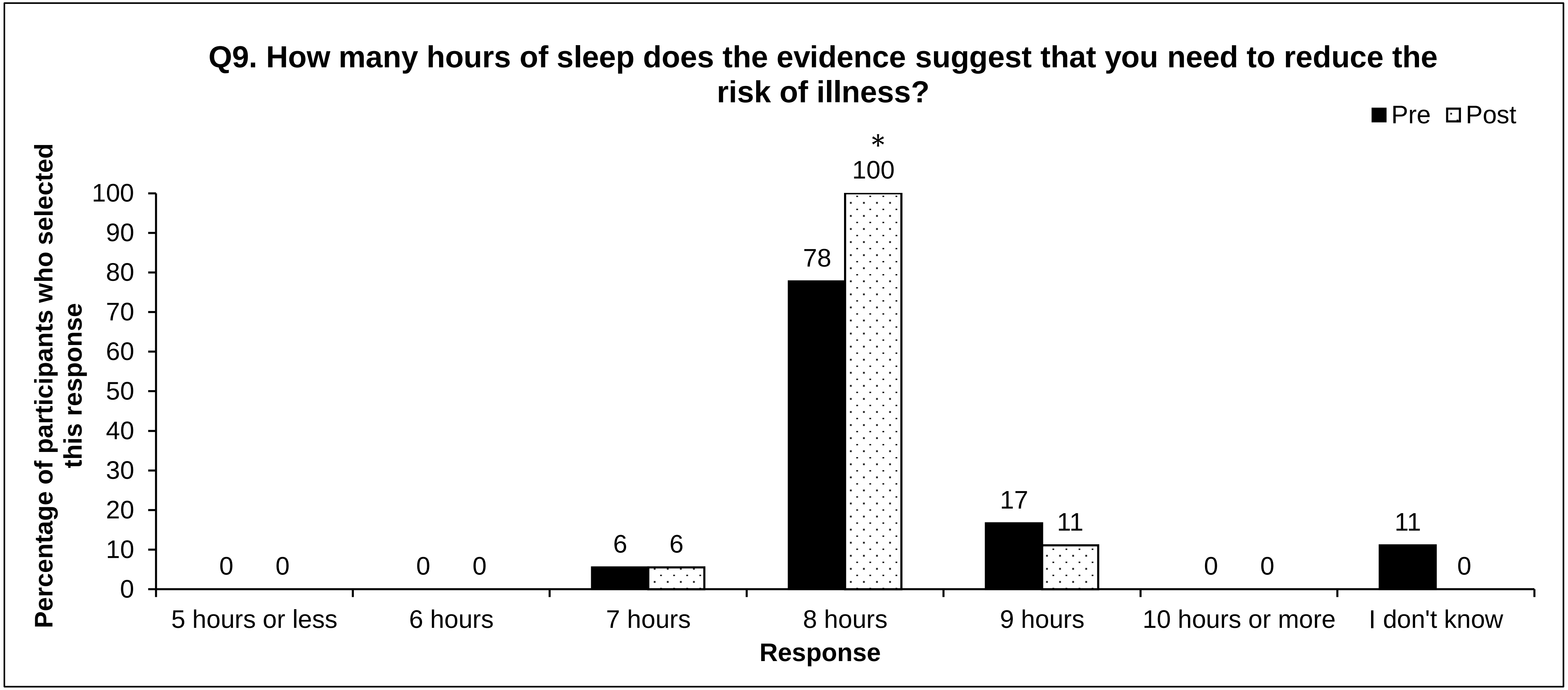

Figure 5.6.9. Pre and post-intervention questionnaire responses to "Q9. How may hours sleep does the evidence suggest that you need to reduce the risk of illness?" * Denotes a significant difference in the distribution of participants who did vs did not select the relevant response pre vs post-intervention. Significance was set at $p<0.05$. Data includes the 18 players who provided pre and post questionnaire responses.

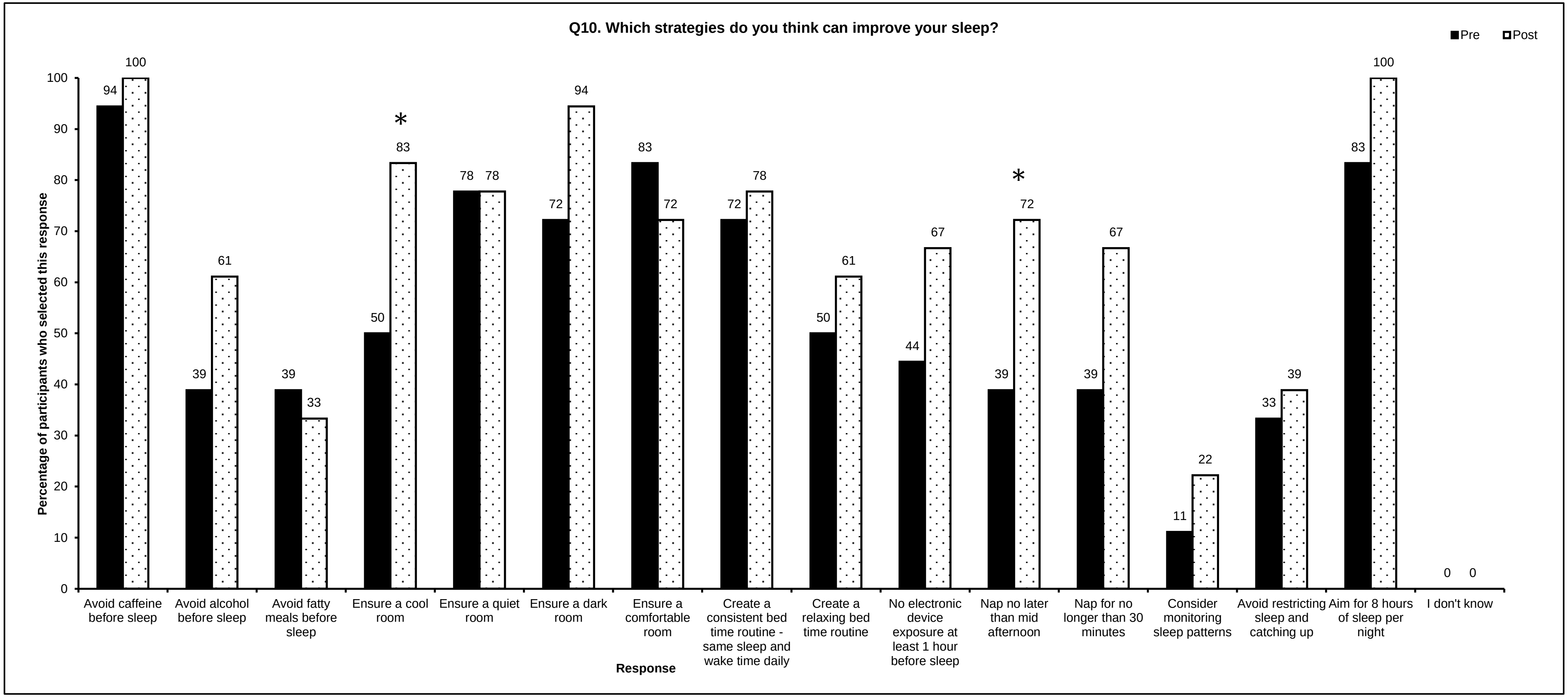

Figure 5.6.10. Pre and post-intervention questionnaire responses to "Q10. Which strategies do you think can improve your sleep?" * Denotes a significant difference in the distribution of participants who did vs did not select the relevant response pre vs post-intervention. Significance was set at $p<0.05$. Data includes the 18 players who provided pre and post questionnaire responses.

Appendix 5.7. Link to the consultation and interview transcripts.

https://drive.google.com/drive/folders/1PbuP_ww7qm9s1atsyAIOsIEqh89k8CNs?usp=sharing