University of Exeter | Children's Health and Exercise Research Centre

Health and Wellbeing in Competitive Adolescent Distance Runners: Training Load, Health Problems, and Psychosocial Response to Injury

Submitted by Robert Mann, to the University of Exeter as a thesis for the degree of Doctor of Philosophy in Health and Wellbeing, January 2021.

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature: *Robert Mann* (15/01/21)

ABSTRACT

Although distance running is associated with multiple health benefits, adult-based research indicates that participation is also associated with unfavourable health outcomes, such as running-related injury (RRI). As there is limited literature related to the health problems (i.e., injury and illness) that competitive adolescent distance runners (13-18 years) experience, this research aimed to describe and evaluate the extent of the injury and illness problem in competitive adolescent distance runners in England.

The first study (Chapter 4) demonstrates that session rating of perceived exertion (sRPE), whether reported 0, 15, or 30 minutes following session completion, provides a valid measure of internal training load in adolescent distance runners. This allows sRPE to be used during training and future epidemiological studies. The second study (Chapters 5 and 6) employed a mixed-methods study design. Chapter 5 presents a retrospective epidemiological study (n = 113), whereby the incidence of RRI was 6.3 per 1,000 hours of exposure and the most commonly injured body areas were the knee, foot/toes, and lower leg. Exploratory univariate analyses indicated that a larger number of training sessions per week (volume) and higher specialisation (i.e., intense, year-round training in a single sport with the exclusion of other sports) were both associated with a lower risk of RRI. Chapter 6 investigated psychosocial responses to RRI in those athletes (n = 19) who self-reported a *serious RRI* (>28 days-6 months of time loss). Based upon a reflexive thematic analysis of interview data, fifteen codes and three themes were developed. These data indicate that *serious RRI* acts to 'destabilise athletic identity' in competitive adolescent distance runners. The third study (Chapter 7) presents a prospective cohort study (n = 136), whereby the incidence of RRI was 25 per 1,000 hours of exposure. At any time, the mean weekly prevalence of all

health problems was 24%, regardless of type or sex, reducing to 11% and 4% for substantial and time loss health problems, respectively. These data show that competitive adolescent distance runners are likely to be training and/or competing whilst concurrently experiencing one or more health problems. Also, female athletes self-reported more illnesses, when compared to male athletes. Collectively, these studies provide valuable and novel insight into the health and wellbeing of competitive adolescent distance runners in England. In turn, this thesis will support the development of injury and illness prevention measures.

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LIST OF ABBREVIATIONS

AIMS	Athletic Identity Measurement Scale
aPHV	Age at Peak Height Velocity
AU	Arbitrary Unit
BMI	Body Mass Index
CI	Confidence Intervals
CPET	Cardiopulmonary Exercise Test
CR10 Scale	0-10 Category Scale with Ratio Properties
dRPE	Differential Rating of Perceived Exertion
dRPE-B	Differential Rating of Perceived Exertion: Breathlessness
dRPE-L	Differential Rating of Perceived Exertion: Leg Exertion
EA	England Athletics
ES	Effect Size
ESRC	Economic and Social Research Council
HR	Heart Rate
HR_{max}	Maximum Heart Rate
HR_{rest}	Resting Heart Rate
IP	Incidence Proportion
IQR	Interquartile Range
IR	Incidence Rate
ITL	Internal Training Load
IOC	International Olympic Committee
k	Coefficient
LT	Lactate Threshold
LTP	Lactate Turn Point

MBI	Magnitude-Based Inference
MO	Maturity Offset
OR	Odds Ratio
OSTRC-H	Oslo Sports Trauma Research Center Questionnaire on Health Problems.
PHV	Peak Height Velocity
RPE	Rating of Perceived Exertion
RR	Rate Ratio
RRI	Running-Related Injury
RTA	Reflexive Thematic Analysis
SD	Standard Deviation
sRPE	Session Rating of Perceived Exertion
SWDTP	South West Doctoral Training Partnership
TRIMP	Training Impulse
$TRIMP_E$	Edwards Training Impulse
$TRIMP_I$	Individualised Training Impulse
$TRIMP_L$	Lucia Training Impulse
TRIPP	Translating Research into Injury Prevention Practice
UKA	UK Athletics
$\dot{V}CO_2$	Volume of Carbon Dioxide Production
$\dot{V}_E$	Minute Ventilation
$\dot{V}O_2$	Volume of Oxygen Uptake
$\dot{V}O_{2max}$	Maximum Oxygen Uptake
Y^i	Individualised Weighing Factor
%	Percentage

"It's very hard in the beginning to understand that the whole idea is not to beat the other runners. Eventually you learn that the competition is against the little voice inside you that wants to quit."

Dr. George Sheehan

1. INTRODUCTION

Participation in physical activity has been evidenced to be important for the health and wellbeing of children and adolescents (Biddle and Asare, 2011, Poitras et al., 2016), comprising of physical, psychological, and social benefits (Janssen and LeBlanc, 2010, Tremblay et al., 2010, Eime et al., 2013, Bangsbo et al., 2016). Likewise, adult-based physical activity is associated with several health benefits, including a reduced risk of all cause and cause specific mortality (Zhao et al., 2020), and improved psychological wellbeing in older adults (Taylor et al., 2004). Similar health benefits are also observed in children and adolescents, such as favourable cardiometabolic disease risk profiles (Ekelund et al., 2012, Tarp et al., 2018, Chinapaw et al., 2018). Physical activity, therefore, is promoted by multiple medical and governmental bodies around the world (World Health Organization, 2018), and in the UK (Department of Health and Social Care, 2019).

A popular way of participating in physical activity is via organised sport, providing children and adolescents with an opportunity to be physically active (Jago et al., 2017), improve their cardiorespiratory fitness (Silva et al., 2013), and enhance their psychological wellbeing and social skills (Eime et al., 2013). Notably, time spent participating in organised sport contributes towards the fulfilment of weekly physical activity recommendations (Department of Health and Social Care, 2019), likely due to being associated with higher levels of objectively measured moderate and vigorous intensity physical activity (Marques et al., 2016). Moreover, child and adolescent participation in organised sport predicts subsequent levels of physical activity during adulthood (Perkins et al., 2004, Telama et al., 2006, Kjonniksen et al., 2009). Participation in organised sport as a child and adolescent plays a pivotal role in supporting an individual’s current and long-term health and wellbeing.

From a global perspective, distance running is one of the more popular physical activities among children and adolescents (Hulteen et al., 2017). Although global participation in different physical activities were reliant upon geographical region, distance running was one of the top three activities for adolescents within Europe. Specific to England, distance running was reported as the second most prevalent sport participated in (at least once a week) by children and adolescents (5 to 16 years old), in a school-based setting, accounting for 28% of 2018-19 Active Lives Survey respondents (approximately representing 1,985,100 of the English school pupil population) (Sport England, 2019). When considering the popularity and simplicity of distance running, participation in this organised sport provides a unique opportunity to further encourage children and adolescents to be physically active, conceivably increasing the likelihood of sustained participation in physical activity in young adulthood (Kjonniksen et al., 2009). Also, considering that adult participation in distance running is associated with several health benefits (Oja et al., 2015), including reduced all-cause mortality (Oja et al., 2017, Pedisic et al., 2019), participation as a child and adolescent can be viewed as a positive.

Defined as the period of physical, cognitive, and social development that occurs between childhood and adulthood (Sisk and Foster, 2004), adolescence is a time point when it becomes common to take participation in organised sport more seriously (Myer et al., 2015, Bergeron et al., 2015, Myer et al., 2016). This increased focus on organised sport occurs alongside declining overall levels of physical activity during childhood and adolescence, regardless of sex (Dumith et al., 2011, Farooq et al., 2018). When considering the UK Athletics Athlete Development Model (UK Athletics, 2010), participation in organised sport often involves increased training frequencies, specialised training (i.e., event specific), and an intensified focus on performance outcomes. Specific to distance running, this typically involves training for and/or competing in a variety of different events. Dependent on the chronological age and sex of an adolescent athlete, the sport of distance running can be categorised into ‘middle-distance’ (800 m to 3,000 m) or ‘long-distance’ (5,000 m to 10,000 m) events, alongside a range of other steeplechase, cross-country, and road running events (UK Athletics, 2020). Many of these events are included within the broader sport of track and field (athletics), which also includes sprinting, jumping, throwing, and combined events.

Although participation in distance running has the potential to augment the health and wellbeing of children and adolescents, sport is also associated with adverse outcomes (Emery, 2003). Despite high levels of participation in distance running, little is known about the typical training practices of adolescent distance runners, the extent of health problems (injury and illness), and an athlete’s initial response to such health problems within this specific population. This is especially the case for competitive adolescent distance runners, intent on achieving athletic success as adults (Shibli and Barrett, 2011). Therefore, in order to address these literature gaps, it is important that research focuses on describing and evaluating the extent of health problems in this population, including running-related injury (RRI), and improving our knowledge in relation to competitive adolescent distance runners’ response to RRI. This latter focus should include consideration of psychological and social (i.e., psychosocial) factors (Martikainen et al., 2002), in order to add to the traditional focus on physical factors (Forsdyke et al., 2016).

Findings from systematic and narrative review articles have shown that history of previous sport-related injury is associated with subsequent sport-related injury (Emery, 2003, Murphy et al., 2003, Maffey and Emery, 2007, Caine et al., 2008, Whittaker et al., 2015), irrespective of whether these are recurrent or new sport-related injuries. This highlights the importance of reducing the risk of adolescent distance runners sustaining their first RRI (i.e., primary prevention), as this can prevent subsequent RRI, and increase the likelihood of sustained physical activity and positive performance outcomes. Despite the health benefits associated with distance running, research conducted in adults indicates that participation is also associated with adverse health outcomes, including RRI (van Gent et al., 2007). As distance running often involves consistent training intensities, durations, and frequencies (Seiler, 2010), participation can result in lower limb RRI (Saragiotto et al., 2014), with the lower leg, knee, and foot/toes being the most common RRI sites in adults (van Gent et al., 2007). Systematic review articles highlight large variations in RRI rates (i.e., injuries per 1,000 hours) and incidence proportions (i.e., probability of sustaining an RRI) in adult distance runners (van Gent et al., 2007, Kluitenberg et al., 2015a, Videbaek et al., 2015). While variation in data may be due to differences in research methodology (Tabben et al., 2020), there is markedly less research that has investigated such outcomes exclusively within competitive adolescent distance runners (Rauh et al., 2000, Rauh et al., 2006). Most studies only include distance running as a sub-sample in a wider population of endurance athletes (von Rosen et al., 2017, Moseid et al., 2018, von Rosen et al., 2018a), or as a sub-discipline within a population of track and field athletes (Jacobsson et al., 2012, Jacobsson et al., 2013, Huxley et al., 2014, Pierpoint et al., 2016, Carragher et al., 2019). As a consequence, the sample sizes relating to adolescent distance runners is limited, while also only being included as part of broader analyses. Additionally, a lack of research related to adolescent injury risk has previously been observed across a number of different sports (Steffen and Engebretsen, 2010). This lack of research is an issue because it limits the ability to tailor injury prevention measures to specific sporting contexts, potentially reducing the initial uptake and overall efficacy of such measures.

There is a growing body of evidence indicating that injury risk, as a result of a child or adolescent participating in sport, can be effectively reduced by implementing exercise- and education-based prevention measures (Abernethy and Bleakley, 2007, Caine et al., 2008, Rössler et al., 2014, Lauersen et al., 2014, Emery et al., 2015). In order to prevent injury, the Translating Research into Injury Prevention Practice (TRIPP) framework (Finch, 2006), as an extension of the 'sequence of prevention' model (van Mechelen et al., 1992), needs to be followed. This requires a systematic and sequential approach that initially describes the extent of the problem (via surveillance), before developing, implementing, and evaluating the effectiveness of preventative measures. Yet, as recently argued by Bolling et al. (2018), if such measures are to be effective, it is also important to establish new perspectives that recognise the context in which sport-related injury occurs. One way to achieve such context-specific insight is via qualitative inquiry (Bekker et al., 2020). As a result, psychosocial responses to sport-related injury can also be studied, within the context of competitive adolescent distance running, in order to allow an athlete's experiential knowledge of RRI to inform the development of suitable preventative measures.

Finally, when attempting to describe and evaluate the extent of the injury and illness problem in adolescent distance runners, it is vital to be able to accurately measure internal training load (ITL). Accurate measurement of ITL allows athletes and coaches to assess training adaptations, prevent potentially adverse training outcomes, and optimise athletic performance (Halson, 2014). In turn, this generates knowledge related to typical training practices and facilitates analysis of potential correlates of RRI (risk factors). While ITL has traditionally been measured using heart rate (HR) (Buchheit, 2014), this method is predominantly unfeasible in adolescent populations, due to the requirement of expensive telemetric HR monitors and technical interpretation of data. As a result, session rating of perceived exertion (sRPE) and differential rating of perceived exertion (dRPE) can be used as simple and valid measures of ITL instead (Kasai et al., 2020, Bourdon et al., 2017). These ITL measures require an athlete's subjective rating of perceived exertion (overall, legs, and breathlessness) to be multiplied by session duration (minutes). Yet, the validity of sRPE and dRPE measures of ITL have not, to date, been established in adolescent distance runners. Also, the effect of measurement timing (temporal robustness) on sRPE and dRPE, after the completion of a training session and/or competition, has not been examined.

To summarise, the primary aim of this thesis is to describe and evaluate the extent of the injury and illness problem in adolescent distance runners (13-18 years), aligned to the first step of the TRIPP framework (Finch, 2006). The research related to this aim, involving quantitative and qualitative methods, will provide context-specific data that can be used to support the creation of effective preventative measures. As subsidiary aims, this PhD thesis also: (1) investigates the effect of measurement timing and concurrent validity of sRPE and dRPE, in order to quantify ITL in this population, and (2) explores potential correlates of RRI. This latter aim aligns to the second step of the TRIPP framework. Following a critical review of the current literature (Chapter 2) and having provided an overview of the general methods used when conducting the research presented throughout this thesis (Chapter 3), the data that has been collected and analysed for this thesis is presented within Chapters 4-7. Each of these chapters have been written up as stand-alone pieces (i.e., publications). As the final element of the thesis (Chapter 8), a summary of the key findings will be provided, alongside a discussion about how these findings contribute to existing knowledge, study limitations, future research directions, and a conclusion.

2. LITERATURE REVIEW

The literature concerning the relationships between sport, injury, and health and wellbeing is extensive. Within that broad scope, this literature review is divided into three sections: (1) contextual information about adolescent distance running, (2) measuring internal training load (ITL), and (3) health problems (i.e., injury and illness). Collectively, these sections of the literature review justify why competitive adolescent distance runners need to be viewed as a unique population, requiring context-specific research to support their long-term athletic development.

Specifically, the first section offers contextual information related to adolescent distance running, including definition of key terms (i.e., adolescence and puberty), an overview of the UK Athletics (UKA) Athlete Development Model and England Athletics' (EA) Talented Athlete Pathway, and a summary of the challenges that adolescent athletes might experience, in relation to their health, wellbeing, and performance. Following this, the second section will provide a thorough review of the available literature related to measuring ITL, with an emphasis on the use of simple and cost-effective measures. This section will include an assessment of previous studies that have validated session rating of perceived exertion (sRPE) and differential rating of perceived exertion (dRPE) across different sporting contexts, including discussion related to measurement timing. The third section of the literature review will initially focus on sports injury and illness epidemiology, including a review of the 'sequence of prevention,' key methods and definitions, and prior surveillance studies related to distance running. Different theoretical approaches used to study an athlete's response to sport-related injury will also be critically reviewed, in addition to evaluating related studies that have included adolescent athletes. The literature review will close by clarifying the overarching rationale for this thesis, including details of the aims that this thesis achieves.

2.1 Context Matters: Adolescent Distance Running

Aligned to a recent International Olympic Committee (IOC) consensus statement on youth athletic development, the shared goal of stakeholders involved in youth sport – athletes, parents, coaches, medical/healthcare practitioners, and National Governing Bodies – should be to "develop healthy, capable and resilient youth athletes" (Bergeron et al., 2015, p.843). It is also argued that this goal should be achieved while maintaining both an inclusive and long-term approach to sports participation, supported by structured, progressive, and integrated approaches to youth athletic development. Importantly, this approach should be available for all athletes, irrespective of their perceived athletic talent (Lloyd et al., 2015).

This goal is especially relevant in the sport of track and field (athletics), including distance running, whereby excelling as a youth athlete is by no means essential for, nor a guarantee of, 'later success' (Moesch et al., 2011, Kearney and Hayes, 2018). Indeed, the age of peak competitive performance – acknowledged here as 'later success' – in distance running usually occurs in an athlete's mid- to late-twenties, irrespective of sex (Schulz and Curnow, 1988, Hollings et al., 2014, Allen and Hopkins, 2015). Specific to English athletes, this was demonstrated in a technical report called "Bridging the Gap" (Shibli and Barrett, 2011). Therefore, based upon this context, a long-term and considered approach to youth athletic development can be upheld as the preferred option, for all stakeholders.

Despite a general consensus that excelling as a youth athlete is not a prerequisite for 'later success' in distance running, it has become ever more common for youth athletes to specialise in one sport from an early age (Jayanthi et al., 2013). This is particularly noteworthy, given that it is rarely advised. While an evidence-based definition of youth sport specialisation has not yet been established (Jayanthi et al., 2020), it has been suggested that a high degree of specialisation involves: (1) participation in intensive training and/or competition for more than 8 months per year; (2) deciding to participate in a single main sport; and, (3) quitting all other sports to focus on one sport (or deciding only to participate in one sport) (Jayanthi et al., 2015). Although a sub-group of sports do involve early specialisation, such as gymnastics (Law et al., 2007), this is typically a result of these sports requiring that peak performance is achieved before adulthood. Yet, decisions to specialise in a sport earlier than required might be driven by the substantial financial rewards attached to athletic success (Bergeron et al., 2015), triggered by the way in which sporting organisations compete to identify and develop young athletes, in order to ensure future success. In relation to distance running, in England, this can be observed via the pursuit of scholarships to attend American universities (Malina, 2010), thereby reducing the financial burden of Higher Education and allowing athletes to gain experience in the National Collegiate Athletic Association system (Popp et al., 2011). Historically, these scholarship opportunities have resulted in an influx of international athletes into the American university system (Bale, 1991). That said, data related to the number of English distance runners obtaining these scholarships is not publicly available. Regardless, a trend towards higher degrees of sport specialisation can result in training practices becoming more intense and regular, alongside an increased competition volume and frequency, coupled with inadequate opportunities to rest (Bergeron et al., 2015). Notably, if these training and/or competition loads are superimposed on a developing adolescent athlete, the challenges to their health, wellbeing, and performance might compromise the potential benefits from implementing such an approach in the first instance.

The following section of the literature review defines key terms before providing a brief overview of both the UKA Athlete Development Model (UK Athletics, 2010) and the EA Talented Athlete Pathway (England Athletics, 2020). This section of the literature review finishes by highlighting the challenges that youth athletes, including distance runners, might experience, in relation to their health, wellbeing, and performance.

2.1.1 Defining Terms

In the present thesis, participants were aged between 13 and 18 years. This age range corresponds to common track and field (athletics) age-groups (i.e., U15, U17, and U19), as applied in English Schools' Athletic Association competitions. These age ranges are also applied throughout the latest International Committee Consensus Work Group statement on minimising the risk of injury and illness in youth runners (Krabak et al., 2020). These participants can, therefore, be classed as adolescent distance runners. Nevertheless, it is important to provide additional details related to what this signifies, in relation to adolescence, puberty, growth, and maturation.

2.1.1.1 Adolescence and Puberty

The terms 'adolescence' and 'puberty' are often used interchangeably. However, there are differences between these terms. Adolescence is defined as the period of physical, cognitive, and social development that occurs between childhood and adulthood (Sisk and Foster, 2004). The beginning of adolescence is marked by the onset of puberty, which consists of a series of distinct but interlinked biological changes in hormone levels and physical appearance, including a growth spurt (age at take-off) and the appearance of secondary sexual characteristics (Tanner, 1962). Puberty is also associated with profound changes in drives, motivations, psychology, and social life, continuing through adolescence (Susman and Rogol, 2004, Blakemore et al., 2010, Blakemore and Mills, 2014). Adolescence can, therefore, be viewed as a transitional period of development, between childhood and adulthood, while puberty is the process of physical maturation, associated with several different psychosocial changes, that transforms a child into an adult (Dorn et al., 2010).

The range of biological changes associated with puberty usually occur throughout early adolescence (~10-13 years), whereas mid-adolescence (~14-16 years) and late-adolescence (~17-19 years) are dominated by cognitive, psychosocial, and behavioural aspects of development (McKay et al., 2016). The use of age ranges draws attention to the fact that these changes take place at different chronological ages, dependent on the individual. However, these age ranges are only a guide, supported by the fact that onset of puberty is taking place earlier, while key social transitions (i.e., completion of education and marriage), that have usually marked the end of adolescence, are now much less distinct than in the past – combining to extend adolescence (Sawyer et al., 2018). Nonetheless, it should be stressed that the timing of biological changes associated with puberty is influenced by sex, whereby girls typically experience these changes at an earlier chronological age compared to boys (Malina et al., 2004). When explaining these sex differences, it is important to do so in relation to the terms ‘growth’ and ‘maturation.’

2.1.1.2 Growth and Maturation

Growth can be defined as the biological process that results in an increase in the size of the body, either as a whole or of a specific part of the body (Malina et al., 2004). During puberty, growth involves becoming taller and heavier, increases in the amount of lean and fat tissues, and an increase in organ sizes (Baxter-Jones et al., 2005). In comparison, maturation is the process of reaching a mature state, including sexual and skeletal maturity, and refers to both the timing and tempo of progress towards maturity (Malina et al., 2004). Timing refers to the chronological age at which specific maturational events occur, such as age at maximum stature during the growth spurt (i.e., peak height velocity (PHV)). Tempo refers to the rate at which maturation progresses, or to how quickly or slowly someone passes through different stages of maturation before reaching a mature state. Individuals differ noticeably in the timing and tempo of maturation. In terms of sex differences, data indicate that numerous maturational events occur at an earlier chronological age in girls. For example, Iuliano-Burns et al. (2001) demonstrated that the age at PHV (aPHV) is often achieved earlier in girls (11.8 years), compared to boys (13.4 years), while boys (10.4 cm/year) show a significantly greater magnitude of PHV compared to girls (8.6 cm/year). On average, girls reach maturation around two-years in advance of boys (Tanner, 1971, 1981). The typical curves for growth rate in boys and girls are illustrated in Figure 2.1, using Tanner et al. (1966a, 1966b) ‘standards data’ for British children. This figure also indicates the ‘age of take-off’ (i.e., onset of growth acceleration) and ‘age of PHV,’ based on the same dataset, in addition to overlaying information related to age ranges for both ‘childhood’ and ‘adolescence’ (McKay et al., 2016).

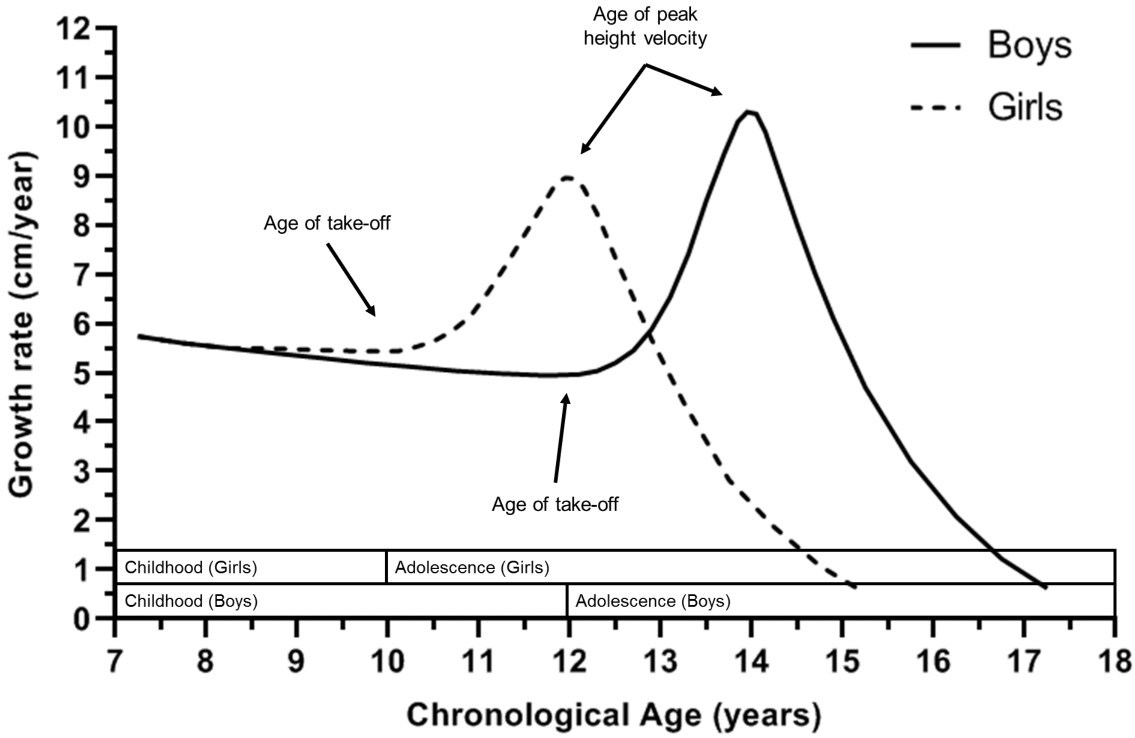

Figure 2.1: Typical curves for the growth rate in boys and girls (supine length or stature), showing a marked increase during the adolescent growth spurt. Figure constructed using data from Appendix I (Table I) in Tanner et al. (1966). Arrows have been added to indicate 'age of take-off' and 'age of peak height velocity,' in addition to textboxes to signify 'childhood' and 'adolescence,' according to typical chronological age ranges reported by McKay et al. (2016).

When combined, an understanding of growth and maturation (timing and tempo) highlights that adolescent athletes of an identical chronological age might vary by several years in relation to their biological maturation (Baxter-Jones et al., 2005) and, therefore, their levels of athletic performance. As a result, chronological age is not a suitable indicator of an adolescent athlete's stage of maturation. Instead, coaches and practitioners should endeavour to include an indicator of biological maturity as part of a training programme (Lloyd et al., 2014). For example, based on determining aPHV, athletes can be aligned according to their biological age (years from PHV) rather than by chronological age (Baxter-Jones et al., 2005) – see Section 3.3.1. Furthermore, the time around PHV (pre-, at, and post-PHV) is characterised by substantial increases in strength, power, maximal velocity, and aerobic endurance (Beunen and Malina, 2008). While there are sex differences (Ford et al., 2011), these increases in physical and physiological performance indicate that adolescence is a vital phase in an athlete's development, especially when considering that aPHV is not affected by regular physical activity and/or participation in organised sport(s) (Beunen and Malina, 2008). However, physical activity levels in children (both sexes) have been demonstrated to decrease with increasing biological age (Thompson et al., 2003). As a result, a number of youth development models have been established in an attempt to account for growth and maturation (Lloyd et al., 2015), while recognising the individuality of changes related to growth and maturation.

2.1.2 UK Athletics Athlete Development Model

Published in May 2010, the UKA Athlete Development Model was created to help inform coaching decisions related to an athlete's progression from pre-puberty to adulthood. This model assumes that an athlete will seamlessly move through an athletic programme from the chronological age of nine years through to achieving a podium finish at a major world championships (UK Athletics, 2010). To achieve this, the model offers information and guidelines regarding an athlete's biological development, training considerations, training and competition requirements, and physical conditioning. It is important to highlight that many different models exist, but for the purposes of this thesis, the UKA Athlete Development Model is best suited to competitive adolescent distance runners.

In a review article, Lloyd et al. (2015) argued that the existing youth development models tend to focus on either 'talent development' or 'athletic development,' as distinctive concepts. Based on this review article, the UKA Athlete Development Model can be judged to maintain the latter focus – aimed at maximising individual potential and participation (Stafford, 2005). As developed by Balyi et al. (2013), this approach attempts to align training prescription according to developmental stages (i.e., maturation) rather than the chronological age of an athlete. Although it does not fall within the scope of this thesis to provide an assessment of different models, it is crucial to highlight that such models accentuate the given importance of adopting individualised approaches when striving to develop youth athletes – acknowledging individual differences in growth and maturation.

Situated alongside the UKA Athlete Development Model, the EA Talented Athlete Pathway (England Athletics, 2020), presented in Figure 2.2, shows the support structure that is available for athletes as they aim to attain representative honours and a podium finish at a major championships. Although this pathway is regularly updated, due to ever-changing funding and policy priorities (Grix and Carmichael, 2012), the premise is based on aligning competitive opportunities with relevant talent programmes to support athletic development. Access to these programmes is not linear (i.e., an athlete can enter at any stage), with a range of opportunities that are increasingly focused on developing a dual-career (i.e., combining sport and work). Nonetheless, there is not currently a uniform research programme that seeks to complement the delivery of these talent pathways, even though there is a clear need to provide an evidence-base to effectively support athletes who are invited to take part in these developmental opportunities.

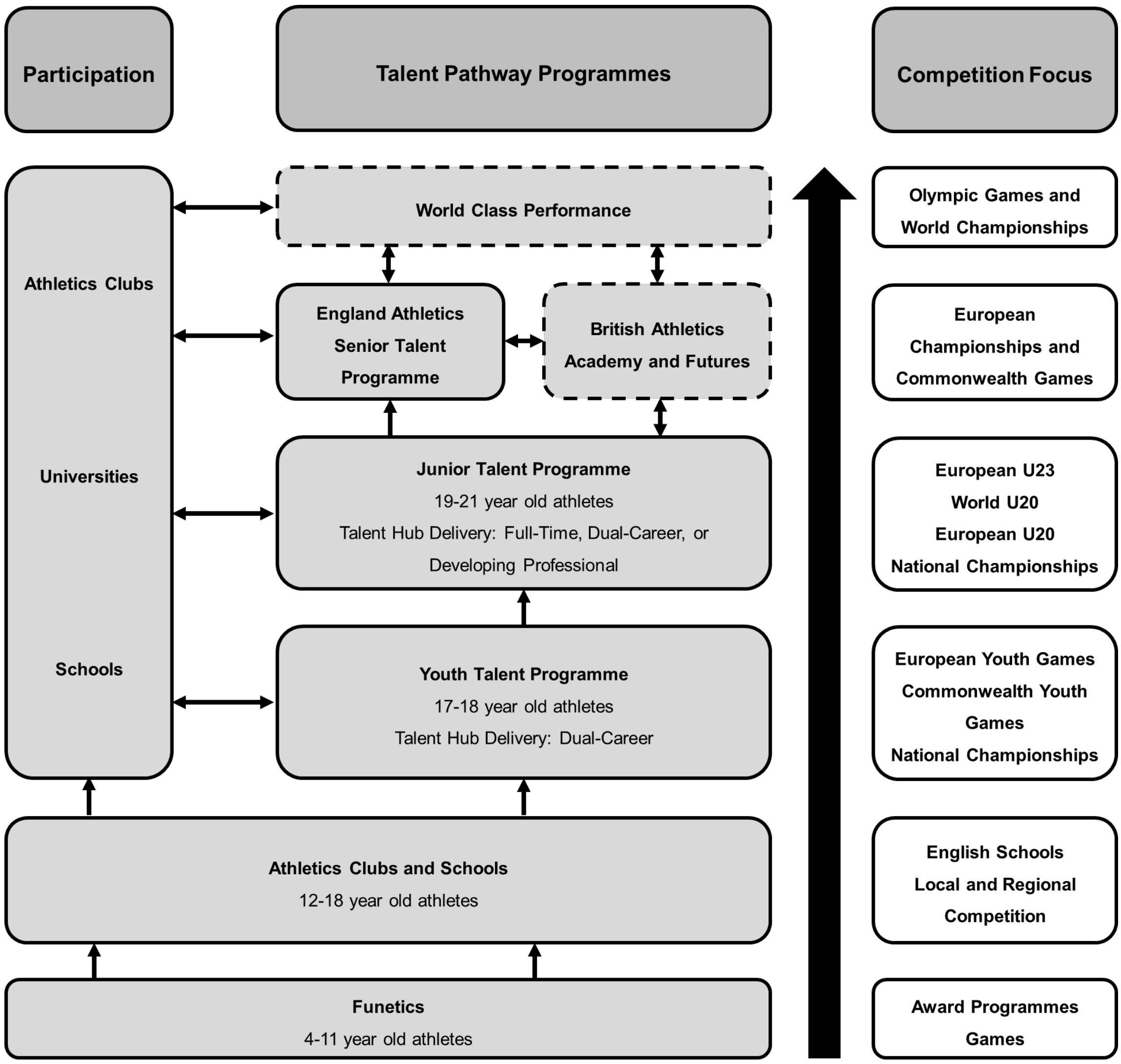

Figure 2.2: England Athletics Talented Athlete Pathway. The dashed lines show those programmes that are led by British Athletics, rather than England Atheltics, while the arrows show the order/relationship between programmes. Adapted from England Athletics (2020), with permission from England Athletics.

As acknowledged by the UKA Athlete Development Model, effective development of young track and field (athletics) athletes is influenced according to their given stage of development (i.e., maturity status). Yet, it is also important to recognise the challenges that youth athletes are likely to encounter throughout adolescence, in terms of their health, wellbeing, and performance.

2.1.3 Challenges to Health, Wellbeing, and Performance

The physical changes that occur throughout maturation (i.e., increases in muscle mass, body fat, and stature) substantially alter an adolescent athlete's body, and, in turn, challenge their health, wellbeing, and performance. One such challenge is the risk of injury (Emery, 2003, Caine et al., 2006, Caine et al., 2008), whereby sports-related injury is a common cause of injury amongst adolescents.

Data in children and adolescents (multiple sports), in Calgary, show an injury rate of 29.4 medical attention injuries/100 students/year (95% confidence intervals (CI): 27.1-31.8) in junior high school students (12-15 years), and 40.2 medical attention injuries/100 students/year (95% CI: 38.4-42.1) in high school students (14-19 years) (Emery et al., 2006b, Emery and Tyreman, 2009). Regardless of sex, child and adolescent participation in distance running has been reported as having a high sport-specific injury incidence rate (Rauh et al., 2000, Rauh et al., 2006), relative to other sports. Previous research has also demonstrated that overuse injuries are common in children and adolescents participating in sport, with the proportion of all sports injuries due to overuse ranging from 46% to 54% (DiFiori et al., 2014). Although the association between growth, maturation, and injury has not yet been fully established (Swain et al., 2018), recent research has shown that skeletal maturation and growth rates are related to bone and growth plate injuries in adolescent track and field athletes (Wik et al., 2020). Likewise, the relationship between high levels of youth sport specialisation and subsequent injury has not been fully established (Fabricant et al., 2016, Waldron et al., 2020), potentially due to the lack of an evidence-based definition of sport specialisation (Jayanthi et al., 2020). Yet, a recent prospective study found that moderately and highly specialised high school athletes had a higher incidence of lower-extremity injuries (50% and 85%, respectively) when compared to low and non-specialised athletes, even when controlling for sex, chronological age, competition volume, and injury history (McGuine et al., 2017). Irrespective of these data, Steffen and Engebretsen (2010) argue that there remains a lack of data on injury risk among elite youth athletes, including distance runners. As a result, injury surveillance in specific populations of elite youth athletes (i.e., competitive athletes (see Section 3.2.3)) was advocated, in order to better inform subsequent research about injury risk factors, mechanisms, and preventative measures (Steffen and Engebretsen, 2010). Collecting data related to whether illness is more (or less) likely to arise in competitive youth athletes can also be incorporated into surveillance studies. As an example, Moseid et al. (2018) showed that illness was more prevalent in youth endurance athletes, when compared with technical and team sport youth athletes, in a cohort of Norwegian Sport Academy High School athletes (n = 320). Section 2.3 of this literature review will, therefore, provide a critical synthesis of injury and illness epidemiology data in relation to adolescent distance running, including a review of theoretical models, methods, and definitions.

Given that sport-related injury can be seen as a challenge to the physical health, wellbeing, and performance of youth athletes, it is also essential to acknowledge how athletes respond to such outcomes in a psychological and social capacity (i.e., psychosocial). However, this perspective is often overlooked (Walker et al., 2007, Forsdyke et al., 2016), alongside how to best support adolescent athletes with their initial recovery and return-to-sport. Nevertheless, a recent study based on a cohort of elite Swedish adolescent athletes reported that sport-related injury resulted in feelings of loneliness, frustration, and self-blame, all of which were deemed to contribute to a loss of athletic identity (von Rosen et al., 2018b). The athletes interviewed in this study (n = 20), via focus groups, were representative of ten different sports (including distance running (n = 3)), having sustained sport-related injuries lasting between two-months and four-years. An understanding of different psychosocial responses to sport-related injury can, therefore, inform the development of injury prevention measures, alongside improving an athlete's ability to recovery from sport-related injury. However, additional context-specific knowledge is required in terms of youth athletes' psychosocial responses to injury, to help mitigate against negative outcomes, whereby the given generalisability of current findings to different contexts can be questioned. When considering these issues, Section 2.3.4 of this literature review will provide a detailed discussion about psychosocial response to sport-related injury.

As a related point, the IOC consensus statement on youth athletic development highlights that psychosocial challenges can occur irrespective of injury (Bergeron et al., 2015), commonly related to training and/or competition stresses, alongside a youth athlete's (in)ability to cope with a number of internal and external stresses (Crocker et al., 2018). Therefore, given that training and/or competition stresses can physically and psychosocially challenge a youth athlete's health, wellbeing, and performance, it is essential to be able to measure their training load using an accurate and validated method (Borresen and Lambert, 2009). As a result, the following section of this literature review will provide a thorough introduction to both external and internal load, before focussing in on sRPE as a useful measure of ITL to apply in adolescent distance running. This section will also consider the use of dRPE and the effect of measurement timing on sRPE and dRPE measures of ITL.

2.2 Measuring Internal Training Load

Improvements in athletic performance can be achieved by carefully modifying different training load parameters (Borresen and Lambert, 2009, Halson, 2014). These parameters include intensity, duration, and volume, each of which can be altered during a training cycle, to ensure that an athlete's level of performance is suitable for their phase of training and/or competition (Smith, 2003). Put another way, training load can be manipulated to accomplish a desired training response from an athlete (Coutts et al., 2018, West et al., 2020). It has also been shown that there is a relationship between training load and injury/illness, supported by several review articles (Drew and Finch, 2016, Jones et al., 2017, Eckard et al., 2018) and consensus statements (Soligard et al., 2016, Schwellnus et al., 2016). However, both the shape and direction of the training load-injury relationship has been shown to vary across studies, as illustrated in the systematic review articles, whereby causal pathways remain poorly understood (Kalkhoven et al., 2021).

Throughout the IOC consensus statements (Soligard et al., 2016, Schwellnus et al., 2016), 'load' is broadly defined as "the sport and non-sport burden (single or multiple physiological, psychological or mechanical stressors) as a stimulus that is applied to a human biological system (including subcellular elements, a single cell, tissues, one or multiple organ systems, or the individual)" (p. 1031 and 1044, respectively). In this thesis, the load being measured is 'physical load,' related to an adolescent athlete's training and/or competition. When monitoring an athlete's training load, the units of measurement can either be categorised as 'external' or 'internal' (Bourdon et al., 2017). External training load is defined as the physical work completed by an athlete (i.e., objective), measured independently of their internal characteristics and determined by the organisation, quality, and quantity of exercise (Impellizzeri et al., 2019). In distance running, an example of external training load is the measure of total distance covered (i.e., total number of miles). External training load is how a coach prescribes training to an athlete. Based on the external training load, the relative physiological, psychological, and biomechanical stress imposed on an athlete can be calculated, which reflects the ITL (Impellizzeri et al., 2019). Specific to distance running, an example of ITL is the use of HR variables during a training session or competition (i.e., time spent in zones) (Borresen and Lambert, 2009, Buchheit, 2014).

As emphasised by Impellizzeri et al. (2019), there is no single or 'gold standard' measure of training load. Instead, training load can be quantified by a number of different variables, each of which aims to describe the external load or internal response during a training session or competition. Impellizzeri et al. (2019) also state that the validity and application of a measure of training load is dependent on the sport-specific context. For example, if measures of acceleration (i.e., peak acceleration (m/s^2)) are used effectively within the context of football (Akenhead and Nassis, 2016), this does not indicate that this measure is directly transferable to the sporting context of distance running.

A thorough review of the different ways to quantify training load, the subsequent training adaptation (i.e., response), and effect on performance, has been offered by Borresen and Lambert (2009), alongside an invited commentary (Lambert and Borresen, 2010). Related to this thesis, a summary and critical appraisal of the common methods used to monitor athlete training load and/or responses in distance running is provided in Table 2.1. These methods have been purposefully selected from the range of methods included in Bourdon et al. (2017) consensus statement. When assessing the range of methods available, it is important to consider that those with either a moderate or high 'cost point' are unlikely to be a feasible option for adolescent distance runners. This perspective is supported by Murray (2017), who, in a brief review paper related to managing training load in adolescent athletes, advised that methods should generally be non-invasive and selected according to the sport-specific context. As a result, the decision to focus on sRPE throughout this thesis is mainly related to feasibility, whereby a valid, cost-effective, and time-efficient way to establish the ITL of adolescent distance runners is required.

Related to adolescent distance running, numerous non-invasive measures of ITL are largely unfeasible, requiring the use of expensive equipment (i.e., telemetric HR monitors) and technical knowledge to support with the interpretation of data (i.e., calculating a training impulse (TRIMP)). Therefore, in this specific context, sRPE can be upheld as a feasible method to measure ITL, while measuring dRPE for legs (dRPE-L) and breathlessness (dRPE-B) may also provide useful insight. For example, these measures have been shown to discriminate between central and peripheral exertion, thus improving the precision of measuring ITL (McLaren et al., 2016). Adopting these measures of ITL also supports Paquette et al. (2020) point that total weekly distance (i.e., volume) should not be used as a primary measure of training load in distance running, due to the likelihood that it frequently misrepresents and underestimates an athlete's training stress and subsequent adaptation. Yet, measures that are reliant upon an adolescent athlete's subjective rating of perceived exertion (RPE) have often been cautioned against (Bourdon et al., 2017), based on the idea that the ability of adolescent athletes to accurately self-report their perception of effort might be unreliable, especially in younger athletes (Groslambert and Mahon, 2006). The following literature review section will, therefore, provide a critical review of the scientific literature related to the measurement and validity of sRPE and dRPE.

Table 2.1: Summary and appraisal of the common methods utilised to monitor training load and/or responses in distance runners. Adapted from Bourdon et al. (2017), *Monitoring Athlete Training Loads: Consensus Statement*, International Journal of Sports Physiology and Performance, 12 (S2), p.162, with permission from Human Kinetics, Inc. (copyright 2006).

Method	Cost	Hardware needed	Software needed	Ease of use	Valid	Reliable	Used to interpret	Used to prescribe	Variables
External Measures									
Time	L	Y	Y/N	H	H	H	Y	Y	Units of time (seconds, minutes, hours, etc.)
Training Frequency	L	N	N	H	H	H	Y	Y	Session count (n)
Distance/mileage	L	Y/N	Y/N	H	H	H	Y	Y	Units of distance (metres, kilometres, etc.)
Movement repetition counts	L	Y/N	Y/N	M-H	H	M-H	Y	Y	Activity count (e.g., number of steps)
Training mode	L	Y/N	N	H	H	H	Y	Y	Running, cycling, weight training, etc.
Speed	L-M	Y	Y/N	M-H	H	H	Y	Y	Speed measures (min/km, km/h, etc.)
GPS measures	M	Y	Y	M	M-H	M	Y	Y	Velocity, distance, time in zones, location, etc.
Internal Measures									
RPE	L	N	Y/N	H	M-H	M-H	Y	Y	Single variable in AU (time dependent)
sRPE	L	N	Y/N	H	M-H	M-H	Y	Y	Single variable in AU (time dependent)
TRIMP	L-M	Y	Y	M	M-H	M-H	Y	Y	Single variable in AU (time dependent)
Wellness questionnaires *	L	N	Y/N	M-H	M	M-H	Y	Y/N	Ratings, checklists, AU scale measures
Psychological inventories (e.g., POMS) *	L-M	N	Y/N	M-H	M-H	M-H	Y	Y	Ratings, checklists, AU scale measures
Heart rate indices	L-M	Y	Y	H	H	M-H	Y	Y	Time spent in HR zones, HR variability, etc.
Oxygen uptake	H	Y	Y	L	H	H	Y	Y	VO_2, metabolic equivalents
Blood lactate	M	Y	Y/N	M	H	H	Y	Y	Concentration

Abbreviations: L, low; M, moderate; H, high; Y, yes; N, no; GPS, Global Positioning System; RPE, rating of perceived exertion; sRPE, session rating of perceived exertion; TRIMP, training impulse; POMS, profile of mood states; HR, heart rate; n, number; min, minutes; km, kilometres; h, hour; AU, arbitrary units; %, percentage; VO_2, volume of oxygen. *Measure of training responses.

2.2.1 Session Rating of Perceived Exertion

First developed by Foster et al. (2001), sRPE has been established as a simple measure of ITL. sRPE is measured by multiplying an athlete's RPE by the total duration (minutes) of a training session. When sRPE was initially used by Foster et al. (2001), a modified version of the 0-10 *Category* scale with *Ratio* properties (CR10 scale) was used to calculate RPE (Borg et al., 1987), as previously applied in studies by Foster et al. (1995, 1996, 1998). Although this is only one of several different ways to measure RPE (Chen et al., 2002, Kasai et al., 2020), the CR10 scale uses verbal anchors, alongside corresponding numbers, allowing athletes to self-report their perceived exertion, as illustrated in Figure 2.3. When deciding what RPE value to self-report, athletes respond to the following question: "How was your workout?" (Foster et al., 2001). For sRPE, this number reflects the entire training session that the athlete has just finished, including their warm-up/cool-down. Once calculated, this measure of ITL represents an arbitrary unit (AU) and can be employed to determine derivative measures of ITL (Haddad et al., 2014b, Williams et al., 2017). For example, weekly training monotony and strain can both be calculated and subsequently monitored (Foster, 1998).

Although sRPE is simple to calculate, Haddad et al. (2014b) highlight that various factors can influence an athlete's self-reported RPE, clarifying the caution shown by Bourdon et al. (2017). For example, relevant to adolescent distance runners, age and cognitive development can affect perception of effort (Groslambert and Mahon, 2006). Related to endurance training, in adults, Roos et al. (2018) found that the survey method, sex, training type, and interaction between measurement timing, TRIMP, and training type can all influence sRPE. Specifically, correlations between sRPE and TRIMP, as an objective measure of ITL, were typically greater when self-reporting sRPE via an online questionnaire (r = 0.80) or mobile device

(r = 0.80), instead of when using a pencil and paper (r = 0.62). These differences in self-reporting method resulted in significant differences between the electronic and paper methods. The authors inferred that this result indicated that reporting via an online questionnaire or mobile device was better, when compared to using pencil and paper, although no attempt was made to explain this difference.

Rating	Descriptor
0	Rest
1	Very, Very Easy
2	Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	
7	Very hard
8	
9	
10	Maximal
•	

Figure 2.3: Modified 0-10 *Category* scale with *Ratio* properties (CR10 scale), used to determine an athlete's self-reported rating of perceived exertion. Copied from Foster et al. (2001), *A New Approach to Monitoring Exercise Training*, The Journal of Strength and Conditioning Research, 15(1), p. 111, with permission from Wolters Kluwer Health, Inc. (copyright 2001).

In relation to sex differences, for the same TRIMP, female athletes self-reported lower sRPE values compared to male athletes. Roos et al. (2018) also highlighted that differences were evident according to training type. For example, a stronger correlation between sRPE and TRIMP was found during interval-, fast-, and hill-based training sessions, while a weaker correlation was noted for recovery-based training sessions. However, the exact coefficients were not reported, and these conclusions were presumably made following visual inspection of the data. Lastly, the interaction between time point, TRIMP, and training type demonstrated that, depending on the TRIMP and training type, the time point when sRPE was self-reported did have an effect. For example, the longer the duration between training session completion and self-reporting sRPE, the lower the sRPE values, when compared to previous time points.

Regardless of sex and potential influencing factors, a systematic review article concluded that sRPE was a valid, reliable, and internally consistent measure of ITL across numerous different sports and age-categories (Haddad et al., 2017). Yet, while evidence generally supports the application of sRPE in adult distance runners, data supporting its application in adolescent distance runners is largely absent (Kasai et al., 2020). Therefore, further data are required in order to support adolescent athletes, coaches, and sports practitioners to manage ITL in a simple, cost-effective, and time-efficient way. Confirming that sRPE is a valid measure of ITL for adolescent distance runners will also allow this measure to be applied in future injury surveillance studies.

2.2.2 Validation of Session Rating of Perceived Exertion

When measuring ITL, it is essential that the chosen method is valid and reliable, thereby genuinely helping an athlete to achieve desired training responses. When validated, sRPE is correlated with objective measures of ITL (concurrent validity), used as an established 'criteria' (Haddad et al., 2017). These criteria are normally a TRIMP, including Banister's TRIMP (Morton et al., 1990), Individualised TRIMP (Manzi et al., 2009), Edward's TRIMP (Edwards, 1993), and Lucía's TRIMP (Lucía et al., 2003), but can include other parameters too, such as oxygen uptake and blood lactate. For example, Lucía's TRIMP is based on three training zones that are calculated according to an athlete's lactate thresholds. While introducing these criteria in detail is beyond the scope of this literature review, details related to several TRIMPs have been included in Chapter 3 (Section 3.5.2). The following sections of this literature review will offer a summary of the adult-based validation studies, related to distance running, and adolescent-based validation studies, related to all sports. For those articles beyond this scope, the invited commentary by Eston (2012) and systematic review article by Haddad et al. (2017) can be viewed as recommended reading. Notably, only studies that aimed to validate the modified CR10 scale have been included within the present literature review (see Table 2.2 and Table 2.3), rather than other RPE scales, such as the Borg RPE scale (6-20) and CR100 scale (Borg and Kaijser, 2006). This decision is based on the fact that the modified CR10 scale was initially designed to monitor training intensity (Foster et al., 2001), as a measure of ITL, and has since become widely used in research and practice. That said, findings from studies that have validated other scales may be used to support statements being made in this review.

Each study included in the present literature review has previously been included within Haddad et al. (2017) systematic review and/or Kasai et al. (2020) scoping review. When combined, these reviews predominantly include scientific literature published between 2000 to 2019. Nonetheless, two further studies were identified while searching relevant databases (i.e., PubMed). These studies, both validating the CR10 scale, were related to a cohort of youth football players (Marynowicz et al., 2020), and several youth team sports (Scantlebury et al., 2017). Studies by Foster et al. (1995) and Foster (1998) were also identified, having pre-dated the search terms used by Haddad et al. (2017) and Kasai et al. (2020). Yet, as these studies also pre-date the formal development of the modified CR10 scale (Foster et al., 2001), they have not been included in this literature review. It should also be noted that the validation of sRPE was not the primary purpose of these latter studies. A research study by Manzi et al. (2015), related to adult distance runners, was also identified when searching relevant databases, even though the date of publication falls within those dates stipulated in Haddad et al. (2017) systematic review. This paper has, therefore, been included in this literature review.

2.2.1.1 Validity of sRPE in Adult Distance Runners

To date, only four studies have been conducted to validate sRPE in a population of adult distance runners, using the CR10 scale. Each of these studies have been summarised within Table 2.2. Notably, only one of these studies included trained distance runners (masters athletes) as part of their sample (Minganti et al., 2011), while the three other studies included habitually active or recreational participants (Herman et al., 2006, Borresen and Lambert, 2008, Manzi et al., 2015).

While methodological designs varied across each study (i.e., number of sessions and choice of criteria), the results indicate that sRPE can be used as a valid tool to measure ITL, whereby the correlations between sRPE and HR-based criterion measures were regularly large (r >0.50) and statistically significant (Cohen, 1992). Although reliability was not often directly assessed, a good level of reliability can be inferred due to the high predictive ability of sRPE. As an example, Minganti et al. (2011) reported a large correlation (r = 0.82) between sRPE and Edward's TRIMP (including periods of rest). Nonetheless, the results of these studies also highlight three separate points of discussion. Firstly, sRPE remains a surrogate for more objective ITL measures (i.e., percentage of maximal oxygen uptake) and, therefore, should only be used when it is unfeasible to employ such objective ITL measures. As a second point, sRPE deviates in accuracy when a proportionately longer amount of time is spent performing low-intensity (i.e., easy and recovery running) and high-intensity (i.e., interval-based running) exercise (Borresen and Lambert, 2008). The application of sRPE may, therefore, overestimate ITL during low-intensity exercise and underestimate ITL during high-intensity exercise when compared with objective measures of ITL. Finally, the influence of including or excluding periods of recovery, as part of interval-based training sessions remains unclear, whereby Minganti et al. (2011) suggested that further investigation was warranted. Based on these points, and in agreement with Minganti et al. (2011), further research is needed to address the validity of sRPE across different training intensities, and to determine whether it is temporally robust at different time points following the completion of a training session or competition.

Table 2.2: Studies reporting the validity of session rating of perceived exertion for determining internal training load using the CR10 scale, in adults, with distance running being the type of sport/physical activity.

Reference	Type of sport / physical activity	Sex	Age range	Sample size	Number of sessions / duration of training	Criteria	Correlations	Significance
Herman et al., 2006	Habitual physical activity (running)	Males Females	33 ± 16 23 ± 1	7 7	7 sessions	$\%VO_{2peak}$ $\%HR_{peak}$ $\%HR_{reserve}$	– – –	$p < 0.05$
Borresen and Lambert., 2008	Habitual physical activity (running)	Males Females	– –	15 18	2 weeks	Edwards' TRIMP Banister's TRIMP	$r = 0.84$ $r = 0.76$	– –
Minganti et al., 2011	Master endurance athletes (running)	Males	45.3 ± 7.3	8	1 training session			
	Interval training with rest periods included in analysis					Edwards' TRIMP	$r = 0.82$	$p = 0.013$
	Interval training without rest periods included in analysis.					Edwards' TRIMP	$r = 0.86$	$p = 0.003$
Manzi et al., 2015	Recreational long-distance runners	Males	36.5 ± 3.8	7	5 months	Edward's TRIMP Individualised TRIMP	r = From 0.67 to 0.82 r = From 0.71 to 0.87	– –

Abbreviations: %, percentage; VO_2, volume of oxygen; HR, heart rate; TRIMP, training impulse; *r*, correlation coefficient between RPE-method and various criterion measures; *p*, level of statistical significance ($p > 0.05$ = non-significance) between RPE-method and various criterion measures; –, not specified.

2.2.1.2 Validity of sRPE in Adolescent Athletes

To date, fifteen studies have attempted to validate sRPE, using the CR10 scale, across many adolescent sporting contexts. These studies are summarised within Table 2.3. Eight out of the fifteen studies focus on a team sport, including football, basketball, rugby union, field hockey, and water polo. Six of these eight studies reported that sRPE can be applied as a valid measure of ITL (Impellizzeri et al., 2004, Lupo et al., 2014, Lupo et al., 2017b, Scantlebury et al., 2017, Vahia et al., 2019, Marynowicz et al., 2020), whereby correlations between sRPE and various criterion measures were often 'large' and statistically significant (Cohen, 1992). Nonetheless, Rodríguez-Marroyo and Antoñan (2015) stated that their data, in a population of youth footballer players, did not support the relationship between sRPE and different HR methods for quantifying ITL. The authors indicated that this finding may be a result of the training sessions that were completed as part of the study, aimed at improving technical ability and tactical understanding (i.e., intermittent), rather than applying an ergometer-based exercise protocol or continuous training sessions, as utilised in other studies. The intermittent nature of training sessions seems to be an issue when using sRPE in team sports. For example, having validated sRPE in elite youth football players, using the CR100 scale, Naidu et al. (2019) stated that further research was required to understand the relationship between the type of training and perceptual responses of a youth athlete. Akubat et al. (2012) also reported that the correlation between sRPE and HR-based measures of ITL might not be as large when doing intermittent training sessions. In terms of the type of training, Rodríguez-Marroyo and Antoñan (2015) reasoned that sRPE may be a superior measure of ITL when performing high intensity training sessions, compared to HR-based ITL measures, due to its ability to combine physical and psychological stress (Impellizzeri et al., 2019).

Although it is important to consider the type of training, it can be argued that this is unlikely to affect sRPE as much in endurance sports, whereby training sessions are likely to be continuous in design, purposely punctuated by periods of recovery (i.e., interval-based sessions). As a result, it is less likely that sRPE, as a global measure of ITL, will be affected by the choice of training session. This argument can be supported by the work of Seiler and Kjerland (2006), who reported a 92% agreement between HR-based quantification of training intensity and the sRPE method (CR10 scale) in a population of elite Norwegian male adolescent cross-country skiers. Although their study did not set out to validate sRPE, Seiler and Kjerland (2006) demonstrated the similarity between these two measures across a number of different sessions and training intensities. Nevertheless, it remains important to consider the effect of different types of training, due to the various physiological and psychosocial factors that can affect an athlete's self-reported RPE values (Kasai et al., 2020). Furthermore, training sessions that are designed to develop technical ability, rather than endurance, such as a session that is focused on steeplechase hurdling form, may reduce the similarities reported by Seiler and Kjerland (2006).

Finally, Akubat et al. (2012) study aimed to relate methods for measuring ITL to changes in aerobic fitness parameters over a six week period, rather than to each other. Therefore, several of the study outcomes are not relevant to this literature review. Regardless, in a population of professional youth football players, it was shown that mean weekly Banister's TRIMP maintained a 'large' correlation with sRPE. Yet, neither of these measures of ITL correlated with changes in aerobic fitness parameters. When discussing this finding, Akubat et al. (2012) suggested that while sRPE correlates to criterion measures of intensity, this does not mean that this definitely extends to the calculation of ‘load,’ whereby intensity is just one of the terms inputted into the equation.

The remaining seven studies focused on individual sports, including martial arts (i.e., taekwondo and karate), sprint kayaking, and swimming. Four out of the five martial arts studies reported that sRPE can be considered as a valid method to measure ITL in adolescent taekwondo and karate athletes (Haddad et al., 2011a, Haddad et al., 2014a, Padulo et al., 2014, Lupo et al., 2017a), across a number of different training modalities (i.e., plyometric and fight training). Validity was assumed based on the fact that correlations between sRPE and various criterion measures were often ‘large’ and statistically significant (Cohen, 1992). However, Lupo et al. (2017a) suggested that sRPE for pre-competitive training sessions should be recorded following a 30-minute cool-down period, representing the best condition for capturing a highly reliable measure of ITL. Also, Haddad et al. (2011a) reported that even though sRPE produced similar ITL values compared to HR-based methods, the magnitude of these correlations was ‘less meaningful’ during specific taekwondo technique interval training and high intensity interval running. Both of these points align to those made in two of the formerly discussed adult-based studies (Borresen and Lambert, 2008, Minganti et al., 2011). Within the remaining martial arts study, Haddad et al. (2011b) compared HR-based methods, sRPE, and ITL between taekwondo technique interval training and high intensity running. Aligned to their hypothesis, this study found that both training modalities elicited similar HR responses, sRPE, and ITL values. However, the correlations between the sRPE and HR-based measures of ITL were ‘weak’ (see Table 2.3), likely explained by the high intensity nature of the training. In this instance, Haddad et al. (2011b) concluded that sRPE could not be used as a valid substitute for HR-based methods when applied to these training modalities.

Both remaining studies, focussed on sprint kayaking and swimming, reported that sRPE could be used as a valid measure ITL, across different training intensities. However, both studies did suggest that external training load measures (i.e., total distance covered) should also be taken into consideration alongside sRPE, due to the potential influence of the prescribed external training load and an athlete's current level of fitness on their self-reported RPE.

At this point, it is important to highlight that the validity of sRPE in a population of adolescent distance runners has not previously been studied, thus justifying the original research carried out in Chapter 4 of this thesis. Given that the application of objective measures of ITL is largely unfeasible within this population, validating sRPE will provide athletes and coaches with a simple and cost-effective way to monitor ITL. This will also enable sRPE to be used in future surveillance studies, in order to capture data related to ITL. However, it is also important to consider the use of dRPE-L and dRPE-B, alongside the effect of measurement timing on self-reported RPE values following session or competition completion.

Table 2.3: Studies reporting the validity of session rating of perceived exertion for determining internal training load using the CR10 scale, in adolescents, across all types of sport/physical activity.

Reference	Type of sport / physical activity	Sex	Age range	Sample size	Number of sessions / duration of training	Criteria	Correlations	Significance
Impellizzeri et al., 2004	Football	Males	17.6 ± 0.7	19	476 individual sessions (7 weeks)	Edwards' TRIMP Banister's TRIMP Lucia's TRIMP	*r* = From 0.54 to 0.78 *r* = From 0.50 to 0.77 *r* = From 0.61 to 0.85	From $p < 0.01$ to $p < 0.001$
Haddad et al., 2011a	Taekwondo	Males	13.1 ± 2.4	10	308 individual sessions (2 weeks)	Edwards' TRIMP Banister's TRIMP	*r* = From 0.56 to 0.88 *r* = From 0.61 to 0.85	$p < 0.001$ $p < 0.001$
	Aerobic training				107 individual sessions	Edwards' TRIMP Banister's TRIMP	*r* = 0.57 *r* = 0.60	$p < 0.001$ $p < 0.001$
	Technical and tactical Taekwondo				105 individual sessions	Edwards' TRIMP Banister's TRIMP	*r* = 0.61 *r* = 0.60	$p < 0.001$ $p < 0.001$
	Intermittent training, plyometrics, and speed training				72 individual sessions	Edwards' TRIMP Banister's TRIMP	*r* = 0.31 *r* = 0.32	$p < 0.01$ $p < 0.01$
Haddad et al., 2011b	Intermittent training in Taekwondo	Males	14 ± 2	18	1 week	Edwards' TRIMP Banister's TRIMP	*r* = 0.20 *r* = 0.14	$p > 0.05$ $p > 0.05$
Akubat et al., 2012	Football	Males	17 ± 1	9	6 weeks	Banister's TRIMP % Δ vLT % Δ vOBLA % Δ LT_{HR} % Δ $OBLA_{HR}$	*r* = 0.75 *r* = 0.13 *r* = 0.40 *r* = 0.20 *r* = 0.15	$p = 0.02$ $p > 0.05$ $p > 0.05$ $p > 0.05$ $p > 0.05$

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Reference	Type of sport / physical activity	Sex	Age range	Sample size	Number of sessions / duration of training	Criteria	Correlations	Significance
Borges et al., 2014	Sprint kayaking	Males	17.1 ± 1.2	6	7 weeks	Banister's TRIMP	r = From 0.62 to 0.15	$p < 0.05$
		Females		4		Banister's iTRIMP	r = From 0.62 to 0.15	$p < 0.05$
Haddad et al., 2014	Taekwondo	Males	15.2 ± 1.5	12	368 sessions (12 weeks)	Banister's TRIMP	r = From 0.53 to 0.86	$p < 0.001$
						Edwards' TRIMP	r = From 0.58 to 0.79	$p < 0.001$
Padulo et al., 2014	Karate	Males	12.5 ± 1.8	11	10 sessions (1 weeks)	Banister's TRIMP	r = From 0.84 to 0.92	$p < 0.001$
						Edwards' TRIMP	r = From 0.84 to 0.97	$p < 0.001$
Lupo et al., 2014	Water polo	Males	12.6 ± 0.5	13	8 sessions / 80 individual sessions (10 days)	Edwards' TRIMP	$r = 0.88$	$p < 0.001$
Rodriguez-Marroyo and Antonan., 2015	Football	Males	11.4 ± 0.5	12	20 sessions	Edwards' TRIMP	$r = 0.17$	$p = 0.335$
de Andrade Nogueria et al., 2016	Swimming	Males	15.8 ± 0.87	10	18 sessions	Total volume	$r = 0.71$	$p < 0.05$
		Females	15.1 ± 0.46	7		Aerobic volume	$r = 0.58$	$p < 0.05$
						High intensity volume	$r = 0.45$	$p < 0.05$
						Severe intensity volume	$r = 0.43$	$p < 0.05$
						Anaerobic volume	$r = 0.35$	$p < 0.05$
Lupo et al., 2017a	Taekwondo	Males	12.0 ± 0.7	5	Pre-competitive and competitive periods	Edwards' TRIMP	$r = 0.71$	$p < 0.05$
		Females	12.0 ± 0.8	4				
Lupo et al., 2017b	Basketball	Males	16.5 ± 0.5	6	15 sessions / 66 individual sessions	Edward's TRIMP	r = From 0.80 to 0.96	$p < 0.001$

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Reference	Type of sport / physical activity	Sex	Age range	Sample size	Number of sessions / duration of training	Criteria	Correlations	Significance
Scantlebury et al., 2017	Field Hockey	Females	16.7 ± 0.8	9	113 sessions (14 weeks)	Edward's TRIMP	r = 0.60	–
	Rugby Union	Males	17.2 ± 0.4	10	170 sessions (14 weeks)	Edward's TRIMP	r = 0.68	–
	Football	Males	17.2 ± 0.8	10	114 sessions (14 weeks)	Edward's TRIMP	r = 0.72	–
Vahia et al., 2019	Football	Males	16.7 ± 1.0	15	160 sessions (7 months)	Edward's TRIMP	r = From 0.54 to 0.88	$p < 0.05$
Marynowicz et al., 2020	Football	–	17.81 ± 0.96	18	804 sessions (18 weeks)	Duration (min)	r = 0.78	$p < 0.001$
						Distance (m)	r = 0.70	$p < 0.001$
						HS running distance (m)	r = 0.52	$p < 0.001$
						Impacts (n)	r = 0.37	$p < 0.001$
						Distance in acceleration (m)	r = 0.70	$p < 0.001$
						Accelerations (n)	r = 0.62	$p < 0.001$
						Player Load (au)	r = 0.64	$p < 0.001$

Abbreviations: %, percentage; Δ, change; vLT, velocity at 2 mmol-L^{-1}; vOBLA, velocity at 4 mmol-L^{-1}; LT_{HR}, heart rate at 2 mmol-L^{-1}; $OBLA_{HR}$, heart rate at 4 mmol-L^{-1}; VO_2, volume of oxygen; HR, heart rate; TRIMP, training impulse; iTRIMP, individualised training impulse; min, minutes; m, metres; n, number; au; arbitrary units; r, correlation coefficient between RPE-method and various criterion measures; p, level of statistical significance ($p > 0.05$ = non-significance) between RPE-method and various criterion measures; –, not specified.

2.2.2 Differential Ratings of Perceived Exertion

Hutchinson and Tenenbaum (2006) have argued that sRPE may oversimplify the psycho-physiological construct of exertion, representative of a 'gestalt score.' As a result, they argue that sRPE might lack sensitivity during high intensity bouts of exercise, whereby this measure of ITL might not fully capture the complete range of exertion signals during exercise. One possible way to overcome this issue is to apply dRPE, including dRPE-L and dRPE-B. As argued by McLaren et al. (2017), by concentrating on peripheral (i.e., dRPE-L) and central (i.e., dRPE-B) exertion, dRPE may provide additional insight compared to that obtained from a single measure of ITL (i.e., sRPE). This could be of benefit to distance runners, whereby a broad range of training intensities need to be completed to improve athletic performance, while athletes often report their sessions according to the perceived impact on their legs (i.e., in relation to delayed onset muscle soreness (Cheung et al., 2003)). As a consequence, accounting for peripheral and central exertion has the potential to improve the ability of a coach, and their athletes, to manage ITL in a more precise manner.

Previous studies have shown that it is possible to discriminate between peripheral and central exertion when using dRPE-L and dRPE-B measures of ITL. However, these studies have mainly been related to adult-based team sports (Weston et al., 2015, Arcos et al., 2015, McLaren et al., 2017), and adolescent-based team sports (Gil-Rey et al., 2015, Wright et al., 2020). Specific to distance running, research completed by McLaren et al. (2016) and Green et al. (2009) investigated the use of dRPE via treadmill running, in adult participants. While McLaren et al. (2016) showed that dRPE can enhance the sensitivity of ITL measurement, from a physiological perspective, Green et al. (2009) found that dRPE-B scores were blunted, potentially less sensitive (compared to sRPE and dRPE-L), and likely to be integrated in the self-reported sRPE score. Despite these conflicting results, the validity of dRPE-L and dRPE-B, in relation to measuring ITL, has yet to be established within a population of adolescent distance runners. Furthermore, as treadmill-based running is not equal to running outside, in terms of energy cost (Jones and Doust, 1996), it is important to validate these measures of ITL based on the typical training environments of adolescent distance runners (i.e., the local athletics track, etc.).

2.2.3 Measurement Timing

Traditionally, RPE has been reported 30 minutes after session completion. This measurement timing has regularly been used when determining sRPE, dRPE-L and dRPE-B, based on Foster et al. (2001) initial research. It was argued that this measurement timing prevented the last part of a training session from influencing an athlete’s self-reported RPE for the entire training session. However, since the application of these measures of ITL have been used due to their simplicity and user-friendliness (McGuigan et al., 2020), it would both be more time-efficient and practical if they could be recorded sooner after training session completion, while retaining their temporal robustness.

Since being introduced by Foster et al. (2001), Christen et al. (2016) highlighted that there has been limited inquiry into the temporal kinetics of sRPE. In the same paper, Christen et al. (2016) concluded that sRPE is a temporally robust measure of ITL for cycle exercise, when self-reporting RPE between five minutes and 24 hours after the completion of a training session. When used in resistance training exercise, Singh et al. (2007) concluded that RPE values should be self-reported between 10 and 30 minutes following training session completion. A very similar conclusion was made by Uchida et al. (2014) when investigating the influence of measurement timing on sRPE in boxing, recommending that RPE values should be reported either 10 minutes or 30 minutes after training session completion. In relation to distance running, Kilpatrick et al. (2009) compared the sRPE 15 minutes following exercise completion, using an OMNI scale, to the RPE reported during the final minute of exercise and to the average of RPE values reported every five minutes during a 30 minute bout of treadmill exercise. The results from this study indicated that sRPE 15 minutes after exercise completion was similar to the RPE values reported during the final minute of treadmill exercise, but significantly higher compared to the average of RPE values self-reported during the treadmill exercise. Based on these findings, Kilpatrick et al. (2009) concluded that sRPE reported 15 minutes after exercise completion was biased by higher levels of exertion in the final minute of exercise. Yet, this study did not include a period of cool-down following the treadmill exercise, as is often standard practice in distance running training. As a result, it can be disputed whether this study can be generalised to more applied settings, whereby RPE is likely to be self-reported after a period of cool-down, thus possibly reducing the influence of high intensity elements of a training session.

In the context of adolescent athletes, two studies have recently investigated the temporal robustness of sRPE in team sports (Phibbs et al., 2017, Scantlebury et al., 2018). Instead of seeking to improve the 'time efficiency' of self-reporting RPE values (i.e., allowing RPE to be self-reported before the standard 30 minute delay post-training session completion), these studies examined whether RPE values were temporally robust when self-reported 24 hours, 72 hours, and one week following training session completion, potentially facilitating a longer retrospective recall. These studies concluded that reporting RPE values 24 hours after training session completion provided a valid and robust measure of ITL. This was shown by the nearly perfect correlations (r = 0.99 and 0.98, respectively) between the 24-hour recall method and the traditional sRPE method (i.e., reported 30 min post-training session completion), used as a criterion measure. Yet, the findings related to applying 72-hour and one-week recall methods showed that these were not as suitable methods for measuring ITL in adolescent team sport athletes, compared to the 24-hour method. In contrast to these findings, Schafer et al. (2013) provide some evidence to support the use of a one-week recall method in a population of recreationally active adults. Using an adult version of the OMNI scale (Robertson, 2004), RPE was self-reported as a global measure, alongside dRPE-L and dRPE-B, in relation to a 'level walk,' 'hilly walk,' and 'run.' When performing regression analyses on these measures, recorded one-week after completion of the various exercise bouts, the magnitude of the correlation coefficients ranged from r = 0.51 to 0.87. When viewed together, these findings highlight that it is feasible to record RPE values after a substantial delay (i.e., 24 hours post-session completion). Yet, when considering the literature that cautions against adolescent athletes using RPE-related measures of ITL (Bourdon et al., 2017), and acknowledging the range of factors that can influence an athlete's reported RPE values (Haddad et al., 2017), seeking to validate sRPE by reducing the time delay between training session completion and self-report represents a more pragmatic approach. This is especially the case if multiple training sessions are completed per day, whereby a 24-hour delay before measurement timing may become confusing for adolescent athletes.

2.3 Health Problems: Epidemiology and Psychosocial Responses to Injury

This part of the literature review will initially introduce the 'sequence of prevention,' including a critical commentary about why complexity needs to be acknowledged. Following this, different types of epidemiological study design will be introduced, alongside a review of the different methods and definitions employed in injury and illness surveillance research. A critique of existing injury and illness epidemiology literature in relation to distance running will then be presented, while also detailing common sport-specific correlates (risk factors) of injury. Finally, the different theoretical approaches used to investigate athletes' psychosocial responses to sport-related injury will be introduced, alongside a review of the literature related to the different aspects of the 'integrated model of response to sport injury,' as first theorised by Wiese-bjornstal et al. (1998).

2.3.1 The Sequence of Prevention

As developed by van Mechelen et al. (1992), the 'sequence of prevention' model suggests that four distinct research steps are needed to effectively prevent sport-related injuries – shown in Figure 2.4. First, the overall extent of the problem must be identified and described, in relation to incidence and severity. The second step requires an assessment of the risk factors (i.e., aetiology) and mechanisms that contribute to the occurrence of injury. These two steps can be completed by using epidemiological study designs. The third step is to design and implement suitable preventative measures, before evaluating their efficacy during the fourth step. It is important that the preventative measures (implemented during step three) are informed by the first and second steps of van Mechelen et al. (1992) model. Also, the effect of the measures must be evaluated by repeating step one of the model. Therefore, this model can be viewed as a cyclical and iterative process.

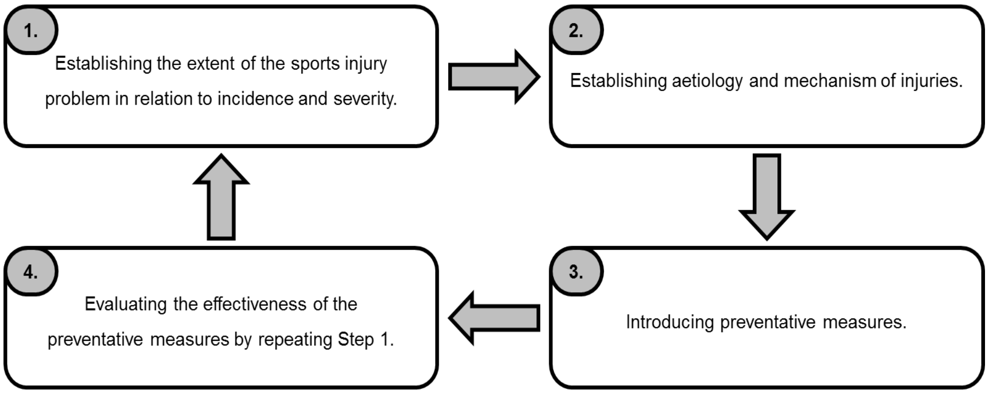

Figure 2.4: The 'sequence of prevention' research model, following a cyclical and iterative four-step process. Adapted from van Mechelen et al. (1992), *Incidence, Severity, Aetiology and Prevention of Sports Injuries*, Sports Medicine, 14(2), p. 84, with permission from Springer Nature (copyright 2012).

While the 'sequence of prevention' model has been regularly used as a research framework within sports injury prevention research (Klügl et al., 2010), providing a sequential research pathway, it has limitations. According to Finch (2006), the main limitation is that this model does not account for how to best implement such preventative measures, specific to the intervention context. For example, in youth sport settings, the implementation of neuromuscular exercises that require extra equipment may not be feasible. Due to this observed limitation, the 'sequence of prevention' model has since been extended to include two further steps, incorporated in the Translating Research into Injury Prevention Practice (TRIPP) framework (Finch, 2006). Figure 2.5 provides a summary of how the TRIPP framework relates to, and compliments, the 'sequence of prevention' research model. Based on the TRIPP framework, the fifth step should aim to describe the intervention context, used to inform suitable implementation strategies, while the sixth step evaluates the overall effectiveness of the preventative measures in the given intervention context (i.e., real-world setting).

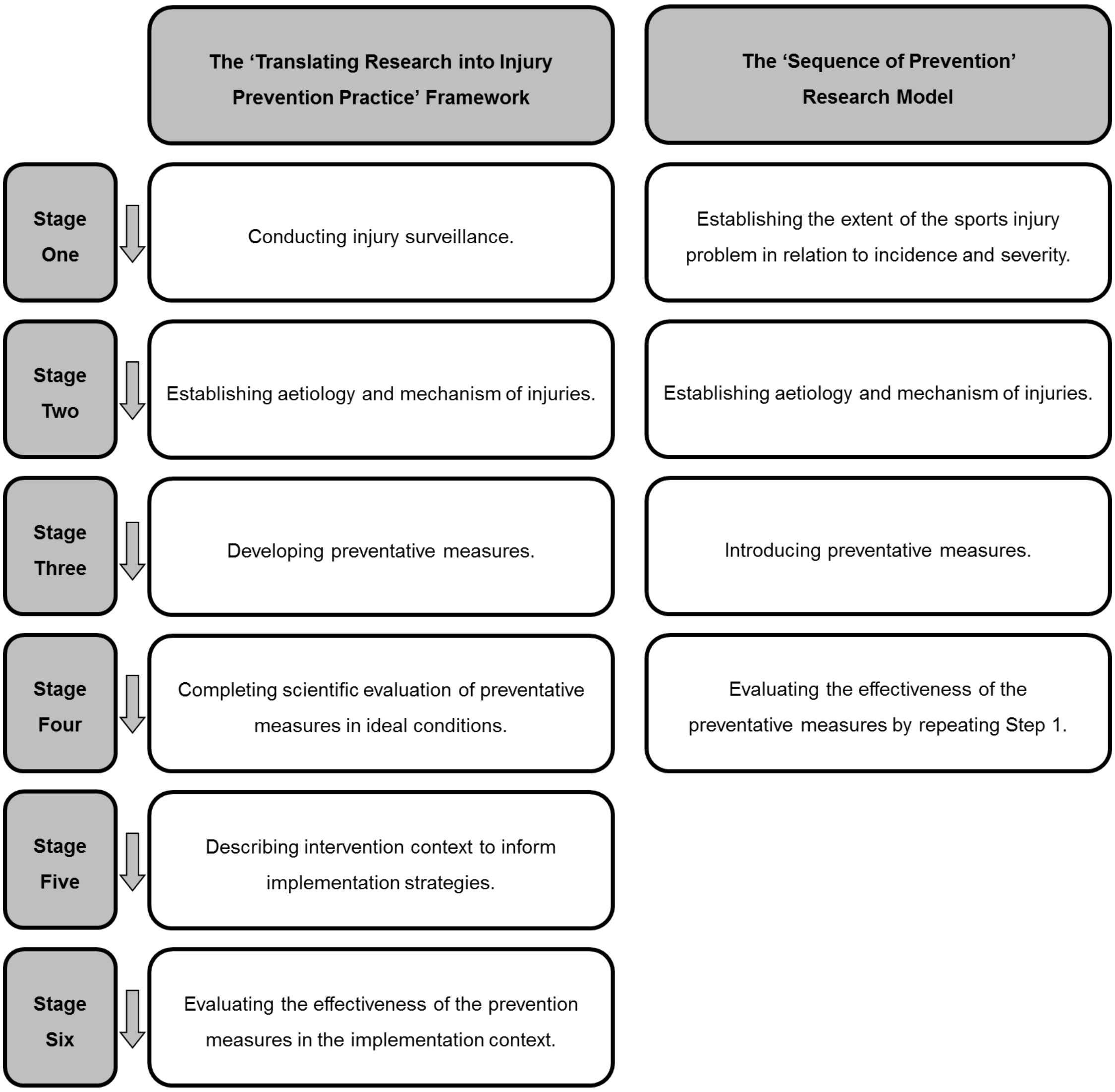

Figure 2.5: Comparison of the four-step 'sequence of prevention' research model and the extended six-step 'Translating Research into Injury Prevention Practice' framework. Adapted from Finch (2006), *A New Framework for Research Leading to Sports Injury Prevention*, Journal of Science and Medicine in Sport, 9, p. 4, with permission from Elsevier (copyright 2006).

While both the 'sequence of prevention' model and TRIPP framework are useful research tools, it is also important to highlight that they were designed according to the previous research experiences of the authors, rather than being informed by scientific evidence. Therefore, as with all models, both of these research tools only provide simplified recommendations for injury prevention. Yet, Finch (2006) highlights that sports injury research does not often advance beyond the second stage of the TRIPP framework, potentially due to the level of resources required to implement and evaluate injury prevention measures. While this point is a good one to make, it should not restrict research aligned to these steps of the TRIPP model, especially when there remains a lack of research that addresses these steps. This is the case within the context of adolescent distance running, whereby the majority of pervious research only includes this population as a sub-sample within broader analyses – as demonstrated in Section 2.3.3.

For the purpose of clarity, Chapters 5-7 of the current thesis are focussed on the first two steps of the 'sequence of prevention' model and TRIPP framework (van Mechelen et al., 1992, Finch, 2006), thereby establishing evidence to inform the direction of future intervention measures (van Mechelen, 1997). Therefore, it is necessary to identify a number of the methodological and definitional issues that need to be considered when conducting epidemiologic studies, as presented in Section 2.3.2. Yet, before presenting these considerations, it remains important to acknowledge the idea of 'complexity,' and how this can be addressed through the first two steps of the 'sequence of prevention,' and TRIPP framework, by embracing qualitative research methods.

2.3.1.1 Acknowledging Complexity

The concept of 'complexity' has been investigated throughout the different steps of the 'sequence of prevention' and TRIPP framework, whereby injuries can be viewed as complex phenomena (Hulme and Finch, 2015, Bittencourt et al., 2016, Bekker and Clark, 2016, Bolling et al., 2018, Hulme et al., 2019). As asserted by

Bekker and Clark (2016), the concept of complexity is related to acknowledging that the interactions across and/or between individual components (e.g., actions of parents and coaches), sub-components (e.g., actions of individual athletes), contexts (e.g., competitive vs. recreational participation), and intervention-based factors (e.g., fidelity), influence injury prevention outcomes. Acknowledging these interactions (and differing levels of complexity) helps to avoid the application of a reductionist approach.

When acknowledging such complexity, Bolling et al. (2018) recommend that the first steps in the 'sequence of prevention' and TRIPP framework should explore the given context of sport-related injuries (van Mechelen et al., 1992, Finch, 2006). The term 'context' relates to the interconnected conditions within which an injury occurs and exists, as a contributory factor to the concept of complexity. This can, therefore, also be framed as the 'specific setting' within which injury prevention measures can be implemented (Aron, 2020). In support of this recommendation, it has been argued that subsequent preventative measures should be aligned to the sport-specific context and needs of the injured athlete(s), not the other way around (Verhagen, 2012), focussing on what works for whom, when, where, and why (Bekker and Clark, 2016).

Based on acknowledging complexity, Bolling et al. (2018) strongly advocate the use of qualitative methods in injury prevention research, as a way to determine a better understanding of the context in which sport-related injury occurs across a number of different individual, socio-cultural, and environmental/policy levels. By addressing this through the first step of the 'sequence of prevention' and TRIPP framework, it is argued that subsequent preventative measures can be created, implemented, and evaluated within a real-world setting, rather than trying to force a 'square peg' (i.e., scientific application of measures in ideal conditions) into a ‘round hole’ (i.e., recognising the sport-specific contexts and needs of athletes). To achieve this, Bolling et al. (2018) recommend developing context-specific ‘how’ and ‘why’ questions that situate injured athletes at the centre of a socio-ecological model (Bronfenbrenner, 1977), as shown in Figure 2.6. Yet, qualitative research methods are regularly overlooked in injury/illness prevention research, regardless of their ability to complement more traditional quantitative approaches (Bekker et al., 2020). Regular use of qualitative research methods would, therefore, improve the pool of evidence available to support their value and subsequent use within this academic field.

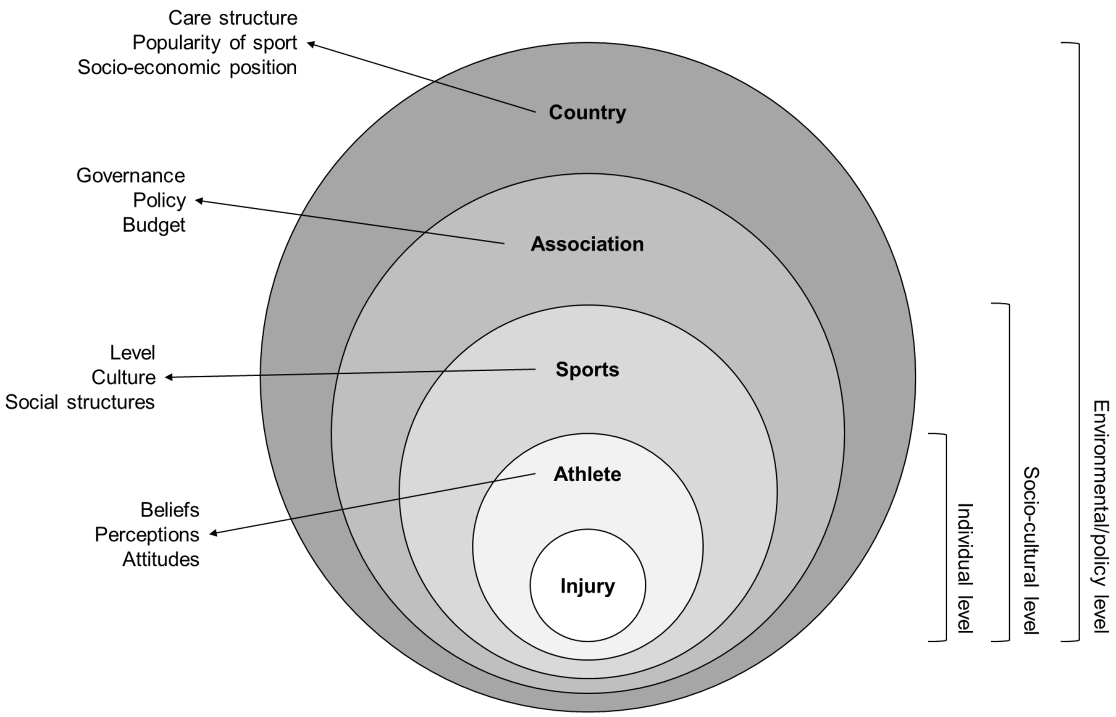

Figure 2.6: A socio-ecological perspective of sports injuries, including individual, socio-cultural, and environmental/policy levels. Copied from Bolling et al. (2018), *Context Matters: Revisiting the First Step of the ‘Sequence of Prevention’ of Sports Injuries,* Sports Medicine, 48, p. 2231, with permission from Springer Nature (open access).

2.3.2 Injury and Illness: Methods and Definitions

2.3.2.1 Study Designs

Epidemiologic studies are either experimental or non-experimental in their design (Rothman et al., 2008a). Experimental study designs can include clinical trials, field trails, and community intervention trials. Yet, if certain experimental study designs are considered to be infeasible and/or unethical, as in the case of the present thesis, non-experimental (observational) study designs can be applied to simulate what might have occurred had an experimental study been performed. Rothman et al. (2008a) state that there are four main types of non-experimental epidemiologic studies: (1) *cohort studies* – in which all participants in a population are categorised according to exposure status and followed over time to attain outcome incidence; (2) *case-control studies* – in which outcomes occurring in a source population and a sample of the source population are categorised based upon their exposure history; (3) *cross-sectional studies* – in which exposure and outcome status are collected at the same time point; and (4) *ecological studies* – in which the units of observation are different groups of participants. In this thesis, two different types of epidemiologic study were performed: (1) a retrospective cross-sectional study (Chapter 5) and (2) a prospective cohort study (Chapter 7). The main feature that separates a prospective from a retrospective study is that the outcome of interest (i.e., sport-related injury) has already happened prior to data collection in a retrospective study.

2.3.2.1.1 Cross-Sectional Study Design

Cross-sectional studies are concerned with describing the general characteristics of the distribution of an outcome of interest (i.e., injury). This can be in relation to person, place, and time (Hennekens and Buring, 1987). When related to person, for example, this can include demographic factors, such as age or sex, alongside lifestyle factors, such as weekly training load or number of distance running races per year. This study design assesses the presence or absence of both exposure and an outcome of interest in participants, at a set point in time, often described as taking a “snapshot.” Yet, it is possible to add a temporal element to traditional cross-sectional studies. This can be achieved by allowing retrospective recall of information related to the outcome of interest. An example of this study design, in relation to injury epidemiology, is given by Woollings et al. (2015). In this study, participants were required to recall their training profiles (frequency, volume, and intensity) and injuries (type, site, and severity). Adopting this approach allows for the analysis of incidence (the number of new occurrences of the outcome over a period of time), rather than prevalence (the proportion of participants who have the outcome at a given point in time) (Knowles et al., 2006b).

As stated by Rothman et al. (2008a), cross-sectional studies do not need to have aetiologic objectives. Yet, if aetiological inferences are made from cross-sectional data, then an awareness of their limitations is important. The main limitation of employing a cross-sectional study design is that because exposure and outcome are assessed simultaneously, no evidence of a temporal relationship between exposure and outcome of interest can be provided. As a result, causality cannot be established. Another issue is that outcomes with a long duration can be overrepresented in cross-sectional studies, whereas short duration outcomes can be underrepresented. This is referred to as length-biased sampling (Rothman et al., 2008a). In relation to injury, this is likely to result in overreporting of long-term outcomes, reflective of ‘serious’ (>28 days-6 months) and ‘long-term’ (>6 months) time loss injuries (Timpka et al., 2014a), and underreporting of minor injuries.

Despite the known limitations of cross-sectional study designs, Sedgwick (2014a) highlights that they are generally quick, simple, and cost effective to perform. This is largely due to the fact that they are often completed via questionnaire. Another benefit of this study design is the fact that there will be no loss to follow-up, as participants are only involved at one specific time point, rather than having to use repeated measures. Based on these observations, cross-sectional study designs are often conducted before using a prospective cohort study, thereby providing useful information about relevant outcomes to inform subsequent studies.

2.3.2.1.2 Cohort Study Design

Cohort studies follow participants over a specified period of time to determine the development of an outcome of interest. This type of study can either be performed in a retrospective or prospective manner.

According to Hennekens and Buring (1987), cohort studies are appropriate when there is sufficient evidence to suggest an association between exposure and an outcome of interest. This evidence may have initially been produced from a cross-sectional study. Cohort studies are also deemed to be appropriate when the gap between exposure and development of the outcome is relatively short, thereby minimising the potential for loss to follow-up. In injury and illness epidemiology, this can feasibly be addressed by using an 'inclusive' definition of injury/illness (Section 2.3.2.2), whereby it is likely that more injuries/illnesses will be registered compared to a study that is solely designed to identify a particular injury/illness. This is also true for when the outcome of interest occurs relatively frequently, so that the sample size does not have to be especially large.

Across two short research papers, Sedgwick (2013, 2014b) highlights that many of the advantages and disadvantages of retrospective study designs are similar to those for prospective cohort study designs. For example, an advantage of both designs is that exposure to risk factors is recorded before the occurrence of the outcome, thereby allowing temporality to be investigated. Both study designs also allow for the calculation of incidence. However, as retrospective studies rely upon information about historical events, they often require participants to self-report data over a longer period of time. As a result, recall bias (see Section 2.3.2.3) is more likely to influence study findings. Nonetheless, prospective study designs are a lot more resource intensive to conduct. Therefore, in the context of injury and illness epidemiology, study design decisions should be made prudently (i.e., balancing the likelihood of participant dropout against allocating sufficient time for the outcome of interest to be observed) and, if feasible, only implemented after the completion of a more simplistic cross-sectional study.

2.3.2.2 Defining Health Problems

Regardless of study design, choosing the most appropriate definition for reporting health problems (i.e., injury and illness) can be difficult, whereby it is important to recognise that ‘one size does not fill all’ (Clarsen and Bahr, 2014). As an umbrella term, an ‘athletic health problem’ has been defined as any condition that reduces an athlete’s normal state of full health, irrespective of its consequences on the athlete’s sports participation or performance, or whether the athlete sought after medical attention (Clarsen et al., 2020). This overarching definition is consistent with the latest IOC consensus statement on methods for recording and reporting epidemiological data on injury and illness in sport (Bahr et al., 2020).

Specific to team sports, arguments for using either an 'inclusive' (i.e., 'all injuries') or more 'exclusive' (i.e., >7 day time loss) definition have previously been made (Hodgson et al., 2007, Orchard and Hoskins, 2007, Cross et al., 2018). Within a population of novice adult distance runners, Kluitenberg et al. (2016) showed that the choice of injury definition (i.e., running-related pain, training-reduction, time loss of one day or one week) impacts injury incidence and the location of injury. For example, related to the same dataset, the use of different injury definitions resulted in injury incidence figures ranging from 18.7 to 239.6 injuries per 1,000 hours of running participation. The definitions related to these incidence figures were as follows: (1) "presence of running-related pain, resulting in absence from all planned running sessions for one week or more," and (2) "running-related pain experienced during ≥1 running session, regardless of the consequences for that running session," respectively (Kluitenberg et al., 2016, p. 471). This stresses the need to standardise injury recording and reporting methods, achievable via application of consensus paper recommendations (Timpka et al., 2014a, Bahr et al., 2020). Clarsen and Bahr (2014) highlight that consensus recommendations regularly provide the following three definitions: (1) all complaints, (2) medical attention, and (3) time loss. These three definitions have also been described in a systematic review of the different categories used to define running-related injury (RRI) (Yamato et al., 2015). As shown in Figure 2.7, the number of health problems that are likely to be recorded varies according to the chosen definition, while each definition is related to various strengths and limitations. For example, using an 'all complaints' definition is most likely to best represent the total burden (overall impact) of injury/illness, but the reliability of the data may be reduced due different interpretations of what constitutes a recordable injury/illness (Clarsen and Bahr, 2014).

Based on the various strengths and limitations of different definitions, as reviewed by Clarsen and Bahr (2014), it is important to decide on a definition that considers the context within which the study is taking place, and the availability of resources. Consideration should also be given to how the chosen definition may affect how injury risk is (re)presented and related to previous research findings (Brooks and Fuller, 2006, Yamato et al., 2015, Kluitenberg et al., 2016). Notably, an 'inclusive' ('all complaints') definition is generally supported across the relevant consensus statements (Bahr et al., 2020, Timpka et al., 2014a). This is likely to be because this approach results in a good representation of the total burden of injury/illness, while allowing for other definitions to be subsequently applied (i.e., time loss).

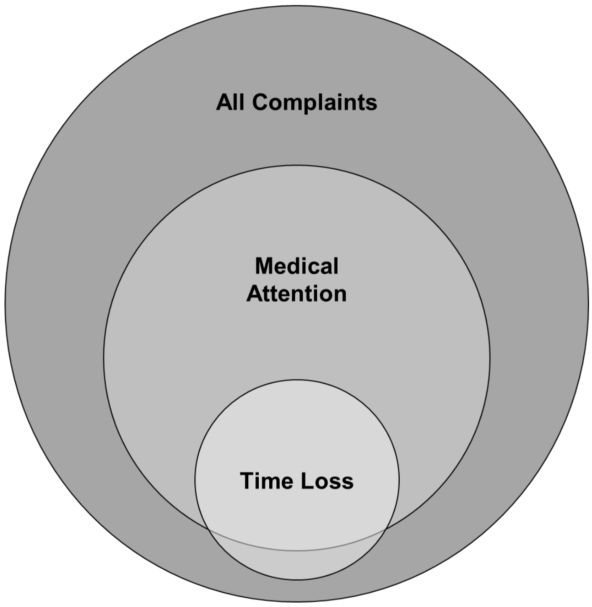

Figure 2.7: Interaction between different health problems (i.e., injury and illness) definitions. Circle size represents the relative number of health problems likely to be registered (not to scale). Copied from Clarsen and Bahr (2014), *Matching the choice of injury/illness definition to study setting, purpose and design: one size does not fit all!,* British Journal of Sports Medicine, 48, p. 511, with permission from BMJ Publishing Group Ltd. (copyright 2014).

2.3.2.3 Data Collection Methods

There are many ways to collect data on health problems. Given that the selection of methods used for data collection has been reported to impact the outcome of injury and illness surveillance studies (Finch and Mitchell, 2002, Tabben et al., 2020), it is important that the selected methods are suitable for the specific study context and objectives (Ekegren et al., 2016). As identified in the most recent IOC consensus statement (Bahr et al., 2020), decisions need to be made in relation to five different variables, as shown in Figure 2.8.

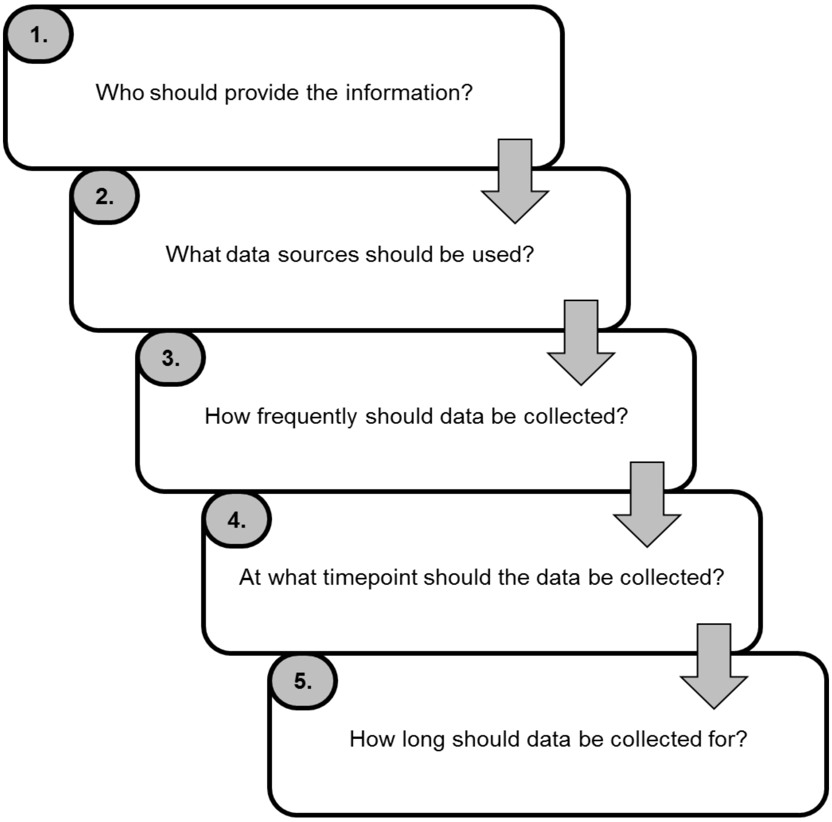

Figure 2.8: Variables to consider when conducting injury and illness surveillance research. Adapted from Bahr et al. (2020), *International Olympic Committee consensus statement: Methods for recording and reporting of epidemiological data on injury and illness in sport 2020,* British Journal of Sports Medicine, 54(7), p.385, with permission from BMJ Publishing Group Ltd. (copyright 2020).

First, a decision needs to be made about who provides the information regarding injury and illness. While it is expected that an athlete will share details in relation to whether or not they have sustained an injury or illness, this information could be recorded by a number of other individuals, including coaches, physiotherapists, physicians, or research staff. As a result, the study context is likely to influence who is best placed to record this data. For example, in the context of an American High School system, Yard et al. (2009) demonstrated that Athletic Trainers were more reliable and accurate data recorders, compared to coaches. Based on pilot study data in a population of elite youth football players, Shrier et al. (2009) found that athlete self-reported data was consistent (i.e., matching responses) with data recorded by their parents and coaches related to the type of injury, side of injury, and place where the injury occurred. Yet, data were inconsistent when recording details related to injury date and the underlying cause of injury. Based on these data, Shrier et al. (2009) proposed that athlete self-report methods could be used as a low-cost alternative to recording medical diagnoses through the employment of a sports physician – an approach which is not always feasible. The application of athlete self-report methods can, therefore, be supported within the context of adolescent distance running, in England, whereby most coaches are volunteers, and amateurism continues to be promoted as the 'grass-roots' philosophy of track and field athletics. Irrespective of who is deemed to be best placed to record this data, it is necessary to provide them with detailed information about how to complete their task accurately (World Health Organization, 2001). Connected to this first factor, decisions surrounding what data sources should be used to obtain data related to injury and illness also need to be made.

One of the most objective methods to capture the circumstances of a sports injury is video recording, enabling detailed retrospective analysis of injury mechanisms

(Krosshaug et al., 2005). However, a limitation of this method is that it is largely impractical to record all training sessions and competitions, while this method has also been shown to identify less than half of all recorded injuries in a Norwegian professional football league, when cross-referenced with data recorded by team physicians (Andersen et al., 2004). In the context of adolescent distance running, competitions are usually not recorded, meaning that this method is unachievable. Furthermore, this method cannot capture information related to illness. Therefore, use of medical records and/or clinical examinations completed by physicians or physiotherapists can be upheld as best practice, allowing injury/illness diagnoses to be recorded in as much detail as possible (Bahr et al., 2020). Yet, this relies on having access to physicians or physiotherapists throughout the data collection period, which may not be feasible in certain study contexts, including adolescent distance running. As a result, injury/illness surveillance studies that include youth athletes, outside of elite training environments and/or major competitions (Steffen and Engebretsen, 2010), have been difficult to conduct, possibly due to a lack of resources and access to suitable data collection methods (Goldberg et al., 2007, Ekegren et al., 2016).

Due to these identified issues, athlete self-report can be used as a primary source of data, often collected by means of completing a questionnaire (Saw et al., 2015). For example, the Oslo Sports Trauma Research Center Questionnaire on Health Problems (OSTRC-H) provides a possible solution for study contexts that do not have access to medical staff, alongside other questionnaire-based methods (i.e., completion of a standardised training diary). Using the OSTRC-H method allows health problems to be prospectively monitored, based on athlete self-report, irrespective of whether athletes take part in competition or whether medical staff are available (Clarsen et al., 2013, Clarsen et al., 2014, Clarsen et al., 2020).

While this method is discussed in further detail in Section 3.4.5.2, it is important to state that the OSTRC-H has previously been validated against standard injury registration methods, in young adults, and successfully applied in different youth sport contexts (Clarsen et al., 2013, Clarsen et al., 2014, Pluim et al., 2016, Moseid et al., 2018, von Rosen et al., 2018a, Leppänen et al., 2019). Reporting data that is generated from the OSTRC-H, in relation to severity and burden, is detailed within Section 2.3.2.4.

Regardless of which athlete self-report data collection method is selected, a clear limitation is the reliance on athletes to consistently provide accurate and truthful data. The issue of recall bias might become more evident when longer periods of recall are used (Coughlin, 1990), such as requiring athletes to self-report injuries over a retrospective period of 12-months. For example, Gabbe et al. (2003) have shown that, in a population of community level Australian football players (adults), recall accuracy decreases as the level of detail requested increases. This study compared the 12-month retrospective injury recall of participants to prospective injury surveillance data, recorded by physiotherapists, finding that all participants (100%) were successfully able to recall whether or not they had been injured in the last 12-months. Accurate recall of the number of injuries and body regions of injuries, but not the diagnoses, was achieved by almost 80% of the participants, whereas only 61% were able to recall the number, body regions, and diagnoses of injuries. Similar findings were reported within a population of male professional football players in Norway, whereby 30% of the injuries recorded by medical staff throughout a 3-month period were not recalled by players (Bjørneboe et al., 2011). Adopting a slightly different approach, retrospective interviews with athletes and coaches in relation to injuries sustained throughout the previous 5-6 months, in a population of elite ski and snowboard athletes, was shown to provide the ‘most complete picture,' compared to the records of technical delegates and medical staff (Flørenes et al., 2011).

Whether these data can be judged as 'acceptable' relates back to the given study context, and whether athlete self-report is deemed to be the most feasible option to capture injury/illness data. As a further point, there is a lack of data related to recall bias in youth sport contexts. Therefore, while recall bias can be expected to be an issue, it is difficult to know to what extent this may be the case. However, available data related to adolescent self-report of their height, weight, and course grades suggest that this method provides a reasonably valid substitute compared to objective methods (Winters et al., 1990). A similar finding has been reported in relation to self-reported weight change amongst adolescents and young adults (Field et al., 2007). Overall, these results indicate that the level of detail required to be recalled by participants, alongside the chosen length of recall, needs careful consideration when planning studies, whereby the limitations of athlete self-report methods need to be recognised.

As a third variable, the frequency of data collection needs to be considered. For a retrospective study design, this will involve data being collected at just one point in time, requiring recall (i.e., injury history over the previous 12-months). Yet, for prospective studies, the frequency of data collection should be based upon the expected 'burden' that the specific study population is likely be able to manage, while attempting to minimise the level of intrusion into the daily lives of those recording data (Bahr et al., 2020). Similarly, the fourth and fifth variables relate to the time point at which data should be collected from participants (e.g., on the day of injury/illness, on the following day, or within one week), alongside the overall duration of data collection (e.g., throughout a tournament or whole year). Both of these variables were reported to influence the implementation of athlete self-report measures by Saw et al. (2015). Therefore, as previously highlighted, decisions related to these variables should aim to minimise the overall 'level of intrusion' into the daily lives of those recording data, while aligning to the specific study objectives. This is especially important for youth athletes, who are identified as a 'vulnerable population' when it comes to applying for research ethics (Sutton et al., 2003, Harriss et al., 2019).

Associated with each of these five variables, it is also important to consider how data will be captured. Suitable methods range from a traditional 'pen and paper' approach, through to electronic methods, such as text messaging and web-based systems. As outlined by Bahr et al. (2020), electronic methods avoid duplication of data and reduce the chance of human error, as associated with traditional 'pen and paper' approaches, while being more cost-effective and dynamic in relation to providing data reports (Malik et al., 2015). Yet, there are conflicting findings in relation to the ability of different electronic methods to attain high response rates from participants (Nilstad et al., 2014, Barboza et al., 2017, Bromley et al., 2018, Clarsen et al., 2020), whereby engagement can be affected by numerous factors (Saw et al., 2015). This further emphasises that data collection decisions need to be made in relation to the study context and objectives.

Having considered each of these different variables related to conducting injury and illness surveillance research, it has become apparent that athlete self-report is likely to be an effective data collection method within the context of adolescent distance running. This is primarily due to the fact that the current organisation of adolescent distance running, in England, means that athletes are not likely to be supported by medical staff. As an extension of this point, the individual nature of distance running also means that not all training sessions will be overseen by a coach. Therefore, this level of training autonomy means that athlete self-report is one of the only feasible options. Nonetheless, acknowledgement of the limitations surrounding athlete self-report measures will be necessary when writing data up for publication, while expected participant burden should be carefully considered when designing study protocols.

2.3.2.4 Reporting Data on Health Problems

Greenland and Rothman (2008b) state that epidemiologic studies have to be able to determine the frequency of outcome occurrence, either in absolute or in relative terms. Throughout this thesis, the outcome of interest is injury and illness, while the following measures of outcome frequency have been used: (1) incidence rate, (2) incidence proportion, (3) clinical incidence, and (4) prevalence. Alongside these measures, severity and burden have also been used to report data on injury and illness (Bahr et al., 2018). This range of measures reflects that different types of study design were used in this thesis (see Section 2.3.2.1), while there is not a single approach to expressing risk appropriately (Bahr et al., 2020). Therefore, the following section of the literature review will provide a brief overview of these measures. Definitions and typical uses of these terms are presented in Table 2.4. As a separate point, absolute numbers of injuries/illnesses are also presented in this thesis. Yet, as this measure is straightforward to calculate, it is not discussed in this chapter.

Table 2.4: Definitions and typical use of epidemiological measures when reporting data on health problems (injury and illness).

Measure	Definition	Typical Use of Measure
Incidence Rate	The occurrence of new injuries/illnesses within a specific population during a specific period of time, expressed as a ratio.	Calculated to determine the total number of new injuries/illnesses per athlete/1,000 hours of participation or per athlete/year. Rate ratios can also be calculated based on this measure.
Incidence Proportion	The proportion of a specific population at risk who become injured/ill during a specific period of time.	Calculated to determine the average probability that an athlete would sustain at least one injury/illness during a specific period of time. Risk ratios can also be calculated based on this measure.
Clinical Incidence	The occurrence of injury/illness per athlete, defined as the number of injuries/illnesses during a specified period of time divided by the total number of athletes at risk.	Calculated to address the expected frequency of injury/illness during a specific period of time, in relation to the total population. It is used as a measure of resource utilisation.
(Point) Prevalence	The proportion of a specific population who have injury/illness at a specific point in time.	Used to quantify the number of injuries/illnesses at a particular point in time relative to the size of the population at risk.
Severity	The overall seriousness of an injury/illness. This can be measured in several different ways, including ‘time loss,’ athlete self-reported consequences, and the clinical extent or financial cost.	Used to capture the tangible impact that injuries/illnesses have at an individual, team, or societal level, typically reported in relation to time lost (days) from training and competition.
Burden	Equal to the product of injury/illness incidence (reported per 1,000 participation hours) and severity (reported as mean time loss days), reported as severity/1,000 participation hours.	Typically applied as a ‘risk matrix,’ whereby severity is plotted against incidence with criteria (i.e., shading) incorporated within the graph to evaluate levels of risk.

2.3.2.4.1 Incidence

The term ‘incidence’ refers to the total number of new occurrences of an outcome during a specified period of time (Greenland and Rothman, 2008b). Importantly, incidence figures consider different levels of exposure, allowing relative levels of occurrence to be calculated. Depending on choice of numerator and denominator values, incidence can be determined in numerous different ways, either indicating a ‘rate,’ a ‘risk,’ or measure of ‘resource utilisation’ (Knowles et al., 2006b).

Incidence rate is defined as the number of new injuries/illnesses (incident number) in a population divided by a specific period of time (exposure) and is not a direct measure of risk. It is recommended that incidence rate includes a standard time window for the population at risk, such as injuries/illnesses per hour, to allow for comparison between studies (Timpka et al., 2014a, Bahr et al., 2020). Within the present thesis, incidence rate has been presented according to ‘per athlete/1000 hours of participation’ and ‘per athlete/year,’ highlighting that incidence rate is a dynamic process (Greenland and Rothman, 2008b). To assess how much higher (or lower) the incidence rate is between two distinct groups (i.e., male and female athletes), it is possible to determine the ‘rate ratio’ (RR) (Greenland et al., 2008), calculated by dividing one groups’ incidence rate by the other.

In a specified period of time, it is also possible to convey the incident number of injury/illness cases relative to the size of the population at risk, commonly referred to as an incidence proportion (Greenland and Rothman, 2008b). Within a sporting context, incidence proportion can be calculated by dividing the number of athletes that became injured/ill over a specified period of time (i.e., one season) by the number of athletes at risk at the start of this period (i.e., initial study population) (Knowles et al., 2006b). A notable difference between incidence rate and incidence proportion is that, to calculate incidence proportion, the numerator only considers the number of injured/ill athletes, rather than the total number of injuries/illnesses. Also, given that risk can be defined as the likelihood of an event occurring within a specified period of time, an incidence proportion can be seen as an estimate of average risk (Greenland and Rothman, 2008b). Therefore, a 'risk ratio' can also be calculated by dividing one groups' incidence proportion (i.e., boys) by the other (i.e., girls) (Greenland et al., 2008).

As a third measure of incidence, clinical incidence can be utilised to address the expected frequency of an outcome, in relation to a specified population (Knowles et al., 2006b). To calculate clinical incidence, the total number of injuries/illnesses in a specified time period is the numerator, while the number of athletes at risk at the start of this time period is the denominator. Therefore, clinical incidence is a measure of 'resource utilisation,' rather than being considered as a 'rate' or 'risk.' While Knowles et al. (2006b) express concern with this measure, they only do so when clinical incidence is reported independent of incidence rate and incidence proportion measures.

2.3.2.4.2 Prevalence

The term 'prevalence' refers to the proportion of individuals in a population who have experienced the outcome of interest at (or during) a specified period of time (Greenland and Rothman, 2008b). Prevalence can be calculated by dividing the number of athletes with an injury/illness at (or during) a specified period of time by the total population at risk (Timpka et al., 2014a, Bahr et al., 2020), thereby not accounting for different levels of exposure. When reported at a specified period of time (i.e., one week), known as 'point prevalence,' serial measurements allow for average prevalence to be calculated across a period of time (i.e., a season). Also, it is crucial to recognise that unlike incidence measures, focussed on the number of new injuries/illnesses, prevalence is focussed on the number of athletes with an injury/illness (Greenland and Rothman, 2008b, Bahr et al., 2020).

2.3.2.4.3 Severity

The severity of health problems can be measured in a number of different ways, including 'time loss,' an athlete's self-reported consequences of injury/illness, and the clinical extent and financial cost of injury/illness (Timpka et al., 2014a, Timpka et al., 2014b, Bahr et al., 2020). Therefore, decisions regarding how to measure severity should be made relative to study contexts and objectives, with strengths and limitations related to each approach.

Based on previous consensus statement recommendations (Timpka et al., 2014a, Bahr et al., 2020), the duration of time loss (days) is the most commonly applied severity measure (Fuller, 2007). This approach reflects the total number of days that an athlete is unavailable for training or competition, recorded from the day of onset until the athlete becomes 'fully available' again. When reporting these data, time loss can be separated into severity categories (i.e., 0, 1 day, 2-3 days, 4-7 days, 8-28 days, >28 days-6 months, >6 months), known as 'time bins.' Although this measure is straightforward and generally reflects injury/illness severity, it is possible for athletes to return to training or competition before a 'full recovery' has been achieved. If this is the case, then time loss measures will underestimate the absolute severity of injury/illness (Bahr et al., 2020); the same is true for those injuries/illnesses that limit performance, but do not stop or restrict the athlete from participating (Bahr, 2009). Given that presenteeism is commonplace among elite adolescent athletes (Mayer et al., 2018), whereby athletes train and/or compete despite an underlying health problem, this is likely to be the case in a population of adolescent distance runners. On the contrary, time loss may be overestimated if athletes decide against returning to training and/or competition after a serious injury/illness, even though they might be physically capable to do so.

To address the concern that athletes might experience injuries/illnesses that limit performance, but do not prevent them from participating, the OSTRC-H has been developed (Clarsen et al., 2013, 2014, 2020). When validating the OSTRC-H in a cohort of 313 elite adult Norwegian athletes, Clarsen et al. (2013) demonstrated that 419 overuse injuries (236 athletes) were recorded using the OSTRC-H, while only 40 overuse injuries (82 athletes) were recorded using standard methods (i.e., weekly injury reports completed by coaches), thereby supporting the argument that using a lime loss measure underestimates severity (Bahr, 2009). Specifically, the OSTRC-H allows athletes to self-report reduced sports participation, training modifications, performance reductions, and injury/illness symptoms (Clarsen et al., 2020). Based on responses to these different questions, a severity score can be calculated at specific time points, ranging from 0 to 100 (see Section 3.4.5), with the cumulative score being used to monitor injury/illness severity over time (Bahr et al., 2020); ‘substantial’ injuries/illnesses can also be identified. While this method addresses a limitation of time loss severity measures, the severity score and identification of ‘substantial’ injuries/illnesses are not yet validated outcomes (Clarsen et al., 2020).

Finally, the severity of injury/illness can also be measured according to clinical outcomes, including requirement of medical attention, patient-reported outcome measures, and recording cases of permanent disability and death (Timpka et al., 2014b, Bahr et al., 2020). Measures related to the financial cost of injury/illness may also be calculated, potentially related to professional athlete salaries (Hickey et al., 2014) or cost of sports injury hospitalisations (Yang et al., 2007).

2.3.2.5.4 Burden

The burden of injuries/illnesses can be calculated as the product of incidence and mean severity, usually reported as time loss days/1000 hours of participation and evaluated through the use of risk matrices and risk contours (Fuller, 2007, 2018, Bahr et al., 2018). However, to address the previously identified issues related to using time loss as a measure of severity, mean OSTRC-H severity scores can be used instead (Bahr et al., 2020).

A risk matrix is a graphical representation of severity plotted against incidence, including the application of 'criteria' to the graph (i.e., shading), allowing for the visual assessment of risk. An example of a risk matrix is provided in Figure 2.9. To overcome a number of limitations associated with risk matrices, such as the possibility of making inconsistent risk evaluations (Cox et al., 2005, Cox, 2008), 'risk contours' can be overlaid onto risk matrices. These contours represent all points of equal injury burden on a risk matrix (Fuller, 2007, Fuller, 2018), assisting with the evaluation of risk. However, to avoid distortion of contours and possible evaluation errors, it is advocated that linear scales are used on both axes (Fuller, 2018). If developed correctly, the creation of a risk matrix allows different injuries and illnesses to be compared in a visually appealing and simple way. This is very helpful when trying to communicate the level of risk to potential end-users of the data, such as coaches and National Governing Bodies. For example, in relation to Figure 2.9, the knee can be identified as the body region that represents the highest burden of sudden onset and gradual onset injuries (both located between the first and second contours in the risk matrix). Nevertheless, due to the greater severity associated with sudden onset knee injuries, it could be advised that more attention is given to understanding this pattern of injury, despite the slightly lower incidence. In turn, injury prevention measures to reduce the risk of sudden onset knee injuries could be a beneficial approach in this context (i.e., elite Norwegian endurance athletes).

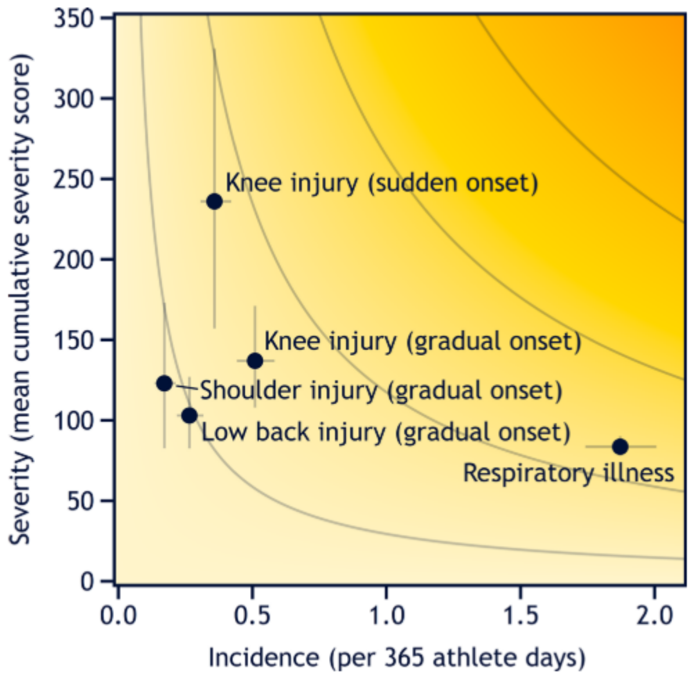

Figure 2.9: Risk matrix based on Oslo Sports Trauma Research Center Questionnaire on Health Problems severity scores illustrating the burden of injuries and illnesses affecting elite Norwegian endurance athletes (unpublished data). Error bars represent 95% confidence intervals. Reprinted with permission from BMJ Publishing Group Ltd. (copyright 2020), Bahr et al., 2020, *International Olympic Committee consensus statement: Methods for recording and reporting of epidemiological data on injury and illness in sport 2020 (including STROBE Extension for Sport Injury and Illness Surveillance (STROBE-SIIS)),* British Journal of Sports Medicine, 54(7), p. 385.

2.3.3 Injury and Illness Epidemiology in Adolescent Distance Runners

Having provided a review of the methods and definitions usually applied in injury and illness epidemiology research, it is important to provide an evaluation of previous studies that have investigated injury and illness in adolescent distance runners. As a result, the following sections of this literature review will critique the available data related to the incidence, prevalence, severity, and burden of health problems (injury and illness). This will initially focus on RRI in adolescent distance runners, including an overview of commonly affected body regions and potential correlates of RRI (i.e., risk factors), followed by a review of the existing data related to illness.

2.3.3.1 Incidence

Before reviewing the available epidemiological data related to the incidence of RRI within adolescent distance runners, it is crucial to emphasise that there is an abundance of data related to the incidence of RRI in adult distance runners. This is demonstrated by the range of systematic reviews (and meta-analyses) that have been published related to the incidence of RRI (Hoeberigs, 1992, van Mechelen, 1992, van Gent et al., 2007, Tonoli et al., 2010, Videbaek et al., 2015). Although this is a desirable situation, there are less data available related to adolescents. As injury prevention measures should be established for the specific context in which they will be used (Bekker and Clark, 2016, Bolling et al., 2018), it can be reasoned that providing a review of the adult-based studies is not required. This argument is enhanced when acknowledging that adult-based data should not just be extrapolated to adolescent populations. As a result, instead of providing an extensive review, comparison will be made to adult-based studies included in the most recent systematic reviews (Tonoli et al., 2010, Videbaek et al., 2015). These reviews have been selected as they differentiate between different types of runner in their analyses (i.e., novice and competitive athletes), allowing for meaningful comparisons to be made with adolescent data and the population of interest throughout this thesis.

In the primarily adult-based systematic review by Tonoli et al. (2010), only those studies published between 1999 and 2010 were included. A total of nineteen studies were analysed, within which novice, recreational, competitive, marathon, cross-country, and novice runners were represented. Notably, the data related to cross-country runners were drawn from studies of High School athletes in the USA (Rauh et al., 2000, 2006), as included in Table 2.5. As is often the case in injury epidemiology (Knowles et al., 2006b), the use of different injury definitions limited comparison between studies in this systematic review, while the use of different study designs may have affected the incidence rates related to RRI. As a further point, the article by Tonoli et al. (2010) did not report RRI incidence per 1,000 hours of distance running participation, regarded as a suitable way to report risk and compare between studies and different sports (Bahr et al., 2020).

In an attempt to address this issue, the systematic review and meta-analysis by Videbaek et al. (2015) identified the incidence of RRI per 1,000 hours in different types of runners. This included novice, recreational, and ultra-marathon runners, in addition to track and field athletes. Studies published between 1987 and 2014 were eligible for inclusion, with thirteen studies being included in the review. Due to a lack of studies related to ultra-marathon runners (n = 1) and track and field athletes (n = 2), meta-analyses were only conducted in relation to the novice and recreational runners. Since Videbaek et al. (2015) published this review article, a number of other studies have been conducted in relation to the incidence of RRI in adult distance runners. When appropriate, these studies will also be used as a point of comparison with available adolescent data, including a cohort of Dutch trail runners (Hespanhol Junior et al., 2017), groups of novice, recreational, and experienced runners (Kluitenberg et al., 2015b, Kemler et al., 2018), those training for a specific event (van Poppel et al., 2014, Baltich et al., 2017, Hollander et al., 2018, Dallinga et al., 2019, Franke et al., 2019), and cohorts of elite track and field athletes (Feddermann-Demont et al., 2014, Edouard et al., 2015, Edouard et al., 2020, Lundberg Zachrisson et al., 2020).

Related to the incidence of general RRI in adolescent distance runners, without focussing on a specific RRI outcome (i.e., medial tibial stress syndrome), a total of eighteen studies were identified to have reported such epidemiological data. Nevertheless, three of the identified studies, each of which include High School athletes from the USA (Chandy and Grana, 1985, Lowe et al., 1987, McLain and Reynolds, 1989), could not be retrieved and/or only an abstract could be obtained. The remaining fifteen studies are summarised in Table 2.5 and Table 2.6, split according to whether they focussed on cross-country runners or track and field athletes. Studies that included both types of runner are included in both tables.

As points of similarity, all identified studies related to cohorts of adolescent cross-country runners were conducted in an American High School setting (Table 2.5), having employed prospective study designs. For the studies that reported clinical incidence for RRI (Garrick and Requa, 1978, Shively et al., 1981, Beachy et al., 1997), figures ranged from 0.02 to 0.66 injuries per athlete in male athletes, and from 0.00 to 0.65 injuries per athlete in female athletes. Yet, due to the differences in study durations, injury definitions, and data collection methods, these results are difficult to compare. For example, injury was defined as “any event that altered the ability of a participant to compete or practise in a usual manner” by Shively et al. (1981, p. 47), while Beachy et al. (1997) defined injury “as any complaint that required the attention of the athletic trainer, regardless of the time lost from activity" (p. 676). As an extension of this point, these studies tended not to report the data collection methods in sufficient detail, nor did they account for RRI incidence per 1,000 hours of exposure (Knowles et al., 2006b).

Concentrating on those studies that did report RRI incidence per 1,000 hours of exposure ('all RRI') in adolescent cross-country runners (Rauh et al., 2000, Rauh et al., 2006), figures ranged from 13.1 to 17.0, including data from both male and female athletes. In an effort to compare these data with adult distance runners, the RRI incidence per 1,000 hours of exposure (time loss definition) in a cohort of Dutch trail runners (Hespanhol Junior et al., 2017), including male and female athletes, was reported as 7.7. As a comparable type of runner (i.e., trail vs. cross-country), this figure is distinctly lower than the data reported for adolescent cross-country runners. When these data are split according to sex, female athletes were found to have a higher incidence of RRI per 1,000 hours of exposure ('all RRI'), ranging from 16.7 to 19.6, compared to male athletes, ranging from 10.9 to 15.0 (Rauh et al., 2000, Rauh et al., 2006). These sex differences were statistically significant. Notably, the data included within the study by Rauh et al. (2014) is an analysis of the first four weeks of data collected as part of a preceding study (Rauh et al., 2006), only reporting data on initial RRI. Nonetheless, the incidence for initial RRI is similar across each of the three studies (Rauh et al., 2000, Rauh et al., 2006, Rauh, 2014), ranging from 8.7 to 10.4 per 1,000 hours of exposure. For female athletes, the incidence of initial RRI ranged from 10.4 to 11.9, while ranging from 7.6 to 9.4. Sex differences were only reported as significant in one of the three studies (Rauh et al., 2000)

Table 2.5: Epidemiological injury data (incidence) for adolescent cross-country runners.

Reference	Population (country)	Sample size n (%m) [total n]	Age range (y) Mean ± SD	Design	Duration	Injury definition	Collection method	Total injuries	Injury Incidence	Injury incidence per 1,000 h of exposure		
										Total	m	f
Garrick and Requa, 1978	High School athletes (USA)	167 (84) [3,049]	—	P	2 y	TL	Athletic trainers	50	m = 0.29 † f = 0.35 †	—	—	—
Shively et al., 1982	High School athletes (USA)	576 (68) [11,285]	—	P	1 y	TL	Coaches and physicians	9	m = 0.02 † f = 0.00 †	—	—	—
Beachy et al., 1997	High School athletes (USA)	1288 (39) [14,318]	—	P	8 y	APC/MA	Athletic trainers	843	m = 0.66 † f = 0.65 †	—	—	—
Rauh et al., 2000	High School athletes (USA)	3,233 (37)	—	P	15 y	TL	Coaches and/or athletic trainers	1,622	—	13.1	10.9	16.7
Rauh et al., 2006	High School athletes (USA)	421 (56)	—	P	1 s (11 w)	TL	Coaches	316	—	17.0	15.0	19.6
Rauh, 2014 [1]	High School athletes (USA)	421 (56)	m = 15.6 ± 1.2 f = 15.6 ± 1.1	P	1 s (4w)	TL	Coaches	67 *	—	9.4	7.8	11.4

Abbreviations: n, number of adolescent cross-country runners; %, percentage; m, male; f, female; [total n], total number of participants enrolled in study, including all sports and adults; y, year(s); SD, standard deviation; h, hours; P, prospective; R, retrospective; s, season; w, weeks; —, not specified; TL, time loss; APC, any physical complaint; [1], data included in this study is an analysis of the first month of data from Rauh et al. (2006); *, number of injured athletes; †, clinical incidence (total number of new injuries during a specified period of time divided by total number of athletes at risk).

In Table 2.6, the RRI incidence for adolescent track and field athletes is reported from identified studies. As argued in a recent study of male adolescent track and field athletes (Martínez-Silván et al., 2020), included in Table 2.6, the heterogeneity of track and field study populations is frequently a limitation when interpreting results, whereby athletes from different track and field disciplines are grouped together despite their differences. This issue is evident across most of the studies included in Table 2.6. For example, when grouping data based upon 'track events,' sprint, hurdle, and distance running disciplines all remain grouped (Shively et al., 1981, Beachy et al., 1997, Knowles et al., 2006a), even though they require different athletic skillsets. As a result, data specific to distance running has been reported in Table 2.6, where possible, representing two studies that were conducted at the same Qatari sports academy (Fourchet et al., 2011, Martínez-Silván et al., 2020).

Solely focussing on those studies that reported RRI incidence per 1,000 hours of exposure in adolescent track and field athletes (Knowles et al., 2006a, Jacobsson et al., 2013, Pierpoint et al., 2016, von Rosen et al., 2017, von Rosen et al., 2018a, Martínez-Silván et al., 2020), figures ranged from 0.72 to 3.89 in male athletes, and 0.99 to 4.60 in female athletes. Nevertheless, these data still remain difficult to compare due to the range of different study designs, injury definitions, and data collection methods applied across these studies. Likewise, comparison to adult-based data is problematic as sex differences are not always reported (Videbaek et al., 2015), and/or the RRI incidence is reported per 1,000 registered athletes, based on data recorded at international track and field events (Feddermann-Demont et al., 2014, Edouard et al., 2015, Edouard et al., 2020).

Table 2.6: Epidemiological injury data (incidence) for adolescent track and field and endurance athletes.

Reference	Population (country)	Sport(s)	Sample size n (%m) [total n]	Age range (y) Mean ± SD	Study design	Study duration	Injury definition	Collection method	Total injuries	Injury Incidence	Injury incidence per 1,000 h of exposure		
											Total	m	f
Garrick and Requa, 1978 [1]	High School athletes (USA)	All T&F events	516 (60) [3,049]	—	P	2 y	TL	Athletic trainers	174	m = 0.33 † f = 0.35 †	—	—	—
Shively et al., 1982	High School athletes (USA)	All track events	2,823 (60) [11,285]	—	P	1 y	TL	Coaches and physicians	36	m = 0.02 † f = 0.01 †	—	—	—
Watson and DiMartino, 1987	High School athletes (USA)	All T&F events	257 (68)	15.8 ± 1.3 [b]	P	1 s (77 d)	TL	Coaches and/or athletic trainers	41	0.16 †	—	—	—
D'Souza, 1994	Competitive T&F athletes (UK)	All T&F events	147 (65)	18.0 ± 2.5	R	1 y	TL	Custom questionnaire	90 *	—	—	—	—
Beachy et al., 1997	High School athletes (USA)	All track events	2736 (44) [14,318]	—	P	8 y	APC	Athletic trainers	1,940	m = 0.68 † f = 0.73 †	—	—	—
Knowles et al., 2006	High School athletes (USA)	All track events	2,269 (44) [15,038]	—	P	3 y	MA	Custom questionnaire	143	—	—	1.06	1.18

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Reference	Population (country)	Sport(s)	Sample size n (%m) [total n]	Age range (y) Mean ± SD	Study design	Study duration	Injury definition	Collection method	Total injuries	Injury Incidence	Injury incidence per 1,000 h of exposure		
											Total	m	f
Fourchet et al., 2011	Elite T&F athletes (Qatar)	Distance running	24 (100) [110]	—	P	3 y	MA	—	23	1.0 [††]	—	—	—
Jacobsson et al., 2013 [2]	Elite T&F athletes (Sweden)	All T&F events	126 (44) [292]	m = 17.0 ± 0.0 f = 17.0 ± 0.20	P	1 y	APC	Custom questionnaire	61 **	—	—	3.89	3.13
Pierpoint et al., 2016	High School athletes (USA)	All T&F events	—	—	R	5 y	MA/TL	Athletic trainers	2,485	—	0.84	0.72	0.99
von Rosen et al., 2017	Elite High School athletes (Sweden)	Distance running	31 (58) [150]	17 (16-18) [c]	P	26 w	APC	OSTRC-H	36	—	4.0	2.9	4.6
von Rosen et al., 2018a	Elite High School athletes (Sweden)	Endurance running [3]	76 (50) [284]	17 (17-18) [d]	P	52 w	APC	OSTRC-H	103	—	5.3	—	—
Martínez-Silván et al., 2020	Elite T&F athletes (Qatar)	Distance running	66 [a] (100)	m = 15.3 ± 1.6	P	5 y	MA/TL	Physiotherapists and/or physicians	57	—	—	3.7	—

Abbreviations: n, number of adolescent track and field and/or endurance athletes; %, percentage; m, male; f, female; [total n], total number of participants enrolled in study, including all sports and adults; y, year(s); SD, standard deviation; h, hours; T&F, track and field; P, prospective; R, retrospective; s, season; d, days; w, weeks; —, not specified; TL, time loss; APC, any physical complaint; MA, medical attention; OSTRC-H, Oslo Sports Trauma Research Center Questionnaire on Health Problems; [1], reported results are identical to Requa and Garrick (1981) paper; [2], only including adolescent athletes (study included adults and adolescents); [3], includes orienteers and track and field distance runners; [a], number of athlete seasons; [b], age range for all participants enrolled at beginning of study, including those omitted from analysis; [c], median (range); [d], median (25^{th}-75^{th} percentiles); *, number of injured athletes; age range of athletes at time of data collection (retrospectively reporting data for when they were 18-19 y); **, proportion (%) of athletes with at least one injury during study period; [†], clinical incidence (total number of new injuries during a specified period of time divided by total number of athletes at risk); [††], incidence rate (injuries per player year). N.B. Participants in the studies by von Rosen et al. (2017, 2018a) are drawn from the same cohorts of athletes. However, only distance runners are included in the first study, with these runners being combined with orienteers in the second study.

As a final observation, only one of the identified studies included a cohort of UK-based adolescent athletes (D'Souza, 1994). Nonetheless, the age of participants within this study ranged from 14 to 32 (i.e., included adults), while it can be argued that this data is now outdated. Both of these observations support the argument that context-specific surveillance data should be used to inform the development of prevention measures, whereby the study by D’Souza (1994) is not especially well aligned to inform such measures for competitive adolescent distance runners in England. As a result, this literature gap needs to be addressed (i.e., there is a limited amount of data related to adolescent distance runners based in England), whereby the application of current findings is largely constrained to the particular cohorts included within each of the identified studies, due to issues related to the generalisability of these data (Rothman et al., 2008b).

2.3.3.2 Prevalence

Alongside the studies identified that have reported the incidence of RRI, a number of studies have reported data in relation to the proportion of athletes who sustain an RRI at (or during) a specific period of time. This includes several studies, each including adolescent distance runners, which have utilised the OSTRC-H as part of their prospective data collection (von Rosen et al., 2017, von Rosen et al., 2018a, Moseid et al., 2018, Carragher et al., 2019). An overview of these studies is provided in Table 2.7.

Table 2.7: Epidemiological injury data (prevalence) for adolescent distance runners included as sub-samples in prospective cohort studies. Each study used the Oslo Sports Trauma Research Center Questionnaire on Health Problems data collection method and applied an "any physical complaint" definition of injury.

Reference	Population (country)	Sport(s)	Sample size n (%m) [total n]	Age range (y) Mean ± SD	Study Duration	Total injuries	Average weekly prevalence (%) (95% confidence intervals)					
							All injuries			Substantial injuries		
							Total	m	f	Total	m	f
von Rosen et al., 2017	Elite High School athletes (Sweden)	Distance running	31 (58) [150]	17 (16-18) *	52 w	36	32.4 (30.3-34.5)	39.3 (36.7-41.9)	21.9 (18.3-25.5)	17.0 (15.2-18.8)	23.2 (20.7-25.6)	8.2 (5.7-10.7)
Moseid et al., 2018	Elite High School athletes (Norway)	Endurance sports [1]	69 (67) [320]	m = 16.2 ± 0.3 f = 16.1 ± 0.03	6 m	79	15.0 (8.0-25.0)	—	—	22.0 (14.0-33.0)	—	—
von Rosen et al., 2018a	Elite High School athletes (Sweden)	Endurance running [2]	76 (50) [284]	17 (17-18) **	52 w	103	19.4 (18.3-20.5)	—	—	9.9 (9.3-10.5)	—	—
Carragher et al., 2019	Elite T&F athletes (Ireland)	Endurance sports [3]	25 (76) [70]	m = 17.3 ± 0.7 f = 17.3 ± 0.5	1 s (30 w)	17	25.9 (15.6-36.1)	21.6 (12.0-31.3)	38.3 (26.9-49.7)	15.4 (6.9-23.8)	13.6 (5.5-21.6)	20.2 (10.8-29.6)

Abbreviations: n, number of adolescent distance runners; %, percentage; m, male; f, female; [total n], total number of participants enrolled in study, including all sports; y, year(s); SD, standard deviation; T&F, track and field; w, weeks; m, months; s, season; —, not specified; [1], includes athletes from the following endurance sports: track and field, biathlon, cyclo-cross, cross-country skiing, Nordic combined, orienteering, paddling, and swimming; [2], includes orienteers and track and field distance runners; [3], includes middle- and long-distance runners, alongside race walk athletes; *, median (range); **, median (25th-75th percentiles). N.B. Participants in the studies by von Rosen et al. (2017, 2018a) are drawn from the same cohorts of athletes. However, only distance runners are included in the first study, with these runners being combined with orienteers in the second study.

Focusing on the average weekly prevalence data related to all injuries, including both sexes, figures ranged from 15.0% to 32.4%. In three of the four identified studies (von Rosen et al., 2017, von Rosen et al., 2018a, Carragher et al., 2019), the average weekly prevalence data related to substantial injuries was lower than the all injuries data, as is typically the case, whereby figures ranged from 9.9% to 17.0%. However, in the study related to Norwegian High School athletes (Moseid et al., 2018), average weekly prevalence data increased for substantial injuries. A potential explanation for this finding is related to the problems that the authors encountered with the electronic distribution of the OSTRC-H questionnaire. This included a weekly average response rate of 66% for the elite sport athletes in the sample and reliance upon supplementary interviews to account for missing data. Therefore, a situation might have arisen whereby those athletes who experienced a more substantial injury had an increased motivation to complete the OSTRC-H questionnaire, akin to recall bias. Alternatively, the range of different endurance sports included in this sample may have resulted in the higher weekly prevalence of substantial injuries, compared to a population that only consisted of adolescent distance runners.

In relation to sex differences, two of the four identified studies reported separate data for male and female adolescent distance runners/endurance sport athletes (von Rosen et al., 2017, Carragher et al., 2019). There was no discernible pattern to these data, with the average weekly prevalence of all injuries and substantial injuries being higher in male athletes, compared to female athletes, in one study (von Rosen et al., 2017), whilst being the opposite in the other study (Carragher et al., 2019). Nonetheless, sex as a potential risk factor for injury in adolescent distance runners will be discussed in Section 2.3.3.4.

Although not included in Table 2.7, the studies conducted by Moseid et al. (2018) and Carragher et al. (2019) also reported average weekly prevalence data related to acute and overuse injury. For all endurance sport athletes, when applying an all injuries definition, the prevalence of acute injuries ranged from 2.0% to 4.3%, and from 12% to 21.6% for overuse injuries. For substantial injuries, prevalence of acute injuries ranged from 1.0% to 2.6%, and from 6.0% to 12.8% for overuse injuries. These data align to previous evidence indicating that overuse is often the most common mode of onset within the sport of distance running, including adult and adolescent athletes (van Mechelen, 1992, DiFiori et al., 2014, van der Worp et al., 2015, Brenner, 2016). When reporting sex differences, Carragher et al. (2019) demonstrated that male athletes had a higher prevalence of acute injuries when applying both an all injuries (5.5% vs. 0.9%) and substantial injuries (3.5% vs. 0.0%) definition. However, male athletes had a lower prevalence of overuse injuries when applying both an all injuries (16.2% vs. 37.4%) and substantial injuries (10.1% vs. 20.2%) definition. Sex differences related to endurance sport athletes and prevalence of acute/overuse injuries were not presented by Moseid et al. (2018).

As an extension of a previous point, the heterogeneity of previous studies can be perceived as a limitation when interpreting these data. For example, each of the studies included in Table 2.7 include a sub-sample of endurance sport athletes or distance runners, each of which are incorporated as part of a broader sample. As a result, these studies are able to provide useful insight into the prevalence of injury in youth sport, yet lack detail related to the separate sports included within the study population. To address this limitation, future research should endeavour to include more homogenous study samples, to provide a comprehensive insight into the prevalence of injury within that population.

2.3.3.3 Body Region, Severity, and Burden

Based on the epidemiological data presented in the preceding sections, the lower limb can be identified as the most commonly affected body region for RRI within adolescent distance runners. This aligns to adult-based data (van Gent et al., 2007, Tonoli et al., 2010, Kluitenberg et al., 2015a), whereby the most frequently reported RRI body areas are located in the lower limb (i.e., knee and lower leg), regardless of distance runner type (i.e., novice or competitive). To better illustrate this point, using data from those studies included in Table 2.7, the proportion of RRIs that occurred in the lower limb is shown in Figure 2.10. The study conducted by Moseid et al. (2018) has not been included as the proportion of RRIs according to body region and area was not detailed. Across the remaining three studies, the proportions of 'all RRI' located in the lower limb were 94.4% (n = 34) (von Rosen et al., 2017), 94.2% (n = 97) (von Rosen et al., 2018a), and 93.9% (n = 31) (Carragher et al., 2019), respectively. Similar findings are reported in the studies included in Table 2.5, Table 2.6, and a paper by Huxley et al. (2014) that reported data on the most common sites in youth Australian track and field athletes.

In relation to the severity of RRI, the duration of time loss (number of days/weeks) is frequently reported. Related to those studies included across Table 2.5, Table 2.6, and Table 2.7, time loss data is reported in fourteen of the seventeen studies. However, time loss data are reported differently across these studies, while data related to cumulative severity scores and burden are also reported across a range of these studies. Thus, data are hard to compare between studies. For example, severity was categorised according to whether an athlete had missed at least five days of training, required assessment from a sports physician, or required an x-ray by Garrick and Requa (1978), while Shively et al. (1981) categorised severity according to if surgery was required or if the rest of the season was missed.

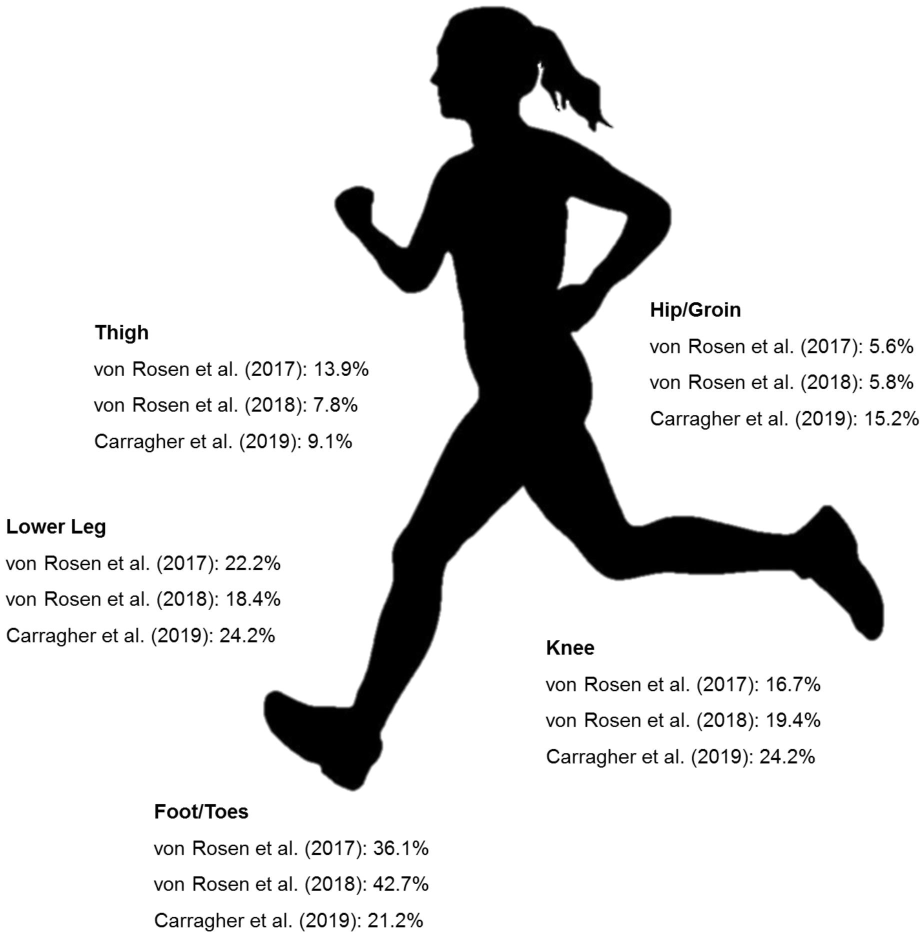

Figure 2.10: Proportion (%) of running-related injuries sustained in the lower limb according to different body areas of adolescent distance runners and endurance athletes. N.B. proportions were rounded to one decimal place and additional data from these studies are detailed in Table 2.7.

When reporting data according to different time loss severity categories (i.e., 'time bins'), comparison between studies becomes more straightforward. In two of the fourteen studies (Rauh et al., 2000, 2006), time loss was categorised according to four time bins: 1-4 days, 5-14 days, ≥ 15 days, and missing the remainder of a season, with the data being reported as an RRI incidence rate per 1,000 hours of distance running participation according to time loss category. Both of these studies included cross-country runners from American High Schools. As an initial trend across these data, the incidence rate for RRI reduced as the severity of RRI increased. This trend was observable for all injuries, including when these data were split according to sex. For example, the incidence rate for RRI resulting in 1-4 days of time loss ranged from 9.6 to 11.2, while season ending injuries led to an incidence rate of 0.8 in both studies. This trend was noticeable in three further studies that used different time bins to categorise severity data (Fourchet et al., 2011, Rauh, 2014, Pierpoint et al., 2016), including American High School cross-country runners and elite adolescent track and field athletes. However, this trend was not observed across all of the identified studies. This was most noticeable in a study by Jacobsson et al. (2013), whereby the proportion of injuries increased according to an increase in the severity of time loss. For example, the proportion of injuries in youth male track and field athletes (all event groups) increased from 23% for minor injuries (1-7 days of time loss), to 29% for moderate injuries (8-20 days of time loss), before reaching 47% for severe injuries (>21 days of time loss). For the youth female track and field athletes (all event groups), these proportions were 19%, 26%, and 55%, respectively. Across all of the track and field athletes (youth and adults) included in this study, 51% of all injuries led to more than three weeks of time loss. While the highest proportion of injuries were minor (1-7 days of time loss), ranging from 53-54%, two of the more recent studies also reported high proportions of moderate (8-28 days of time loss) and severe (>28 days of time loss) injuries in cohorts of adolescent track and field athletes (Carragher et al., 2019, Martínez-Silván et al., 2020). Notably, when split according to sex and event group, Carragher et al. (2019) found that female endurance athletes reported a higher proportion of severe injuries (37.5%), when compared to male endurance athletes (16%). Further investigation related to sex differences across different distance running contexts (i.e., event groups) is required.

Three out of the fourteen identified studies assessed injury severity according to the OSTRC-H severity score method (von Rosen et al., 2017, Moseid et al., 2018, von Rosen et al., 2018a), also used as a measure of burden (Bahr et al., 2020). Throughout the study by Moseid et al. (2018), average weekly severity scores and cumulative severity scores were reported for acute and overuse injuries, as originally detailed by Clarsen et al. (2013). Related to a cohort of Norwegian elite adolescent endurance athletes (both sexes), the average weekly severity score was 29 (interquartile range (IQR): 18, 44) for overuse injuries and 37 (IQR: 22, 48) for acute injuries, while average weekly cumulative severity scores were 71 (IQR: 28, 276) and 79 (IQR: 28, 162), respectively. When using a slightly different approach, the other two studies reported a cumulative severity score that had been adjusted according to the number of respondents, known as the severity grade, and detailed the most severe injuries according to body region. In a cohort of Swedish elite adolescent distance runners, the most severely affected body regions included the knee, foot, and lower leg, reporting severity grades of 3.9, 2.6, and 2.4, respectively (von Rosen et al., 2017). Within a separate cohort of Swedish elite adolescent distance runners, the most severely affected body regions included the thigh, knee, and foot, reporting severity grades of 2.0, 2.7, and 3.1, respectively (von Rosen et al., 2018a).

Finally, Martínez-Silván et al. (2020) reported data related to the burden of RRIs according to time loss days per 1,000 hours of exposure. Specific to adolescent endurance athletes, the burden of RRIs was 84.5 (95% CIs: 80-89), while ‘other bone injuries’ (excluding fractures) and non-specific pain were reported as the most burdensome RRIs within this cohort, reported as 23.5 (95% CIs: 21.1-26.0) and 9.5 (95% CIs: 8.1-11.2) time loss days per 1,000 hours, respectively.

2.3.3.4 Potential Correlates of Injury in Adolescent Distance Running

As a subsidiary aim of this thesis, potential correlates of RRI (risk factors) will be investigated. Effective identification of potential risk factors is important when attempting to establish the aetiology of RRIs, aligned to the second step of both the ‘sequence of prevention’ model and TRIPP framework (see Figure 2.5). This enables athletes and coaches, alongside other key stakeholders, to modify their practice in an effort to reduce the risk of RRIs. In turn, successful management of the risk of RRI is key for maximising athlete availability and performance (Roe et al., 2017). As originally proposed by Meeuwisse (1994), a number of factors need to interact for an injury to occur. These factors are often grouped according to whether they are ‘internal’ to an individual athlete (i.e., sex), known as intrinsic risk factors, or ‘external’ to the athlete (i.e., training practices), known as extrinsic risk factors. In turn, the interaction between the different intrinsic and extrinsic risk factors is what makes an athlete susceptible to injury.

Since Meeuwisse (1994) introduced a linear model for assessing sports injury causation, complex multi-factorial injury prevention models have been developed in an effort to better understand injury risk factors in a non-linear context (Gissane et al., 2001, Meeuwisse et al., 2007). Relevant to different sporting contexts, the dynamic and recursive model proposed by Meeuwisse et al. (2007) emphasises the adaptive response of an athlete before and after injury. As illustrated in Figure 2.11, this model accounts for intrinsic and extrinsic risk factors, alongside repeat sports participation. An athlete’s susceptibility to injury, therefore, can progress over time based on variations in intrinsic and extrinsic risk factors after exposure.

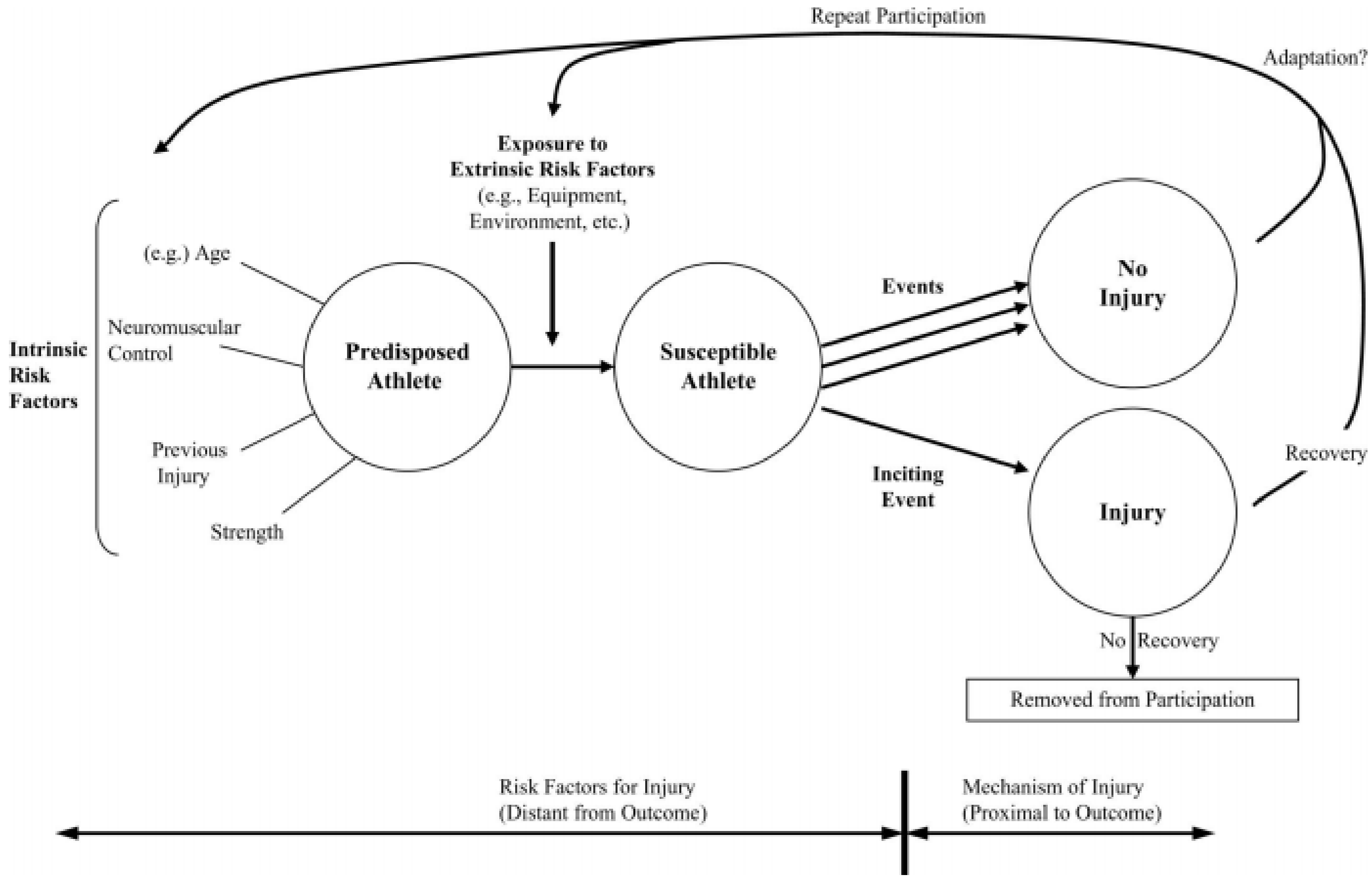

Figure 2.11: A dynamic, recursive model of aetiology in sport injury. Reprinted with permission from Wolters Kluwer Health, Inc. (copyright 2007), Meeuwisse et al., 2007, *A dynamic model of etiology in sport injury: The recursive nature of risk and causation*, Clinical Journal of Sport Medicine, 17(3), p. 217.

To improve our understanding of the complex nature of sports injury, ‘complex systems theory’ has been developed (Hulme and Finch, 2015, Bittencourt et al., 2016, Bekker and Clark, 2016, Hulme et al., 2019). This theory extends the work of von Bertalanfly (1956) to the field of Sports Medicine, whereby injuries are seen as complex phenomena (i.e., related to environmental, psychological, social, and physiological factors, etc.), occurring due to interactions between different phenomena, which might create regularities (i.e., risk profiles) that lead to an emergent pattern (Bittencourt et al., 2016). While this approach moves from identifying ‘risk factors’ to ‘risk profiles,’ thereby expanding our perception of the many contributing factors (i.e., complexity), it is only proposed as an alternative methodological approach (Hulme et al., 2019). Thus, aligning to the traditional approach, the following section of this literature review will focus on identifying the common risk factors for RRI related to adolescent distance running.

The evidence related to minimising the risk of injury in youth runners has recently been reviewed in a consensus statement by Krabak et al. (2020). As a result, the evidence provided as part of the consensus statement will be used as the basis for the subsequent sections of the literature review, alongside more general risk factors for injury in child and adolescent sport (Emery, 2003, Caine et al., 2008, Fabricant et al., 2016). It should also be stated that as the examination of potential correlates of RRI is a subsidiary aim in this thesis, the risk factors presented here only provide a considered snapshot of the evidence, rather than a comprehensive appraisal. As an extension of the studies reviewed throughout this thesis, related to general RRI outcomes, Krabak et al. (2020) also included studies that reported epidemiological data related to specific RRI outcomes in youth distance runners. These specific RRI outcomes included medial tibial stress syndrome (Bennett et al., 2001, Plisky et al., 2007, Yagi et al., 2013), stress fractures (Yagi et al., 2013, Tenforde et al., 2013, Changstrom et al., 2015), and medical disqualification injuries (i.e., season- or career-ending) (Tirabassi et al., 2016). When required, these studies will be discussed within the context of risk factors for RRI. It is also important to emphasise that multiple systematic reviews are available related to risk factors for RRI in adult distance runners (Hoeberigs, 1992, van Mechelen, 1992, van Gent et al., 2007, Saragiotto et al., 2014, van der Worp et al., 2015, Hulme et al., 2017). Therefore, when appropriate (i.e., due to a lack of evidence related to adolescent distance runners), data from these reviews will be used.

2.3.3.4.1 Sex

Sex is an intrinsic and non-modifiable risk factor. Within the recent youth running consensus statement (Krabak et al., 2020), it was stated that the current evidence strongly supports that female runners are at a higher risk for RRI and greater time loss from RRI, when compared to male runners. These findings were consistent across prospective cohort studies of High School cross-country and track athletes in the USA and Japan. For example, using RR data, female cross-country runners (RR 2.6, 95% CI: 1.0 to 7.5) and track and field athletes (RR 2.6, 95% CI: 1.7 to 4.0) were more likely to sustain a medical disqualification injury, when compared to male runners/athletes (Tirabassi et al., 2016).

This evidence is largely contrary to that reported in adult-based distance runners, whereby the majority of studies do not report differences in RRI according to sex (Hulme et al., 2017), even though some sex-specific risk factors have previously been identified (van der Worp et al., 2015). This evidence is also contrary to that reported in different youth sports, and performance levels, whereby the available data indicate that male athletes are generally at a greater risk of injury, compared to female athletes (Emery, 2003). Although this is not consistent across all youth sports, it does suggest that the data related to youth distance runners is relatively conflicting and requires further examination.

2.3.4.4.2 Chronological Age, Growth, and Maturation

Chronological age is an intrinsic and non-modifiable risk factor. Specific to youth distance runners, Krabak et al. (2020) suggest that there is a lack of data related to whether chronological age is a risk factor for RRI, while the available evidence is conflicting. This apparent lack of data may be related to the fact that different studies have considered different age ranges to frame their study sample, thereby making it difficult to frame consensus recommendations. Emery (2003) reports that the risk of injury increases with chronological age across most youth sports, whereby the peak injury rate is regularly in the oldest age-groups (i.e., under 18s) that are included in youth sport studies. This has recently been demonstrated in a four-season prospective study of elite youth football academy athletes (Qatar), aged from under 9 to under 19 years, whereby the highest injury burden was reported in the under 18 and under 19 age groups (Materne et al., 2020). Despite this evidence, Caine et al. (2008) suggest that the relationship between age and injury rates within youth sport is likely to be sport-specific, implying that additional evidence might be required in the case of youth distance runners, including data that is adjusted for exposure.

Alongside chronological age, both growth (i.e., growth rate) and maturation (i.e., maturity status, tempo, and timing) are intrinsic and non-modifiable risk factors. While not addressed in Krabak et al. (2020) consensus statement, a systematic review by Swain et al. (2018) stated that the available evidence does not support the association between growth, maturation, and musculoskeletal conditions (i.e., pain, injuries, and fractures). However, the available studies related to elite track and field athletes and High School distance runners are relatively consistent. For example, based on a cohort of elite male track and field athletes, including data across 117 athlete-seasons, Wik et al. (2020) reported that rapid growth in stature and leg length, skeletal maturity status, and maturity tempo represent risk factors for certain types of injury (i.e., bone and growth plate injuries). In a similar cohort of male athletes, based at the same Qatari sports academy, it was found that late maturing athletes (based on estimated age of PHV) were more likely to sustain foot, ankle, and lower leg injuries when compared to average and early maturing athletes (Fourchet et al., 2011). A similar result was also reported in a cohort of American High School runners (Tenforde et al., 2013), whereby female athletes reporting stress fractures frequently had a later menarche than uninjured athletes, potentially related to other complications (i.e., relative energy deficiency in sport).

2.3.3.4.3 Stature, Body Mass, and Body Mass Index

As highlighted by Krabak et al. (2020), there are a limited number of studies that have investigated the impact of stature and body mass on injury risk in youth distance runners. Stature can be regarded as both an intrinsic and non-modifiable injury risk factor, whereas body mass is both an intrinsic and modifiable injury risk factor. Based upon a prospective cohort study of 421 American High School cross country runners (14-18 years old), Rauh et al. (2006) found that stature and body mass were not significantly different between injured and non-injured adolescent athletes, when grouped according to sex. While this study was based on general RRI outcomes, a similar study of 230 Japanese High School runners (15-18 years old) reported no significant differences in the rate of lower limb stress fractures, as a specific RRI outcome, in relation to initial stature and body mass throughout a three-year follow-up period (Yagi et al., 2013). Although this evidence indicates that stature and body mass are not associated with an increased risk of RRI within adolescent distance runners, a limited amount of adult-based data indicates that there is some evidence for a positive association between male runners of greater stature and lower limb RRI (van Gent et al., 2007, Hulme et al., 2017). In relation to body mass, adult-based data is equivocal, whereby there is inadequate evidence to support that either higher or lower body mass significantly influences the risk of RRI (van der Worp et al., 2015, Hulme et al., 2017).

Body mass index is an intrinsic and modifiable injury risk factor. Available studies related to adolescent distance runners show that body mass index, unlike stature and body mass, is associated with an increased risk of specific RRI outcomes (Krabak et al., 2020). For example, data indicates that female adolescent runners with a body mass index below 19 kg/m^2 have almost three times greater risk for stress fractures, when compared to those with a body mass index above 19 kg/m^2 (Tenforde et al., 2013). Yet, adolescent cross country runners with a body mass index between 20.2-21.6 kg/m^2 has been identified to be 7.3 times more likely to experience medial tibial stress syndrome, irrespective of sex (Plisky et al., 2007). Specific to adult-based runners, it has been found that, despite equivocal results, neither a higher nor a lower body mass index can be strongly supported as influencing the risk of RRI (Hulme et al., 2017).

2.3.3.4.5 History of Previous Injury

As an intrinsic and non-modifiable risk factor, history of previous injury is regularly cited as a risk factor for future injury within different adolescent- and adult-based sporting contexts (Emery, 2003, Murphy et al., 2003, Fulton et al., 2014). History of previous injury is reported as a risk factor across all of the adult-based distance running systematic reviews (Hoeberigs, 1992, van Mechelen, 1992, van Gent et al., 2007, Saragiotto et al., 2014, van der Worp et al., 2015, Hulme et al., 2017). While the timeframe in which the influence of previous injury is studied can vary, it is common for this to be reported over the prior 12-months in distance running (Saragiotto et al., 2014). Furthermore, available evidence shows that previous injury of any type might increase the risk for a number of subsequent lower limb injuries (Toohey et al., 2017).

Specific to adolescent distance runners (Krabak et al., 2020), the results from five cohort studies of competitive High School runners show that there is an increased risk for general and specific lower limb RRI for runners with a history of previous injury compared to those without, with RRs ranging from 1.2 to 9.14 (Rauh et al., 2000, Rauh et al., 2006, Plisky et al., 2007, Reinking et al., 2010, Tenforde et al., 2013). Although the history of previous injury has been evidenced as a risk factor for injury among adolescent distance runners, it is also crucial to recognise that the previous injury might not have a causal effect on the subsequent injury (Hamilton et al., 2011b). In fact, it can be argued that this remains the case unless it is possible to precisely measure and account for all other injury risk factors that may contribute to a subsequent injury.

2.3.3.4.6 Training Practices

The term ‘training practices’ incorporates several extrinsic and modifiable factors that may influence the risk of RRI in adolescent distance runners, such as training intensity, frequency, and volume. Largely due to a limited pool of evidence and/or conflicting findings, Hulme et al. (2017) have previously found it difficult to draw conclusions in relation to the influence of different training distances, durations, frequencies, and paces on the given risk of RRI in adult middle- and long-distance runners. In relation to youth distance runners, Krabak et al. (2020) also found it difficult to draw conclusions, whereby only a limited amount of evidence was able to support various risk factors for RRI related to training practices. The available evidence included a study by Rauh (2014) that analysed the relationship between summer training practices and the risk of RRI throughout the first month of a cross-country season in a cohort of 421 American High School distance runners. Among the runners that trained during the summer, those who ran eight or fewer weeks or infrequently varied short and long mileage runs on different days were more likely to sustain an RRI in the first month of the cross-country season. This was found to be especially the case for female athletes. A number of studies have also investigated the effect of training load on the risk of RRI. For example, in a cohort of 103 elite Australian track and field athletes (13-17 years old), Huxley et al. (2014) found that injured athletes trained at a higher intensity and sustained higher annual training loads when aged between 13-14 years, whilst also completing more high intensity training sessions when aged between 15-16 years.

As an additional facet of training practices, an athlete’s level of specialisation can also be viewed as an extrinsic and modifiable risk factor for RRI. For example, based on the results from two systematic reviews (Fabricant et al., 2016, Bell et al., 2018), available evidence does support modest associations between a high level of specialisation and overuse injury. Yet, the studies included in both review articles include large heterogeneous samples of youth athletes, mostly consisting of team sport athletes, whereby sport-specific outcomes are not often reported. Thus, as stated in Section 2.1.3, the association between high levels of sport specialisation and injury has not yet been fully established, with further research and definitional rigour being required (Waldron et al., 2020, Jayanthi et al., 2020).

2.3.3.6 Illness Epidemiology

Elite adult endurance athletes have an increased susceptibility to illness when participating in major international outdoor athletics championships (Edouard et al., 2019). It is also believed that endurance athletes more commonly sustain upper and lower respiratory tract infections due to having to maintain particularly high training volumes and intensities (Schwellnus et al., 2010). Yet, data related to illness is rarely reported in prospective studies that are conducted outside of major championships, including the Youth Olympic Winter and Summer Games (Ruedl et al., 2012, Van Beijsterveldt et al., 2015, Steffen et al., 2017) and major international athletics championships (Edouard et al., 2019). Outside of major championships, only four epidemiological studies were identified that included data related to the prevalence of illness in adolescent distance runners, each of which adopted the OSTRC-H data collection method (von Rosen et al., 2017, von Rosen et al., 2018a, Moseid et al., 2018, Carragher et al., 2019). As a result, each of these studies utilised similar definitions of illness, whereby cases were self-reported by participants and included those health problems that affected body systems other than the musculoskeletal system, such as a respiratory system, as well as non-specific, psychological, and social problems. Specific details related to these studies have already been included in Table 2.7. In the studies published by von Rosen et al. (2017, 2018a), using similar cohorts of athletes (see Table 2.6 and Table 2.7), the prevalence of illness for all distance runners ranged between 14.0% (95% CIs: 11.2-16.9%) and 14.6% (95% CIs: 13.7-15.5%). In relation to sex differences, von Rosen et al. (2017) reported that the prevalence of illness was 16.3% (95% CIs: 12.1-20.4) in female athletes, and 12.2% (95% CIs: 9.1-15.2%) in male athletes. This discernible difference between female and male athletes was non-significant. Within the same study, von Rosen et al. (2017) reported that the most common illnesses were cold and flu, categorised as upper respiratory tract infections. Data related to the incidence, severity, and burden of illness was not reported within either of these studies, nor was a detailed discussion of illness types included either.

In the studies conducted by Moseid et al. (2018) and Carragher et al. (2019), the average weekly prevalence of illness was reported for all illnesses and substantial illnesses. These data were visibly lower in the study by Carragher et al. (2019), including a cohort of elite Irish endurance athletes, whereby the prevalence of all illnesses was 6.9% (95% CIs: 0.9-12.8%) for all endurance athletes, 8.9% (95% CIs: 2.2-15.5%) for female endurance athletes, and 5.8% (95% CIs: 0.3-11.2) for male endurance athletes. In contrast, Moseid et al. (2018) reported the average weekly prevalence of all illnesses, specific to a cohort of elite Norwegian endurance sport athletes, as 23% (95% CIs: 15-35%). This prevalence figure was higher compared to the adolescent technical (p = 0.035) and team sport (p = 0.002) athletes also included within this study. These average weekly prevalence figures for all illnesses fall either side of that reported within an adult-based cohort of elite Norwegian endurance athletes (Clarsen et al., 2014), whereby prevalence was reported as 16% (95% CIs: 13-18). While sex differences were not presented by Moseid et al. (2018), it is noticeable that female distance runners/endurance sport athletes tend to report a higher prevalence of illness (von Rosen et al., 2017, Carragher et al., 2019). Yet, as this is only based on a small number of studies, further data are required to support this observation. In the study by Carragher et al. (2019), the most commonly reported illnesses for the endurance athletes were upper respiratory tract infections, representing 81.8% of all illnesses, and those illnesses affecting the gastrointestinal system, representing 9.1% of all illnesses. This level of detail, related to types of illness, was not provided by Moseid et al.

(2018). Regardless, the high proportion of upper respiratory tract infections aligns with available adult-based data (Schwellnus et al., 2010).

In relation to substantial illnesses, Carragher et al. (2019) found that the average weekly prevalence of all illnesses, specific to endurance athletes, was 2.1% (95% CIs: 1.3-5.4%). These data were reported as 2.6% (95% CIs: 1.1-6.3%) and 1.8% (95% CIs: 1.3-5.0%) in female and male endurances athletes, respectively. In comparison, Moseid et al. (2018) reported the average weekly prevalence of substantial illnesses to be 15% (95% CIs: 8-25). Similar to the data related to all illnesses, the prevalence figures for substantial illnesses fall either side of that reported in an adult-based cohort of elite Norwegian endurance athletes (Clarsen et al., 2014), whereby prevalence was reported as 8% (95% CIs: 6-10). The differences between the adolescent-based studies are likely to be related to the different sample sizes, whereby a total of 69 endurance athletes were included in the study by Moseid et al. (2018), while only 25 were included within the study by Carragher et al. (2019). However, the study durations (24-weeks vs. 30-weeks) and time periods (between October and May vs. December and July) remained similar, thereby supporting the idea that variation exists between different cohorts of athletes.

Both of these papers also extended their analyses by reporting data in relation to the self-reported severity of illnesses (Moseid et al., 2018, Carragher et al., 2019). These data were largely omitted in the other two studies, having been focussed on RRI (von Rosen et al., 2017, 2018a). In relation to illness severity, Carragher et al. (2019) found that the highest proportion of illnesses were minor (1-7 days of time loss) for all endurance athletes (68.2%), female endurance athletes (57.1%), and male endurance athletes (73.3%). As no severe illnesses (>28 days of time loss) were self-reported, the remaining proportion of illnesses were of a moderate severity (8-28 days of time loss). Moseid et al. (2019) also found that the majority of illnesses were short in duration, reporting the median duration of illnesses as one week (IQR: 1, 2). Also, the average weekly severity of illnesses for endurance athletes was reported as 51 (IQR: 29,72), while the cumulative severity score was 72 (IQR: 37, 140). When compared to the same data on RRI, the average weekly severity score was higher than that reported for both acute and overuse injuries, while the cumulative severity score (i.e., burden) was similar to that reported for acute and overuse injuries.

2.3.4 Psychosocial Responses to Injury

While an improved understanding of the epidemiological data related to the health problems (injury and illness) that competitive adolescent distance runners usually experience is important, as addressed in previous sections, knowledge relating to how athletes respond to sport-related injury and the ensuing recovery process (i.e., rehabilitation) is of equal value. Yet, this perspective is regularly overlooked (Walker et al., 2007, Forsdyke et al., 2016), especially within youth sport contexts (Weiss, 2003). It can be argued, therefore, that better knowledge related to how competitive adolescent distance runners respond to RRI will improve subsequent RRI recovery processes and support in the development of context-specific injury prevention measures. Likewise, it is important to realise that adolescent distance runners might not have previously sustained an RRI, suggesting that an ability to better support these athletes may have a significant positive impact on their long-term health and wellbeing. As a consequence, this section of the literature review will start by introducing theoretical approaches that have previously been used to investigate different psychosocial responses to sport-related injury. This initial critique of the different theoretical approaches will lead to a comprehensive description of the 'integrated model of response to sport injury,' as proposed by Wiese-bjornstal et al. (1998). Previous literature that aligns to different aspects of this model will be reviewed following this initial description. Research studies that have included adolescent endurance athletes will be prioritised, in an attempt to align the reviewed literature with the athletes that this thesis is focused on.

Before introducing the theoretical approaches that have previously been used to investigate psychosocial responses to sport-related injury, it is crucial to highlight that previous research has studied psychosocial aspects of sport-related injury from both a pre-injury and post-injury perspective. However, as this thesis does not examine pre-injury perspectives in detail (i.e., no attempt is made to identify psychosocial antecedents to sport-related injury), theoretical approaches focused on this perspective have not been included in this review. Nonetheless, the review article by Williams and Andersen (2007) can be viewed as recommended reading, alongside the systematic review and meta-analysis by Ivarsson et al. (2017). Theoretical approaches have also been established in terms of coping/managing with a return-to-sport (Podlog and Eklund, 2007), as the final part of the 'recovery continuum,' as detailed in a recent consensus statement related to return-to-sport decision making (Ardern et al., 2016). Yet, as the present thesis has focused on psychosocial responses to RRI, alongside the initial recovery process, these approaches are also not included in this literature review. Finally, employing the same approach as used when detailing potential correlates (risk factors) of injury in adolescent distance runners (Section 2.3.3.4), research related to responses to sport-related injury has previously been reviewed (Brewer, 2007, Walker et al., 2007). Therefore, this research will be used to inform this section of the literature review, alongside a systematic review related to psychosocial factors associated with outcomes of sport-related injury recovery (Forsdyke et al., 2016).

2.3.4.1 Theoretical Approaches

An athlete's initial response to sustaining a sport-related injury can be problematic (Herring et al., 2006, Wiese-Bjornstal, 2010), potentially resulting in a number of different psychosocial outcomes (and further physical (i.e., biological) outcomes) that affect their recovery. In a health context, the term 'psychosocial' is related to the influence of social factors on an individual's mind or behaviour, and the given interrelationship between behavioural and social factors (Martikainen et al., 2002). Therefore, in an attempt to account for the variety of psychosocial and physical factors related to sport-related injury, multiple theoretical approaches have been proposed to investigate how these factors affect an athlete's response to sport-related injury, and the recovery process. These include a biopsychosocial model, stage models, and cognitive appraisal models, all of which are introduced below.

2.3.4.1.1 Biopsychosocial Models

As a broad theoretical approach, Brewer et al. (2002) proposed a biopsychosocial model related to recovering from sport-related injury. This theoretical model can be viewed as an extension of the original work of Engel (1977), who developed the initial biopsychosocial model that has since been applied in the field of Sports Medicine (Jull, 2017). As shown in Figure 2.12, this model allows for concurrent consideration of the comparative contribution of different biological, psychological, and social factors when aiming to understand the intermediate biopsychosocial outcomes (e.g., rate of recovery) and ensuing recovery outcomes (e.g., readiness to return-to-sport). This model also accounts for injury characteristics (e.g., body region, severity) alongside sociodemographic factors (e.g., sex, age). Although this model accounts for multiple factors, it was suggested that the psychological factors maintain the central mediating role on the recovery process, and eventual return-to-sport (Brewer et al., 2002). It should also be emphasised that the comparative contribution of these factors does differ among individuals, while the contribution of these factors can change during the recovery process too. Related to these points, this model also theorises that the psychological factors retain a bidirectional relationship with the biological factors and social/contextual factors. This is also true for the relationship between the psychological factors and the intermediate outcomes, and with injury recovery outcomes (Brewer, 2007).

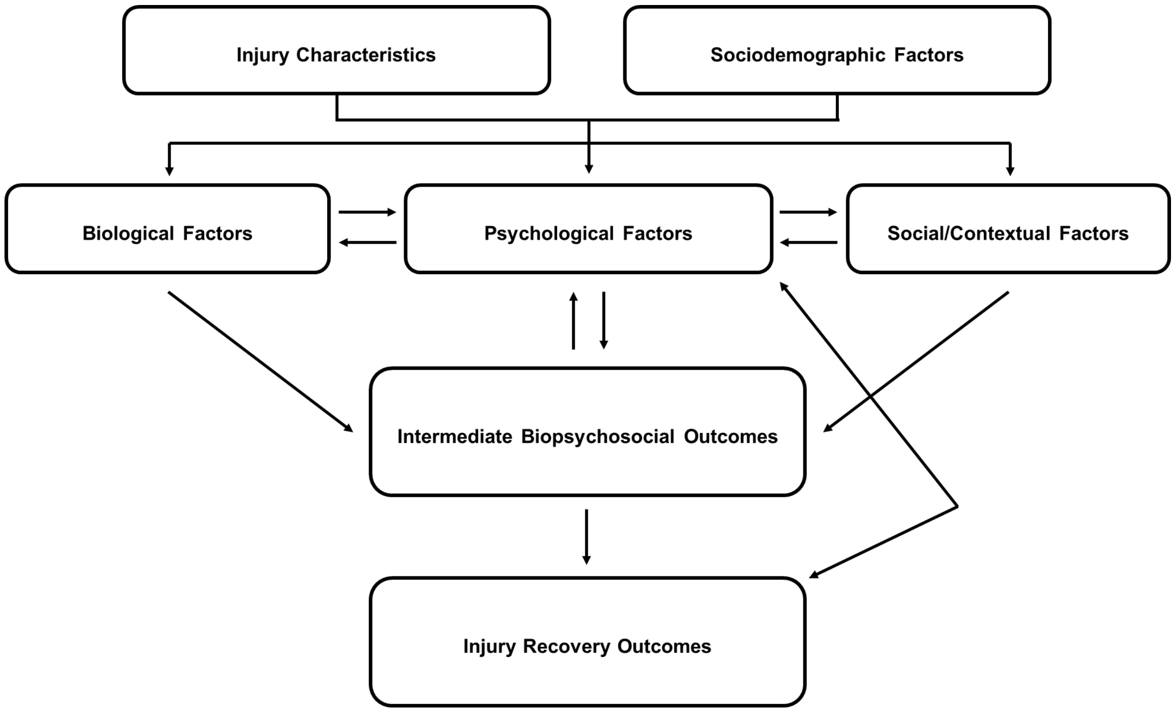

Figure 2.12: Adapted biopsychosocial model of sport injury rehabilitation.

It should also be noted that a biopsychosocial model of stress and athletic injury and health has been proposed by Appaneal and Perna (2014). This model posits that emotional, behavioural, and physiological aspects (akin to biological factors) of stress response need to be considered in combination with attention disruption to fully understand the possible pathways that mediate the relationship between psychosocial stress and adverse health outcomes, such as injury. One benefit of adopting this model is that it clarifies mediating physiological pathways between athletes' stress response and adverse health outcomes.

Although these biopsychosocial models present broad theoretical frameworks to study the different responses to sport-related injury, and subsequent recovery process, this breadth is also viewed as a limitation (Brewer et al., 2002). For example, Brewer et al. (2002) proposed biopsychosocial model does not provide explanations for how different responses to sport-related injury can influence recovery outcomes (Brewer, 2007), while the underlying idea of 'eclecticism' may make judgments related to implementing intervention measures challenging (Jull, 2017). Furthermore, no indication is provided in these models about which factors are likely to be the most important in relation to the quality and experience that an individual has during their recovery from a sport-related injury. Therefore, to ascertain in-depth knowledge about different psychosocial factors, including the relationships between such factors, studies have also used stage models and cognitive behavioural models.

2.3.4.1.2 Stage Models

Having been adapted from research focussed on grief and loss, stage models have traditionally been used to describe responses to sport-related injury (Brewer, 2007). As the 'grief response' has been theorised as a response to the loss of a significant other, object, or ability, the parallels to sustaining a sport-related injury are evident (Evans and Hardy, 1995). Such a model assumes that sport-related injury signifies loss and that an athlete's ensuing response occurs in a predictable sequence (Walker et al., 2007). One of the more commonly applied stage models, to investigate sport-related injury, was first proposed by Kübler-Ross (2005). This model theorises that 'a grieving athlete' moves through five sequential stages: (1) denial, (2) anger, (3) bargaining, (4) depression, and (5) acceptance. Although previous research has supported the idea that an athlete can respond to a sport-related injury in a way that is consistent with a grief response, the contention that their response always follows these stages has not been consistently supported (Brewer, 1994). On the contrary, how an athlete responds to a sport-related injury seems to be particularly variable, whilst being specific to the context within which each athlete resides. As a result, models that acknowledge the individual and contextual differences related to an athlete's response to sport-related injury have been theorised as alternative approaches, such as cognitive appraisal models.

2.3.4.1.3 Cognitive Appraisal Models

Cognitive appraisal models are frequently used to obtain a more comprehensive insight related to how an athlete responds to a sport-related injury (Walker et al., 2007), accounting for individual differences (Brewer, 1994). Based upon theories related to stress and coping (Brewer, 2007), these models provide a theoretical framework for investigating how an individual assesses a stressful situation, such as a sport-related injury, how they appraise the extent of this stress, and how this appraisal affects how they cope with their given situation – viewed as a recursive process. Although several cognitive appraisal models have been theorised and applied to sport-related injury, the 'integrated model of response to sport-related injury,' first established by Wiese-bjornstal et al. (1998), is deemed to be the most comprehensively developed and accepted model (Brewer, 2007). As this model has been applied within Chapter 6 of the present thesis, Section 2.3.4.2 of this literature review introduces this model in more detail, whilst offering a critique of previous literature that aligns to the different aspects of this model. However, the above overview of different theoretical approaches highlights that no single model dominates the literature surrounding responses to sport-related injury, whereby decisions should be made based on the specific aims of the study.

2.3.4.2 Integrated Model of Response to Sport-Related Injury

The integrated model of response to sport-related injury, as shown in Figure 2.13, contends that a range of different personal and situational factors determine an athlete's initial cognitive appraisal of their injury, in addition to their subsequent emotional (e.g., grief) and behavioural (e.g., risk taking behaviours) responses. Therefore, an athlete's grief response, that of which is the overarching focus of stage models, is subsumed within this integrated model (Wiese-bjornstal et al., 1998). This model also considers the impact of psychosocial variables before the onset of sport-related injury, as first developed by Andersen and Williams (1988). Based on an athlete's cognitive appraisal of their sport-related injury, in combination with their emotional and behavioural responses, physical and psychosocial recovery outcomes become apparent. These outcomes can either be positive or negative. Together, these three distinct elements of the model (i.e., cognitive appraisal, emotional response, and behavioural response) are referred to as the 'dynamic core.'

The 'dynamic core' highlights that the relationship between cognitive appraisals, and emotional and behavioural responses is reciprocal, whereby the predominant pathway (indicated by the larger arrows in Figure 2.13) is that cognitive appraisal affects emotions, which then affects behaviours (Walker et al., 2007) – resulting in positive or negative psychosocial recovery outcomes. Notably, these recovery outcomes do not necessarily take place at the same time. It is also important to highlight that this model is viewed as a recursive process, whereby an athlete is able to reappraise their situation according to evolving contextual factors.

As reviewed by Brewer (2007), there is an ample amount of empirical support for the 'integrated model of response to sport-related injury.' As a result, the following section of the literature review will not simply duplicate this prior review. Instead, the focus will be on those studies that have included endurance athletes and/or adolescent athletes as participants. At this point, it should also be mentioned that in their study related to the return-to-sport experiences of adolescent athletes, Podlog et al. (2013) contended that this was the first study to consider adolescent perspectives on sport-related injury. Given that this study was published relatively recently, further research related to adolescent athletes is certainly justified. This is especially the case in relation to competitive adolescent distance runners, due to the lack of previous research and contextual knowledge.

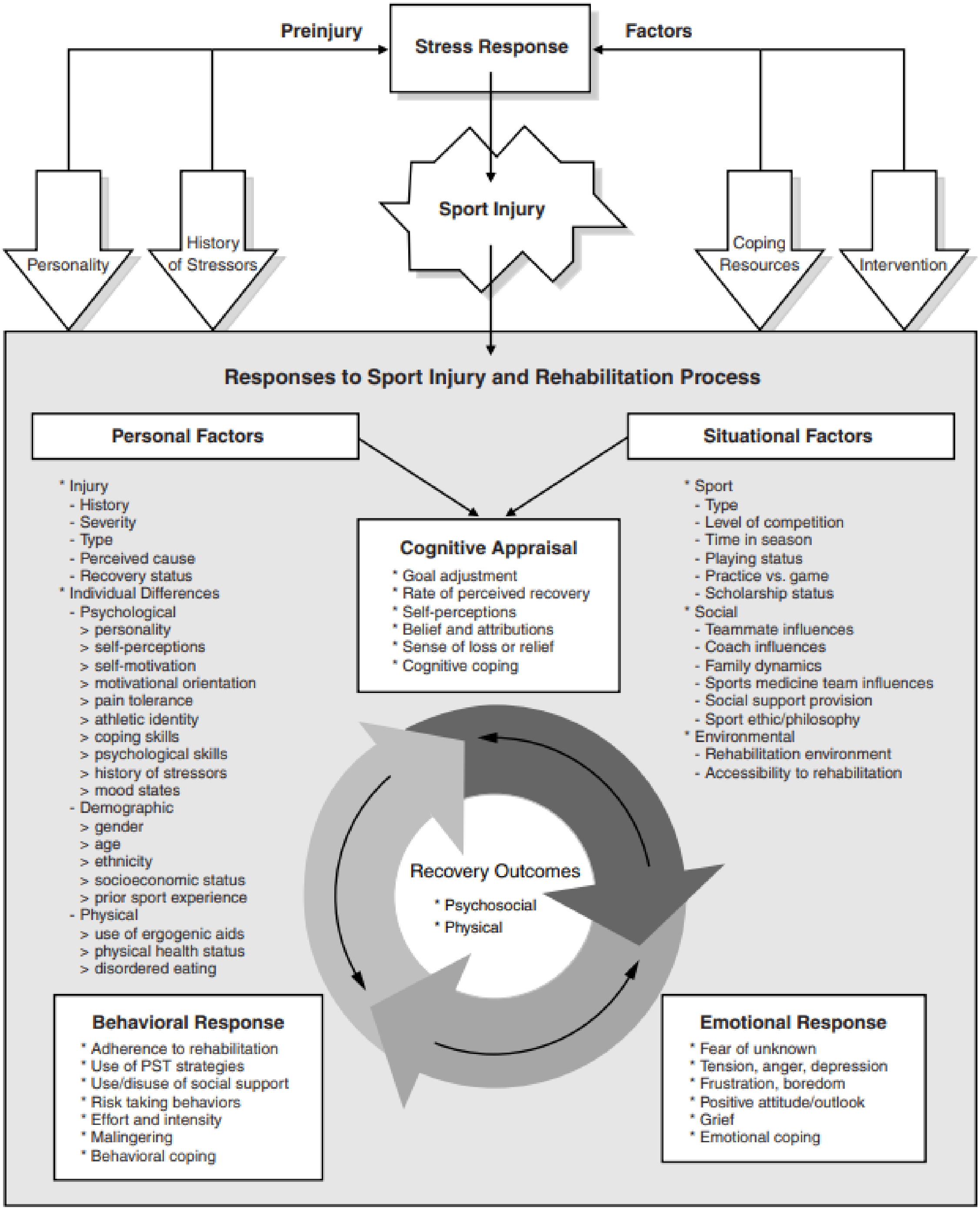

Figure 2.13: The integrated model of response to sport injury. Reprinted with permission from Taylor & Francis Group (copyright 1998), Wiese-Bjornstal et al., 1998, *An integrated model of response to sport injury: Psychological and sociological dynamics*, Applied Sport Psychology, 10(1), p. 49.

One of the most relevant studies to have examined psychosocial responses to sport-related injury, in relation to this thesis, was conducted in a cohort of elite Swedish adolescent athletes (von Rosen et al., 2018b). In this study, data derived from five focus groups (4-6 athletes per group), including three distance runners (total sample, n = 20 athletes), demonstrated that sport-related injury can result in negative psychosocial outcomes, including feelings of loneliness, frustration, and self-blame. In turn, each of these outcomes led to an overarching theme that an athlete's 'sense of athletic identity' was threatened by their sport-related injury. The athletes involved in the focus groups for this study had been injured between two-months and four-years, with five of the athletes still injured at the time of the interview. In reference to the 'integrated model of response to sport injury,' this study also identified a range of personal and situational factors that influenced the recovery process. For example, an athlete's ability to cope (i.e., coping skills), classified as a personal factor, was seen to be a key aspect of their initial cognitive appraisal and ensuing psychosocial response. In terms of situational factors, the amount of social support that athletes received was considered to be important, whereby limited levels of support were received beyond an athlete's immediate friendship circle. Despite these astute findings, this study did not try to interpret their results in relation to a pre-existing theoretical model, as detailed in Section 2.3.4.1. This can be seen as a study limitation. Also, due to the small sub-sample of adolescent distance runners (n = 3), it is unlikely that these results are generalisable to other cohorts of adolescent distance runners.

In a separate study, Podlog et al. (2013) applied basic psychological needs theory to assess adolescent athletes' experiences of sport-related injury. Although this theoretical approach is more often applied when studying psychological aspects of an athlete's return-to-sport (Podlog and Eklund, 2007), rather than responses to sport-related injury, the findings remain relevant to this literature review. Having conducted semi-structured interviews with eleven elite Australian adolescent athletes who had sustained a severe injury (≥4 weeks of time loss), including one track and field athlete (event preference not specified), the results highlighted the following four themes: (1) injury stress, (2) coping strategies, (3) experiences with social support, and (4) recovery outcomes. Related to the initial response to their sport-related injury, it was typical for these athletes to struggle with the prospect of missing substantial periods of competition (i.e., injury stress), aligning to the emotional response of 'frustration,' as previously described by von Rosen et al. (2018b). A degree of worry and anxiety was also shown by athletes in relation to how their sport-related injury would affect their performance. When considering coping strategies and social support, Podlog et al. (2013) reported that the elite adolescent athletes rarely employed coping strategies, while social support from their parents, teammates, coaches, medical professionals, and role models was considered to be helpful in their response to sport-related injury, as a situational factor. This finding dovetails with the results offered by von Rosen et al. (2018b), whereby social support was judged to be an important factor, but was not often received beyond an athlete's immediate friendship group. While these findings are relevant to adolescent distance runners, the generalisability of these data are limited. Therefore, it is essential to identify whether these psychosocial responses to sport-related injury are also evident in competitive adolescent distance runners, in order to provide these athletes with context-specific support following RRI.

In relation to the recursive process that athletes can experience when recovering from sport-related injury (i.e., reappraisal based upon evolving contextual factors), a study conducted by Jelvegård et al. (2016) provides relevant insight for distance runners. Including a sample of twenty elite Swedish adult distance runners, it was evidenced that an athlete's initial cognitive appraisal of an RRI influenced the subsequent recovery outcomes. For example, if an athlete classified their RRI as having a gradual onset, then the ensuing behavioural response was often varied and resulted in 'overactivity.' As a consequence, instead of reducing their training load until a full recovery was attained, athletes would continue to train despite the pain that the RRI caused. This was typically accompanied be 'magical thinking,' whereby athletes believed that the RRI would resolve itself, without intervention. On the contrary, if an athlete sustained a sudden onset RRI (or illness), then the behavioural response normally led to an adjusted training load until a full recovery was made. This study also showed that intervention from a medical professional could alter an athlete's behavioural response, whereby knowledge of a diagnosis allowed distance runners to adjust their training load to safeguard their recovery, rather than simply continuing to train through the pain. This finding aligns to the results of a separate study that included a cohort of twelve elite international long-distance runners (Bargoria et al., 2020). Based on a thematic analysis of semi-structured interviews, it was found that the main strategy that these elite athletes used to stay healthy and maintain their superior performance was characterised by continually paying attention to possible symptoms of RRI (or illness), listening to medical advice, and not allowing situational factors to influence their decision to adjust their training load when they suspected that they had sustained an RRI (or illness). When viewed collectively, these studies highlight that an elite distance runner's psychosocial response to RRI, and subsequent recovery, is a complex process and dependent upon the given context within which the athlete performs. Therefore, similar types of academic inquiry (i.e., context-specific) are necessary in order to gain insight into how competitive adolescent distance runners respond to RRI, alongside their subsequent reappraisals of RRI.

Within the previous three paragraphs it has been established that an adolescent athlete's psychosocial response to, and recovery from, a sport-related injury can be influenced by situational factors (Podlog et al., 2013, von Rosen et al., 2018b), while elite adult distance runners frequently respond to gradual onset injuries by continuing to train, despite pain (Jelvegård et al., 2016). When viewed together, it becomes apparent that 'context matters,' whereby the specific type of sport and performance level might affect an athlete's cognitive appraisal of a sport-related injury. As a result, previous literature that has focused on the concept of 'playing hurt' (Roderick et al., 2000), often referred to as presenteeism, becomes relevant. Yet, further research is required to explore whether this is an issue for competitive adolescent distance runners. This concept is related to the notion that an athlete would be able to rationalise training and/or competing while also experiencing a health problem (Curry, 1993, Nixon, 1992, Nixon, 1993), believed to be influenced by situational factors that may affect an athlete's response to sport-related injury. Specific to a cohort of elite German adolescent athletes (14-18 years), the extent of risk-taking behaviour related to playing hurt was reported to be associated to the level of significance that an athlete ascribed to their 'sports environment,' in comparison to their 'non-sports environment' (Schnell et al., 2014). This study also found that athletes who were deemed to be perfectionists and were focused on their performance were more willing to take on physical and social risks. However, as a contrary finding in a similar cohort of adolescent athletes, Mayer et al. (2018) found that elite endurance sport athletes were the least willing group to compete while hurt (i.e., experiencing pain). Due to these contrasting findings, an examination of whether presenteeism occurs within a cohort of competitive adolescent distance runners is justified.

2.4 Summary and Research Aims

The shared goal of all stakeholders involved in youth sport should be to "develop healthy, capable and resilient youth athletes" (Bergeron et al., 2015, p.843). In order to better understand how to accomplish this goal, in relation to competitive adolescent distance runners, in England, this chapter has reviewed the existing literature in relation to the following interconnected topics: (1) measuring training load, with an emphasis on the use of simple and cost-effective measures of ITL; (2) injury and illness epidemiology, including discussion related to the 'sequence of prevention,' commonly applied research methods and definitions of key terms, and previous epidemiologic studies related to adolescent distance running; and (3) the range of theoretical approaches used to assess an athlete's response to sport-related injury. Based on this literature review, it was recognised that: (1) the temporal robustness and validity of sRPE and dRPE, in relation to measuring ITL, has yet to be established within this population; (2) previous epidemiologic studies have tended to only include adolescent distance runners as a sub-sample within larger and heterogenous study populations, theoretically resulting in a loss of context-specific detail; and (3) there is a lack of prior research and contextual knowledge in relation to competitive adolescent distance runners' psychosocial response to RRI.

To address these gaps in the available literature, the primary aim of this thesis is to describe and evaluate the extent of the injury and illness problem in competitive adolescent distance runners (13-18 years) in England, thereby aligning to the first step of the 'sequence of injury prevention.' As subsidiary research aims, this thesis will also: (1) investigate the effect of measurement timing and concurrent validity of sRPE, dRPE-L, and dRPE-B, in order to quantify ITL in this population, and (2) explore potential correlates of RRI (risk factors). This latter aim aligns to the second step of the 'sequence of injury prevention.' More specifically, this thesis will:

- Investigate the temporal robustness and concurrent validity of using sRPE as a measure of ITL in adolescent distance runners (Chapter 4).
- Apply a retrospective study design to examine the typical training practices and descriptive epidemiology of RRI in a cohort of competitive adolescent distance runners, while also exploring potential correlates (risk factors) of RRI (Chapter 5).
- Use semi-structured interviews to investigate the psychosocial responses to *serious RRI* (>28 days-6 months of time loss) in a cohort of competitive adolescent distance runners (Chapter 6).
- Apply a prospective cohort study design to describe the prevalence, incidence, severity, and burden of health problems (injury and illness) in a cohort of competitive adolescent distance runners (Chapter 7).
- Provide a summary of the key findings and practical applications stemming from this thesis, as well as offering thoughts related to the possible future directions of research based on these findings (Chapter 8).

3. GENERAL METHODS

The four original research chapters (Chapters 4 to 7) included in this thesis stem from three separate studies. As a mixture of quantitative and qualitative research methods were used throughout this thesis, this chapter first provides a rationale for adopting a pragmatic (mixed methods) approach. Following this, an overview of how health problems (injuries and illnesses) were recorded and reported within this thesis will be provided, before detailing the given equipment, procedures, and outcomes used in each study. More specific details can be found in each original research chapter (Chapters 4 to 7). Each study received ethics approval from the Sport and Health Sciences Ethics Committee (see Appendix A). Throughout this section, please note that the term ‘principal investigator’ refers to Robert Mann.

3.1 Pragmatic Approach

Paradigms represent *worldviews* that influence how a research scientist designs, implements, and represents their research (Guba and Lincoln, 1994). There has been continual debate concerning the strengths, weaknesses, and compatibility of quantitative and qualitative research paradigms – referred to as *the paradigm wars* (Bryman, 2008). The contention that these paradigms are incompatible has subsided (Bryman, 2006), with mixed methods approaches now being advocated (Johnson and Onwuegbuzie, 2004, O'Cathain, 2009, Gibson, 2016). Situated within the research paradigm of *pragmatism*, mixed methods approaches enable researchers to employ quantitative and/or qualitative methods that are deemed to be most suitable for the purpose of scientific inquiry, justified on ‘pragmatic’ rather than ‘ideological’ grounds (O'Cathain et al., 2007). This thesis is orientated towards the paradigm of *pragmatism*, accepting the existence and importance of objective and subjective research domains (Johnson and Onwuegbuzie, 2004).

The phrase ‘orientated towards’ is important when discussing the adoption of a mixed methods approach in relation to this thesis. Across the three studies, only the second study (Chapters 5 to 6) adopted a ‘genuine’ mixed methods approach. In this second study, quantitative methods were given dominant status, compared to the qualitative methods (a QUANTqual weighting), having been conducted in a sequential manner (Johnson and Onwuegbuzie, 2004), in that the quantitative research (Chapter 5) was followed by the qualitative research (Chapter 6). This approach is defined as an *explanatory sequential* mixed methods design (Fetters et al., 2013). Yet, across each of the studies (Chapters 4 to 7), implementing a pragmatic approach has enabled the research – overseen by a multidisciplinary supervisory team – to draw upon the given strengths of different research fields, in order to employ the research method (i.e., qualitative, quantitative, or mixed methods) that was most suitable for achieving the research aims. Furthermore, *pragmatism* was adopted due to the overarching focus on the practical application (i.e., within a real-world setting) of the results from this thesis, thereby supporting the health and wellbeing of competitive adolescent distance runners.

3.2 Study Designs

The four original research chapters (Chapters 4 to 7) included within this thesis stem from three separate studies. An overview of the methods applied in each of these studies is presented in Table 3.1, including details related to study design, data collection, and study sample size.

Table 3.1: Methodological overview of included studies in this thesis

	Study I	**Study II**		**Study III**
	Chapter 4	Chapter 5	Chapter 6	Chapter 7
Method	Quantitative	Mixed Methods		Quantitative
Design	Prospective cohort	Retrospective cross-sectional	Semi-structured interviews	Prospective cohort
Data collection	Laboratory and field-based	Web-based questionnaire	Semi-structured interviews	Web-based questionnaire
Sample size (n)	15	113	19	136

Abbreviations: n, number.

Study I (Chapter 4) used a prospective cohort study design, whereby participants completed a laboratory visit, followed by a two-week mesocycle of normal training. Data collection for this study took place between May and September 2017. In terms of a research field, this study aligns to *Applied Sports Physiology*.

Study II used a sequential mixed methods study design, whereby participants were required to complete a retrospective questionnaire (Chapter 5), before a sub-sample of the participants were invited to take part in semi-structured interviews (Chapter 6). Chapter 5 applied a retrospective cross-sectional design, with data collection occurring between April and December 2018. Data collection for Chapter 6 took place between November 2018 and February 2019. In terms of aligning to research fields, Chapter 5 aligns to *Sports Medicine*, while Chapter 6 aligns to *Qualitative Research in Sport and Exercise*.

Study III (Chapter 7) employed a prospective cohort study design, based upon completion of an online questionnaire (submitted weekly). Data collection for this study took place between May and October 2019 (24-week follow-up). In terms of research field, this study also aligns to *Sports Medicine*.

3.2.1 Ethics Approval

Each of the three studies, as shown in Table 3.1, received ethics approval. Each application was reviewed and approved by the Sport and Health Sciences Ethics Committee, University of Exeter, before commencing each study. The ethics approval certificates for Study I (170315/B/03), Study II (171206/B/02), and Study III (180801/B/02) are included in Appendix A.

Throughout each study, all necessary precautions were taken to guarantee the safety of participants during data collection. For example, all researchers involved with data collection had to have obtained relevant Disclosure and Barring Service checks to certify their ability to work with adolescent participants – identified as vulnerable persons (Crane and Broome, 2017).

3.2.1.1 Informed Consent and Assent

All potential participants and their parent(s)/legal guardian(s) were provided with a participant information sheet that detailed the purpose of the study in question, as well as the procedures involved and likely time commitments. Once potential participants and their parent(s)/legal guardian(s) were happy to proceed, having had any of their questions answered, informed consent and assent was obtained from both parties. Both the participant information sheet and informed consent/assent forms received ethics approval before being distributed, having been written with a suitable readability level for adolescent participants. These forms could be completed online or as a paper copy. All participants over the age of 16 years were only required to provide informed consent, without consent being required from their parent(s)/legal guardian(s). This aligns with clinical trial guidelines in the UK, whereby patients over the age of 16 years are regarded as autonomous adults (Modi et al., 2014). An example of a participant information sheet is provided in Appendix B, and examples of a consent and assent form are provided in Appendix C.

3.2.1.1.1 General Data Protection Regulation Compliance

General Data Protection Regulation principles were followed throughout both the informed consent/assent and data collection processes, whereby responsibility for compliance resided with the principal investigator. While outside the scope of this thesis, an article by Chico (2018) that examines the impact of General Data Protection Regulation on health research is recommended.

3.2.2 Funding

Funding is provided from an Economic and Social Research Council (ESRC) PhD studentship (ES/J50015X/1), via the South West Doctoral Training Partnership (SWDTP). This studentship (1+3) covered tuition fee costs for both the Master of Research and PhD programmes, as part of the SWDTP Health and Wellbeing pathway, alongside a monthly stipendiary and an annual training support grant. This funding was used to complete all studies included in this thesis. No funding was provided by England Athletics (EA). Nonetheless, each study benefited from in-kind support from EA, such as allowing access to stakeholders and offering appropriate platforms for research dissemination.

Funding was also provided by the ESRC, via the SWDTP, to support a number of activities related to this thesis. This included receiving funding to undertake a three-month overseas institutional visit, a three-month student placement, and a student research impact project (see Appendix D (sensitive information has been removed, such as personal email addresses)).

3.2.3 Participants

All participants that volunteered were classified as being *competitive adolescent distance runners*. For each study in this thesis, participants were included if they were a member of an England Athletics affiliated athletics club and aged between 13 and 18 years. Also, in Study I, participants had to be training for a specific middle-distance running event, ranging from 800 m up to 3,000 m (including steeplechase). Whereas, within Study II and Study III, participants had to be training for and/or competing in a distance running event, ranging from 800 m up to 10,000 m (including steeplechase). When combined, these inclusion criteria allow the participants to be broadly classified as 'competitive adolescent distance runners.' In addition to these criteria, potential participants were excluded from enrolling in a study if they were unable to fully understand the study procedures and/or were unable to commit to completing the study protocol. Study specific inclusion/exclusion criteria are provided in each of the papers (Chapters 4-7).

While recommendations are in place for adult athletes (Swann et al., 2015), there are currently no best practice recommendations in relation to how researchers should define and categorise elite performance in adolescent populations. Yet, previous research has adopted the term 'elite' (Jacobsson et al., 2012, Huxley et al., 2014, von Rosen et al., 2017, Moseid et al., 2018, von Rosen et al., 2018a), while the International Olympic Committee (IOC) highlight that ‘elite’ youth athletes have a superior athletic talent, undergo specialised training, receive expert coaching support, and compete from an early chronological age (Mountjoy et al., 2008). Nonetheless, in this thesis, the term ‘competitive’ is used, instead of the term ‘elite.’ This term allows for a general description of performance levels, with further details being presented in the descriptive characteristics section of each chapter, if required. This approach allows the reader to determine the performance level of participants for themselves, rather than employing loosely defined ‘elite’ terminology. For example, in Study II and Study III, the current performance level of participants is given (i.e., Club, County, Regional, National, or International). In short, the term ‘elite’ is not used in this thesis based on the fact that it can mean different things according to different national, sporting, and age-group contexts, nor is it a predictor of future success. As a result, the term ‘competitive’ provides an accurate and honest description of this population.

3.2.4 Inclusion in Multiple Studies

As part of the mixed methods approach employed in Study II, the 19 participants who took part in Chapter 6 had already participated in Chapter 5.

Due to the inclusion and exclusion criteria applied across all three studies, a number of participants were included in multiple studies. Two participants took part in all three studies. One participant took part in both Study I and Study III. An additional fifteen participants took part in Study II and Study III, with two of these participants having also been included in Chapter 6, as part of Study II.

3.3 Participant Information

A range of participant information was collected during the course of this thesis. The participant information that was consistently reported across each study is described in further detail below.

3.3.1 Age and Maturation

3.3.1.1 Chronological Age

Chronological age was calculated as a decimal to the nearest 0.1 year between date of birth and date of testing (i.e., decimal age). In Study I, the reported age is age taken during the laboratory visit. In Study II and Study III, the reported age is age taken on the date of initial questionnaire completion. Specific to Chapter 5 and Chapter 7, chronological age was used to establish a participant's age-group as either 13-14 years (under 15), 15-16 years (under 17), or 17-18 years (under 19). These age-groups align to the UK Athletics (UKA) Rules for Competition (UK Athletics, 2020).

3.3.1.2 Training Age

Training age refers to the number of years that an athlete has spent training in a specific sport (Lloyd and Oliver, 2012). In Study II and Study III, training age was self-reported by each participant, determined by their response to the question – "How many years have you participated in distance running?". The reported age is based on the training age detailed on the date of questionnaire completion.

3.3.1.3 Biological Age

In adolescents, biological maturation occurs independently of chronological age. This means that individuals of the same chronological age can differ greatly in relation to their maturity status, known as biological age (Baxter-Jones et al., 2005). To account for this difference, age at peak height velocity (PHV) can be calculated to allow for comparisons to be made between participants and groups, as a somatic indicator of maturity. However, as calculating age at PHV requires the collection of longitudinal data during adolescence, sex specific equations (Moore et al., 2015) were applied in this thesis to calculate the maturity offset (MO) of participants. The equations require information about a participant's chronological age and stature (cm). The MO equation used for boys:

Equation 3.1: -7.999994 + (0.0036124 * (Age * Stature))

$R^2 = 0.896$; SEE = 0.542

Whereby R^2 represents the R-square change and SEE represents the standard error of the estimate.

The MO equation used for girls:

Equation 3.2: -7.709133 + (0.0042232 * (Age * Stature))

$R^2 = 0.898$; SEE = 0.528

Based on their MO, each participant's maturity timing and tempo were subsequently calculated, as a categorical measure of maturity. Maturity timing was categorised into three groups: pre-PHV (< -1 MO), at-PHV (between -1 and +1 MO), or post-PHV (> +1 MO). Maturity tempo was categorised as either early (i.e., age at PHV is 1 year (or more) less than reference age at PHV), late (i.e., age at PHV is 1 year (or more) more than the reference age at PHV), or average (i.e., between the early and late definitions), by applying sex-specific average PHV ages (Baxter-Jones et al., 2005). MO was reported in Chapter 4, with both maturity timing and tempo being reported in Chapter 5 and Chapter 7.

Although this approach is one of many possible indicators of maturity, each with their own strengths and limitations (Baxter-Jones et al., 2005), calculating MO is a quick, inexpensive, and non-invasive measurement, highly suitable for both cross-sectional and epidemiological studies. However, it important to stress that these equations only predict MO. As a result, there are issues related to the suitability of this approach for early- and late-maturing participants (Malina and Kozieł, 2014a, 2014b, 2018), due to the inaccuracy of the equations. Also, the participants in these studies (Moore et al., 2015, Malina and Kozieł, 2014a, 2014b, Kozieł and Malina, 2018) were not necessarily 'athletic,' nor actively engaged in competitive sport. Therefore, while convenient, their accuracy and application in such populations warrants further investigation.

3.3.2 Anthropometric Measures

Stature and body mass were either measured (Study I) or self-reported (Study II and Study III) in this thesis. Based upon these measures, body mass index (BMI) was also calculated, in addition to BMI cut points.

3.3.2.1 Stature

In Study I, stature was assessed using a wall-mounted stadiometer (Seca 217; Seca GmbH, Hamburg, Germany). When taking this measurement, participants removed their shoes and placed their heels against the base of the stadiometer, with feet together, and stood upright and looked forward. With the head being in the Frankfort Horizontal Plane, stature was taken to the nearest 0.1 cm.

Within Study II and Study III, stature was self-reported by participants in cm (to the nearest 1.0 cm) or feet and inches (to the nearest 1.0 inch). Stature that was self-reported in feet and inches was converted to cm, before being reported to the nearest 1.0 cm. A limitation of this method is that adolescent participants both underestimate and overestimate their stature (Brener et al., 2003, Tokmakidis et al., 2007, Sherry et al., 2007), when self-reporting this measurement. According to Sherry et al. (2007) literature review, the reported differences are deemed to be relatively small (range of mean stature differences = -1.1 cm to 2.4 cm), with Brener et al. (2003) being regarded as an outlier, reporting differences of 6.6 cm for males and 6.9 cm for females. It should also be noted that the measurement of stature via self-report has also been validated in adult-based epidemiological studies (Spencer et al., 2002), often supported on the grounds of study feasibility.

3.3.2.2 Body Mass

In Study I, body mass was assessed using digital scales (Seca 704; Seca GmbH, Hamburg, Germany). Participants were instructed to remove shoes and/or heavy clothing before this assessment. Body mass was measured to the nearest 0.1 kg.

Within Study II and Study III, body mass was self-reported by participants in kg (to the nearest 1.0 kg) or stone (to the nearest 0.1 stone). Body mass that was self-reported in stone was converted to kg, before being reported to the nearest 1.0 kg. One limitation of this methodology is that adolescent participants tend to underestimate their body mass (Brener et al., 2003, Tokmakidis et al., 2007, Sherry et al., 2007), when self-reporting this measure. According to Sherry et al. (2007) literature review, differences in means ranged from -4.0 kg to -1.0 kg in females, and from -2.6 kg to 1.5 kg in males. However, it is typical that overweight and obese adolescents show greater bias and variability when self-reporting their body mass, compared to non-obese adolescents (Elgar et al., 2005). Given that a lower body mass can have a positive effect on running economy (Saunders et al., 2004), this limitation is unlikely to be an issue in adolescent distance runners. Yet, due to this body type desirability (i.e., pursuit of leanness), it is also plausible that body mass may be underestimated in this population. This argument can be supported by research involving Norwegian Elite Sport High School athletes, whereby losing weight to enhance performance was reported as a key reason for dieting (Martinsen et al., 2010). In the same population, it was also found that the prevalence of eating disorders was higher in the Elite Sport High School athletes, compared to age-matched controls (Martinsen and Sundgot-Borgen, 2013).

Finally, as was the case for stature, the measurement of body mass via self-report has been validated in adult-based epidemiological studies (Spencer et al., 2002), being advocated on the grounds of study feasibility.

3.3.2.3 Body Mass Index

BMI was determined using the following equation:

Equation 3.3: BMI = body mass (kg) / stature (m^2)

Based on absolute values, BMI was subsequently divided into three subgroups – underweight, normal, or overweight/obese – by applying age and sex specific cut points (Cole et al., 2000, Cole et al., 2007). These cut points were based on international growth reference data, including data from the UK. BMI cut points were reported in Chapter 5 and Chapter 7. BMI, as an absolute value, was not reported in any of the studies.

As both stature and body mass were self-reported by participants, to calculate BMI, it is important to emphasise that the possible discrepancies between self-reported and measured anthropometric values may reduce the accuracy of BMI, and the subgroup categorisation. However, within a population of Swedish adolescents (Ekström et al., 2015), web-collected BMI has been shown to be a valid and cost-effective alternative to measuring BMI. Within Ekström et al. (2015) paper, weight was underestimated by an average of 1.1 kg and height was overestimated by an average of 0.5 cm, resulting in an underestimation of BMI by 0.5 kg/m^2. However, it should also be noted that the accuracy of self-reported BMI reduces with an increasing BMI (Ekström et al., 2015). Therefore, this remains unlikely to be an issue in adolescent distance runners due to the aforementioned body type desirability. This aligns with Elgar et al. (2005) argument that self-report methods remain as an important health surveillance tool in adolescent populations, but should not be used to detect weight problems. Therefore, the use of self-reported stature, body mass, and BMI throughout this thesis can be regarded as a valid, reliable, and feasible approach.

3.3.3 Performance Characteristics

Information about the performance characteristics of participants was collected in Study II and Study III, as part of a self-report questionnaire. This information allowed participants to be sub-categorised according to performance level within this thesis.

3.3.3.1 Current Performance Level

Participants were required to self-report their current level of performance in relation to the following categories of representation: Club, County, Regional, National, and International. These categories were chosen as they reflect the typical performance pathway applied within distance running, in England, whereby improved performances and displaying talent development can lead to enhanced representative opportunities. Current performance level was reported in Chapters 5-7.

3.3.3.2 Level of Specialisation

Based on previous studies (Jayanthi et al., 2013, 2015), a three-point scale was used to categorise level of specialisation as *low*, *moderate*, or *high*. In these studies, sports specialisation was defined as “intense, year-round training in a single sport with the exclusion of other sports” (Jayanthi et al., 2013, p.252). Based on this definition, level of specialisation was categorised according to self-reported answers (i.e., ‘Yes/No’) to the following three questions: (1) Is distance running your main sport?, (2) Have you quit other sports to focus on distance running?, and (3) Do you train or participate in distance running for more than 8 months a year?.

If a participant answered ‘yes’ to a question, they were awarded one point. The sum of responses to each of these questions was used to categorise level of specialisation. Three points was categorised as *high specialisation*, two points as *moderate specialisation*, and one point as *low specialisation*. Data related to these categories were reported in Chapter 5.

While this method is often used (Myer et al., 2015, Myer et al., 2016, Bell et al., 2016, Post et al., 2017, Pasulka et al., 2017, McGuine et al., 2017), it is important to recognise that sport specialisation is still a poorly defined concept (Jayanthi et al., 2013, 2015, Buckley et al., 2017). For example, based upon the definition applied in this thesis, the chronological age at which it is considered too early for a *high* level of specialisation is not stated, performance level is not included, nor is specific detail about training volume, frequency, and intensity. Regardless, this approach was considered to be the most feasible and effective way to report level of specialisation in this thesis, allowing for comparison to other studies that have applied the same method.

3.4 Recording and Reporting Data on Health Problems

This section will define terms and concepts related to recording and reporting data on health problems (i.e., injury and illness). Details related to the justification of the chosen definitions have been included in Section 2.3.2 of the literature review (Chapter 2). The composition of this section is based on two relevant consensus statements (Timpka et al., 2014a, Bahr et al., 2020), supported by justifications of methodological decisions taken throughout the completion of this thesis. This section relates to Study II and Study III.

3.4.1 Defining Health Problems

Applied as an ‘umbrella term,’ an athletic health problem is defined as:

> *Any condition that reduces an athlete’s normal state of full health, irrespective of its consequences on the athlete’s sports participation or performance, or whether the athlete sought medical attention.*

This definition was established by Clarsen et al. (2020), as an extension to how the World Health Organisation define health. This definition includes, but is not limited to, injury and illness. Specific to this thesis, running-related injury (RRI) is defined as:

> *Any physical complaint that resulted from distance running participation (i.e., training or competition), irrespective of the need for medical attention or time loss from distance running activities.*

Whereas illness is defined as:

> *Any complaint or disorder experienced by an athlete, not related to injury, irrespective of the need for medical attention or time loss from distance running activities.*

These definitions align with the most recent IOC consensus statement (Bahr et al., 2020) and the track and field (athletics) consensus statement (Timpka et al., 2014a). Importantly, these definitions are inclusive, allowing for a broad range of injuries and illnesses to be captured. As illustrated in Figure 2.7, this can include anything from initial pain and discomfort (‘all complaints’), through to medical attention and time loss (Clarsen and Bahr, 2014). Health problems that resulted from activities that were not related to participation in distance running were excluded from analysis.

In Chapter 5 and Chapter 7, health problems were classified as having caused time loss if they led to the athlete being unable to participate fully in distance running training or competition the day after the incident had occurred (Timpka et al., 2014a). In Chapter 5, only RRI were self-reported by participants. Due to the retrospective study design, these self-reported RRI had to have occurred during the 12-months preceding completion of the retrospective questionnaire. Medical attention RRI was also classified within Chapter 5, defined as:

> *Any injury that involved the assessment of a participant's condition (injury) by a medical or healthcare practitioner.*

In Chapter 7, RRI and illness were both self-reported by participants. Based upon the application of the Oslo Sports Trauma Research Center Questionnaire on Health Problems (OSTRC-H), health problems were also defined as 'substantial' within Chapter 7. This definition, developed by (Clarsen et al., 2013, 2014), was applied if a health problem caused moderate or severe reductions in training volume, moderate or severe reductions in performance, or a complete inability to participate in distance running (i.e., health problems where athletes self-reported option 'c.', 'd.' or 'e.' as part of question 2 or 3), as shown in Figure 3.1. Therefore, using the 'substantial' health problems definition is likely to counteract the issue of participants overreporting minor and transient health problems (i.e., those with non-specific symptoms) when applying an inclusive definition of health problems (Clarsen et al., 2013).

Question 1: Participation

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

a. Full participation without health problems (0)
b. Full participation, but with injury/illness (8)
c. Reduced participation due to injury/illness (17)
d. Cannot participate due to injury/illness (25)

Question 2: Training Volume

To what extent have you reduced your training volume due to injury, illness, or other health problems during the past week?

a. No reduction (0)
b. To a minor extent (6)
c. To a moderate extent (13)
d. To a major extent (19)
e. Cannot participate at all (25)

Question 3: Performance

To what extent has injury, illness, or other health problems affected your performance during the past week?

a. No effect (0)
b. To a minor extent (6)
c. To a moderate extent (13)
d. To a major extent (19)
e. Cannot participate at all (25)

Question 4: Symptoms

To what extent have you experienced symptoms/health complaints during the past week?

a. No symptoms/health complaints (0)
b. To a mild extent (8)
c. To a moderate extent (17)
d. To a severe extent (25)

Figure 3.1: The four questions included in the Oslo Sports Trauma Research Center Questionnaire on Health Problems, including their given numerical value (in brackets). Adapted from Clarsen et al., 2020, *Improved reporting of overuse injuries and health problems in sport: An update of the Oslo Sports Trauma Research Center questionnaires,* British Journal of Sports Medicine, 54(7), p. 392, with permission of BMJ Publishing Group Ltd. (copyright 2020).

3.4.2 Mode and Cause of Onset

In Chapter 5 and Chapter 7, participants did not classify RRI according to their mode or cause (mechanism) of onset. Instead, the mode of onset (gradual or sudden) was classified by the principal investigator, following data collection. In a similar way, the cause of onset (traumatic or overuse) in Chapter 5 was classified by the principal investigator, following data collection. The cause of onset was not classified in Chapter 7. While the term ‘mechanism of onset’ has been used in the most recent IOC consensus paper (Bahr et al., 2020), the term ‘cause of onset’ was applied in this thesis, based on the terminology used in the Athletics consensus paper (Timpka et al., 2014a). It is also recognised that using a dichotomous classification, as applied in Chapter 5, has been argued against, due to the fact that aetiological subtilties may be missed (Bahr et al., 2020).

3.4.3 Multiple Health Problems

In Study I and Study II, it is recognised that participant’s may have sustained more than one health problem. Therefore, it was essential to be able to accurately identify whether any of the subsequent health problems were either ‘recurrences’ or ‘exacerbations’ (Bahr et al., 2020). To address this, participants were able to clarify whether they had previously reported their injury or illness. Based on this self-reported information, it was possible to determine whether this was (1) a new health problem, (2) a recurrent health problem (i.e., when a full recovery had been made from the initial health problem), or (3) an exacerbation (i.e., when a full recovery had not yet been made). A recurrent health problem was recorded as a ‘new case,’ linked to a separate unique identification number. In Chapter 7, these decisions were guided by a classification tree, as proposed by Hamilton et al. (2011a), alongside self-reported information from participants (i.e., open textbox to report ‘any other information’). However, the classification tree was only used as a guide, and was not used when reporting data in Chapter 7 (i.e., total number of exacerbations) due to the fact that medical diagnoses were not recorded in this study. Likewise, due to the retrospective study design applied in Chapter 5, these decisions were based on the self-reported information from the questionnaire.

3.4.4 Classifying Health Problems

Within this thesis, health problems were self-reported by participants. Therefore, RRI were only classified according to their body region and body area. This is due to the fact that the self-reporting of injury diagnosis (tissue type and pathology) has been shown to be less reliable, compared to self-reporting the number of injuries and their body region/area (Gabbe et al., 2003). Likewise, in Chapter 7, illnesses were only classified according to their symptoms, rather than providing a diagnosis too. This methodology is justified based upon the fact that adolescent distance runners do not have guaranteed access to medical support. Therefore, medical diagnoses were not feasible in these studies.

In Chapter 5, self-reported RRI was classified based on the consensus statement for track and field athletes (Timpka et al., 2014a). In contrast, throughout Chapter 7, self-reported health problems were classified according to the most recent IOC consensus statement (Bahr et al., 2020). Except for minor semantic differences (i.e., lower extremity vs lower limb), these classification approaches are identical. The application of different consensus statements is a consequence of decisions made when designing each study, based on wanting to employ the most recent recommendations at the time of writing (Timpka et al., 2014a, Bahr et al., 2020).

In relation to the classification of illnesses in Chapter 7, self-reported symptoms were independently reviewed and classified by the principal investigator and a medical doctor, to identify the main affected organ system. Once classified, any differences were discussed, and the main affected organ system was agreed on. These organ systems were aligned to those recommended in the IOC consensus paper (Bahr et al., 2020).

3.4.5 Severity of Health Problems

There are many different ways to report the severity of health problems, including time loss, self-reported consequences, clinical assessment, and/or the economic impact. In this thesis, time loss and self-reported consequences have been used. In relation to self-reported consequences, the OSTRC-H was employed. These different approaches are explained in further detail below:

3.4.5.1 Time Loss

In Chapter 5 and Chapter 7, injury severity was reported according to the time loss bins recommended within the Athletics consensus paper (Timpka et al., 2014a): *slight* (1 day), *minimal* (2-3 days), *mild* (4-7 days), *moderately serious* (8-28 days), *serious* (>28 days-6 months), or *long-term* (>6 months). The duration of self-reported time loss, in Chapter 5, was subsequently used as an inclusion criteria for Chapter 6, whereby participants who had self-reported a *serious* or *long-term* injury were invited to take part in a semi-structured interview. When applying this method, severity was reported as a total number of time loss days, alongside the median and interquartile range, as recommended in the recent IOC consensus paper (Bahr et al., 2020).

3.4.5.2 Oslo Sports Trauma Research Center Questionnaire on Health Problems

Within Chapter 7, the severity of health problems was also measured according to self-reported consequences of participants. To achieve this, the OSTRC-H was used (Clarsen et al., 2013, 2014). The updated version of the OSTRC-H was not used in Study III, as it was not available when designing the study and completing data collection (Clarsen et al., 2020).

The OSTRC-H consists of four questions related to a participant's (1) participation in training/competition, (2) training volume, (3) performance, and (4) symptoms of health problems during the previous seven days (one week). The response to each of these questions is given a value between 0 and 25, with 0 (minimum) representing 'no problems' and 25 (maximum) representing 'severe problems.' The wording and assigned value of these questions are detailed in Figure 3.1. These values were allocated in order to maintain as even a distribution from 0 to 25, while still using whole numbers (Clarsen et al., 2013). The sum of these four responses, ranging from 0 (minimum) to 100 (maximum), determines whether the health problem can be classified as a 'substantial health problem,' or not, as detailed in Section 3.4.1. If participants responded to all four questions with the minimum value, the OSTRC-H was completed for that week. However, if participants did report a health problem, they were asked to self-report whether it was an injury or an illness. Based on this information, participants were then required to record the anatomical location of their injury or the main symptoms that they experienced for an illness. Participants also recorded the number of days of complete time loss from training and competition, whether the health problem had previously been recorded, and to whom it had been reported to, i.e., medical doctor or physiotherapist. Each participant was able to self-report a maximum of four health problems per week. Details of procedures related to the OSTRC-H are provided in Section 3.5.3.2, including its weekly distribution.

As a relatively new methodological approach, the OSTRC-H has shown good validity and reliability in samples that have included distance runners (Clarsen et al., 2014). For example, the OSTRC-H was demonstrated to have a high internal consistency when all questionnaires were analysed (Cronbach's $\alpha = 0.96$), as well as for non-injury cases (Cronbach's $\alpha = 0.97$) (Clarsen et al., 2014). However, one limitation of this method is that the severity score is reported as an arbitrary unit (AU). This has not been validated as a proxy measure of severity (Bahr et al., 2020). Therefore, severity was measured using two separate methods: time loss and self-reported consequences (i.e., OSTRC-H).

3.5 Study Equipment, Procedures, and Outcomes

This section provides a detailed overview and justification of the study equipment, procedures, and outcomes used in the present thesis. This section also intends to highlight and address a number of methodological limitations.

3.5.1 Cardiopulmonary Exercise Testing

In Study I, each participant completed a cardiopulmonary exercise test (CPET) to determine their maximum oxygen uptake ($\dot{V}O_{2max}$), lactate threshold (LT), lactate turn point (LTP), and maximum heart rate (HR_{max}). The same motorised treadmill, gas analyser, lactate analyser, and heart rate monitoring system were used throughout this study.

3.5.1.1 Equipment

For the CPETs carried out in Study I, all exercise was undertaken on a motorised treadmill (Pro XL; Woodway GmbH, Weil am Rhein, Germany). Participants wore a rubber oronasal facemask (Hans Rudolph, Shawnee, KS, USA), connected to a turbine and gas sampling line, which were connected to a metabolic cart (Cortex Metalyzer III B; Cortex Biophysik GmbH, Leipzig, Germany). This procedure permitted breath-by-breath collection of volume of oxygen uptake ($\dot{V}O_2$), volume of carbon dioxide production ($\dot{V}CO_2$), and minute ventilation ($\dot{V}_E$), which allows for subsequent calculation of derivatives such as $\dot{V}O_{2max}$. The metabolic cart was calibrated for gas and volume prior to each CPET using standard calibration gas (5% CO_2, 17% O_2) and a 3.0 litre calibration syringe (Hans Rudolph, Shawnee, KS, USA). Ambient pressure and temperature were also recorded prior to each CPET, in order to calculate a standard conditions of temperature, pressure, and dry (STPD) value.

Throughout each CPET, participants wore a telemetric heart rate (HR) monitor (T31; Polar Electro, Kempele, Finland), whereby HR was recorded every one second. Fingertip capillary blood samples (~100 µL per sample) were collected at the end of each stage during each CPET. A spring-loaded lancet (Safety-Lancet Super; Sarstedt AG & Co, Nümbrecht, Germany) was initially used to draw a fingertip blood sample, before being collected in a heparinised microvette (CB 300 FH tubes; Sarstedt AG & Co, Nümbrecht, Germany). Once collected, each blood sample was immediately analysed for lactate, in duplicate, using a calibrated automatic lactate analyser (YSI 2300; Yellow Springs Instruments). This lactate analyser was self-calibrated before each CPET and was maintained by trained laboratory support staff.

Participant's Rating of Perceived Exertion (RPE) was obtained at regular intervals during the CPET via the modified 0-10 *Category* scale with *Ratio* properties (CR10 scale) (Foster et al., 1995). The modified CR10 scale (A4 size), as shown in Figure 2.3, was held in front of the participant when they were required to report their RPE, allowing them to point at the given verbal descriptor and/or rating that best reflected their perceived exertion at that time point. A verbal explanation of how to use the modified CR10 scale was given to participants before their CPET.

3.5.1.2 Procedures

A two-stage incremental exercise test to volitional exhaustion was employed (Jones, 2007), utilising a discontinuous step-incremental phase (stage 1) and a continuous-incremental verification phase (stage 2); both stages are illustrated in Figure 3.2. This approach has been designed for use with middle- and long-distance runners. Before the CPET, participants were familiarised with all study procedures and the HR monitor was fitted. Once the HR monitor had been fitted correctly, participants rested in the laboratory for ten-minutes, in a seated position. At the end of this rest period, a baseline blood sample was collected and resting heart rate (HR_{rest}) was recorded, before a standardised warm-up on the treadmill was performed – five-minutes of walking and running, up to 8 km·h^{-1}.

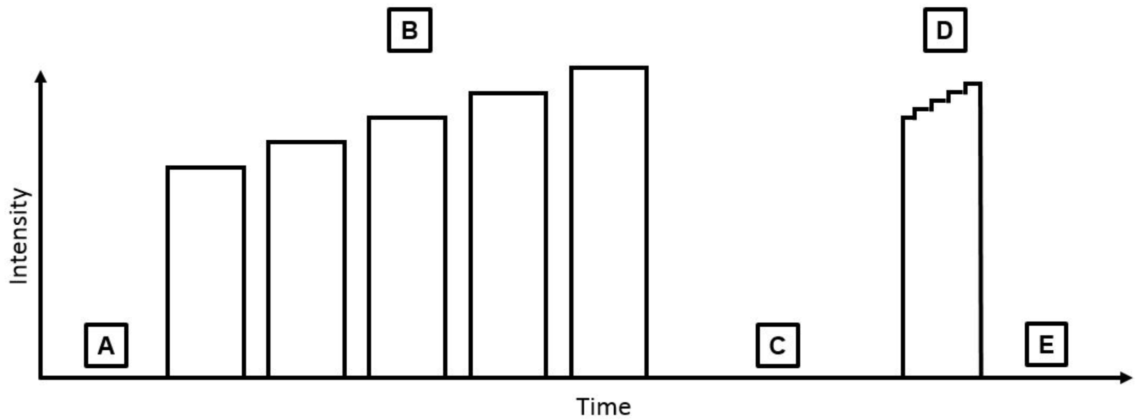

Figure 3.2: Two-stage incremental exercise test: (A) standardised five-minute warm-up; (B) discontinuous step-incremental phase (initial velocity based upon performance level); (C) ten-minutes active recovery; (D) continuous-incremental verification phase; (E) cool-down (self-determined duration and velocity). During part (B) of the incremental exercise test, intensity was speed-based (km·h^{-1}), whereas, during part (D), intensity was gradient-based (%).

3.5.1.2.1 Discontinuous Step-Incremental Phase

Following the standardised warm-up, the first stage of the CPET consisted of five to eight three-minute stages. The initial treadmill velocity was set between 11.0 and 13.0 $km \cdot h^{-1}$ for male participants and 11 $km \cdot h^{-1}$ for female participants. This velocity was determined according to each participant's current level of performance (i.e., time in a recent competition) and starting velocity prediction charts (Jones, 2007). During this stage, the treadmill gradient was fixed at 1.0%, in order to accurately reflect the energetic cost of running outdoors (Jones and Doust, 1996). HR was recorded every one second during this stage of the CPET.

Having completed the first three-minute stage, a one-minute rest period was taken, whereby the participant straddled their legs either side of the treadmill belt. This rest period allowed for assessment of RPE and the collection of a capillary blood sample. Following the one-minute rest, the participant started their second three-minute stage, whereby the treadmill velocity had been increased by 1 $km \cdot h^{-1}$. This staged process continued until both blood lactate had exceeded 4 $mmol \cdot L^{-1}$ and the participant's HR was within 5 to 10 beats per minute of their predicted HR_{max}, using the following equation:

Equation 3.4: Predicted HR_{max} = 220 – chronological age

While the accuracy of this equation, initially theorised by Fox et al. (1971), has been queried within paediatric populations (Mahon et al., 2010, Gelbart et al., 2017), its use as a secondary verification criteria, alongside the primary endpoint criteria of blood lactate, ensured a robust determination of exhaustion.

Following completion of this discontinuous step-incremental phase, participants were allowed ten-minutes of active recovery before the continuous-incremental verification bout started. This involved removing the oronasal facemask and allowing participants to get off the treadmill. If requested, participants were allowed to walk on the treadmill during this recovery period. The term ‘active’ is used to highlight that participants did not have to remain in one position, i.e., lying in a supine position. No measurements were taken during this recovery period.

3.5.1.2.2 Continuous-Incremental Verification Bout

Following the ten-minutes of active recovery, the second stage of the CPET started. The oronasal facemask was fitted again, with the gas and HR data collection being resumed. This stage involved running at a fixed velocity, using the following equation:

Equation 3.5: Starting Velocity = Final Stage Velocity - 2 $km \cdot h^{-1}$

With the treadmill set at the determined velocity, the treadmill gradient was increased by 1.0% each minute until volitional exhaustion (gradient started at 1.0%). HR was recorded every one second during this stage of the CPET. Once volitional exhaustion had been achieved, RPE was assessed and a capillary blood sample was collected. Participants were encouraged to complete a cool-down following the CPET, with the treadmill velocity being self-determined.

An example of the $\dot{V}O_2$ response, from a single participant, throughout the two-stage incremental exercise test is shown in Figure 3.3.

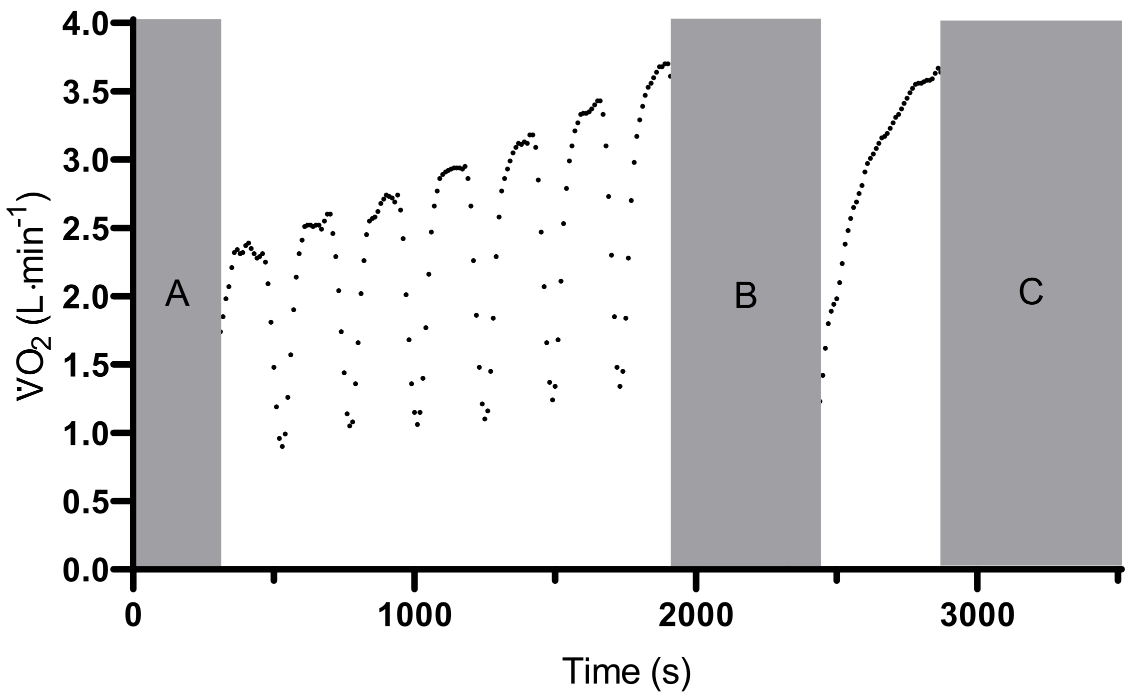

Figure 3.3: Example of a participant's $\dot{V}O_2$ response to the two-stage incremental exercise test, used to determine $\dot{V}O_{2max}$. Shaded boxes indicate periods of warm-up (Box A), active recovery (Box B), and cool-down (Box C). The active recovery (Box B) also indicates the end of *discontinuous step-incremental phase* (stage one) and start of the *continuous-incremental verification bout* (stage two).

3.5.1.3 Outcomes

Following the completion of a CPET, all raw data were exported to a Microsoft Excel Spreadsheet. $\dot{V}O_2$, $\dot{V}CO_2$ and $\dot{V}E$ data were exported in a breath-by-breath format before being smoothed into 10-second averages for analysis. $\dot{V}O_{2max}$ was accepted as the highest 10-second $\dot{V}O_2$ observed during the CPET.

LT and LTP were visually obtained by plotting blood lactate against running velocity, as described by Jones (2007). As two blood lactate values were recorded for each capillary blood sample, these values were averaged before subsequent analysis. LT was accepted as the first sustained increase in blood lactate above baseline levels. LTP was accepted as a distinct and sustained breakpoint in blood lactate following LT. These results were approved by two independent reviewers. An example of this analysis process is shown in Figure 3.4. The test-retest reliability of these physiological parameters (LT and LTP) has been shown to be highly reproducible in elite junior distance runners.

HR data was smoothed into 10-second averages, with HR_{rest} being accepted as the lowest 10-second average recorded during the 10-minute seated rest period before the CPET. HR_{max} was accepted as the highest 10-second average observed during the CPET. Recording RPE values was primarily to familiarise each participant with this measure, before completion of a second phase of data collection – a two-week mesocycle of training. As a result, no subsequent analysis was carried out with these data.

3.5.2 External and Internal Training Load

In Study I, having completed a CPET to determine $\dot{V}O2max$, LT, LTP, HR_{rest}, and HR_{max}, each participant completed a two-week mesocycle of training. Throughout the mesocycle, participants recorded their running-related training in a logbook (including external and internal training load) and wore a HR monitor for all of their training sessions/competitions. An abridged version of this logbook, detailing the written instructions, a copy of the modified CR10 scale, and an example of a training session report form, is included in Appendix E. To compliment the written instructions included in this logbook, the principal investigator verbally explained how to use this logbook to each participant, following their CPET.

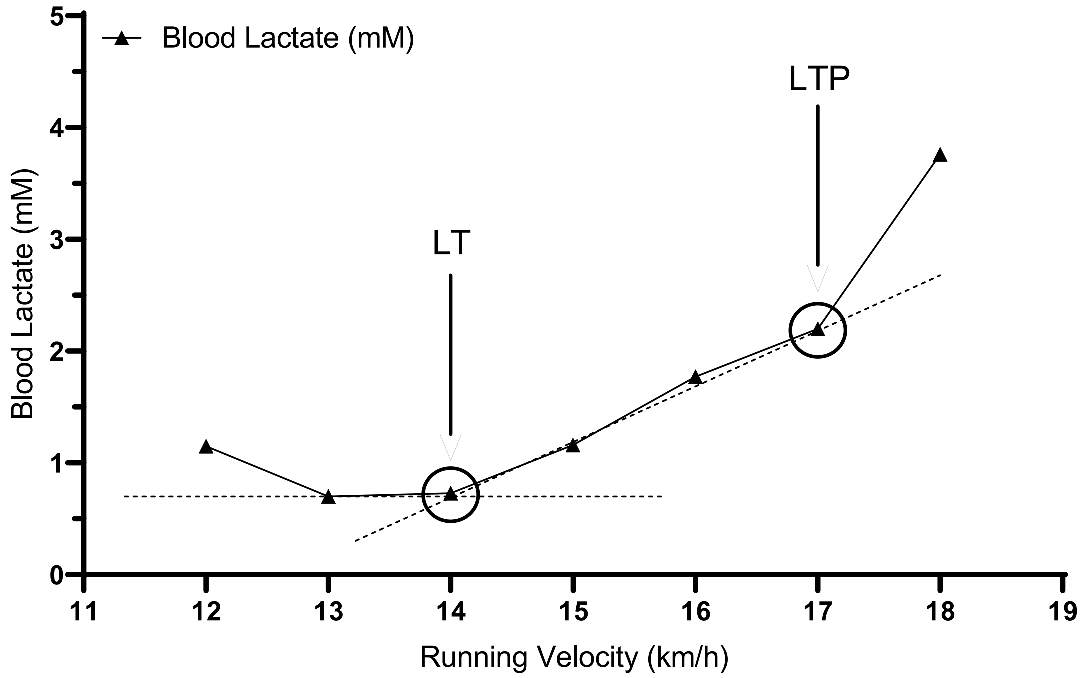

Figure 3.4 Example of establishment of lactate threshold (LT) and lactate turn point (LTP) by plotting blood lactate against running velocity.

3.5.2.1 Equipment

Throughout the two-week training mesocycle, participants recorded their training in a logbook (Appendix E). A paper copy of this logbook was given to participants (and fully explained) at the end of their laboratory visit, having completed a CPET. The logbook had capacity for each participant to report a maximum of 15 running-related training sessions, only one of which is shown in Appendix E.

Participants were provided with a personally coded telemetric HR monitor (Team 2 System; Polar Electro, Kempele, Finland). Each participant was required to use this HR monitor during each of their running-related training sessions, with HR being recorded using a one second epoch. Instructions for using the logbook and HR monitor were given to each participant following the CPET (Appendix E).

3.5.2.2 Procedures

During the two-week mesocycle of regular training, participants completed their usual distance running training, as prescribed by themselves and their coach. No attempt was made to interfere with this regular training prescription. Throughout the two-week mesocycle, the following information was reported by participants, in the logbook (Appendix E), immediately after each training session was finished: (1) the date and start time of the session, (2) total session duration (reported in minutes), (3) total distance covered (reported in miles or kilometres), (4) details about the type of session, alongside a brief session description (i.e., inclusion of a warm up), (5) sRPE, dRPE-L, and dRPE-B at the following time points: 0 min post-session, 15 min post-session, and 30-min post-session, (6) comments about the session, and (7) details of other sporting activity completed on that day. Total session duration and distance covered included warm-up/cool-down elements of a training session. To aid timely self-reporting of RPE values, participants were instructed to take their logbook with them to each distance running related training session. The modified CR10 scale was included as part of the training logbook, alongside a set of written instructions (Appendix E), to help participants accurately record the different RPE values. Participants were instructed to wear the individually coded telematic HR monitor for each of their training sessions. At the end of the two-week mesocycle of regular training, both the logbook and HR monitor were returned to the principal investigator. Data generated from these logbooks were subsequently analysed, as explained in the following section.

3.5.2.3 Outcomes

For each training session, RPE was self-reported by participants, as a preliminary measure of ITL (Halson, 2014). sRPE was subsequently calculated for each training session by using the following equation:

Equation 3.6: sRPE = RPE x session duration (min)

The reported RPE value was based on the CR-10 Borg scale (Borg et al., 1987, Borg, 1998). Having previously been validated in adult and adolescent populations (Chen et al., 2002), this scale translates perceived exertion (from 'rest' to 'maximal') into a numerical value. The sRPE calculation was completed for each RPE measure (whole body, leg exertion, and breathlessness) at the point of training session completion ($sRPE_0$, $dRPE\text{-}L_0$, and $dRPE\text{-}B_0$), 15-minutes post-session ($sRPE_{15}$, $dRPE\text{-}L_{15}$, and $dRPE\text{-}B_{15}$), and 30-minutes post-session ($sRPE_{30}$, $dRPE\text{-}L_{30}$, and $dRPE\text{-}B_{30}$). In each of these acronyms, s = sessional, while d = differential. Each value was expressed as an arbitrary unit (AU).

Three individualised HR-based training load methods were used during Study I, as criterion measures of ITL. Each of these methods can be defined as a training impulse, known as a TRIMP, and were all expressed as an AU. The first method was an individualised TRIMP ($TRIMP_I$), developed by Manzi et al. (2009), in a population of distance runners. $TRIMP_I$ weights training duration, recorded in minutes, using an individualised weighting factor (Y^i) for each participant. Y^i is based on each individual participant's blood lactate response throughout a CPET, rather than having to apply a sex- or team-specific exponential factor (Morton et al., 1990, Stagno et al., 2007). $TRIMP_I$ was calculated as follows:

Equation 3.7: $TRIMP_I = TD \times \Delta HR \times Y^i$

Within this equation, TD represents training session duration, in minutes, and ΔHR is the HR ratio. The HR ratio is calculated as follows:

Equation 3.8: $\Delta HR = [(HR_{TS} – HR_{rest}) / (HR_{max} – HR_{rest})]$

Within this equation, HR_{TS} is the average HR recorded during a training session.

To calculate Y^i, each participant's blood lactate profile was plotted against the fractional elevation in HR (%), with an exponential line of best fit providing the calculation of the weighting factor, whereby *e* = base of the Napierian logarithms, and $x = \Delta HR$. An example of how Y^i was calculated for a participant is detailed in Figure 3.5, as a screenshot of an Excel Spreadsheet.

The second TRIMP was calculated by using the Edwards summated HR zone score method (Edwards, 1993), referred to as $TRIMP_E$. The $TRIMP_E$ method calculates the product of the accumulated training session duration, recorded in minutes, spent in five different HR zones, multiplied by a coefficient relative to each HR zone, before summating the results. These HR zones were based on a percentage range of each individual participant's HR_{max}. $TRIMP_E$ was calculated as follows:

Equation 3.9: $TRIMP_E = (Z1_T \times 1) + (Z2_T \times 2) + (Z3_T \times 3) + (Z4_T \times 4) + (Z5_T \times 5)$

		30 second averages at end of each stage.				
Running Speed (km/h)	Blood Lactate (mM)	Heart Rate (bpm)	Heart Rate Fraction (%)	VO2 (ml/kg/min)	V'O2	V'CO2
11						
12	1.15	145	73	44	2.28	2.01
13	0.70	155	78	49	2.55	2.29
14	0.73	165	83	52	2.69	2.43
15	1.16	174	88	56	2.91	2.69
16	1.77	181	91	61	3.15	2.93
17	2.20	189	95	65	3.40	3.25
18	3.76	192	97	71	3.67	3.62
19						

HR Rest	55
HR Max	198

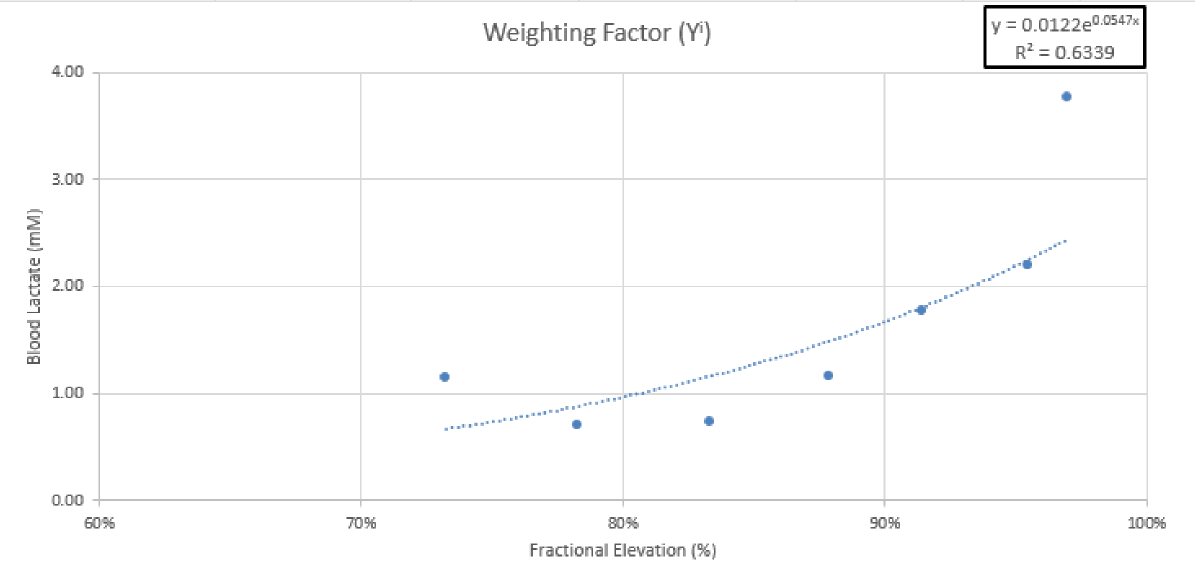

Figure 3.5: An example of how an individualised weighting factor (Y^i) was calculated for each participant, using an Excel Spreadsheet.

Within this equation, $Z1_T$ is the total amount of time spent in Zone 1 during a training session. Each subsequent HR zone is represented by the next number in the series, i.e., Z2, Z3, Z4, and Z5. Each of the different HR zones, and their relative coefficient, are shown in Table 3.2.

Table 3.2: Heart rate zones applied when using the Edwards training impulse ($TRIMP_E$), in addition to their relative coefficient.

HR Zone	% of HR_{max}	Coefficient
Zone 1	50% - 60%	1
Zone 2	60% - 70%	2
Zone 3	70% - 80%	3
Zone 4	80% - 90%	4
Zone 5	90% - 100%	5

The third TRIMP was calculated by using a modified version of $TRIMP_E$, based upon the work of Lucía et al. (2003), known as $TRIMP_L$. The $TRIMP_L$ method calculates the product of the accumulated training session duration, recorded in minutes, spent in three different HR zones, multiplied by a coefficient relative to each HR zone, before summating the results. The different HR zones were based on reference HR values obtained during each participant's CPET, using LT and LTP data as arbitrary cut points. $TRIMP_L$ was calculated as follows:

Equation 3.10: $TRIMP_L = (Z1_T \times 1) + (Z2_T \times 2) + (Z3_T \times 3)$

As explained in Equation 3.10, $Z1_T$ is the total amount of time spent in Zone 1 during a training session. Each subsequent HR zone is represented by the next number in the series, i.e., Z2, Z3, Z4, and Z5. Each of the different HR zones, and their relative coefficients, are shown in Table 3.3. These HR zones are also illustrated in Figure 3.6.

Table 3.3: Heart rate zones applied when using the Lucia training impulse ($TRIMP_L$), in addition to their relative coefficient.

HR Zone	Exercise Intensity	Coefficient
Zone 1	Below lactate threshold	1
Zone 2	Between lactate threshold and lactate turn point	2
Zone 3	Above lactate turn point	3

While several measures of ITL were calculated in Study I, sRPE was also used as a measure of ITL as part of the data collection process in Study II (Chapter 5) and Study III (Chapter 7). Therefore, Study I can be upheld as complementary to the subsequent studies conducted within this thesis, whereby sRPE was used to record ITL in competitive adolescent distance runners.

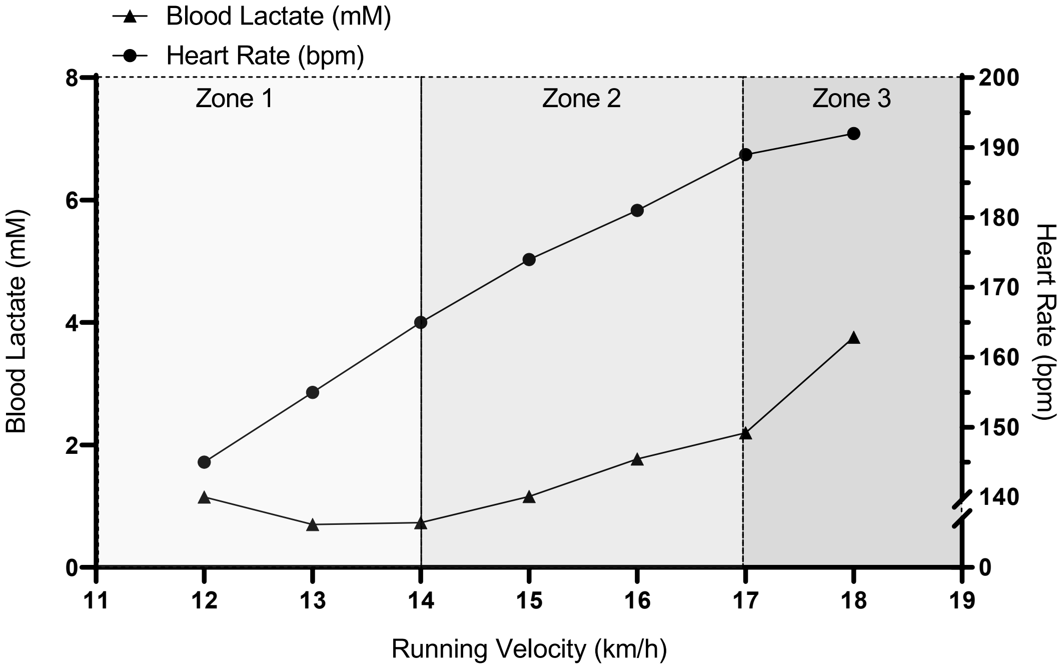

Figure 3.6: Example of how heart rate zones were calculated according to lactate threshold (LT) and lactate turn point (LTP) data, based on Lucia's training impulse ($TRIMP_L$) method. Zone 1 (1st shaded box) represents exercise intensity below the LT. Zone 2 (2nd shaded box) represents intensity between the LT and LTP. Zone 3 (3rd shaded box) represents an intensity above LTP.

3.5.3 Questionnaires

In Study II and Study III, participants were required to complete a retrospective questionnaire. In Study II, the responses to this questionnaire were reported in Chapter 5. These responses also informed the participant recruitment process in Chapter 6. In Study III, an abridged version of this questionnaire was applied at baseline, before the completion of a weekly questionnaire (prospective), during a 24-week follow-up period. Copies of the retrospective questionnaire (Appendix F) and weekly questionnaire (Appendix G) have both been included as appendices. The elements that were omitted from the retrospective questionnaire in Study III, to limit the time burden on participants, are highlighted in Appendix F.

3.5.3.1 Equipment

Both questionnaires were completed via an online platform, Qualtrics (Qualtrics XM., Provo, Utah, USA). This platform is compatible with computers and mobile devices. A screenshot of the Qualtrics platform has been included in Appendix H. Participants could access the questionnaires via a weblink that was distributed during data collection, with specific distribution procedures having been detailed in Section 3.5.3.2. Data were initially downloaded and managed using a Microsoft Excel spreadsheet.

3.5.3.2 Procedures

Initial development of the retrospective questionnaire was based on methods applied in previous studies (Jacobsson et al., 2012, Huxley et al., 2014, Woollings et al., 2015), each of which employed a retrospective study design and included a sample of adolescent athletes. These studies were used to determine what sections should be included in the retrospective questionnaire, in order to best capture relevant data in a population of adolescent distance runners.

Once the retrospective questionnaire had been designed, key stakeholders (n = 12) were asked to assess the questionnaire's face validity. This involved checking whether the questionnaire was suitable for adolescent distance runners and measured what it intended to. The group of key stakeholders included adolescent distance runners (n = 4), their parents/legal guardians (n = 3), coaches (n = 3), physiotherapists (n = 2). All feedback that was subsequently integrated into the questionnaire design was shared amongst these stakeholders for a final round of feedback. All co-authors involved with Chapter 5 actively reviewed the content of this questionnaire and ensured that relevant variables were measured.

When completing the retrospective questionnaire, participants were required to self-report information related to the following: (1) background demographics, (2) performance history, (3) training practices (including a training diary), (4) the Athletic Identity Measurement Scale (AIMS) (Brewer et al., 1993), (5) medical history, and (6) level of sport specialisation. Questionnaire logic was applied to ensure that participants provided all required information. No time restrictions were imposed for completing the questionnaire, with participants allowed to save progress and return to the questionnaire at a different time point, if required.

Specific to *medical history*, participants were instructed to self-report whether, in the past 12-months, they had had an injury that had resulted from their distance running participation, irrespective of the need for medical attention or time loss. If an injury was reported, details about the date of initial injury (mm/yyyy), injury type, how they were injured, the type of session that they were participating in when the incident occurred, the affected body area, total time loss, and what treatment they had access to, were collected. All of these sections allowed open text box entries, with the ability to report an infinite number of RRI. Subsequent questions detailed whether any of these RRI were recurrent and/or ongoing, alongside information about ongoing medical attention. Information about pain, discomfort, or physical problems that were caused by distance running was also self-reported.

The retrospective questionnaire was also used at baseline in Study III, having been abridged (Appendix F). Once this questionnaire had been completed by participants at baseline, the weekly questionnaire was distributed to enrolled participants every Sunday afternoon (4 pm), via email, during the 24-week follow-up period. This weekly questionnaire included the following elements: (1) the OSTRC-H (Clarsen et al., 2013, 2014, 2020), (2) a training diary/logbook, and (3) the adolescent version of the Profile of Mood States (Terry et al., 1999). The content of the weekly questionnaire remained the same throughout each of the 24-weeks. If participants did not complete the questionnaire, email reminders were sent out the following day (Monday), after two days (Wednesday), and after four days (Friday). The participant's parents/legal guardians were copied into an email reminder after two and four days. If a response had not been received after five days (Saturday), the principal investigator would send an SMS reminder to all non-responders. If the questionnaire remained unanswered by the time the next one was distributed, the participant was categorised as a non-responder for that specific week (i.e., missing data).

It should be noted that the AIMS and adolescent version of the Profile of Mood States data have not been analysed in this thesis. Yet, participant responses to the AIMS (Brewer et al., 1993) were incorporated into each of the semi-structured interviews (Chapter 6). Therefore, further details about the AIMS can be found in Section 3.5.4. Similarly, specific information about how the OSTRC-H was used has already been explained in Section 3.4.5.2. Moreover, in relation to the training diary, participants were encouraged to self-report their given RPE values for each training session immediately following session completion.

3.5.3.3 Outcomes

Based on participant responses throughout both the retrospective questionnaire and weekly questionnaire (prospective), a number of outcomes were calculated. Several outcomes from the retrospective questionnaire were subsequently used as potential correlates (risk factors) of RRI in an exploratory univariate logistic regression analysis, as part of Chapter 5.

3.5.3.3.1 Demographics

In the retrospective questionnaire, questions were asked in relation to each participant's date of birth, sex, stature, body mass, age-group, and how long they had participated in the sport of distance running. Using this information, age-, maturation-, anthropometric-, and performance-based outcomes, as previously reported (see Section 3.3), were calculated. These outcomes were subsequently used as potential correlates of RRI.

3.5.3.3.2 Running Background

This section of the retrospective questionnaire included questions related to event preferences, performance level, and coaching support. Event preference was reported as an outcome based on each participant's main distance running event (i.e., 800 m up to 10,000 m, including steeplechase). Participants also self-reported other distance running events that they competed in, whereby 'single-event' (i.e., only one event) or 'multiple-event' (i.e., ≥two events) preference was also reported as an outcome. This outcome was subsequently used as a potential correlate of RRI.

Participants were also required to self-report whether they had access to an athletics coach, and if this coach set their training. Dichotomous participant responses (yes/no) were used as a potential correlate of injury. Each participants current performance level – Club, County, Regional, National, or International – was also self-reported, as explained in Section 3.3.3.1, and was used as an outcome and potential correlate of RRI.

While in a different section of the retrospective questionnaire, the answers for the questions related to level of specialisation, as previously explained within Section 3.3.3.2, were also used as an outcome and potential correlate of RRI.

3.5.3.3.3 Training Practices

This section of the retrospective questionnaire required participants to self-report the number of months per year, weeks per month, days per week, and hours per day that they participate in distance running. This was allowed to be an average of their participation levels over the previous 12-months. Likewise, an average session duration was self-reported, in addition to how many distance running events they had competed in throughout the previous 12-months. Responses to these questions were used as outcomes in the final analysis of Chapter 5. Questions in this section were also related to typical training surfaces (athletics track, tarmac/road, or grass/cross-country), inclusion of a warm-up and/or cool-down, and whether they do any strength and conditioning exercises. The latter three elements were subsequently used as outcomes and potential correlates of RRI in Chapter 5.

In both the retrospective and weekly questionnaires, participants were instructed to complete a training diary. In the retrospective questionnaire, this diary reflected a typical week of their distance running training from the previous 12-months. Whereas in the weekly questionnaire, this diary represented the week of training that had just been completed. These diaries required participants to self-report total session duration (reported in minutes), total distance covered (reported in kilometres), a description of the type of training session (open text box entry), rating of perceived exertion (modified CR10 scale), and specific details about the session (open text box entry). Based upon these responses, weekly training volume, intensity (including ITL, via the use of sRPE), and frequency could be calculated as outcomes in Chapter 5 and Chapter 7. Based on the findings from Study I, participants were instructed to record their RPE values within 30-minutes of training session completion, in addition to the other daily training outcomes.

3.5.3.3.4 Prevalence, Incidence, and Number of Health Problems

In Chapter 5, the incidence proportion (IP), reported as a percentage (%), was calculated to determine the average probability that a participant would sustain at least one RRI during the 12-month study follow-up period. The equation used to determine IP was as follows:

Equation 3.11: Incidence Proportion: (total number of injured participants during study period) ÷ (number of participants at risk at start of study period)

Clinical incidence, reported per 100 participants/year, was also calculated in Chapter 5. This was used to determine what the expected frequency of RRI is, given a certain number of participants. The equation used to calculate clinical incidence was as follows:

Equation 3.12: Clinical Incidence = (total number of running-related injuries during study period) ÷ (number of participants at risk at start of study period)

Clinical incidence is regularly reported in sports injury literature (Knowles et al., 2006b). However, it is important to recognise that this measure neither represents a rate nor a risk (Knowles et al., 2006b). Regardless, it was used in this thesis to allow for comparison between studies, as a measure of resource utilisation.

RRI incidence rate (IR) was also calculated in Chapter 5 to determine the number of RRI per participant/1,000 hours of distance running participation. The equation used to determine IR was as follows:

Equation 3.13: Incidence Rate = (total number of injuries during study period) ÷ (total number of participant exposure hours during study period)

The IR allows for an understanding about what the rate of RRI is per unit of exposure (hours), thereby accounting for participant time at risk. IP and IR were calculated, alongside 95% confidence intervals (CI) (Marshall, 2005, Knowles et al., 2006b), according to sex and injury severity ('all RRI,' 'time loss RRI,' and 'medical attention RRI'), in addition to the total number (n) and proportion (%) of RRI in each category. IR was also reported for each injury body region and area.

To compare the relative risk of injury according to sex (i.e., male vs. female), risk ratios (related to IP) and rate ratios (related to IR) were calculated. To calculate the risk ratio in one group (i.e., male participants), relative to another (i.e., female participants), the following equation was used:

Equation 3.14: Risk Ratio = (incidence proportion in group one) ÷ (incidence proportion in group two)

To determine the rate of injury in one group (i.e., male participants), relative to another (i.e., female participants), a rate ratio was calculated using the following equation:

Equation 3.15: Rate Ratio = (incidence rate in group one) ÷ (incidence rate in group two)

When reported, male participants were used as the referent group, meaning that the higher or lower risk/rate was related to the male participants. 95% CI were calculated for the risk ratios and rate ratios (Greenland and Rothman, 2008a).

Specific to Chapter 7, prevalence measures were calculated on a weekly basis for the following: all health problems, substantial health problems, time loss health problems, 'all RRI,' 'substantial RRI,' 'time loss RRI,' 'all illnesses,' 'substantial illnesses,' and 'time loss illnesses.' The mean prevalence and 95% CI were calculated for the entire study period and stratified by sex. Also, the incidence of each type of health problem – all health problems, all RRI, and all illnesses – was expressed as the number of cases per participant/year (52-weeks) and stratified by sex. To reduce the likelihood that health problems were initially overreported, each participants first week of data were excluded from subsequent analyses, as previously recommended (Clarsen et al., 2013).

3.4.3.3.5 Mode and Cause of Onset

In both Chapter 5 and Chapter 7, following data collection, mode of onset (gradual or sudden) was classified by the principal investigator. Specific to Chapter 5, the cause of onset (i.e., traumatic or overuse) was also classified by the principal investigator, following data collection.

3.4.3.3.6 Classification of Health Problems

In Chapter 5 and Chapter 7, RRI were classified according to body region and body area. Also, in Chapter 7, illnesses were classified according to the organ system that was mainly affected.

3.4.3.3.7 Severity and Burden of Health Problems

In Chapter 5 and Chapter 7, injury severity was classified according to time loss: *none* (0 days), *slight* (1 day), *minimal* (2-3 days), *mild* (4-7 days), *moderately serious* (8-28 days), *serious* (>28 days-6 months) or *long-term* (>6 months). In Chapter 7, these time bins were also applied to illnesses. In Chapter 5, injuries were classified according to medical attention and reported as an outcome.

In Chapter 7, a weekly severity score was recorded for all participants and all separate health problems, based on their responses to the four central questions. At the end of data collection, the cumulative severity score for each case by summing the weekly scores was recorded, and an average weekly severity score was calculated for all cases. The cumulative severity for all health problems, all RRI, and all illnesses were reported as an outcome, and stratified by sex.

Also in Chapter 7, severity scores for each health problem were summed and divided by the cumulative severity score for all health problems, to reflect the relative burden of RRI and illnesses as a proportion of the total health burden (Bahr et al., 2018). Subsequently, a risk matrix was produced, based upon the severity and incidence of health problems in all affected injury body areas and illness organ systems, stratified by sex.

3.5.4 Semi-Structured Interviews

As part of Study II, a sub-sample of participants from Chapter 5 volunteered to take part in a semi-structured interview about their experience of RRI. Specifically, interviews were conducted with competitive adolescent distance runners who had self-reported a 'serious RRI' (>26 days-6 months of time loss) when completing the retrospective questionnaire, as described in Section 3.5.3. These interviews (n = 19) were used to facilitate an analysis related to responses to *serious RRI*, as the second element of the explanatory sequential mixed methods study design (see Section 3.1). The data generated from these interviews were analysed and reported in Chapter 6 of this thesis.

3.5.4.1 Equipment

A paper copy of the semi-structured interview guide was taken to each interview. This interview guide is discussed further throughout Section 3.5.4.2 and has been included in Appendix I. Pen and paper were taken to each interview, used to record field notes during and immediately after the interview. All interviews were recorded on a Dictaphone (Sony ICD-PX333) to enable verbatim transcription and subsequent analysis.

3.5.4.2 Procedures

The development of the interview guide was based on discussions between the principal investigator and Bryan Clift. These discussions were informed by previous literature that had explored the initial response to and consequences of sport-related injury in adolescent athletes (e.g., Podlog et al., 2013, von Rosen et al., 2018b), alongside wider reading and experiential knowledge. The finalised semi-structured interview guide is included in Appendix I, while specific sections included within this interview guide are detailed later in this section.

In the semi-structured interview guide, 'probing questions' have been included to complement each of the central questions, as shown in Appendix I. For example, when asking about a participant's current training practices, one of the probing questions focuses on whether they enjoy these training practices. Such questions were included to help maintain the direction of the interview (Smith and Sparkes, 2016), while encouraging the interviewee to provide rich and thick descriptions (Smith and Caddick, 2012). It is important to highlight that the 'probing questions' included within the interview guide is not an exhaustive list. This is due to the fact that each interview was a unique interaction, resulting in slightly different lines of questioning based on each interviewee's response to questions and the overall flow of the interview.

All of the interviews (n = 19) were conducted by the principal investigator on a one-to-one basis (i.e., only the interviewer and interviewee were present). That said, throughout five of the interviews, one of the participant's parents/legal guardians was present throughout. While present, the parent/legal guardian was asked to and did maintain a passive role during the interview. This request was made due to previous research having suggested that a child's ability to express their views can be influenced (either positively or negatively) by the presence of a parent/legal guardian (Gardner and Randall, 2012). Therefore, this request was an attempt to ensure that the parent/legal guardian did not actively participate in the interview.

Regardless of whether a parent/legal guardian was present, each interview took place at a convenient location for the participant. These locations included: the participants home (n = 9), a coffee shop (n = 4), an athletics club meeting room (n = 3), a leisure centre meeting room (n = 2), or a school classroom (n = 1). The location, date, and time of these interviews was decided by the participant and their parents/legal guardians. This approach ensured equity and safety between interviewer and interviewee (Herzog, 2012), whereby the interviewer is able to be adaptable to the preference of the interviewee. As a result, the interviews required the principal investigator to travel to each of the chosen locations.

At the start of each interview, participants were reminded of the purpose of the study, in addition to general information (i.e., use of a Dictaphone to record the interview, etc.), before verbally (re)confirming their consent/assent. Following the introduction, each interview was split into the following sections: (1) background information and (2) injury experiences. The first section of the interview included questions related to their typical training practices, aims and ambitions, athletic identity, and what they (dis)liked about the sport of distance running. Related to athletic identity, participants completed the AIMS (Brewer et al., 1993) to facilitate in-depth discussion related to this concept. The second section concentrated on each participant's experience of *serious RRI* and their perceptions about what factors commonly cause RRI. The order of questioning was shaped by the semi-structured interview guide (see Appendix I), with the intention being that the first section helped to develop rapport with the interviewee, while the second section provided a more direct line of questioning. Although this may not be viewed as a conventional approach, the development of rapport with adolescent interviewee's was deemed to be a vital element of the interview process. This is something that has been previously noted in relation to interviewing young children (Irwin and Johnson, 2005). The principal investigator's own knowledge of distance running and RRI also helped to build rapport with each interviewee.

More specifically, the AIMS is a ten-item scale that measures the given strength and exclusivity of a participant's identification with the 'athlete role' (Brewer et al., 1993). As detailed by Everhart et al. (2020), AIMS can be used to measure injury outcomes and return-to-sport, while being predictive of post-injury psychological distress. In this instance, AIMS was used to facilitate in-depth discussion relating to how their typical athletic identity and how this was influenced by *serious RRI*. A copy of AIMS is included in Appendix I, as part of the interview guide. In terms of procedure, participants were given sufficient time to read each item and choose a number between one ('strongly disagree') and seven ('strongly agree') that best represented their answer. Having been allowed sufficient time to answer all of the items, the participant's responses were discussed in detail. This methodological approach (i.e., using questionnaires within qualitative interviews) has previously been utilised in health services research, whereby it "provided useful triggers to stimulate conversation on a particular topic and enabled a deeper understanding" (Adamson et al., 2004, p.143). In this instance, knowledge about the participant's identification with the 'athlete role' was considered to be essential in order to gain an improved understanding about their response to sustaining a *serious RRI*.

Field notes recorded during and immediately after the interview were typed up as a Word document at the earliest possible convenience. Also, each interview was transcribed verbatim by the principal investigator as soon as it was possible to do so. Each transcribed interview was subsequently emailed to the corresponding interviewee in order for them to confirm that they were happy that it accurately represented the interview. This process is typically known as 'member checking' and, in this instance, is utilised to support the overall trustworthiness of the data, rather than claiming to provide any additional validation and/or verification (Smith and McGannon, 2018, McGannon et al., 2019).

3.5.4.3 Outcomes

Following the transcription of each interview, a reflexive thematic analysis (RTA) approach was applied to analyse each interview (Braun and Clarke, 2019a). This was achieved via a six-stage process (Braun and Clarke, 2006), as explained in Section 3.6.3. When pooled, the interviews generated 463 double-lined A4 pages of data (i.e., verbatim transcripts). The average length of the interviews was 52 minutes, ranging from 37 to 83 minutes. Following the RTA, fifteen codes and three themes were established. Each of the themes, and their associated codes, contributed towards the development of an overarching understanding of RRI in competitive adolescent distance runners.

3.6 Data Analysis

3.6.1 Sample Size Calculations

For each of the quantitative studies (Chapter 4, Chapter 5, and Chapter 7), an *a priori* sample size calculation was completed using G-power (Faul et al., 2007, 2009). Reference values from previous literature were used to inform the effect size (ES) statistics and sample size was calculated using an 80% statistical power

(1-β) and a significance (α) level of 5%. Each of these sample sizes included an estimated 10% dropout rate.

For the qualitative study (Chapter 6), the sample size was determined according to the number of participants who self-reported at least one serious (>28 days-6 months) or long-term (>6 months) RRI, as part of Chapter 5. While the concept of data saturation was not applied when conducting interviews, the analysis of interview data evidenced that there was significant repetition of responses across each interview. Therefore, it can be asserted that data saturation was achieved (Vasileiou et al., 2018, Braun and Clarke, 2019b), indicating the appropriateness of this sample size (n = 19).

3.6.2 Statistical Analyses

Data were analysed using IBM SPSS Statistics (versions 24.0 and 26.0; IBM., Chicago, USA) for all quantitative studies (Chapter 4, Chapter 5, and Chapter 7). In combination with SPSS, a Microsoft Excel spreadsheet, as published by Hopkins (2007), was used to analyse magnitude-based inferences (MBI) in Chapter 4. Within Chapter 7, prevalence and incidence data were analysed using R (version 3.6.1; R Foundation for Statistical Computing., Vienna, Austria).

Data are presented as mean ± standard deviation, unless otherwise stated. Statistical significance was set at a *p*-value of 0.05, while standardised effect size (ES) for mean comparisons were described with reference to Cohen's thresholds (Cohen, 1992): *small*, 0.2, *medium*, 0.5, and *large*, 0.8. Inclusion of ES offers a description of the size of observed effects, independent of sample size (Fritz et al., 2012). Thus, effects that are reported as *large* but nonsignificant may suggest further research with greater power is required.

In Chapter 4, MBI was used (Hopkins et al., 2009). At the time of submission, this was required by the *International Journal of Sports Physiology and Performance*. This process uses 90% CI and the smallest worthwhile ES change of 0.2 (Cohen, 1992), to identify the likelihood that an observed effect was *substantially positive*, *trivial*, or *substantially negative* and reported using quantitative chances (%) and the following qualitative probabilistic terms: <0.5%, *most unlikely*; 0.5%–5%, *very unlikely*; 5%–25%, *unlikely*; 25%–75%, *possibly*; 75%–95%, *likely*; 95%–99.5%, *very likely*; >99.5%, *most likely*. Although this approach was employed based on specific requirements of a journal, it is acknowledged that MBI continues to be a disputed statistical approach (Sainani et al., 2019). For example, analysis of MBI is more likely to result in Type I error (i.e., reporting false positives) and promotes the use of small study samples (Lohse et al., 2020).

In Chapter 5, exploratory univariate binary logistic regression analysis was used to explore potential correlates of RRI. This approach was implemented due to the fact that the sample size was not sufficient to run a multivariate logistic regression.

3.6.3 Reflexive Thematic Analysis

RTA was used to analyse all of the interview transcripts, as developed by Braun and Clarke (2019a). This particular approach to thematic analysis is one of many to have been applied since first being introduced (Braun and Clarke, 2006, Braun and Clarke, 2020a), allowing for reflective and thoughtful engagement with the data and analytical process (Braun and Clarke, 2019a, Braun and Clarke, 2020b, Trainor and Bundon, 2020). At a basic level, thematic analysis provides a method for identifying patterns (i.e., themes) within a dataset, and for understanding and (re)presenting these patterns (Braun et al., 2016). More specifically, the type of

RTA used in Chapter 6 aims to provide a detailed account of the data, anchored by reflexivity, with coding and theme development occurring in a deductive (i.e., directed by existing concepts) and latent (i.e., identifying underlying ideas and assumptions) manner. This process included six recursive phases, each of which were completed as follows:

1. *Data familiarisation* was achieved in the following ways: transcription of each interview conducted by the principal investigator, reading of each transcript between 3-4 times, as advocated by Smith and Sparkes (2016), and discussion of reading with the supervisory team. Microsoft Word was used to manually transcribe the interviews. Transcription was completed largely in parallel with the data collection process (i.e., data familiarisation was not postponed until all interviews had been completed). Passages of the transcribed interviews that were deemed to be of particular interest were underlined. This approach allowed the principal investigator to become familiar with the data, inform subsequent interviews and interview technique, and to build an appreciation of the nascent data.
2. *Initial code generation* was jointly completed by the principal investigator and Bryan Clift, whereby two of the interviews were separately coded (i.e., blinded to one another's coding of the interviews). These codes were then combined and critically discussed, before being used to inform the coding of all remaining interviews, as completed by the principal investigator. This initial process allowed for a comparison of coding choices, styles, naming choices, and underlying ideas in order to challenge, affirm, and work with initial understandings of the data.
3. *Initial theme generation* was completed after having produced the initial codes, whereby the principal investigator grouped codes based on distinct

commonalities in order to create initial themes. This was both an iterative and reflexive process, involving careful consideration of how the initial codes could be combined to reflect a broader conceptualisation of the data (Braun et al., 2016).

4. *A review of initial themes* was completed by the principal investigator and Bryan Clift. This process was used to reflect on whether the initial themes generated from the data credibly answered the research question, moving beyond a descriptive analysis of the data (Braun and Clarke, 2006). These themes were subsequently refined, based on feedback received from all other contributing authors (n = 4). This process ensured that each theme was robust and promoted a key message, appropriately supported by the identified codes.
5. *Defining and naming themes* was achieved by developing an assessment of each theme (and associated codes) with the support of all contributing authors. This included detailing both the scope and focus of each theme, identifying the most insightful data extracts, and deciding on informative theme names. Appendix J details the confirmed theme names, all of the data extracts that were drawn from the interview transcriptions (aligned to relevant codes), and brief descriptions related to the scope and focus of these themes.
6. *Results were written up* by the principal investigator, before sharing a first draft with Bryan Clift. This draft was based on the contents of Appendix J. Once both authors were confident that this accurately pieced together the themes and data extracts, in relation to existing literature and the research question, a second draft was shared with all other contributing authors for further critique and development.

4. THE VALIDATION OF SESSION RATING OF PERCEIVED EXERTION FOR QUANTIFYING INTERNAL TRAINING LOAD IN ADOLESCENT DISTANCE RUNNERS

4.1 Abstract

Purpose: To investigate the effect of measurement timing and concurrent validity of session and differential ratings of perceived exertion (sRPE and dRPE, respectively) as measures of internal training load in adolescent distance runners. **Methods:** A total of 15 adolescent distance runners (15.2 [1.6] years) performed a two-part incremental treadmill test for the assessment of maximal oxygen uptake, heart rate (HR), and blood lactate responses. Participants were familiarised with sRPE and dRPE during the treadmill test using the Foster modified CR-10 Borg scale. Subsequently, each participant completed a regular two-week mesocycle of training. Participants wore an HR monitor for each exercise session and recorded their training in a logbook, including sRPE, dRPE leg exertion (dRPE-L), and breathlessness (dRPE-B) following session completion (0 minutes), 15 minutes post-session, and 30 minutes post-session. **Results:** sRPE, dRPE-L, and dRPE-B scores were all most likely lower when reported 30 minutes post-session compared with scores 0 minutes post-session (%change, ±90% confidence limits; sRPE −26.5%, ±5.5%; dRPE-L −20.5%, ±5.6%; dRPE-B −38.9%, ±7.4%). sRPE, dRPE-L, and dRPE-B all maintained their largest correlations (r = .74-.89) when reported at session completion (0 minutes) in comparison with each of the HR-based criteria measures. **Conclusion:** sRPE, whether reported 0, 15, or 30 minutes post-session, provides a valid measure of internal training load in adolescent distance runners. In addition, dRPE-L and dRPE-B can be used in conjunction with sRPE across all time points (0, 15, and 30 minutes) to discriminate between central and peripheral exertion.

4.2 Introduction

The ability to accurately measure the internal training load (ITL) of an athlete is essential when trying to optimise athletic performance (Borresen and Lambert, 2009) and to prevent adverse training outcomes such as injury or overtraining (Windt and Gabbett, 2017). This is important for coaches and practitioners who prescribe training loads for adolescent athletes (Murray, 2017), whereby early sports specialisation has become more popular and is complicated by growth and maturational issues (Brenner, 2016). Traditionally, ITL has been measured using heart rate (HR) due to the almost linear relationship between HR and volume of oxygen uptake ($\dot{V}O_2$), a measure of energy expenditure, across multiple steady-state submaximal exercise intensities (Astrand and Rodahl, 1986). However, although HR is still regarded as the "gold standard" for non-invasive measurement of ITL (Buchheit, 2014), it is often unfeasible within youth sport, requiring the use of expensive telemetric HR monitors and technical expertise. Consequently, the session rating of perceived exertion (sRPE), an athlete's subjective rating of perceived exertion (RPE) multiplied by session duration (in minutes), has been established as a simple and valid measure of ITL (Halson, 2014).

Based on the formative research of Foster et al. (1995), sRPE is typically reported 30 minutes following session completion. They argued that this approach reduces the effect of the final section of an exercise session on the reported sRPE. However, few studies have investigated the effect of measurement timing on sRPE, especially within youth sport. Therefore, the most suitable time point to report sRPE remains unclear and is largely dependent on the inclusion (or exclusion) of a cooldown (Christen et al., 2016). It has also been argued that sRPE may oversimplify the psychophysiological construct of exertion (Hutchinson and Tenenbaum, 2006), potentially lacking sensitivity during high-intensity exercise. However, through the application of differential ratings of perceived exertion (dRPE), such as leg exertion (dRPE-L) and breathlessness (dRPE-B), it has been shown that it is possible to discriminate between central and peripheral exertion (McLaren et al., 2016), possibly resulting in a more perceptive estimation of ITL. Nonetheless, the validity of sRPE and dRPE measures, in terms of measuring ITL, has yet to be established within adolescent distance running.

sRPE has been validated within many different sports and study populations (Haddad et al., 2017). However, less is known about dRPE-L and dRPE-B, in addition to whether these measures of ITL are valid in adolescent populations. Although previous research has validated sRPE within many youth sport contexts (e.g., water polo and taekwondo), no studies have validated sRPE, dRPE-L, and dRPE-B in adolescent distance runners. This needs addressing due to the popularity of distance running throughout adolescence, whereby these measures cannot be applied based on the research conducted in adult populations (Groslambert and Mahon, 2006) and dissimilar youth sport contexts. Considering that distance running employs a variety of exercise intensities, typically prescribed via external training loads (Mujika, 2017) (i.e., number of intervals), it is essential that the ITL imposed on an adolescent athlete can be effectively monitored by coaches and practitioners.

Therefore, in a population of adolescent distance runners, the purpose of this study was to (1) investigate the effect of measurement timing on sRPE, dRPE-L, and dRPE-B following exercise session completion across three time points (0, 15, and 30 minutes) and (2) to examine the concurrent validity of sRPE, dRPE-L, and dRPE-B as measures of ITL when compared with three individualised HR-based criterion measures.

4.3 Methods

4.3.1 Participants

A total of 15 (3 females) adolescent distance runners (age 15.2 [1.6] years) volunteered to participate in this study. Each participant had to be a member of an England Athletics-affiliated club (aged 13-18 years) and training for a specific middle-distance running event, ranging from 800 m to 3000 m (including steeplechase). A convenience-based sampling procedure was used, with each participant receiving verbal and written information of the study procedures. Parental consent and participant assent were obtained. Ethical approval was granted by the institutional ethics committee (170315/B/03), in agreement with the Declaration of Helsinki.

4.3.2 Experimental Design

This study used a prospective observational research design, where each participant completed one laboratory visit, followed by a two-week mesocycle of training. Data collection took place between May and September 2017.

4.3.2.1 Laboratory Visit

On arrival to the laboratory, participants were familiarised with study procedures, the concept of RPE, and Foster's modified CR10 Borg scale (Foster et al., 1995).

Anthropometric measures, a baseline capillary blood sample, and resting heart rate (HR_{rest}) were collected, followed by the completion of a two-part incremental treadmill test for the assessment of maximum oxygen uptake ($VO2_{max}$), maximum heart rate (HR_{max}), the lactate threshold (LT), and lactate turn point (LTP) (Jones, 2007). All tests were performed on a motorised treadmill (Pro XL; Woodway GmbH, Weil am Rhein, Germany), with pulmonary gas exchange and HR being recorded throughout.

Part one of the test was a discontinuous step-incremental test with increases in running velocity of 1.0 $km \cdot h^{-1}$ at the start of each stage. Following a 5-minute warm-up period of walking and running (up to 8 $km \cdot h^{-1}$), the test began, consisting of five to eight 3-minute stages. The initial treadmill velocity was between 11.0 and 13.0 $km \cdot h^{-1}$ for male participants and 11 $km \cdot h^{-1}$ for female participants, prescribed according to their current performance level, with the treadmill gradient fixed at 1.0%. Each stage was separated by a 1-minute rest period to allow for assessment of capillary blood lactate. Increments in running velocity were continued until blood lactate had exceeded 4 $mmol \cdot L^{-1}$ and HR was within 5 to 10 beats per minute of HR_{max}. After ~10 minutes of active recovery, part two of the incremental test commenced. This involved running at a fixed velocity (final stage velocity: 2 $km \cdot h^{-1}$), with the treadmill gradient increased by 1.0% each minute until volitional exhaustion.

4.3.2.2 Two-Week Mesocycle

Following the laboratory visit (5 [3] days), participants completed a two-week mesocycle of regular training, as prescribed by their athletics coach. The researchers did not alter the training schedules. Throughout the mesocycle, participants documented their training in a logbook, including session duration (in minutes) and the external training load. Participants wore a HR monitor for each exercise session and reported whole-body RPE and dRPE (leg exertion and breathlessness) at session completion (0 minutes), 15 minutes post-session, and 30 minutes post-session.

4.3.3 Experimental Measures

4.3.3.1 Anthropometry

Body mass was measured to the nearest 0.1 kg using digital scales (Seca 704; Seca GmbH, Hamburg, Germany), and stature was measured to the nearest 0.1 cm using a stadiometer (Seca 217; Seca GmbH). Using the participant's body mass and stature, (somatic) maturity was calculated as an offset score (in years) from peak height velocity (Moore et al., 2015).

4.3.3.2 Heart Rate

During the laboratory visit, HR was recorded every 1 second using a telemetric HR monitor (T31; Polar Electro, Kempele, Finland). HRrest was accepted as the lowest 10-second average recorded during a 10-minute period of rest prior to the incremental test. HR_{max} was accepted as the highest 10-second average observed during the incremental test. Throughout the 2-week training mesocycle, HR was recorded every 1 second using an individually coded telemetric HR monitor (Team 2 System: Polar Electro). HR data were uploaded to a specialist software (ProTrainer 5; Polar Electro) before being exported to a spreadsheet (Excel; Microsoft, Redmond, WA) for analysis of ITL. If participants exceeded their laboratory based HR_{max} during an exercise session, then the highest recorded HR value from their training mesocycle was subsequently used for calculating each of the training impulse (TRIMP) methods.

4.3.3.3 Capillary Blood Lactate

A fingertip capillary blood sample (~100 µL) was collected using a heparinised microvette (CB 300 FH tubes; Sarstedt AG & Co, Nümbrecht, Germany). These samples were analysed immediately for lactate using a calibrated automatic analyser (YSI 2300; Yellow Springs Instruments, Yellow Springs, OH) in duplicate and averaged for subsequent analysis. LT and LTP were visually obtained by plotting blood lactate against running velocity and were approved by two independent reviewers. LT was accepted as the first sustained increase in blood lactate above baseline levels. LTP was accepted as a distinct and sustained breakpoint in blood lactate following LT (Jones, 2007).

4.3.3.4 Pulmonary Gas Exchange

$\dot{V}O_2$ was measured using a breath-by-breath automated gas analysis system (Cortex MetaLyzer III B; Cortex Biophysik GmbH, Leipzig, Germany). Volume and gas concentrations were calibrated before each test using standard procedures. $\dot{V}O_{2max}$ was accepted as the highest 10-second $\dot{V}O_2$ observed during the incremental test.

4.3.3.5 Measures of ITL

For each exercise session, sRPE was calculated by multiplying RPE by session duration (in minutes), as reported from the modified CR10 Borg scale (Foster et al., 1995). This category-ratio scale translates perception of effort (from 'rest' to 'maximal') into a numerical score (Borg, 1998), having been previously validated (Borresen and Lambert, 2009). The sRPE calculation was completed for each RPE measure (whole body, leg exertion, and breathlessness) at exercise completion ($sRPE_0$, $dRPE\text{-}L_0$, and $dRPE\text{-}B_0$), 15 minutes post-session ($sRPE_{15}$, $dRPE\text{-}L_{15}$, and $dRPE\text{-}B_{15}$), and 30 minutes post-session ($sRPE_{30}$, $dRPE\text{-}L_{30}$, and $dRPE\text{-}B_{30}$), expressed in arbitrary units. To improve the accuracy of self-reported RPE scores, the incremental treadmill test was used to anchor perception of maximal exertion.

Three individualised HR-based training load methods were used as criterion measures of ITL. First, the individualised training impulse ($TRIMP_I$) was used (Manzi et al., 2009). This method weights training duration using an individualised weighting factor (Y^i) for each participant, based on their blood lactate response to incremental exercise rather than a sex-specific exponential factor (Morton et al., 1990), calculated as follows:

Equation 4.1: $TD \cdot \Delta HR \cdot Y^i$

where TD is the session duration (in minutes) and ΔHR is the HR ratio, determined by the following equation:

Equation 4.2: $\Delta HR = [(HR_{TS} - HR_{rest}) / (HR_{max} - HR_{rest})]$

in which HR_{TS} is the average HR throughout the exercise session.

Y^{i} is calculated by plotting the participant's blood lactate against their fractional elevation in HR, with the exponential line (best fit) providing the calculation of the weighting factor.

Second, the Edwards (1993) summated HR zone score method ($TRIMP_E$) was used. This approach calculates the product of the accumulated session duration (in minutes) of five HR zones by a coefficient relative to each zone (1 = 50%–60% HR_{max}, 2 = 60%–70% HR_{max}, 3 = 70%–80% HR_{max}, 4 = 80%–90% HR_{max}, and 5 = 90%–100% HR_{max}), before summating the results.

Third, a modified version of $TRIMP_E$ based on the work of Lucía et al. (2003) was used. This method ($TRIMP_L$) was calculated by multiplying the time spent in three different HR zones (zone 1 = below the LT, zone 2 = between the LT and the LTP, and zone 3 = above the LTP) by a coefficient (k) relative to each zone (k = 1 for zone 1, k = 2 for zone 2, and k = 3 for zone 3), before summating the results.

4.3.4 Statistical Analyses

Data are presented as mean (standard deviation (SD)). For each participant, we calculated weighted mean session scores for sRPE, dRPE-L, and dRPE-B, at time points 0 minutes, 15 minutes, and 30 minutes to account for the different number of exercise sessions completed per participant. Following this, standardised mean differences (raw and percentage) were calculated between the sRPE, dRPE-L, and dRPE-B scores, at time points 0 minutes, 15 minutes, and 30 minutes, with uncertainty of estimates expressed as 90% confidence limits. Standardised mean differences were also calculated to examine the effect of measurement timing on sRPE, dRPE-L, and dRPE-B scores, at time points 0 minutes, 15 minutes, and 30 minutes, with 90% confidence limits. Paired samples t tests were used to calculate the necessary *p* values, before reporting the differences in relation to the chance of the true effect being substantial or trivial. Results were reported using magnitude-based inferences (mechanistic), informed by the following probabilistic terms: 25% to 75%, possibly; 75% to 95%, likely; 95% to 99.5%, very likely; and >99.5%, most likely. A smallest worthwhile change of 10% was used, in relation to percentage differences between the mean RPE scores, based on the work of Weston et al (Weston et al., 2015).

Within-participant correlations (*r*) were calculated (Bland and Altman, 1995) to examine the relationships between each of the sRPE, dRPE-L, dRPE-B, and HR-based ITL methods (pooled data), at time points 0 minutes, 15 minutes, and 30 minutes. The magnitude of the correlations was interpreted using the following scale (Hopkins, 2007): <0.1, trivial; 0.1 to 0.3, small; 0.3 to 0.5, moderate; 0.5 to 0.7, large; 0.7 to 0.9, very large; and >0.9, nearly perfect. Magnitude-based inferences (mechanistic) were employed (Hopkins et al., 2009) based on the smallest worthwhile effect size of 0.1 (Cohen, 1992) and 90% confidence limits. The chance of the true effect being substantial or trivial was calculated as previously described. The statistical package SPSS (version 24.0; SPSS Inc, Chicago, IL) was used for all analyses, alongside a spreadsheet (Excel; Microsoft) published by Hopkins (2007).

4.4 Results

4.4.1 Descriptive Characteristics

Participant descriptive characteristics are shown in Table 4.1. A total of 76 exercise sessions were completed by the participants. Due to data loss from the telemetric HR monitors, a total of 69 exercise sessions were used for subsequent analysis. The average number of exercise sessions completed per participant was 5 (3) (range 3–11), with the average duration of these sessions being 50.7 (23.5) minutes. Out of the 69 exercise sessions, 42 were interval sessions, 20 were continuous (steady state) runs, and 7 were competitive races (i.e., 800 m). In total, 59 of the exercise sessions included a cooldown. The pooled average $TRIMP_I$, $TRIMP_E$, $TRIMP_L$, sRPE, dRPE-L, and dRPE-B scores (in arbitrary units) during the two-week mesocycle are shown in Table 4.2.

Table 4.1: Descriptive characteristics of the participants.

Characteristic	**Overall (n = 15)**	**Boys (n = 12)**	**Girls (n = 3)**
Age (y)	15.2 ± 1.6	15.0 ± 1.8	15.4 ± 0.8
Stature (cm)	167.2 ± 9.9	168.2 ±10.6	160.7 ± 3.3
Body Mass (kg)	54.3 ± 9.8	55.5 ± 10.2	46.3 ± 2.3
Maturity Offset (y)	1.5 ± 1.5	1.2 ± 1.5	2.7 ± 0.6
VO_{2max} (mL·kg^{-1}·min^{-1})	62.1 ± 5.7	63.7 ± 4.6	55.7 ± 5.5
V_{max} (km·h^{-1})	17.3 ± 2.6	17.7 ± 2.2	15.7 ± 4.1
HR_{max} (b·min^{-1})	201 ± 9	202 ± 9	196 ±10
HR_{rest} (b·min^{-1})	58 ± 10	58 ± 8	55 ± 13
% VO_{2max} at the LT	75.3 ± 5.8	75.4 ± 5.6	74.7 ± 7.7
% HR_{max} at the LT	86.0 ± 10.3	85.1 ± 11.4	89.4 ± 2.6
% VO_{2max} at the LTP	85.9 ± 3.3	86.9 ± 2.8	82.0 ± 2.7
% HR_{max} at the LTP	94.1 ± 3.9	93.8 ± 4.2	95.2 ± 2.7

Abbreviations: VO_{2max}, maximal oxygen uptake; V_{max}, maximal aerobic velocity; HR_{max}, maximal heart rate; HR_{rest}, resting heart rate; LT, lactate threshold; LTP, lactate turn point. Data are represented as mean (SD).

Table 4.2: Internal training load during the two-week training mesocycle using the heart rate and rating of perceived exertion methods (Mean ± SD).

	Overall (69 sessions)	**Boys (62 sessions)**	**Girls (7 sessions)**
$TRIMP_I$ (AU)	24.6 ± 12.2	24.6 ± 12.3	23.9 ± 11.2
$TRIMP_E$ (AU)	137.1 ± 66.9	131.7 ± 63.6	184.7 ± 81.3
$TRIMP_L$ (AU)	67.2 ± 37.9	66.4 ± 38.5	73.9 ± 34.2
$sRPE_0$ (AU)	6.2 ± 2.0	6.0 ± 2.0	7.4 ± 1.9
$sRPE_{15}$ (AU)	5.2 ± 2.1	5.0 ± 2.1	6.6 ± 2.6
$sRPE_{30}$ (AU)	4.5 ± 2.3	4.4 ± 2.1	5.9 ± 3.7
dRPE-L_0 (AU)	6.0 ± 2.0	6.0 ± 2.0	6.6 ± 2.8
dRPE-L_{15} (AU)	5.2 ± 2.1	5.2 ± 2.0	5.7 ± 3.3
dRPE-L_{30} (AU)	4.8 ± 2.3	4.7 ± 2.1	5.3 ± 3.7
dRPE-B_0 (AU)	5.9 ± 2.0	5.8 ± 2.0	6.7 ± 2.4
dRPE-B_{15} (AU)	4.2 ± 2.5	4.0 ± 2.4	5.4 ± 3.5
dRPE-B_{30} (AU)	3.6 ± 2.8	3.4 ± 2.7	5.1 ± 3.8

Abbreviations: AU, arbitrary unit; TRIMPI, individualised training impulse; TRIMPE, Edwards' summated heart rate zone method; TRIMPL, Lucia's training impulse; sRPE, session rating of perceived exertion; dRPE-L, differential rating of perceived exertion for leg exertion; dRPE-B, differential rating of perceived exertion for breathlessness; 0, time point 0 minutes; 15, time point 15 minutes; 30, time point 30 minutes.

4.4.2 Latency Effect

The effect of time on sRPE, dRPE-L, and dRPE-B scores is shown in Table 4.3. Differences between sRPE, dRPE-L, and dRPE-B scores, across each time point (0 minutes, 15 minutes, and 30 minutes), are shown in Table 4.4.

Table 4.3: Effect of time when collecting sRPE, dRPE-L and dRPE-B scores after exercise session completion (0 to 15 minutes, 15 to 30 minutes, and 0 to 30 minutes).

	Raw Change (AU; ± 90% CL)	% Change (± 90% CL)	Qualitative Inference
sRPE			
0 to 15 min	-1.0; ± 0.2	-16.2; ± 3.1	Most likely lower
15 to 30 min	-0.6; ± 0.2	-12.3; ± 2.9	Likely lower
0 to 30 min	-1.6; ± 0.3	-26.5; ± 5.0	Most likely lower
dRPE-L			
0 to 15 min	-0.8; ± 0.2	-13.0; ± 3.4	Likely lower
15 to 30 min	-0.4; ± 0.1	-8.6; ± 2.1	Likely trivial
0 to 30 min	-1.2; ± 0.3	-20.5; ± 4.9	Most likely lower
dRPE-B			
0 to 15 min	-1.7; ± 0.4	-29.3; ± 5.3	Most likely lower
15 to 30 min	-0.6; ± 0.2	-13.6; ± 3.5	Likely lower
0 to 30 min	-2.3; ± 0.5	-38.8; ± 6.8	Most likely lower

Abbreviations: AU, arbitrary unit; CL, confidence limits; sRPE, session rating of perceived exertion; dRPE-L, differential rating of perceived exertion for leg exertion; dRPE-B, differential rating of perceived exertion for breathlessness; min, minutes.

Table 4.4: Differences between sRPE, dRPE-L and dRPE-B scores at time-points 0 minutes, 15 minutes, and 30 minutes.

	Raw Difference (AU; ±90% CL)	% Difference (±90% CL)	Qualitative Inference
0 min			
sRPE vs. dRPE-L	0.1; ± 0.1	2.4; ± 2.2	Most likely trivial
sRPE vs. dRPE-B	0.3; ± 0.1	4.5; ± 1.9	Most likely trivial
dRPE-L vs. dRPE-B	0.1; ± 0.1	2.1; ± 2.2	Most likely trivial
15 min			
sRPE vs. dRPE-L	-0.1; ± 0.3	-1.2; ± 3.1	Most likely trivial
sRPE vs. dRPE-B	1.0; ± 0.3	19.5; ± 4.7	Most likely higher
dRPE-L vs. dRPE-B	1.1; ± 0.3	20.4; ± 4.3	Most likely higher
30 min			
sRPE vs. dRPE-L	-0.2; ± 0.1	-5.3; ± 3.5	Very likely trivial
sRPE vs. dRPE-B	1.0; ± 0.3	22.2; ± 5.3	Most likely higher
dRPE-L vs. dRPE-B	1.2; ± 0.3	28.7; ± 7.1	Most likely higher

Abbreviations: AU, arbitrary unit; CL, confidence limits; sRPE, session rating of perceived exertion; dRPE-L, differential rating of perceived exertion for leg exertion; dRPE-B, differential rating of perceived exertion for breathlessness; min, minutes.

4.4.3 Correlations Between Measures of Internal Training Load

Within-participant correlations between sRPE, dRPE-L, dRPE-B, and each of the HR-based ITL measures ($TRIMP_I$, $TRIMP_E$, and $TRIMP_L$), at each time point (0 min, 15 min, and 30 min), are presented in Table 4.5. Correlations ranged from r = .61 to .89, across all HR-based criterion measures.

4.5 Discussion

To our knowledge, this is the first study to have investigated both the latency effect and concurrent validity of sRPE, dRPE-L, and dRPE-B, as measures of ITL in adolescent distance runners. The main findings were that (1) sRPE, dRPE-L, and dRPE-B scores were all most likely lower when reported 30 minutes post-session, compared with scores reported at session completion (0 minutes) and (2) sRPE, dRPE-L, and dRPE-B all maintained their largest correlations (r = .74 to .89) when reported at session completion (0 minutes), in comparison with each of the HR-based criteria measures.

4.5.1 Latency Effect

Traditionally, sRPE, dRPE-L, and dRPE-B have been reported 30 minutes following session completion to reduce the effect of the final section of an exercise session on an athlete’s self-reported scores (Foster et al., 1995). However, although this approach has been utilised across multiple studies (Haddad et al., 2017), there remains a dearth of scientific literature in relation to the effect of measurement timing on sRPE, dRPE-L, and dRPE-B. This is surprising, given that reporting scores at session completion (0 minutes) would be both practical and time efficient.

Table 4.5: Correlations between sRPE, dRPE-L, dRPE-B and each of the individualised heart rate-based methods of quantifying internal training load.

	$TRIMP_I$			$TRIMP_E$			$TRIMP_L$		
	r	**±90% CL**	**Qualitative Inference**	***r***	**±90% CL**	**Qualitative Inference**	***r***	**±90% CL**	**Qualitative Inference**
$sRPE_0$	0.88	0.12	Most likely positive	0.78	0.20	Most likely positive	0.89	0.11	Most likely positive
$sRPE_{15}$	0.83	0.16	Most likely positive	0.78	0.20	Most likely positive	0.87	0.13	Most likely positive
$sRPE_{30}$	0.78	0.20	Most likely positive	0.74	0.22	Most likely positive	0.84	0.15	Most likely positive
$dRPE\text{-}L_0$	0.84	0.15	Most likely positive	0.74	0.22	Most likely positive	0.84	0.15	Most likely positive
$dRPE\text{-}L_{15}$	0.78	0.20	Most likely positive	0.72	0.24	Most likely positive	0.82	0.17	Most likely positive
$dRPE\text{-}L_{30}$	0.77	0.20	Most likely positive	0.72	0.24	Most likely positive	0.83	0.16	Most likely positive
$dRPE\text{-}B_0$	0.84	0.15	Most likely positive	0.75	0.22	Most likely positive	0.83	0.16	Most likely positive
$dRPE\text{-}B_{15}$	0.71	0.24	Most likely positive	0.67	0.27	Very likely positive	0.77	0.20	Most likely positive
$dRPE\text{-}B_{30}$	0.66	0.27	Very likely positive	0.61	0.30	Very likely positive	0.72	0.24	Most likely positive

Abbreviations: $TRIMP_I$, individualised training impulse; $TRIMP_E$, Edwards' summated heart rate zone method; $TRIMP_L$, Lucia's training impulse; CL, confidence limits; sRPE, session rating of perceived exertion; dRPE-L, differential rating of perceived exertion for leg exertion; dRPE-B, differential rating of perceived exertion for breathlessness; $_0$, time point 0 minutes; $_{15}$, time point 15 minutes; $_{30}$, time point 30 minutes.

Our data evidence a latency effect, whereby sRPE, dRPE-L, and dRPE-B scores were all most likely lower when reported 30 minutes post-session. This finding is in contrast to the laboratory-based work of Christen et al. (2016) conducted in well-trained youth athletes (n = 15; 18.9 [0.7] years), where it was found that measurement timing did not influence sRPE scores during a 24-hour follow-up period, in relation to steady-state and interval cycling exercise. However, these contrasting findings are likely an outcome of differences in exercise mode, as evidenced between cycling and distance running (Millet et al., 2009). This argument is supported by McLaren et al. (2016) who demonstrated more substantial latency effects on sRPE, dRPE-L, and dRPE-B scores for treadmill running when compared with ergometer cycling between session completion (0 minutes) and 30 minutes post-session. However, this study was conducted with older participants (n = 22; 23 [3] years), consisting of male university soccer players. Therefore, although direct comparison with our results is difficult, the direction of the reported latency effect (i.e., decreasing over time) supports our findings. Nonetheless, both of the discussed studies were conducted in a laboratory setting, allowing the ecological validity of these studies to be questioned.

Previous literature has shown that the intensity toward the end of an exercise session and the inclusion (or exclusion) of a cooldown can influence the self-reported sRPE, dRPE-L, and dRPE-B scores (Christen et al., 2016, McLaren et al., 2016). Throughout this study, 59 exercise sessions included a cooldown, even though participants were not obliged to do so. Notably, the 10 exercise sessions that excluded a cooldown were all continuous (steady state) runs. Therefore, it is unlikely that the sRPE, dRPE-L, and dRPE-B scores would have been influenced by the given intensity toward the end of these exercise sessions.

As a result, in contrast to how sRPE was initially implemented by Foster et al. (1995) (i.e., reported 30 min post-session), our findings show that sRPE, dRPE-L, and dRPE-B scores can be reported at session completion (0 minutes) when used with adolescent distance runners. However, in situations where an intense exercise session excludes a cooldown, sRPE, dRPE-L, and dRPE-B may be biased toward higher scores.

4.5.2 Concurrent Validity

The pooled data demonstrate that sRPE, dRPE-L, and dRPE-B all maintained their largest correlations (*r* = .74–.89) when reported at session completion (0 minutes), in comparison with each of the HR-based criteria measures (Table 4.5). In addition, when compared with previous literature (Haddad et al., 2017), these correlations remained consistent (large to very large) across all time points (0 minutes, 15 minutes, and 30 minutes). This finding is similar to that reported by Lupo et al. (2017a), whereby the magnitude of correlation between sRPE and $TRIMP_E$ only marginally increased when reported 30 minutes post-session (*r* = .57), compared with reporting 1 minute post-session (*r* = .55), in young taekwondo athletes (n = 9; 12.0 [0.7] years). Our data show that correlations between sRPE, dRPE-L, dRPE-B, and each of the HR-based criteria measures were similar when reported 0 minutes, 15 minutes, and 30 minutes post-session. Therefore, these findings allow sRPE, dRPE-L, and dRPE-B scores to be reported at session completion (0 minutes), in addition to 15 minutes and 30 minutes post-session.

Previous studies have typically only investigated the validity of $sRPE_{30}$ (Haddad et al., 2017), making direct comparison with our findings limited. Nevertheless, in youth martial arts (Lupo et al., 2017a, Haddad et al., 2011a), individual correlations range from r = .57 to .97 ($TRIMP_E$), across all exercise intensities. However, when solely analysing the aerobic exercise sessions (n = 107) completed by male taekwondo athletes (n = 10; 13.1 [2.4] years), analogous to the external training loads applied in distance running, Haddad et al. (2011a) reported a correlation of r = .57. This correlation is lower than that found in our data (r = .74), at $sRPE_{30}$. In youth team sports, Impellizzeri et al. (2004) found correlations ranging from r = .54 to .78 ($TRIMP_E$) and r = .61 to .85 ($TRIMP_L$) in male footballers (n = 19; 17.6 [0.7] years), whereas Lupo et al. (2014) reported a correlation of r = .88 ($TRIMP_E$) in male water polo athletes (n = 13; 12.6 [0.5] years). These correlations are similar to our data ($sRPE_{30}$), whereby r = .74 ($TRIMP_E$), r = .84 ($TRIMP_L$), and r = .78 ($TRIMP_I$), respectively. However, throughout our study, reporting sRPE, dRPE-L, and dRPE-B scores at session completion (0 minutes) always maintained the largest correlations.

4.6 Practical Applications

Our results indicate that sRPE provides a valid measure of ITL when reported at session completion (0 minutes), 15 minutes, and 30 minutes post-session in adolescent distance runners. This finding is useful for coaches and practitioners, as $sRPE_0$ can be used as a practical and time-efficient approach for monitoring ITL, without having to delay the data collection process. Furthermore, considering that dRPE-L and dRPE-B maintain similar correlations to sRPE across each of the HR-based criteria measures, it can be argued that these differential measures should also be used, due to their high degree of shared variance. For example, the sRPE and dRPE-L measures were very similar in terms of RPE scores (Table

4.2), deterioration over time (Table 4.3), and validity with the HR-based measures of ITL (Table 4.5) at all time points (0 minutes, 15 minutes, and 30 minutes). Furthermore, the very likely higher (15 minutes post-session) and most likely higher (30 minutes post-session) differences between dRPE-L and dRPE-B scores (Table 4.4) indicate that these measures reflect different components of exertion. Therefore, using dRPE-L and dRPE-B alongside sRPE at all time points (0 minutes, 15 minutes, and 30 minutes) may be beneficial during particularly intense periods of training and/or competition to discriminate between central and peripheral exertion.

In relation to study limitations, the collection of sRPE, dRPE-L, and dRPE-B scores were not counterbalanced, possibly resulting in an order effect. In addition, the number of exercise sessions completed per participant ranged from 3 to 11, with data loss from the HR monitors compounding this issue. As a result, future research should extend the monitoring period to capture a more substantial number of exercise sessions.

4.7 Conclusion

Our results indicate that regardless of whether sRPE is reported at session completion (0 minutes), 15 minutes, or 30 minutes post-session, it provides a valid measure of ITL in adolescent distance runners. Our results also highlight that both dRPE-L and dRPE-B can be used in conjunction with sRPE across all time points (0 minutes, 15 minutes, and 30 minutes) to discriminate between central and peripheral exertion.

5. TRAINING PRACTICES AND INJURIES IN COMPETITIVE ADOLESCENT DISTANCE RUNNERS: A RETROSPECTIVE CROSS-SECTIONAL STUDY

5.1 Abstract

Background: Distance running is one of the most popular sports around the world. The epidemiology of running-related injury (RRI) has been investigated in adults, but only a few studies have specifically focused on adolescent distance runners. **Objectives:** (1) To examine the training practices (frequency, volume, and intensity) and descriptive epidemiology of RRI (risks, rates, body regions/areas, and severity) in competitive adolescent distance runners (13-18 years) in England, and (2) to explore potential correlates (risk factors) of RRI. **Methods:** A cross-sectional study design was used. Adolescent distance runners (n = 113) were recruited from England Athletics affiliated clubs. Participants voluntarily completed an online questionnaire between April and December 2018. At the time of completion, responses were based on the participant's previous 12-months of distance running participation. Injury incidence proportions (IP) and incidence rates (IR) were calculated. Potential correlates of RRI were estimated using an odds ratio (OR) and 95% confidence intervals (CI). **Results:** The injury IP was 68% (95% CI: 60% to 77%). The injury IR was 6.3/1000 hours of exposure (95% CI: 5.3 to 7.4). The most commonly injured body areas were the knee, foot/toes, and lower leg; primarily caused by overuse. Exploratory univariate analyses showed a larger number of training sessions per week (volume) is associated with a lower risk of RRI (OR = 0.71, 95% CI: 0.53 to 0.94), and that higher specialisation is associated with a lower risk of time loss RRI (OR = 0.26, 95% CI: 0.11 to 0.63). **Conclusion:** Injury is common in adolescent distance runners, aligned with adult-based research. These data provide guidance for the development of appropriate injury prevention measures.

5.2 Introduction

Distance running is one of the most popular sports around the world (Hulteen et al., 2017). Although distance running is associated with numerous health benefits (Pedisic et al., 2019), adult-based research shows that participation is also associated with adverse health outcomes such as injury (van Gent et al., 2007, Videbaek et al., 2015). Injuries sustained from distance running are usually situated in the lower extremity, with the lower leg, knee, and foot/toes being the most commonly injured body areas (van Gent et al., 2007, Edouard et al., 2020). Systematic reviews highlight different injury rates ranging from 2.5 to 33.0 injuries per 1000 hours of exposure (Videbaek et al., 2015), and incidence proportions between 3.2% and 79.3% in adult distance runners (van Gent et al., 2007, Kluitenberg et al., 2015a). The variation in study results could be explained by differences in research methodology (Tabben et al., 2020). Regardless, there is less research that has investigated injuries in adolescent distance runners (13-18 years) (Rauh et al., 2000, Rauh et al., 2006, Jacobsson et al., 2012, Huxley et al., 2014, Pierpoint et al., 2016, von Rosen et al., 2017, von Rosen et al., 2018a). This is an issue given that distance running is the second most prevalent sport amongst adolescents in England (Sport England, 2021), whereby an understanding of common running-related injuries (RRI) during maturation is important for supporting long-term athletic development. This is supported by a recent International Olympic Committee (IOC) consensus paper that recommends that youth athletic development should be evidence-informed (Bergeron et al., 2015). Also, the few available studies usually focus on adolescent track and field (athletics), only including distance running as a sub-sample (Jacobsson et al., 2012, Huxley et al., 2014, Pierpoint et al., 2016, Carragher et al., 2019).

Although excelling as an adolescent track and field athlete is unessential for success as a senior athlete (Moesch et al., 2011, Kearney and Hayes, 2018), research has shown that 90% of youth athletes in the UK decide to specialise in selected events from an early age (13-14 years) (Shibli and Barrett, 2011). Research has also highlighted that youth sport specialisation is positively associated with injury history (Post et al., 2017, Fabricant et al., 2016). Therefore, the trend towards early sport specialisation is a concern in relation to adolescent distance runners (Myer et al., 2015), whereby 'success' for endurance athletes is usually attributed to consistent (and monotonous) training intensities, durations, and frequencies (Seiler, 2010). These demanding training practices could contribute to RRI (Nielsen et al., 2012), yet little is known about the training practices of adolescent distance runners, or whether age, growth, and maturation related issues, contribute to RRI in this given population. A better understanding of the training practices and RRI of adolescent distance runners can inform the development of injury prevention measures. Therefore, the primary purpose of this study was to examine the training practices (frequency, volume, and intensity) and provide descriptive epidemiology of RRI (risks, rates, body regions, body areas, and severity) in competitive adolescent distance runners in England. The secondary purpose was to investigate potential correlates (risk factors) of RRI in this population.

5.3 Methods

5.3.1 Study Design

This was a cross-sectional study based on the completion of an online questionnaire. Data collection took place between April and December 2018.

5.3.2 Participants

Participants were included if they were a member of an England Athletics affiliated athletics club, aged between 13 and 18 years, and training for and/or competing in a distance running event (800m up to 10,000m, including steeplechase). Participants were excluded if they were unable to fully understand the study procedures, did not meet the inclusion criteria, and/or failed to complete the full questionnaire. Using convenience sampling, participants were recruited directly from England Athletics affiliated athletics clubs, with study information being distributed via face-to-face meetings, email, and/or social media. Because of the nature of participant recruitment, it was not possible to determine the total number of athletes approached to take part in this study. Both parental consent and participant assent were obtained before completion of the questionnaire. Ethics approval was granted by the institutional ethics committee (171206/B/02).

5.3.3 Data Collection Procedure

5.3.3.1 Study Questionnaire

Participants completed the questionnaire via the online platform (Qualtrics XM., Provo, Utah, USA), which is compatible with computers and mobile devices. The questionnaire included sections related to background demographics (e.g., date of birth), performance history (e.g., event preferences), training practices (e.g., weekly training volume), medical information (e.g., history of injury and/or 'pains or discomforts'), and athletic identity. Development of the questionnaire was based on methods used in previous studies (Jacobsson et al., 2012, Huxley et al., 2014, Woollings et al., 2015). Key stakeholders were also involved in the development of the study questionnaire to ensure it was suitable for the target audience. This included adolescent distance runners, parents, athletics coaches, and sports physiotherapists.

5.3.3.2 Injury Definition and Classification

The primary outcome measure was RRI, defined as any physical complaint that resulted from distance running participation (i.e., training or competition), irrespective of the need for medical attention or time loss from distance running activities. This definition of RRI was named 'all RRI' and included self-reported 'pains or discomforts.' RRI needed to have occurred during the 12-months immediately preceding questionnaire completion. This definition was adapted from an IOC consensus statement on load in sport and injury risk (Soligard et al., 2016), and from a consensus statement on injury and illness research design in studies on track and field (Timpka et al., 2014a). RRI that required medical attention and RRI resulting in time loss from full distance running participation were also recorded. Time loss injuries were classified according to their severity: none (0 days), slight (1 day), minimal (2-3 days), mild (4-7 days), moderately serious (8-28 days), serious (>28 days-6 months) or long-term (>6 months) (Timpka et al., 2014a). Medical attention injuries were classified as any RRI that involved the assessment of a participant's condition by a medical or healthcare practitioner. Both broad and narrow definitions of RRI were used to capture the full range of RRI (Clarsen and Bahr, 2014). Although mode (gradual onset or sudden onset) and cause (traumatic or overuse) of RRI were self-reported by participants, this excluded any self-reported ‘pains or discomforts,’ as they were not classified according to these outcomes.

5.3.3.3 Intrinsic and Extrinsic Risk Factors

Data collection included the assessment of potential intrinsic and extrinsic injury risk factors. These risk factors were selected based on previous youth sport injury studies (Emery, 2003, Caine et al., 2008, Fabricant et al., 2016), and adult-based distance running injury studies (van Gent et al., 2007). Potential intrinsic risk factors included sex, age-group, stature, body mass, body mass index (BMI), maturity timing, maturity tempo, training age, performance level, level of specialisation, and history of previous injury. Potential extrinsic risk factors included event preferences, training practices (volume and intensity), use of a coach, inclusion of a warm-up or cool-down, and inclusion of strength and conditioning as part of their weekly training.

Age-group was categorised according to age ranges: 13-14 years (U15), 15-16 years (U17) and 17-18 years (U19). BMI was divided into three subgroups by applying age and sex specific cut points (i.e., underweight, normal, and overweight/obese) (Cole et al., 2000, Cole et al., 2007). To estimate maturity timing and tempo, each participant’s age at peak height velocity (PHV) was determined by applying sex-specific maturity offset equations (Moore et al., 2015). Subsequently, maturity timing and tempo were categorised according to previous research (Baxter-Jones et al., 2005). Training age (i.e., number of years participating in distance running) and current performance level (i.e., club, country, regional, national, international) were self-reported. Level of specialisation was categorised as low, moderate, or high according to how participants responded to the following questions: “Is distance running your main sport?”, “Have you quit other sports in order to focus on distance running?”, and “How many months of the past year did you participate in distance running?” (Jayanthi et al., 2013, Jayanthi et al., 2015). History of previous injury was self-reported by participants.

To establish event preference, participants self-reported the number of distance running events that they trained for and/or competed in. Selecting one event was categorised as a “single event preference”, while two or more events was categorised as a “multi event preference”. Training practices were self-reported as hours per week and days per week. These variables were also used to calculate injury incidence rates (IR). To calculate internal training load (ITL), each participant self-reported their most recent training week, including the duration (minutes), distance (km or miles), session type (i.e., interval session), and rating of perceived exertion (RPE) for each of their training sessions. Weekly session RPE (sRPE) was subsequently calculated, having been validated as a measure of ITL in adolescent distance runners (Mann et al., 2019). Use of a coach, inclusion of a warm-up/cool-down, and inclusion of a strength and conditioning programme were categorised via binary (yes/no) self-report responses.

5.3.4 Statistical Methods

The statistical software SPSS (version 26.0; IBM., Chicago, USA) and an Excel spreadsheet (Microsoft., Redmond, USA) were used to conduct the analysis. An *a priori* target sample size of 151 participants was calculated based on a logistic regression analysis identifying an effect of 1.75 for the odds ratio (OR) between the predictor variables and RRI with an 80% power and alpha of 0.05 (van Gent et al., 2007). Incidence proportion (IP), reported as a percentage (%), was calculated to determine the average probability that a participant would sustain at least one injury during the 12-month study period. Clinical incidence, reported per 100 participants/year, was calculated to determine the proportion of participants who experienced RRI during the 12-month study period. IR was calculated to establish the number of RRI per participant/1,000 hours of exposure to distance running. To compare the relative risk between male and female participants, risk ratios (related to IP) and rate ratios (related to IR) were calculated. When reported, male participants were used as the referent group, meaning that the higher or lower risk/rate is related to the male participants (Knowles et al., 2006b). 95% confidence intervals (CI) were calculated for IP and IR (Marshall, 2005), in addition to the risk and rate ratios (Greenland and Rothman, 2008a). Median and interquartile range (IQR) statistics were calculated for multiple RRI and time loss RRI. Means and standard deviations (SD) were calculated for continuous variables. Percentages (%) were calculated for categorical variables. Sex differences were analysed using independent samples t-tests for continuous variables and Chi-squared tests for categorical variables. Differences between age-group training practices were analysed using one-way ANOVA. Pairwise comparisons were subsequently used to explore differences between age-groups. Statistical significance was set at an alpha level of 0.05, and effect sizes for mean comparisons were described using Cohen's thresholds (small=0.2, medium=0.5, large=0.8) (Cohen, 1992).

Body regions and areas of RRI were described using frequencies and proportions (%). Using RRI as the dependent variable (including time loss and medical attention definitions), exploratory univariate binary logistic regression analysis was conducted using the previously defined intrinsic and extrinsic injury risk factors, chosen according to previous research (van Gent et al., 2007, Fabricant et al., 2016, Caine et al., 2008, Emery, 2003). Linearity and overdispersion assumptions were assessed, with risk factors being excluded from analysis if assumptions were violated. Based on the limited sample size, no exploratory multivariate analysis was conducted.

5.4 Results

5.4.1 Descriptive Characteristics

A total of 115 (65 female) adolescent distance runners volunteered to participate in this study and completed the questionnaire. Two participants were excluded from the results as they were not members of an England Athletics affiliated Club, resulting in a sample of 113 (64 female) adolescent distance runners. Participant descriptive characteristics are shown in Table 5.1 with sex differences reported. Age-group based training practices are presented in Table 5.2. ANOVA revealed a significant age group effect for sessions per week ($p = 0.012$) with the 13-14 age-group reporting fewer sessions per week than the 17-18 year age-group ($p = 0.013$).

Table 5.1: Descriptive characteristics of the participants (data presented as mean and SD, unless otherwise stated)

Characteristic	Overall (n=113)	Male (n=49)	Female (n=64)	*p*-Value	Effect Size
Age, years	15.9 (1.5)	15.9 (1.5)	16.0 (1.6)	0.65	0.06
Training age, years	5.6 (2.4)	5.6 (2.1)	5.7 (2.5)	0.77	0.04
Age-group (N, %):				X^2 =0.94	
13-14 years	36 (32%)	16 (33%)	20 (31%)		
15-16 years	43 (38%)	19 (39%)	24 (38%)		
17-18 years	34 (30%)	14 (29%)	20 (31%)		
Stature, cm	168.8 (8.6)	173.7 (8.3)	165.0 (6.9)	< 0.01	1.15
Body mass, kg	52.8 (8.7)	57.4 (9.4)	49.3 (6.0)	< 0.01	1.06
BMI cut points (N, %):				X^2 = 0.02	
Underweight	32 (28%)	8 (16%)	24 (38%)		
Normal	80 (71%)	40 (82%)	40 (62%)		
Overweight	1 (1%)	1 (2%)	0 (0%)		
Maturity timing (N, %):				X^2 < 0.01	
Pre-PHV	0 (0%)	0 (0%)	0 (0%)		
At-PHV	15 (13%)	12 (24%)	3 (5%)		
Post-PHV	98 (87%)	37 (76%)	61 (95%)		
Maturity tempo (N, %):				X^2 = 0.11	
Early	0 (0%)	0 (0%)	0 (0%)		
Average	102 (90%)	47 (96%)	55 (86%)		
Late	11 (10%)	2 (4%)	9 (14%)		
Current performance level (N, %):				X^2 = 0.62	
Club	23 (20%)	11 (22%)	12 (19%)		
County	25 (22%)	8 (16%)	17 (27%)		
Regional	19 (17%)	10 (20%)	9 (14%)		
National	41 (36%)	17 (35%)	24 (37%)		
International	5 (4%)	3 (6%)	2 (3%)		
Level of specialisation (N, %):				X^2 = 0.61	
Low	9 (8%)	5 (10%)	4 (6%)		
Moderate	39 (35%)	15 (31%)	24 (38%)		
High	65 (58%)	29 (59%)	36 (56%)		
Event preferences (N, %):				X^2 = 0.46	
One (single)	8 (7%)	2 (4%)	6 (9%)		
Two or more (multiple)	105 (93%)	47 (96%)	58 (91%)		
Training practices:					
Sessions per week	4.7 (1.5)	4.9 (1.6)	4.6 (1.5)	0.28	0.20
Weeks per month	4.0 (0.2)	4.0 (0.1)	3.9 (0.3)	0.15	0.27
Months per year	11.0 (2.1)	11.2 (1.7)	10.8 (2.3)	0.31	0.19
Average session duration (min)	57.6 (19.6)	56.1 (17.2)	58.8 (21.3)	0.46	0.14
Average RPE per session (AU)	6.4 (1.4)	6.2 (1.3)	6.5 (1.5)	0.25	0.21
Average sRPE per session (AU)	391.9 (177.7)	373.7 (158.7)	405.9 (191.1)	0.34	0.18
Have a coach (N, %):				X^2 = 0.63	
Yes	109 (96%)	48 (98%)	61 (95%)		
No	4 (4%)	1 (2%)	3 (5%)		
Inclusion of a warm-up (N, %):				X^2 = 0.43	
Yes	112 (99%)	48 (98%)	64 (100%)		
No	1 (1%)	1 (2%)	0 (0%)		

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Inclusion of a cool-down (N, %):				$X^2 = 0.19$
Yes	111 (98%)	47 (96%)	64 (100%)	
No	2 (2%)	2 (4%)	0 (0%)	
Inclusion of a strength and conditioning programme (N, %):				$X^2 = 0.11$
Yes	89 (79%)	35 (71%)	54 (84%)	
No	24 (21%)	14 (29%)	10 (16%)	

Abbreviations: N, number; cm, centimetres; kg, kilograms; BMI, Body Mass Index; PHV, Peak Height Velocity; min, minutes; RPE, Rating of Perceived Exertion; sRPE, Session Rating of Perceived Exertion; AU, Arbitrary Units; X^2, chi squared.
NB: Due to rounding, not all numbers add up to stated N.

Table 5.2: Training practices according to age-group (data presented as mean and SD)

Training practices	13-14 years (n=36)	15-16 years (n=43)	17-18 years (n=34)
Sessions per week *	4.1 (1.2)	4.9 (1.5)	5.1 (1.8)
Weeks per month	3.9 (0.2)	3.9 (0.3)	3.9 (0.2)
Months per year	11.3 (1.6)	10.9 (1.9)	10.6 (2.7)
Average session duration (min)	58.5 (20.5)	53.7 (21.0)	61.7 (16.1)
Average RPE per session (AU)	6.3 (1.3)	6.6 (1.5)	6.3 (1.3)
Average sRPE per session (AU)	379.6 (150.6)	400.8 (198.0)	393.8 (181.6)

Abbreviations: RPE, Rating of Perceived Exertion; sRPE, Session Rating of Perceived Exertion; AU, Arbitrary Units.
NB: Due to rounding, not all numbers add up correctly. *$p < 0.05$ between groups.

5.4.2 Incidence Proportion and Incidence Rate

5.4.2.1 All RRI

Seventy-seven (68%) participants sustained at least one new RRI during the 12-month study period, including self-reported ‘pains or discomforts.’ Thirty-six (47%) reported multiple RRI (median: 2; IQR: 1). The total number of RRI sustained was 142, resulting in an IP of 68% (95% CI: 60% to 77%), and a clinical incidence of 126/100 participants/year (95% CI: 113 to 138). The overall IR was 6.3/1000 hours of exposure (95% CI: 5.3 to 7.4). Eleven (10%) participants had a history of previous RRI.

Thirty-one (63%) male participants sustained 60 RRI (IP = 63% (95% CI: 60% to 77%); clinical incidence = 122/100 participants/year (95% CI: 104 to 141)) compared with forty-six (72%) female participants who sustained 82 RRI (IP =

72% (95% CI: 61% to 83%); clinical incidence = 128/100 participants/year (95% CI: 111 to 145)), resulting in a risk ratio of 0.88 (95% CI: 0.68 to 1.14). The IR for male participants was 5.9/1000 hours of exposure (95% CI: 4.6 to 7.6), and for female participants it was 6.6/1000 hours of exposure (95% CI: 5.3 to 8.2), resulting in a rate ratio of 0.89 (95% CI: 0.68 to 1.33).

5.4.2.2 Time Loss RRI

Sixty-five (58%) participants sustained at least one new time loss RRI during the 12-month study period, including self-reported ‘pains or discomforts.’ A total of 112 (79%) RRI resulted in at least one day of time loss from distance running, resulting in an IP of 58% (95% CI: 48% to 67%), and a clinical incidence of 99/100 participants/year (95% CI: 97 to 101). The IR was 5.0/1000 hours of exposure (95% CI: 4.1 to 6.0). The median amount of time loss was seven days (IQR: 34).

Twenty-nine (59%) male participants sustained 45 RRI (IP = 59% (95% CI: 45% to 73%); clinical incidence = 92/100 participants/year (95% CI: 82 to 100)) compared with thirty-six (56%) female participants who sustained 67 RRI (IP = 56% (95% CI: 44% to 68%); clinical incidence = 105/100 participants/year (95% CI: 98 to 111), resulting in a risk ratio of 1.05 (95% CI: 0.77 to 1.45). The IR for male participants was 4.4/1000 hours of exposure (95% CI: 3.3 to 5.9), and for female participants it was 5.4/1000 hours of exposure (95% CI: 4.3 to 6.9), resulting in a rate ratio of 0.82 (95% CI: 0.63 to 1.34). Figure 5.1 represents the proportion of ‘all RRI’ that resulted in time loss according to severity and sex.

5.4.2.3 Medical Attention RRI

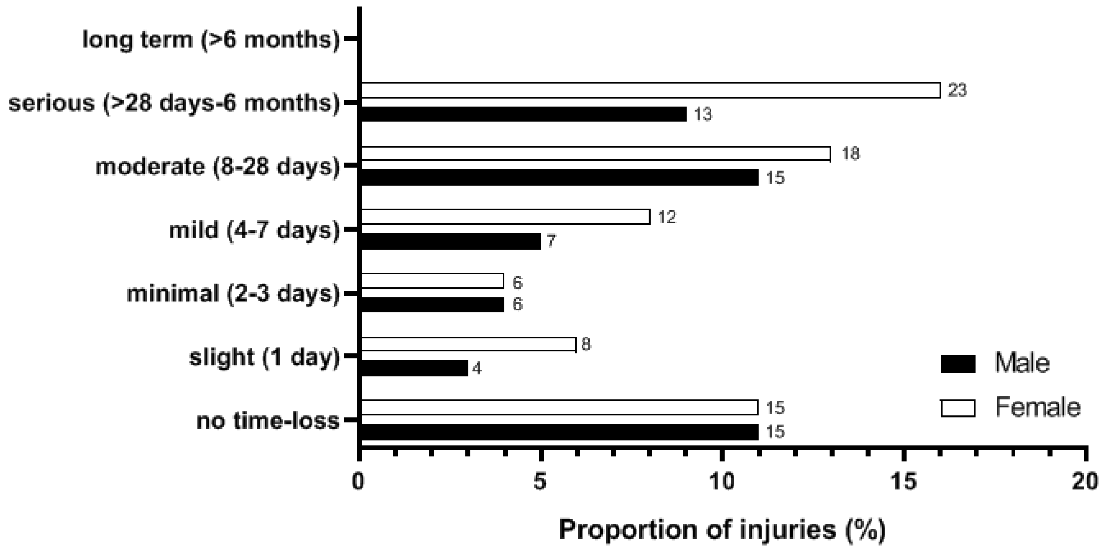
Forty-four (39%) participants sustained at least one new RRI during the 12-month retrospective study period that required medical attention. These participants received medical attention for a total of 59 RRI, resulting in an IP of 39% (95% CI: 30% to 48%), and a clinical incidence of 52/100 participants/year (95% CI: 41 to 63). The IR was 2.61/1000 hours of exposure (95% CI: 2.59 to 2.63).

Fifteen (31%) male participants sustained 19 RRI (IP = 31% (95% CI: 18% to 44%); clinical incidence = 39/100 participants/year (95% CI: 22 to 56)) compared with twenty-nine (45%) female participants who sustained 40 RRI (IP = 45% (95% CI: 33% to 58%); clinical incidence = 63/100 participants/year (95% CI: 49 to 76)), resulting in a risk ratio of 0.68 (95% CI: 0.41 to 1.11). The IR for male participants was 1.9/1000 hours of exposure (95% CI: 1.84 to 1.90), and for female participants it was 3.2/1000 hours of exposure (95% CI: 3.19 to 3.26), resulting in a rate ratio of 0.58 (95% CI: 0.46 to 1.36). Medical attention by a physiotherapist was the most common type of treatment self-reported (92%).

3.3 Injury Characteristics:

Body regions and areas of RRI are summarised in Table 5.3. Excluding self-reported ‘pains or discomfort’, there were a total of 76 self-reported RRI, representing 54% of ‘all RRI.’ Of these 76 RRI, the most commonly reported mode of injury was gradual onset (51%) and the most commonly reported cause of injury was overuse (84%).

Figure 5.1: Proportion of running-related injuries incurring time loss from distance running in days. NB: Due to rounding, not all numbers add up to stated N.



3.4 Potential Correlates:

Exploratory univariate analyses are presented in Table 5.4. Results suggested that the number of training sessions per week was inversely associated with risk of injury, when calculated for 'all RRI.' In relation to time loss injuries, a higher level of specialisation was associated with a lower risk of injury, when compared to a lower level of specialisation.

Table 5.3: Self-reported RRI by body region and area.

Body Region Body Area	**Frequency (%)**	**IR/1000 h (95% CI)**
Lower Extremity	**131 (92.3)**	**5.8 (4.9 to 6.9)**
Knee	31 (21.8)	1.4 (1.0 to 2.0)
Foot/toe	23 (16.2)	1.0 (0.7 to 1.5)
Lower leg	22 (15.5)	1.0 (0.6 to 1.5)
Thigh	17 (12.0)	0.8 (0.5 to 1.2)
Ankle	14 (9.9)	0.6 (0.4 to 1.1)
Hip	11 (7.7)	0.5 (0.3 to 0.9)
Achilles tendon	7 (4.9)	0.3 (0.2 to 0.7)
Groin	6 (4.2)	0.3 (0.2 to 0.6)
Upper Extremity	**1 (0.7)**	**0.1 (0.0 to 0.3)**
Elbow	1 (0.7)	0.1 (0.0 to 0.3)
Head and Trunk	**10 (7.0)**	**0.4 (0.2 to 0.8)**
Lumbar spine/lower back	8 (5.6)	0.4 (0.2 to 0.7)
Pelvis/sacrum/buttock	2 (1.4)	0.1 (0.0 to 0.4)
Total	**142 (100)**	**6.3 (5.3 to 7.4)**

Abbreviations: RRI, Running Related Injuries; IR, Incidence Rate; h, hours; CI, Confidence Intervals.

5.5 Discussion

This study provides novel insights into the training practices and RRI in a population of competitive adolescent distance runners. The key findings were that: (1) the number of training sessions per week (frequency) increased with chronological age; (2) for ‘all RRI,’ the IP was 68% (95% CI: 60% to 77%), and the IR was 6.3/1000 hours of exposure (95% CI: 5.3 to 7.4); (3) the most commonly injured body areas were the knee, foot/toe, and lower leg, with overuse being the most common cause of injury; and (4) “sessions per week” and a “higher level of specialisation” were associated with a lower risk of ‘all RRI’ and time loss RRI, respectively.

Table 5.4: Exploratory univariate logistic regression analyses

	IR/1000 h (95% CI)	All RRI OR (95% CI)	Time loss RRI OR (95% CI)	Medical attention RRI OR (95% CI)
Total number of RRI		142	112	59
Intrinsic Risk Factors				
Sex:				
Male	5.9 (4.6 to 7.6)	1	1	1
Female	6.6 (5.3 to 8.2)	0.76 (0.34 to 1.71)	1.86 (0.87 to 3.96)	0.64 (0.30 to 1.38)
Age-group:				
13-14 years	5.7 (4.1 to 7.9)	1	1	1
15-16 years	6.2 (4.7 to 8.2)	1.57 (0.57 to 4.36)	0.64 (0.25 to 1.63)	1.59 (0.59 to 4.26)
17-18 years	6.8 (5.3 to 8.9)	1.34 (0.50 to 3.62)	0.48 (0.19 to 1.20)	0.88 (0.36 to 2.20)
Stature (cm)	N/A	1.00 (0.96 to 1.05)	1.03 (0.98 to 1.07)	0.97 (0.93 to 1.01)
Weight (kg)	N/A	0.97 (0.93 to 1.02)	1.01 (0.97 to 1.05)	0.99 (0.95 to 1.03)
Maturity timing:				
At-PHV	5.3 (3.1 to 8.9)	1	1	1
Post-PHV	6.4 (5.4 to 7.6)	0.75 (0.22 to 2.54)	0.89 (0.29 to 2.69)	1.32 (0.42 to 4.16)
Maturity tempo:				
Average	6.3 (5.3 to 7.5)	1	1	1
Late	6.2 (3.8 to 9.9)	2.25 (0.46 to 11.00)	0.58 (0.17 to 2.04)	0.56 (0.14 to 2.23)
Training age, years	N/A	0.93 (0.79 to 1.11)	1.05 (0.90 to 1.23)	1.08 (0.92 to 1.27)
Level of specialisation:				
Low	19.8 (11.8 to 33.3)	1	1	1
Moderate	6.6 (5.0 to 8.7)	0.26 (0.03 to 2.23)	0.69 (0.17 to 2.79)	0.53 (0.13 to 2.17)
High	5.5 (4.4 to 6.8)	1.17 (0.51 to 2.71)	**0.26 (0.11 to 0.63)** *	1.33 (0.58 to 3.06)
Extrinsic Risk Factors				
Event preferences:				
One (single)	6.2 (3.2 to 11.9)	1	1	1
Two or more (multiple)	6.3 (5.3 to 7.5)	1.31 (0.30 to 5.81)	1.39 (0.33 to 5.85)	4.86 (0.58 to 40.90)
Training practices:				
Sessions per week	N/A	**0.71 (0.53 to 0.94)** *	0.98 (0.77 to 1.25)	0.85 (0.66 to 1.09)
Average session duration (min)	N/A	0.99 (0.97 to 1.01)	1.01 (0.99 to 1.03)	1.01 (0.99 to 1.03)
Weeks per month	N/A	2.43 (0.27 to 21.60)	1.51 (0.27 to 8.59)	0.77 (0.14 to 4.14)
Months per year	N/A	1.15 (0.91 to 1.46)	1.05 (0.88 to 1.27)	1.08 (0.90 to 1.29)
Have a coach:				
Yes	6.2 (5.2 to 7.3)	1	1	1
No	10.9 (4.9 to 24.1)	1.42 (0.14 to 14.13)	0.23 (0.02 to 2.33)	1.59 (0.22 to 11.76)
Inclusion of a strength and conditioning programme:				
Yes	6.0 (5.0 to 7.2)	1	1	1
No	7.6 (5.3 to 11.0)	1.53 (0.55 to 4.24)	1.30 (0.52 to 3.28)	0.74 (0.29 to 1.90)

Abbreviations: IR, Incidence Rate; RRI, running-related injuries; h, hours; CI, Confidence Intervals; OR, Odds Ratio; cm, centimetres; kg, kilograms; PHV, Peak Height Velocity; min, minutes. NB: Self-reported 'pains or discomforts' are included in each of the RRI outcomes. The following risk factors were excluded from analyses due to violation of statistical assumptions: body mass index cut points; current performance level; average weekly rating of perceived exertion; average weekly session rating of perceived exertion; use of warm-up; use of cool-down. * $p < 0.05$.

5.5.1 Training Practices

The results highlight that the number of training sessions per week (frequency) are significantly different between age-groups, with a higher number of weekly sessions being recorded in the older 17-18 age-group, compared to the 13-14 age-group. This finding supports that reported in a cohort of elite Australian youth track and field athletes, and the notion that performance athletes in ‘centimetres, grams, or seconds’ sports increase their training practices during late adolescence (Huxley et al., 2014, Moesch et al., 2011). However, no other significant differences were found between age-groups, in relation to the training practices of these athletes. This might be because a large proportion (58%) of these adolescent distance runners had higher levels of specialisation and broadly similar training ages, regardless of sex.

The fact that both the volume and intensity of training practices do not differ much between age-groups is concerning, especially considering that distance running is a late-specialisation sport (Moesch et al., 2011, Kearney and Hayes, 2018). For example, the average number of training months per year (11.0) in this cohort exceeds current evidence-based recommendations, having been associated with injury history in youth athletes (Post et al., 2017). However, it is important to recognise that self-reported intensity was based on perceived exertion. Therefore, this does not mean that other physiological or biomechanical measures of intensity did not vary between participants and the different age-groups.

In further contradiction to the training recommendations (Post et al., 2017), the exploratory analyses highlight that the more training sessions (volume) that an adolescent runner completes per week, was associated with a lower risk of injury. When only including time loss RRI, a higher level of specialisation was also associated with a lower risk of injury, compared to those with a lower level of specialisation. Although there are several confounding factors to consider when interpreting these results, whereby these associations could well be bidirectional, they suggest that the current training recommendations may need revaluating for specific sports. However, it is clear that analytic epidemiological data is required to detail what this may mean for competitive adolescent distance runners, having quantified the association between training exposure and RRI.

5.5.2 Running-Related Injury

For 'all RRI,' the reported injury IP was particularly high within this population (68%), towards the higher end of data reported in adult distance runners (range: 19.4% to 79.3%) (van Gent et al., 2007). When considering exposure time, the reported injury IR (6.3/1000 hours of exposure), for 'all RRI,' was slightly higher than that found in a two different cohorts of elite Swedish adolescent distance runners (4.0 to 5.3/1000 hours of exposure) (von Rosen et al., 2018a, von Rosen et al., 2017). Yet, these rates are lower than those found in recreational (7.7/1000 hours of exposure) and novice (17.8/1000 hours of exposure) adult runners (Videbaek et al., 2015). Overall, these IP and IR results indicate that this cohort of competitive adolescent distance runners may have a greater training volume (exposure) than in other sports, whereby the particularly high IP may be a result of this greater training volume.

The injury IR for male participants (5.9/1000 hours of exposure), for 'all RRI,' is higher than that reported in several other youth sports, with a similar injury IR to that found in youth football studies (Caine et al., 2008). A similar pattern was found in terms of the injury IR for female participants (6.6/1000 hours of exposure), indicating a lack of significant sex differences. This is further supported by a nonsignificant rate ratio between the male and female participants in this study (rate ratio = 0.89; 95% CI: 0.68-1.33). Notably, the studies reporting injury IR in a population of youth cross-country runners calculated this outcome according to the number of injuries per 1000 athletic exposures, making comparison of results difficult (Rauh et al., 2000, Rauh et al., 2006).

The injury IP for those RRIs that required medical attention was 39%, while the largest proportion of RRIs incurring time loss were categorised as “serious” (25%). Although this is an interesting finding, highlighting that a quarter of RRIs resulted in more than 28-days of time loss (up to 6-months), this may be due to recall bias. On the contrary, the large proportion of RRIs incurring “no time loss” (22%) was due to participants being able to register “any physical complaint” when self-reporting RRI, whereby 45% (n = 30) of self-reported ‘pains or discomforts’ did not result in time loss.

RRIs were most commonly reported in the lower extremity, with the knee, foot/toe and lower leg being the most frequently injured body areas. These affected body areas are comparable to those reported in elite adult and adolescent track and field athletes (Jacobsson et al., 2012). Likewise, the most common self-reported cause of injury was overuse, which supports previous findings (DiFiori et al., 2014). These data indicate that injury prevention measures for adolescent distance runners should predominantly focus on reducing the risk of lower extremity RRI caused by overuse.

5.5.3 Methodological Limitations

The main limitation of this study is the use of a cross-sectional study design. As a result, it is not possible to determine temporal relationships between potential injury risk factors and RRI. Recruitment difficulties resulted in a limited sample size is, also considered a study limitation. While this is not a limitation for the descriptive data, the limited sample size meant that only exploratory univariate analyses were conducted when investigating potential correlates of RRI. The convenience sampling method may also have led to a non-representative sample.

Recall bias is a further study limitation, whereby the accuracy of data was dependent upon self-report. This type of bias often results in participants under-reporting minor injuries, leading to an artificially greater proportion of severe injuries. While there was a high proportion of serious time loss RRI, the proportion of RRI that incurred no time loss was also elevated. Nonetheless, research has shown that participants can accurately recall the total number of injuries, and the body region/area of the injury, when providing a 12-month self-reported history (Gabbe et al., 2003). However, as that research was based in a different sporting context, the effect of recall bias remains unclear within this study. Social desirability bias is also possible, whereby participants could have over-reported their training practices (frequency, volume, and intensity).

5.6 Conclusion

This study found that the injury IR for competitive adolescent distance runners, for ‘all RRI,’ is slightly higher than that reported in studies that have included youth endurance athletes, but lower when compared to studies that only included adult distance runners. This study also demonstrated that the injury IP for ‘all RRI’ was particularly high, potentially explained by a greater training volume (exposure) in competitive adolescent distance runners, when compared to other youth sports.

The knee, foot/toe, and lower leg were the most commonly injured body areas, with overuse being the most common cause of injury. There was a high level of specialisation within this population, and the total number of training sessions per week (frequency) increased with age. In relation to the risk of incurring RRI, a higher level of specialisation was associated with a lower risk of injury, compared to those with a lower level of specialisation. In relation to incurring a time loss injury, increased training frequency was associated with a lower risk of injury. However, due to the limited sample size, this exploratory univariate analysis needs to be substantiated via comprehensive analytical epidemiology. Therefore, a prospective cohort study should be conducted in order to establish temporal relationships between potential injury risk factors and RRI in this population.

6. RUNNING-RELATED INJURY IN COMPETITIVE ADOLESCENT DISTANCE RUNNERS: A QUALITATIVE STUDY OF PSYCHOSOCIAL RESPONSES

6.1 Abstract

Distance running is one of the most popular sports among children and adolescents around the world. However, previous adult- and adolescent-based research indicates that injury is prevalent when participating in distance running. Although knowledge related to the extent of the injury problem is important, an understanding of athletes' psychosocial responses to running-related injury (RRI), applying a qualitative lens of inquiry, is frequently overlooked by researchers. As a result, the purpose of this study was to investigate the psychosocial responses to '*serious RRI*' (i.e., >28 days-6 months of time loss) in competitive adolescent distance runners in England. Nineteen adolescent distance runners were interviewed about their experiences of *serious RRI*, focussing on their response to and subsequent recovery from *serious RRI*. Based on a reflexive thematic analysis, three themes were developed: (1) *performance uncertainty*, (2) *injury (mis)management*, and (3) *contested identity*. These three themes were found to support a number of the theoretical relationships proposed in Wiese-Bjornstal et al. (1998) 'integrated model of response to sport injury,' alongside various other research findings. In turn, all of these themes contributed towards an overarching understanding that *serious RRI* acts to destabilise the athletic identity of competitive adolescent distance runners, as a psychosocial recovery outcome. Practical recommendations are made in terms of improving recovery processes following *serious RRI* and developing injury prevention measures in this particular sporting context. These recommendations also include supporting competitive adolescent distance runners to develop and implement effective coping skills for when RRI does occur, regardless of severity.

6.2 Introduction

From a global perspective, distance running is one of the most popular sports among children and adolescents (Hulteen et al., 2017). Youth participation in sport and physical activity is associated with various health benefits (Janssen and LeBlanc, 2010, Poitras et al., 2016). Yet, adult- and adolescent-based research studies highlight that participation in distance running is associated with adverse outcomes, such as running-related injury (RRI) (van Gent et al., 2007, Krabak et al., 2020). Sport-related injury has also been shown to be prevalent in competitive adolescent track and field athletes, including distance runners as a sub-sample (Jacobsson et al., 2012, Jacobsson et al., 2013, Huxley et al., 2014, von Rosen et al., 2018a, Moseid et al., 2018, Carragher et al., 2019). Although knowledge of the extent of the injury problem (i.e., surveillance, aetiology, and mechanisms) is important, insight related to athlete responses to sport-related injury is frequently overlooked (Walker et al., 2007), including consideration of various psychological and social (i.e., psychosocial) factors (Forsdyke et al., 2016). As a consequence, an improved understanding about how competitive adolescent distance runners respond to RRI, from a psychosocial perspective, is likely to improve subsequent recovery processes and support the development and implementation of context-specific injury prevention measures.

Despite research examining psychosocial aspects of sport-related injury regularly being overlooked, it has previously been demonstrated that sport-related injury can result in negative outcomes in a cohort of elite Swedish adolescent athletes (Von Rosen et al. 2018). These negative outcomes included feelings of loneliness, frustration, and self-blame, each of which contributed to the overarching theme of a ‘loss of athletic identity.’ However, as distance runners are typically included as a sub-sample within broader sporting populations, as is the case in the above-mentioned study, it is plausible that this causes a loss of contextual detail. This is an essential point when considering that endurance athletes, including distance runners, are expected to sustain particularly intense and monotonous training practices (Seiler, 2010); theorised as ‘endurance work’ by McNarry et al. (2020), and demanding a ‘circle of commitment’ by Yair (1990, 1992). As a result, distance runners may experience unique psychosocial responses to RRI, thereby justifying further investigation. This is also important in relation to adolescent athletes, whereby youth athletic development and the risk of sport-related injury can be affected by growth and maturation (Bergeron et al., 2015).

As an additional point related to context, it is crucial to recognise that there is a growing evidence-base suggesting that the risk of sport-related injury, as a result of youth sport participation, can be effectively reduced by implementing exercise- and/or education-based prevention measures (Abernethy and Bleakley, 2007, Caine et al., 2008, Rössler et al., 2014, Lauersen et al., 2014, Emery et al., 2015). The majority of the studies that contribute to this evidence-base have, however, focussed on team sports, rather than individual and/or endurance sports. These prevention measures are, therefore, mostly inappropriate for adolescent distance runners, whereby contextual information related to this population is still required to support the development of effective prevention measures. This aligns to an argument recently made by Bolling et al. (2018), emphasising the importance of establishing perspectives that acknowledge the specific context in which sport-related injury occurs. This argument highlights that it should be common practice to use an athlete’s experiential knowledge to cultivate an improved understanding of the given sport-related injury problem and, in turn, to inform the development of preventative measures. This contextual information may also allow athletes, when suitably supported by coaches, family, friends, and healthcare practitioners, to adjust their psychosocial response to (and recovery from) sport-related injury, due to insight that is informed by their immediate sporting context. One way to determine this context-specific knowledge is via qualitative inquiry (Bekker et al., 2020), whereby adopting research methods that focus on athlete perceptions and experiences can help to generate athlete-centred knowledge about psychosocial responses to sport-related injury.

The aim of this study was to investigate the psychosocial responses to '*serious RRI*' (i.e., >28 days-6 months of time loss) in a cohort of competitive adolescent distance runners. The findings from this study, constructed via semi-structured interviews, provide an improved understanding of typical psychosocial responses to *serious RRI* that can be used to enhance subsequent recovery processes and inform the development of future injury prevention measures in this particular sporting context.

6.2.1 Theorising Responses to Sport-Related Injury

Previous research has examined aspects of sport-related injury from both a pre- and post-injury perspective. Pre-injury research seeks to establish the processes that underlie an athlete's predisposition to sport-related injury. As demonstrated by Johnson (2011), history of stressors, personal factors, fatigue, and ineffective coping were found to precede the onset of acute injury, based on interviews with competitive adult athletes in Sweden (n = 20). In contrast, post-injury research considers psychosocial aspects of sport-related injury across a variety of different 'recovery phases.' These recovery phases include an athlete's initial response to sustaining a sport-related injury, their recovery from sport-related injury, and the management of their return-to-sport. For example, in a systematic review, Ardern et al. (2013) reported that there is preliminary evidence that positive psychological responses were associated with a higher rate of successful return-to-sport.

Within a health context, the term 'psychosocial' is related to the influence of social factors on an athlete's mind or behaviour, and the interrelationship between social and behavioural factors (Martikainen et al., 2002). Therefore, in an attempt to understand how different psychosocial and physical (i.e., biological) factors affect an athlete's response to sport-related injury, and recovery, several theoretical approaches have been developed. These include a biopsychosocial model (Engel 1977; Brewer, Andersen, and Van Raalte 2002), stage models (Kübler-Ross 2005; Brewer 2007), and cognitive appraisal models (Wiese-bjornstal et al. 1998; Walker, Thatcher, and Lavallee 2007). Nonetheless, it has been observed that no single approach predominates the literature surrounding sport-related injury (Forsdyke et al., 2016).

As a widely accepted theoretical framework (Walker et al., 2007), Wiese-bjornstal et al. (1998) 'integrated model of response to sport injury' suggests that a combination of personal and situational factors determine an athlete's initial cognitive appraisal of a sport-related injury, in addition to their subsequent emotional (e.g., fear of unknown and frustration) and behavioural (e.g., utilising social support) response. This model also considers the impact of different variables before the onset of sport-related injury, as first proposed by Andersen and Williams (1988). Based on an athlete's cognitive appraisal of their injury, in addition to their emotional and behavioural response, physical and psychosocial recovery outcomes become apparent. Specifically, these three components (i.e., cognitive appraisal, emotional response, and behavioural response) are seen as the 'dynamic core' of the integrated model, each of which interact and result in positive or negative recovery outcomes for the athlete. This is conceptualised as a recursive process, whereby an athlete continually reappraises their situation in response to evolving contextual factors. Specific to competitive adult distance runners, an athlete's initial cognitive appraisal of an RRI was found to play a role in their chosen behavioural response, thereby influencing RRI recovery outcomes (Jelvegård et al., 2016). This research demonstrated that if an athlete classified their RRI to have a gradual onset (i.e., lacking a definable sudden onset event), then the subsequent behavioural response was varied, resulting in 'overactivity.' As a result, instead of reducing training and competition loads, viewed as the typical response to a sudden onset RRI (i.e., resulting from a specific/identifiable event), overactivity was characterised by continuing to train, regardless of pain. This decision was regularly supported by a belief that the RRI would resolve itself, thereby prolonging the overall recovery process.

Wiese-bjornstal et al. (1998) integrated model also recognises that an athlete's appraisal and response to sport-related injury is bounded by their socialisation in a particular sports culture (i.e., situational factors). For example, the concept of playing hurt, known as presenteeism, is usually reported in adult- and adolescent-based competitive sport, whereby athletes rationalise pain and sport-related injury as a normal aspect of their participation (Roderick et al., 2000, Schnell et al., 2014, Mayer and Thiel, 2016, Mayer et al., 2018). Specific to a cohort of elite German adolescent athletes, the extent to which such risks are taken was shown to be associated to the level of importance that an athlete gave to their chosen 'sports environment,' compared to their 'non-sports environment' (Schnell et al., 2014). This study also reported that athletes who sought perfection and were focused on performance were more willing to take on physical and social risks. However, in a similar study cohort, Mayer et al. (2018) found that the willingness to play hurt was lowest in endurance sport athletes. Based on these contrasting findings, it is crucial to investigate whether presenteeism is evident in competitive adolescent distance runners, in order to tailor future RRI prevention measures to this sport-specific context.

For the purpose of this study, Wiese-bjornstal et al. (1998) integrated model was employed to structure the interpretation of the results, related to psychosocial responses to *serious RRI*, with the data being analysed in a deductive and latent way (Braun and Clarke, 2019a). Application of this model adds value to this analysis by enabling a detailed understanding of competitive adolescent distance runners' responses to *serious RRI*. This knowledge can subsequently be used to inform the development and implementation of future RRI prevention measures, while improving recovery processes specific to this specific sporting context.

6.3 Methods

6.3.1 Philosophical Assumptions and Study Design

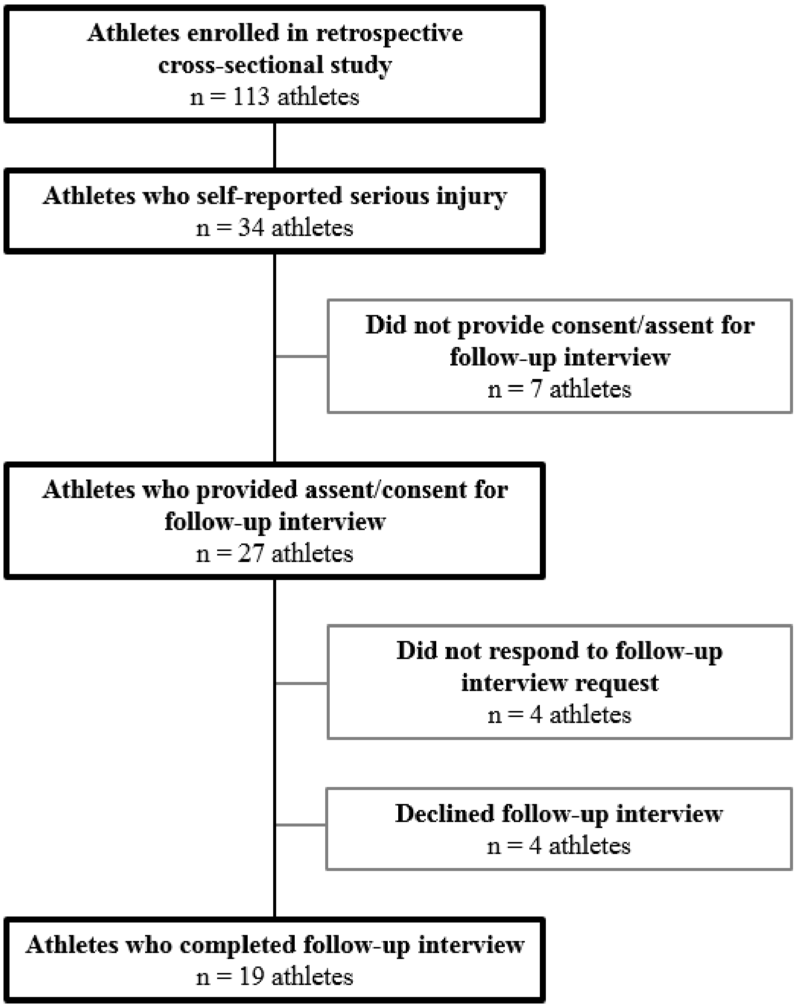
Working within a pragmatic philosophical assumption, the study in this chapter stemmed from the post-positivist approach applied in a prior study (Chapter 5), which set up the interpretivist approach adopted here. Within an interpretivist approach, this study adopts ontological relativism (i.e., reality is a finite subjective experience) and epistemological constructivism (i.e., that meaning and knowledge are constructed and subjective). In alignment with these philosophical assumptions and the aim of the study, the chosen data collection method was semi-structured interviews.

This study used semi-structured interviews to facilitate an analysis related to the psychosocial responses to *serious RRI* within a cohort of competitive adolescent distance runners. Semi-structured interviews were utilised to collect open-ended data with an emphasis on creating a meaningful and 'emergent' dialogue between interviewer and interviewee (Kvale and Brinkmann, 2009, DeJonckheere and Vaughn, 2019). All interviewed participants were recruited from a previous retrospective cross-sectional study, as presented in Chapter 5. Interviews were conducted between November 2018 and February 2019. Ethics approval was provided by the institutional ethics committee (171206/B/02), whereby written parental consent and participant assent were obtained before each interview.

6.3.2 Participants

Participants were recruited from a previous study (Chapter 5). This study included participants (n = 113) who were members of an England Athletics affiliated club, aged between 13 and 18 years, and training for and/or competing in a distance running event (800 m up to 10,000 m, including steeplechase). Participants from the previous study were eligible to partake in this study if they self-reported at least one *serious* (i.e., resulted in >28 days-6 months of time loss) or *long-term* (i.e., resulted in >6 months of time loss) *RRI* (Timpka et al., 2014a), applying a 'criterion' purposive sampling technique (Patton, 2002). This sampling technique was applied to identify and select all cases that met the predetermined inclusion criteria. Only participants who self-reported *serious* or *long-term RRI* were included in the current study to ensure that the severity (i.e., duration of time loss) of the RRI allowed for sufficient insight into an athlete's responses to RRI, rather than including injuries that were more transient. In the previous study, 34 participants self-reported at least one *serious RRI*, while no *long-term RRIs* were reported. Of these 34 participants, a total of 27 provided consent to be interviewed (Figure 6.1). When invited to be interviewed, a total of 19 volunteered to take part and were subsequently interviewed. This sample size (n = 19) aligns to those reported in similar studies (van Wilgen and Verhagen, 2012, Bolling et al., 2019, Bargoria et al., 2020), while representing the maximum number of participants that had volunteered to take part in this study. Although significant repetition of responses became apparent during the interview process, pertaining to data adequacy (Vasileiou et al., 2018), the authors did not endeavour to apply the concept of ‘data saturation’ (Braun and Clarke, 2019b). Participant information is shown in Table 6.1.

Figure 6.1: Study flow chart illustrating participant enrolment for the semi-structured interviews



6.3.3 Procedure

As part of the consent process for the previous study, participants were given the option to be contacted to take part in a follow-up interview, if eligible (i.e., had self-reported at least one *serious* or *long-term RRI*). Those who self-reported at least one *serious RRI* and consented to participate in a follow-up interview (n = 27) were initially contacted via email (Figure 6.1). Semi-structured interviews were carried out by the principal investigator (Robert Mann) on a one-to-one basis except for on five occasions, whereby either a parent or legal guardian was present throughout (Table 6.1). When present, the parent or legal guardian was asked to maintain a passive role. Each of the 19 interviews took place at a convenient location for the participant (e.g., athletics club, family home, coffee shop), as agreed in advance with the participant's parent or legal guardian. At the start of each interview, participants were reminded of the study purpose and (re)confirmed their consent/assent. Participants were not given any information related to the interviewer's reasons for conducting this research. If requested, this information was discussed after the interview. The principal investigator (i.e., interviewer) did have experience of distance running and RRI. This insight was useful for building rapport, empathising, and making sense of the participants' experiences of RRI. Following an introduction, each interview was split into two parts: (1) background information, and (2) injury experiences. The first part focused on participants' typical training practices, aims and ambitions, athletic identity, and what they (dis)liked about the sport of distance running. The second part focused on their personal experiences of *serious RRI* (e.g., response to RRI, outcomes of RRI, and support received) and perceptions related to what factors commonly cause RRI. A summary of the main points was provided at the end of each of the two parts, in order for the interviewer to check for understanding.

Table 6.1: Descriptive characteristics of interviewed athletes

ID	Sex	Age	Competitive Level	Injuries	ID	Sex	Age	Competitive Level	Injuries
P01	Female	14	County	Hip	P11	Female	16	National	Lower leg, Knee
P02	Male	17	Regional	Groin	P12	Male	15	International	Hip
P03*	Female	13	Club	Foot/toe	P13	Male	17	National	Lower leg
P04*	Female	16	Regional	Foot/toe	P14*	Male	14	Club	Thigh
P05	Male	18	National	Lower leg	P15	Female	18	National	Foot/toe
P06*	Female	13	Regional	Knee	P16	Female	17	County	Ankle, Foot/toe
P07	Male	15	Club	Knee	P17	Female	17	National	Achilles tendon
P08	Male	15	County	Thigh	P18	Female	16	Regional	Knee
P09	Female	17	Club	Knee	P19*	Female	14	Regional	Knee
P10	Female	14	Club	Groin					

Average age: 16.0 (Standard Deviation = 1.6). *Interviewed with one of their parent's present. Injuries are reported by body area. Abbreviations: ID, Identification Code.

The order of questioning was initially shaped by the semi-structured interview guide (Appendix I), co-developed by the principal investigator and Dr Bryan Clift. Yet, each interviewee-interviewer interaction was unique, with different probing questions being used to allow the interviewee to give rich and thick descriptions (Smith and Caddick, 2012). The average length of these interviews was 52 minutes, ranging from 37 to 83 minutes. Prior to the interviews, no relationship had been established with the participants other than via email correspondence with them (and their parents/legal guardians) to coordinate a suitable date and venue for the interview. All interviews were recorded on a Dictaphone (Sony ICD-PX333) for subsequent transcription and analysis. Field notes were recorded during and immediately after the interview. Once transcribed verbatim by the principal investigator, member checks were completed with participants via email. No transcripts were queried/corrected by participants. Following this process, all audio files of these interviews were deleted.

6.3.4 Data Analysis

To help better understand the typical psychosocial responses to *serious RRI* in competitive adolescent distance runners, a reflexive thematic analysis (RTA) approach was used to analyse all of the interviews, via a six-stage process (Table 6.2), as developed by Braun and Clarke (2006, 2014, 2019a). The type of RTA adopted for this analysis aimed to provide a detailed account of the data with coding and theme development occurring in both a deductive (i.e., directed by existing concepts and ideas) and latent (i.e., identifying underlying ideas and assumptions) way (Braun and Clarke, 2019a). Relevant literature, in relation to sport-related injury and athlete health protection, was used to inform and guide each stage of the RTA process. To begin this process, the first and last author separately coded two of the interview transcripts. Having coded these transcripts, the same two authors compared their coding choices, styles, naming choices, and underlying ideas in order to discuss, challenge, affirm, and work with understandings of the data. Once these preliminary thoughts had been shared, this process continued as follows: (1) the remaining transcripts were coded by the first author, alongside the generation of initial themes (derived from the data) and identification of data extracts; (2) the first and last authors reviewed codes and refined these initial themes; (3) feedback was provided in relation to these initial themes by all other co-authors; and (4) suitable data extracts were sorted according to confirmed themes, including deciding on an informative name for each theme. All data analysis was carried out using Microsoft Word. When presenting codes and themes, participant quotes were selected as representative examples. Each quote includes the relevant participant's identification code and related line numbers. All quotes have been edited for clarity and coherence, whereby, for example, filled pauses and repeated words were removed.

Table 6.2: Description of process undertaken during each phase of the reflexive thematic analysis process.

Phase	Description of process undertaken
1. Familiarisation with the data	Verbatim transcription of each interview was initially used to familiarise the first author (RM) with the data. Following this, RM read and re-read the data, to become more familiar with its content.
2. Generating initial codes	Initially, two interview transcripts were separately coded by the first (RM) and second (BC) author, with their thoughts being discussed. These discussions informed the subsequent coding of all other transcripts by RM, before systematically collating all generated codes and data extracts. This process was informed by previous research and the predisposition of RM, in relation to relevant topics.
3. Searching for initial themes	In parallel with the second phase of this process, RM combined codes into initial themes by collating data relevant to each theme. Suitable data extracts were also identified, aligned to each code.
4. Reviewing themes	RM and BC reviewed the initial themes against the dataset, to determine whether they convincingly answer the research question. These themes were subsequently refined, with feedback being provided by all other authors. This process ensured that each theme was robust and promoted a key message.
5. Defining and naming themes	Having reviewed and identified themes, all authors developed a detailed assessment of each theme. This included detailing both the scope and focus of each theme, aligning data extracts to themes, and deciding on informative theme names. These themes are represented in Table 6.3.
6. Writing up	RM developed the first draft of the analysis section and shared with BC for academic critique. Once both authors were happy that this accurately pieced together the themes and data extracts, in relation to existing literature, this was shared with all other authors for further critique and development.

6.3.5 Methodological Rigour

In terms of methodological rigour (and trustworthiness), this study was aligned to a relativist ontology and constructivist epistemology. This means that ‘universal criteria’ for assessing the quality of qualitative research are not applied in a prescriptive (i.e., checklist) fashion (Burke, 2016). Instead, evaluative criteria are study-specific and drawn from a continually expanding list of quality indicators that are open to reinterpretation (Sparkes and Smith, 2009). Specific to this study, the following criteria were drawn from previously applied quality indicators (Tracy, 2010): (1) worthiness of topic area; (2) rich rigour (e.g., use of suitable theoretical constructs that inform subsequent analysis); (3) resonance (e.g., ensuring that the research is accessible to, influences, and affects a wide range of audiences); (4) significant contribution (e.g., addressing a gap in the current literature); and (5) meaningful coherence (e.g., applies methods aligned to the research purpose and manages to interconnect literature with the results and discussion).

6.4 Results

The RTA process, used to investigate psychosocial responses to *serious RRI* in a cohort of competitive adolescent distance runners, led to the development of fifteen codes and three themes. The three themes were named: (1) *performance uncertainty*, (2) *injury (mis)management*, and (3) *contested identity*. Each of these themes, and their associated codes (Table 6.3), contributed towards the development of the overarching understanding of *serious RRI* as *destabilising athletic identity* in competitive adolescent distance runners. This overarching understanding demonstrates that, as a psychosocial recovery outcome of *serious RRI*, the degree to which a competitive adolescent distance runner identifies with their status as an athlete is undermined by sustaining a *serious RRI*. In turn, this *destabilisation* results in cognitive (re)appraisals that subsequently impact upon competitive adolescent distance runners' ability to return-to-running.

6.4.1 Performance Uncertainty

The first theme generated from the data, *performance uncertainty*, was represented by 15 of the 19 participants. This theme was characterised by participants' experiences and expressions of self-doubt related to their ability to perform at an expected (self-perceived) performance level, as a psychosocial response to RRI. This resulted in expressions of anxiety and worry about their return-to-competition, being selected for teams, and achieving pre-injury levels of performance. For a large proportion of participants, these expressions of anxiety and worry were frequently reflected by 'worst-case' and negative thinking:

> *I'm worried about when I'll be able to get back [to running] and whether it's going to affect my running career. Because, obviously it's been a long time and it's become clear that it's not going to be a very quick fix at all.* (P15, lines 590-593)

Table 6.3: Themes and codes generated from semi-structured interviews, related to psychosocial responses to running-related injury.

Theme Code	Participant Quotes
Performance Uncertainty	
Worry, anxiety, uncertainty, and loss	*It [the injury] made me feel worse as I couldn't do the one thing I loved, and I knew that I was losing fitness and everything, mainly because a rule of thumb in Athletics is that however long you take off; it takes double to get back to where you were.* (P08, lines 576-579)
Comparison	*You can see everyone else improving and getting better and you're, like, that could be me, but I can't get better. I can't improve because I'm injured, and I'm not able to do it.* (P19, lines 408-410)
Frustration	*One of the things that we do in our training group is that if you're injured you turn up and you cycle next to the group. You help out. You help with the training and things like that. And me doing that is so painful, like, having to turn up and watch everyone else doing what you want to be doing. You're there but you're not doing it [running]. That is one of the worst things because you know that everything is so close, yet so far.* (P13, lines 283-289)
Missed opportunity and disappointment	*I was really pissed off because it was National Indoors at the weekend, and all I had to do was stay fit for that week. And then in the dying moment. Just tapering into it [National Indoors], I'd managed to injure myself at the worst possible time. I was quite down about it all.* (P05, lines 362-367)
Injury (Mis)Management	
Pushing through the pain	*I can feel my injuries coming and I just ignore them and I'm, like, they will just sort themselves out, because I need to stick to my training plans and what I need to do. And I think that that just makes it [the injury] worse. Well, it's not going to make it [the injury] any better.* (P17, lines 805-808)
Return-to-running	*I kept trying [to return], which I think was partly the problem. But I kept on going out, psyching myself up to do it [running], putting my trainers on, starting to run, running for, like, ten seconds, having to stop and then walking for a bit and trying to stretch it [the injured body area]. I kept thinking to myself, I can make it [the injury] better.* (P09, lines 606-610)
Self-diagnosis and treatment	*I know I've got some friends, now, who've got injuries. And they've had specialised programmes for them [the injuries]. I didn't have any of that. I just remember using internet a lot.* (P16, lines 460-463)
Access to medical support	*I just wish that as soon as I felt the pain, that I had just stopped and gone to see the Physio as soon as possible. And they could have told me what to do. I reckon, had*

	I done that, I wouldn't have been out for as long and would have been fine to start again after one week. (P12, lines 478-483)
Injury Prevention	*I do my physio exercises every day now, just to make sure that it [the injury] doesn't happen again, and I'll always be careful to warm-up, and if something feels sore, I should stop.* (P14, lines 393-395)
Contested Identity	
Unidimensional identity	*I base everything around running. So, not being able to do it would leave a lot of gaps and I wouldn't be able to look forward to doing a race or being able to have big aims.* (P19, lines 238-241)
Self-presentation	*I suppose if someone asks what you do, my first thing is that I run, at a national level. And just, that's my thing, I suppose. Yeah. If people ask, that's what I say is the main thing I do.* (P05, lines 142-145)
Confirming identity	*Hopefully, I'll never get it [the injury] again because it was a horrible place to be at, but I just view it [the injury] as something that made me stronger. If I didn't have it [the injury], I wouldn't have realised that I can be stronger, to improve, and prevent getting injured again.* (P04, lines 616-620)
Questioning Identity	*I think that sport does make you feel good about yourself and it does make me feel better. But I don't need it [sport]. I think that being injured recently has given me that outlook. Before I would have said, "oh, I do need sport to feel good," but I've found other things that I now see as more important. Well, not more important, but equally important, as my sport.* (P13, lines 199-205)
Injury as an excuse	*I think it's [the injury] lasted so long, I kind of get a bit sick and tired of saying, "oh, but I've been injured." And I feel like it sounds so, like, "oh, yeah, of course she's been injured." I don't want to seem like I'm using the whole knee thing or, like, just before with my knee injury I was anaemic. And I don't want to seem like I'm using excuses.* (P09, lines 357-362)
Forms and types of support	*When it [the injury] was quite bad at the start, my Mum was quite kind. You know, she was there. I get quite upset when I'm injured and I'm not the best person to be around. And when I couldn't run, she was there to talk to. But I, kind of, keep myself to myself when I'm injured. I don't really talk to other people.* (P11, lines 524-528)

N.B. When necessary, the subject of a sentence has been added in square brackets.

Participants' anxiety, worry, uncertainty, and sense of loss were regularly amplified by an ability to compare current and previous levels of performance to their own performance when they returned from injury and to athletes that they compete against. One participant illustrated how comparison was made possible through freely available online data of running times (*The Power of 10*: https://www.thepowerof10.info). The duration of their RRI combined with their ability to compare performances contributed to their sense of *performance uncertainty*:

> *I know I shouldn't care about how people look at my Power of 10, and stuff like that. But because I haven't done a race in so long, if I now do one and it doesn't go well, it reflects me as an athlete, rather than just the current form that I'm in, as I don't have any form from last year.* (P09, lines 200-205)

Altered training practices, often viewed as a subsidiary to performance, also became a way of creating comparison. In turn, this shifted participants' attention during their recovery, forcing them to revise their previous (i.e., pre-injury) distance running aims and ambitions. Training alterations, metaphorised as 'moving the goalposts,' were often perceived as disruptive and non-preferable to participants, contributing to feelings of frustration and annoyance:

> *I got quite frustrated after a while that I couldn't do anything. I had so much more free time, but I just didn't know what to do really.* (P14, lines 198-201)

These feelings also evoked a sense of confusion, whereby ‘not knowing what to do’ contributed to their *performance uncertainty*. A sense of missed opportunity and disappointment were also expressed by participants:

> *During the track season we've got this massive thing about everyone taking part and doing as much as they can. But obviously, I was having to do less. So, I would keep having to turn them [teammates] down. That didn’t feel great because I didn’t want to let the club down.* (P18, lines 349-353)

This sense of disappointment was typically represented in a manner that framed an athlete’s psychosocial response to RRI as being ‘let down’ by oneself, and ‘letting down’ others. The notion that this sense of disappointment was self-directed supports the idea that *performance uncertainty* is likely a result of elevated performance expectations, as a by-product of being a competitive adolescent distance runner. As such, *serious RRI* initially acts to disrupt an athlete’s ability to train and perform to the level that has come to be expected of them, leading to uncertainty around their own ability to perform in the present moment, and following their return-to-running. Due to the individual nature of distance running, whereby achievement is primarily judged against a stopwatch (Bale, 2004), this uncertainty is exacerbated by direct comparison to an athlete’s own performance level (current and previous) and that of their opponents.

6.4.2 Injury (Mis)Management

The second theme generated from the data, *injury (mis)management*, was represented by 16 of the 19 participants. *Injury (mis)management* was characterised by the idea that, while injured, participants navigated their recovery with limited knowledge, resources, and access to medical support. Participants communicated their reliance on self-diagnosis and self-treatment of their injuries. Moreover, it became apparent that this process of self-navigation was preceded by a willingness to 'push through' pain and initial signs and symptoms of an RRI (e.g., 'niggles,' 'slight pains,' 'hurting a little bit'), irrespective of the potential implications. One participant stated that:

> *It wasn't too bad to run on, but I had slight pains in my knee. I just thought that it would be nothing and that it would be alright, and you can get through it. But it kept building, and building, until the point when I just couldn't run on it anymore, because it was just too painful.* (P07, lines 261-265)

Following attempts to 'push through' pain, management of *serious RRI* was rarely optimal, whereby trial and error approaches were frequently employed in an attempt to return-to-running as quickly as possible, exemplified here:

> *I still tried to run, but every time I ran it would be painful afterwards. So, I went back to have more physio treatment.* (P01, lines 429-431)

In some instances, participants acted against the wishes of their wider support network, as demonstrated here:

> *Whenever I'd see my coach, they'd be like: "oh, the best thing to do is rest it." No, it's not. I can rest it my whole life and when I do go back to running it [the injury] will still be there.* (P10, lines 740-742)

These trial and error approaches seemed to perpetuate a participant's apparent 'loss of control' over their situation and contributed to disrupting their athletic sense of self. Among the resources participants used for self-diagnosis and self-treatment of injury (e.g., discussion with other runners who had previously experienced similar injury symptoms), the internet was the most commonly referenced resource. One participant aptly phrased it like this:

> *I was YouTubing how to tape. I was Googling stretches and trying to Google where the pain was and what it [the injury] was. I was trying to diagnose it [the injury], because I didn't know what I had. I feel like once you've got something [an injury], you can Google how to treat it and you can find a lot of stuff on it.* (P09, lines 635-639)

Internet-based diagnoses rarely aligned with those provided by physiotherapists and/or other healthcare professionals, about which another participant spoke:

> *Before I saw the physio, I was really upset because I thought that it [the injury] was a stress fracture. And then when I saw the physio, I was relieved, because I was like: "oh, I'm glad it wasn't a stress fracture."* (P11, lines 502-505)

Although access to medical support was not always sought, when it was, a substantial amount of time had often passed between the onset of the RRI and treatment:

> *I got an appointment with a GP [General Practitioner] and then got the GP to refer me to a specialist, which took a long time. I had to put it all on the NHS [National Health Service], which was quite annoying because it was something that should have taken two weeks, but it took a couple of months.* (P13, lines 470-474)

In addition to this slower than desired access to medical support, the data highlighted different appraisals of the support received. On the one hand, participants' wanted a medical diagnosis to assuage their 'worst-case' thinking, whilst regarding the recovery programme as a burden:

> *It's quite a depressing thought when you go to the physio and they give you a pile of exercises that you need to do every day for the rest of your life. And it just gets bigger and bigger and bigger.* (P10, lines 744-746)

On the other hand, the medical support was followed in meticulous fashion, in order to recover from the *serious RRI* and prevent reinjury or exacerbation:

> *Now I do them [exercises set by physio] every day. Even if I don't train, I do them. It's something I didn't do before I was injured that I just think everyone should be doing, but they won't until they get injured.* (P09, lines 803-805)

Notably, both of these approaches are reactionary, occurring post-injury, instead of adopting a proactive approach, whereby injury prevention measures are followed before injury occurs. Yet, as a result of their *serious RRI*, the latter approach was subsequently evangelised. In this instance, the *serious RRI* can be viewed as a 'learning experience,' one that allows reflection on the recovery process and an improved knowledge of injury prevention. Such contrasting responses to medical support also suggest a large degree of variance between how participants appraise their recovery either as 'burdensome' or as a 'positive challenge.'

6.4.3 Contested Identity

The third theme generated from the data, *contested identity*, was represented by 15 of the 19 participants. *Contested identity* represents the notion that the athletic identity of an adolescent distance runner is challenged as a result of *serious RRI*, requiring a response. Before displaying how participants appeared to respond, including the various forms and types of support received, it is important to state that participants in this study often maintained a unidimensional identity, which one participant phrased like this:

> *I don't really do too much outside of running. I fully committed to it a couple of years ago, and it pretty much takes up all my time. I don't really do a lot other than run and recover, really.* (P05, lines 102-105)

Participation in distance running was also viewed in a positive way by participants, as a 'point of difference' among peers, in relation to their self-presentation. Another participant shared this sentiment in this way:

> *It's nice being able to have something that's specific to me. Rather than just being the same as everyone else.* (P18, lines 223-224)

Although most participants maintained a unidimensional identity, participants displayed two contrasting types of cognitive appraisal, in response to their *serious RRI*. While these appraisals were polarised within this study, categorised as 'types,' it is important to state that this also illustrates diversity of appraisal whereby, in a larger population, this would likely be somewhat less contrasting. The first type of appraisal saw participants 'rise to the challenge,' brought about by the *serious RRI* and, in several cases, increased their motivation to return:

> *It [the injury] didn't demotivate me. When I came back, I was more motivated because I was like: "Okay. I really need to catch up the time I've lost."* (P17, lines 738-740)

The second type of appraisal was to further question their own participation in distance running, casting doubt over their suitability to this endurance sport. In a few cases, this type of appraisal resulted in a decision to limit further participation, as a response to *serious RRI*:

> *I have almost stopped running completely because I got so badly injured. Just constant injury, all of the time. I was just thinking: "I'm not getting anywhere. I need to go back and restart." Like, fix everything and then go forward.* (P10, lines 51-55)

In support of this second type of appraisal, whereby a participant further questions their athletic participant and identity, participants indicated that RRI was occasionally seen as an excuse for when performance did not align with their (or others) expectations:

> *Sometimes it's normally just a confidence thing. If I've got some tape on it [the injury], it won't hurt. But sometimes, when I'm injured, it's just showing you that if you don't do very well [in a race], then it's okay. I'm injured. I've got tape on. That's why I didn't do very well.* (P10, lines 964-968)

Using RRI as an excuse can be seen as a way for participants to protect their athletic identity, often constructed and maintained by competition outcomes and performance levels. However, the different forms and types of support that participants received while injured also seemed to play a major role in their response to identity contestations. On several occasions, the role of an athletics coach seemed vital in maintaining the relationship between the injured athlete and their normal training group, whereby 'not being forgotten' was perceived as an important factor related to their appraisal of the *serious RRI*. For example:

> *My coach was good at constantly texting me to check I was okay. They would try to get updates from me, which I think helped because it made me know that they were there, in a way. That they were not just going to forget about me.* (P15, lines 505-508)

Although also related to the theme of "*injury (mis)management*," the degree to which *serious RRI* can act to contest athletic identity becomes knotted with how a participant interacts with different forms of support – social, physical, and personal – provided by coaches, family, friends, and healthcare practitioners.

6.5 Discussion

To the authors knowledge, this is the first research study to have investigated psychosocial responses to *serious RRI* in a cohort of competitive adolescent distance runners. The RTA process led to the development of three themes: (1) *performance uncertainty*, (2) *injury (mis)management*, and (3) *contested identity*. These findings support/confirm a range of the theoretical relationships proposed within Wiese-bjornstal et al. (1998) 'integrated model of response to sport-related injury.' That is, each of the developed themes can be regarded as a psychosocial response to *serious RRI*, while the development of these themes also evidences the interaction between different elements of the model (i.e., *cognitive appraisal*, *emotional response*, and *behavioural response*). When viewed collectively, these three themes were understood to frame *serious RRI* as *destabilising athletic* *identity*, as a psychosocial recovery outcome, in competitive adolescent distance runners, thereby impacting subsequent cognitive (re)appraisals and their ability to effectively return-to-running.

Participants described a range of personal and situational factors that influenced their *cognitive appraisal* of *serious RRI*. For example, two recurrent factors were related to participants' self-perceived capacity to 'push through' pain (i.e., personal factor), and their often-limited ability to access medical support in a timely way (i.e., situational factor). These factors contributed to the observation that *serious RRI* was regularly *mismanaged* by competitive adolescent distance runners, whereby self-diagnosis, self-treatment, and a willingness to return-to-running as soon as possible were consistent *behavioural responses*. Significantly, these *behavioural responses* often resulted in reactionary approaches to injury prevention, whereby onset of RRI triggered the implementation of preventative measures. Within the academic field of Sports Medicine, these approaches can be categorised as secondary (i.e., early treatment of injury in order to prevent exacerbation) or tertiary prevention (i.e., rehabilitation and treatment aimed at reducing further complications and the long-term burden of an injury) (Jacobsson and Timpka, 2015). However, these reactionary approaches are at odds with the scientific literature surrounding injury risk factors, whereby 'history of previous injury' is often cited as a risk factor for subsequent injury in adult and adolescent distance runners (van Gent et al., 2007, Saragiotto et al., 2014, van der Worp et al., 2015, Hulme et al., 2017, Krabak et al., 2020). As a result, the present study indicates that primary prevention (i.e., implementing measures aimed at reducing the risk of an index injury occurring) should be a key focus when developing RRI prevention measures for competitive adolescent distance runners. By advocating a primary prevention approach, these athletes will be more likely to remain injury free, thereby increasing the likelihood of being able to achieve their athletic potential in early adulthood (Kearney and Hayes, 2018), as is often required in late specialisation sports (Moesch et al., 2011). Nevertheless, it is not clear how primary prevention would fit within this sport-specific context, whereby adolescent distance runners are predominantly self-managing RRI, neither is it guaranteed that primary prevention measures will reduce the risk of RRI. As a result, further research is required to consider how such measures would be applied in practice, recognising that the best injury prevention measures are those that will be adopted and sustained by athletes, coaches, National Governing Bodies, and other key stakeholders (Emery and Pasanen, 2019).

In terms of participants' capacity to 'push through' pain, this has previously been identified as an issue in sport generally (see Roderick et al. (2000)), whereby there is an underlying perception that normalising pain and injury is a requirement of participation. For example, within a cohort of competitive Danish adult distance runners, ignoring pain was self-reported as an injury risk factor (Johansen et al., 2017). Additionally, willingness to play hurt (i.e., presenteeism) has been shown to be prevalent among elite adolescent athletes (Mayer et al., 2018), typically associated with the level of importance that an athlete gives to their sports environment, in comparison to their non-sports environment (Schnell et al., 2014). Yet, Mayer et al. (2018) also demonstrated that endurance athletes experience no direct social pressure to play hurt (i.e., from coaches). This is supported by the present study, whereby a coach actively endorsed rest, rather than continued participation. Although not explained by the present study, this willingness to push through pain and return-to-sport as soon as possible could be a by-product of the intense and monotonous training practices that competitive distance runners are required to maintain (Seiler, 2010), whereby athletes might not want to take time away from training and competition. This argument is supported by participants detailing an initial sense of loss, in relation to injury causing a loss of fitness. The results of the present study, therefore, imply that the development of future injury prevention measures should aim to address the notion that you can successfully ‘push through’ pain, as a *behavioural response* to overcoming symptoms of an index RRI. This is in alignment with the long-term strategies of champion long distance runners (Bargoria et al., 2020), who stated that their ability to sustain health and performance was derived from not allowing external pressures to distract them when a reduction in training load was necessary. As a consequence, competitive adolescent distance runners should also be encouraged to improve their understanding about how to perceive pain and initial symptoms of RRI, in order to support the implementation of effective RRI prevention measures.

Following initial *cognitive appraisal*, *serious RRI* usually led to a negative *emotional response*, such as worry, anxiety, uncertainty, a sense of loss, and frustration. This *emotional response*, as a result of their *serious RRI*, tended to be amplified when opportunities to compete had to be missed, an athlete was able to compare their current (post-RRI) performance level with other athletes and their own previous performance level, in a tangible way, and they perceived that they were letting down themselves or their teammates. Viewed together, these observations indicate that *performance uncertainty* can be upheld as a psychosocial outcome of *serious RRI* within competitive adolescent distance runners. The different types of negative *emotional response* reported in this study are similar to those found in a cohort of elite Swedish adolescent athletes (von Rosen et al., 2018b), and National Collegiate Athletic Association student-athletes (Tracey, 2003, Clement et al., 2015). Also, the range of factors that were seen to amplify an athlete’s *emotional response* align to stresses related to competence, relatedness, and autonomy, as reported in a study of elite adolescent athletes' experience of injury recovery and return-to-sport (Podlog et al., 2013). These results imply that the participants in the present study may not have had adequate knowledge of appropriate coping strategies that may enable them to offset their negative *emotional response*. For example, previous research, conducted in winter sports (Gould et al., 1997, Bianco et al., 1999), has highlighted that the use of cognitive coping strategies by injured athletes allows their *emotional response* to be more positive, focused on successful recovery. This suggests that increased effort should be made to educate adolescent distance runners about the benefits of employing coping strategies, regardless of their previous injury experience. Future research should explore the effectiveness of different coping strategies in a cohort of competitive adolescent distance runners, to inform best practice.

According to the Wiese-bjornstal et al. (1998) 'integrated model,' athletic identity is identified as a 'personal factor' that can influence an athlete's *cognitive appraisal* of sport-related injury. Athletic identity is defined as the degree to which an individual identifies with the status of being an athlete (Brewer et al., 1993). Previous research has shown that the athletic identity of athletes increases from late childhood to adolescence, staying elevated into young adulthood unless participation in sport is stopped (Houle et al., 2010). In the present study, *serious RRI* led to a *contested identity*, whereby athletes displayed different 'types' of cognitive appraisal, categorised as either 'confirming identity' or 'questioning identity.' The latter appraisal, indicating that athletic identity might decrease as a response to *serious RRI*, aligns with previous adult-based research indicating that athletic identity diminishes following the onset of an sport-related injury (Brewer and Cornelius, 2010), and other identity-threatening events (Lavallee et al., 1997, Brewer et al., 1999, Grove et al., 2004). This finding has previously been reported in a cohort of elite Swedish adolescent athletes too (von Rosen et al., 2018b), whereby RRI was perceived to be a threat to identity. Contrastingly, RRI also confirmed the athletic identity of some participants, acting to strengthen motivation and passion for distance running and, in turn, a successful return-to-running. Although somewhat counterintuitive, this response to RRI supports the fact that the majority of participants within the present study kept a unidimensional identity. Therefore, athletic identity foreclosure – defined as an athlete who does not engage in exploratory behaviour, while making a strong commitment to sport as their primary source of identity (Brewer and Petitpas, 2017) – might influence an athletes psychosocial response to *serious RRI*. For example, a unidimensional identity is more likely to cause a blinkered approach to recovery (i.e., successful recovery becomes their only objective). Future research should explore the potential implications of athletic identity foreclosure within this specific sporting population, alongside decisions surrounding early sport specialisation.

Regardless of the ‘type’ of response (i.e., ‘confirming’ or ‘questioning’ athletic identity), this study highlights that effects on athletic identity can influence an athlete’s initial cognitive appraisal of *serious RRI* and represents a psychosocial recovery outcome. As the overarching theme indicates, *serious RRI* acted to *destabilise athletic identity*. Theoretically, this finding supports Walker et al. (2007) argument that psychosocial recovery outcomes can also impact subsequent cognitive (re)appraisals of RRI. Therefore, within this study, the effect of *serious RRI* on competitive adolescent distance runners’ athletic identity can be theorised as both a psychosocial response and outcome. As such, it is apparent that this specific population of athletes requires access to suitable forms of support when injured, including improved access to medical support, thereby facilitating accurate and timely diagnosis of RRI. In turn, access to such support could lead to improved understanding of RRI, potentially improving an athletes' response to *serious RRI* and return-to-running, without *destabilising athletic identity*. Even though additional research is required to substantiate these claims, it might be reasonable for such forms of support to be embedded within existing youth athletic development programmes.

6.5.1 Methodological Limitations

One limitation of this research is related to recall bias, a common dilemma in qualitative research. Due to the study design, these interviews were based on RRIs that had occurred up to one year prior to the participants enrolment in the study, as reported in Chapter 5. Different amounts of time (i.e., weeks and months) had passed since the initial onset of the RRI and interview completion. Therefore, recall of their RRI experiences might have been partially reduced by the time the interview was conducted. Regardless, the similarity between these findings and previous literature emphasise a degree of credibility (trustworthiness), alongside the attainment of *naturalistic*, *transferable*, and *analytical* types of generalisability (Smith, 2018). Although not necessarily a limitation, it is also important to highlight that the results are representative of one interpretation of the data, influenced by the first author's own experience of distance running and RRI, alongside relevant research and coaching expertise. Likewise, it is accepted that Wiese-bjornstal et al. (1998) 'integrated model of response to sport injury' is not the only framework in which to interpret the results from this study (Brewer, 2007). Though no single framework predominates the existing evidence (Forsdyke et al., 2016), the use of such a model maximises attention paid to individual differences in an athlete's psychosocial response to injury, without having to rather rigidly assign codes and themes according to stage-based theoretical approaches (Walker et al., 2007).

6.6 Conclusion

The current study was designed to investigate psychosocial responses to *serious RRI* in a cohort of competitive adolescent distance runners, providing qualitative insight related to the extent of the injury problem within this sporting-context. The results indicated that three types of psychosocial response to *serious RRI* were common between participants. These included (1) *performance uncertainty*, (2) *injury (mis)management*, and (3) *contested identity*. When viewed collectively, it was demonstrated that *serious RRI destabilised athletic identity* as a psychosocial recovery outcome. This study highlights that the development of injury prevention measures for competitive adolescent distance runners should target primary prevention, whereby the aim is to reduce the risk of index injury occurrence. Integrated within such measures, the idea of 'pushing through' pain should be addressed in order to manage the perception that pain and RRI are obligatory elements of participation in distance running. Furthermore, increased effort needs to be made to support adolescent distance runners develop effective coping skills, for when RRI does occur, regardless of severity, in conjunction with improved access to suitable medical support. Future research should explore the efficacy of different coping skills and the potential implications of athletic identity foreclosure in a cohort of competitive adolescent distance runners. In turn, this knowledge may improve competitive adolescent distance runners' psychosocial responses to RRI, thereby improving their ability to recover and return-to-running in a timely manner.

7. PREVALENCE AND BURDEN OF HEALTH PROBLEMS IN COMPETITIVE ADOLESCENT DISTANCE RUNNERS: A 6-MONTH PROSPECTIVE COHORT STUDY

7.1 Abstract

Objectives: To describe all health problems (injuries and illnesses) in relation to type, location, incidence, prevalence, time loss, severity, and burden, in competitive adolescent distance runners in England. **Design:** Prospective observational study. **Methods:** 136 competitive adolescent distance runners (73 female athletes) self-reported all health problems for 24-weeks between May and October 2019. Athletes self-reported health problems using the Oslo Sports Trauma Research Center Questionnaire on Health Problems. **Results:** The incidence of running-related injury per 1,000 hours of exposure was markedly higher, compared to previous research. At any time, 24% (95% Confidence Intervals (CI):21-26%) of athletes reported a health problem, with 11% (95% CI:9-12%) having experienced a health problem that had substantial negative impact on training and performance. Female athletes reported noticeably more illnesses, compared to male athletes, including higher prevalence, incidence, time loss, and severity. The most burdensome health problems, irrespective of sex, included lower leg, knee, and foot/toes injuries, alongside upper respiratory illnesses. The mean weekly prevalence of time loss was relatively low, regardless of health problem type or sex. **Conclusion:** Competitive adolescent distance runners are likely to be training and competing whilst concurrently experiencing health problems. These findings will support the development of injury and illness prevention measures.

7.2 Introduction

Distance running is one of the most popular sports among children and adolescents around the world (Hulteen et al., 2017). In England, distance running has been reported to be the second most prevalent sport among adolescents (Sport England, 2021). Although distance running is associated with multiple health benefits in later life (Pedisic et al., 2019), adult-based research indicates that participation is also associated with negative health outcomes, such as injury (van Gent et al., 2007). In adolescent distance runners, there is a lack of research that has investigated such outcomes (Steffen and Engebretsen, 2010). This population is often included as a sub-group within larger multi-sport samples of adolescent athletes (von Rosen et al., 2018a, von Rosen et al., 2017, Pierpoint et al., 2016, Moseid et al., 2018, Carragher et al., 2019, Jacobsson et al., 2012), whereby sex differences have been investigated within a heterogenous population rather than at sport-specific levels (von Rosen et al., 2018a, Moseid et al., 2018, Pierpoint et al., 2016, Jacobsson et al., 2012). Regardless, in those studies that include adolescent distance runners, the reported running-related injury (RRI) incidence ranges from 0.84 to 17.0 per 1,000 hours of exposure (Rauh et al., 2000, Rauh et al., 2006, Pierpoint et al., 2016, von Rosen et al., 2017), and injury prevalence ranges from 15 to 32% (Jacobsson et al., 2012, Moseid et al., 2018, Carragher et al., 2019). While these studies used different methodologies (Tabben et al., 2020), which may account for these differences, data suggest that the most frequently injured anatomical body region is the lower limb, with the knee (Rauh et al., 2000, Rauh et al., 2006, Jacobsson et al., 2012, Huxley et al., 2014, von Rosen et al., 2017, Carragher et al., 2019, von Rosen et al., 2018a), lower leg (Jacobsson et al., 2012, Huxley et al., 2014, von Rosen et al., 2017, von Rosen et al., 2018a, Carragher et al., 2019), and ankle (Rauh et al., 2000, Rauh et al., 2006, Huxley et al., 2014, Jacobsson et al., 2012, Pierpoint et al., 2016) being the most commonly affected body areas. However, due to small sample sizes and narrow age ranges, there is limited opportunity to generalise these findings to other distance running populations.

Another limitation of the existing distance running literature (adult and paediatric populations) is that numerous epidemiological studies use a time loss or medical attention injury definition, and often do not account for illness within their study design (Bahr et al., 2020). Therefore, these studies may have underestimated the total number of health problems (injuries and illnesses) (Tabben et al., 2020, Clarsen et al., 2013, Clarsen and Bahr, 2014, Bahr et al., 2020), while ignoring the potential impact of illnesses. For example, injuries that do not result in time loss, and allow athletes to continue to participate regardless of the injury, may be missed. This "loss of detail" is exacerbated when studying adolescent athletes and not examining sex differences within sub-groups of broader sporting populations (i.e., focusing upon track and field athletes, instead of distance runners). This is an important consideration given that the growth and maturation of adolescent athletes differs according to sex (Bergeron et al., 2015, Wik et al., 2020). Therefore, any sex differences related to the burden of health problems, defined as the cross-product of severity and incidence (Bahr et al., 2018), may require further attention, with the possibility of developing sex- and event-specific injury and illness prevention measures.

The purpose of this study was to describe the prevalence, incidence, severity, and burden of health problems within a population of competitive adolescent distance runners in England, using a prospective cohort study design. Specifically, the study aimed to: (1) describe all health problems in relation to type, location, incidence, prevalence, time loss, severity, and burden, and (2) describe sex differences related to these outcomes.

7.3 Methods

7.3.1 Study Design

This was a 24-week prospective cohort study based on weekly completion of an online questionnaire. Data collection took place between May and October 2019. This timeframe was chosen to reflect the international and domestic outdoor track and field season (approx. April until September) and the start of the cross-country season (approx. October to March).

7.3.2 Participants

A total of 644 distance runners (athletes) from 210 England Athletics affiliated athletics clubs, aged between 13 and 18 years, were invited to participate in this study. These athletes were selected to take part based on achieving a Top-50 performance in their given age-group during 2018, according to the publicly-available *Power of 10* database, for all distance running events from 800 m up to 10,000 m, including the steeplechase (Power of 10, 2020). The Top-50 performances for each distance running event were collated according to the age-groups used in the *Power of 10* database: 13-14 years (U15), 15-16 years (U17), and 17-19 years (U20). Data extracted from the *Power of 10* database included: event ranking, performance time, name of athlete, year in age-group, name of coach, and name of athletics club. These data were not retained for analysis. Athletes that had achieved a Top-50 performance in their third year as an U20 were excluded due to being over the age of 18 years. Once exported, any duplicate data were identified (i.e., the same athlete achieving a Top 50 performance for multiple distance running events) and athletes were grouped according to their athletics club affiliation. Once collated, each athletics club was contacted by letter and email with study information and which athletes were eligible to take part. Each athletics club was actively encouraged to share this study information with eligible athletes, their coach, and guardians. If interested, these athletes were able to enrol onto the study by contacting the principal investigator (Robert Mann) via email or telephone. Athletes were excluded from the study if they were injured at the time of study enrolment, not aged between 13 and 18 years old, unable to fully understand the study procedure, and/or failed to complete the consent/assent forms and/or baseline questionnaire. Both informed consent and assent were obtained before an athlete completed the baseline questionnaire. A flow diagram of the recruitment process is presented in Figure 7.1. Ethics approval was granted by the institutional ethics committee (180801/B/02).

Athletes provided data on a rolling basis. During the first 4 weeks, the sample size (n) increased by the following amount: 98 (week 1), 16 (week 2), 19 (week 3), and 3 (week 4). The final study sample consisted of 136 athletes (73 female). Regardless of the athletes' given week of enrolment, data were collected up to week 24. In relation to internal validity, the sex split within this study sample was 54% female, compared with 46% male. Within the total available sample (n = 644), the sex split was 48% female, compared with 52% male.

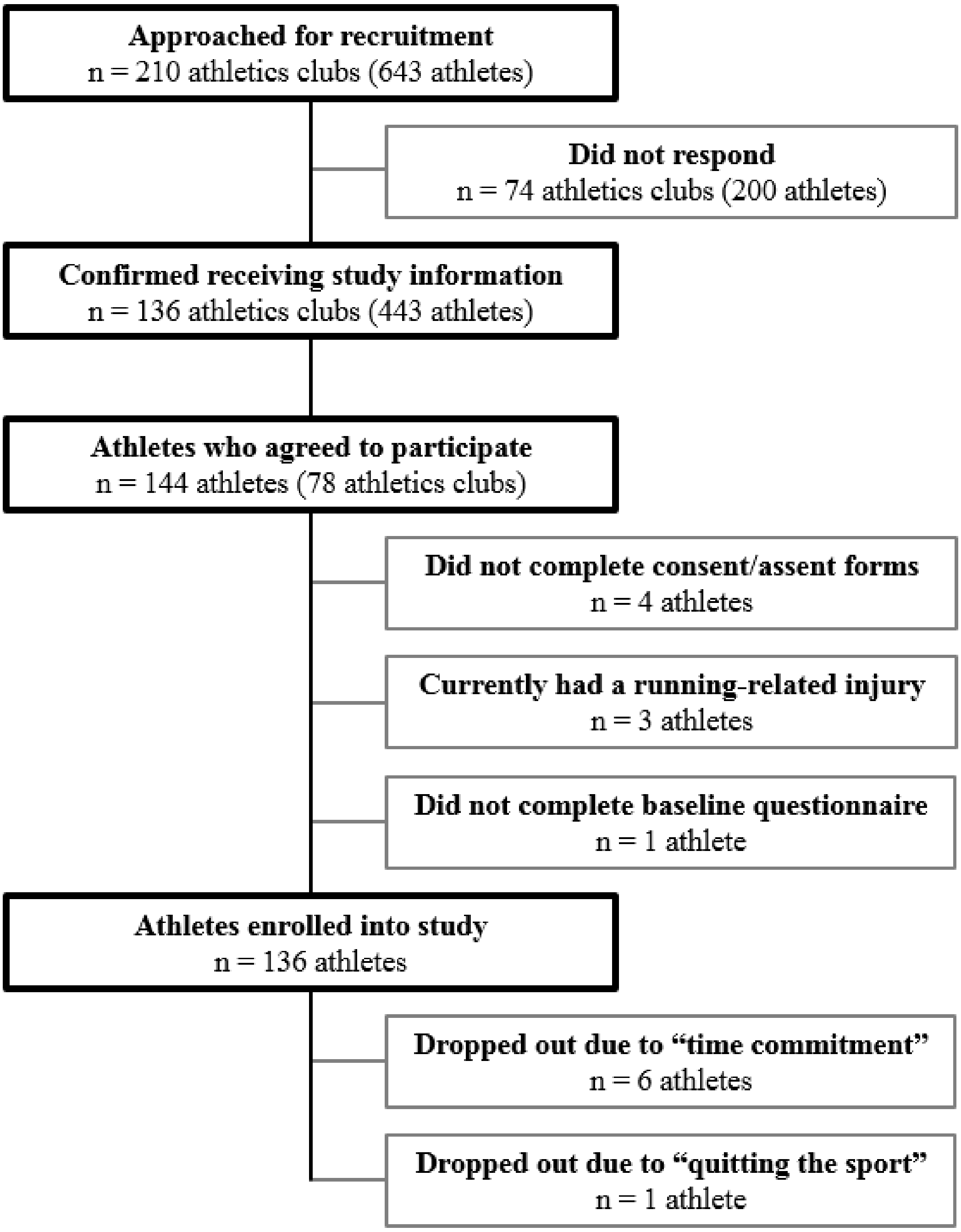


Figure 7.1: Study flow chart illustrating participant recruitment, enrolment, and dropout. N.B. Due to the nature of data collection, it is not possible to confirm whether all 443 athletes received study information. Only the athletics clubs confirmed receipt of this information

7.3.3 Data Collection Procedures

7.3.3.1 Baseline Questionnaire

Before starting weekly data collection, each athlete completed a baseline questionnaire via Qualtrics XM (Provo, Utah, USA), an online platform that is compatible with computers and mobile devices. The questionnaire included sections on background demographics (e.g., date of birth), performance history (e.g., event preferences), training practices (e.g., sessions per week), and medical information (e.g., injury history). This questionnaire was based on previous research (Jacobsson et al., 2012, Huxley et al., 2014, Woollings et al., 2015), and developed for a prior study (see Chapter 5). Key stakeholders were involved in the development of this questionnaire to ensure that it was appropriate for the target audience (face validity). This included adolescent distance runners, parents, athletics coaches, and sports physiotherapists (n = 12). A copy of the baseline questionnaire has been included in Appendix F.

Participant characteristics for the athletes were calculated from these questionnaire responses. Chronological age (decimal age) was calculated, before being categorised according to age-group: 13-14 years (U15), 15-16 years (U17), and 17-18 years (U19). Training ages (i.e., number of years participating in distance running); stature (cm), body mass (kg), current performance level (i.e., club, county, regional, national, or international), and injury history were all self-reported. Each athlete's age at peak height velocity (PHV) was determined by applying sex-specific maturity offset equations (Moore et al., 2015), and used to estimate maturity timing and tempo (Baxter-Jones et al., 2005).

7.3.3.2 Weekly Data Collection

Injury and illness data were collected using the Oslo Sports Trauma Research Center questionnaire on health problems (OSTRC-H) (Clarsen et al., 2013, Clarsen et al., 2014, Clarsen et al., 2020). The questionnaire has demonstrated good validity and reliability in samples including runners (Clarsen et al., 2014). It consists of four questions about athlete participation in sport, training volume, sports performance, and symptoms of health problems during the previous 7 days (Clarsen et al., 2013). The response to each of these questions is given a value between 0 and 25, with 0 (minimum value) representing "no problems" and 25 (maximum value) representing "severe problems." The four values were summed to calculate a severity score from 0 to 100 for each recorded health problem. If the athlete answered all four questions with the minimum value (full participation without health problems, no reduction in training volume or sports performance, and no symptoms), the OSTRC-H was completed for that week. If athletes reported a health problem, they were asked to self-report whether it was an injury or an illness. Athletes were asked to record the anatomical location of all reported injuries, and the main symptoms experienced for all reported illnesses. For all recorded health problems, athletes were asked to record the number of days of complete time loss from training and competition, whether the health problem had previously been recorded, and who the health problem had been reported to (i.e., nobody, medical doctor, or physiotherapist). Athletes were able to report multiple health problems per week. Alongside the OSTRC-H, athletes were also asked to self-report a weekly training diary, having been encouraged to record this throughout the week. Each weekly training diary allowed athletes to detail the type, total duration, distance covered, and rating of perceived exertion related to all of their running-related training sessions or competitions. Athletes also completed the adolescent version of the Profile of Mood States (Terry et al., 1999). A copy of the weekly questionnaire has been included in Appendix G.

The OSTRC-H was sent to athletes on a weekly basis (every Sunday) by email from 5th May until 13th October 2019 (24 weeks) and was completed via Qualtrics XM. If athletes did not complete the questionnaire, email reminders were sent on the following day (Monday), after two days (Wednesday), and after four days (Friday). The athlete's parents or legal guardians were copied into the email reminders after two and four days, respectively. If a response had still not been received after five days (Saturday), the principal investigator would send an SMS reminder to non-responders. If the questionnaire remained unanswered by the time the subsequent weekly questionnaire was distributed, the athlete was categorised as a "non-responder" for that specific week and recorded as missing data.

7.3.3.3 Definition and Classification of Health Problems

Aligned with recent consensus statements (Timpka et al., 2014a, Bahr et al., 2020, Soligard et al., 2016, Schwellnus et al., 2016), a "broad" definition of health problems was used, recording all health problems regardless of time loss and/or the need for medical attention. Health problems were classified as an injury if they affected the musculoskeletal system and were classified as an illness if they affected a specific organ system or represented general symptoms. Athletes did not classify injuries as having an acute or overuse mechanism. Instead, the principal investigator classified injury onset as gradual or sudden. Health problems were defined as "substantial" if they caused moderate or severe reductions in training volume, moderate or severe reductions in performance, or complete inability to participate in distance running, according to the OSTRC-H scoring guide (Clarsen et al., 2013, Clarsen et al., 2014). Health problems were classified as having caused time loss if the injury or illness led to the athlete being unable to participate fully in distance running training and competition the day after the incident occurred (Timpka et al., 2014a, Bahr et al., 2020).

7.3.3.4 Prevalence Calculations

The following prevalence measures were calculated on a weekly basis: all health problems, substantial health problems, time loss health problems, all injuries, substantial injuries, time loss injuries, all illnesses, substantial illnesses, and time loss illnesses. The mean prevalence and 95% confidence intervals (CI) were calculated for the entire study period and stratified by sex. To avoid potential overreporting of health problems, each athlete’s first week of data were excluded from analyses (Clarsen et al., 2013).

7.3.3.5 Incidence and Relative Burden of Health Problems

After reviewing each athlete’s questionnaire responses for the entire season, a list of cases was compiled that included the following details: type of health problem, body region and area (for injuries) or main organ system affected (for illnesses), number of weeks reported, cumulative time loss days, and cumulative severity score. To identify the main organ system affected for illnesses, the athletes’ self-reported symptoms were independently reviewed and classified by the principal investigator and a medical doctor, using recommended categories (Bahr et al., 2020). Once classified, differences were discussed, and the main affected organ system was subsequently agreed upon (percentage agreement =

89%). The severity of each case was also based on its cumulative time loss, reported as: *none* (0 days), *slight* (1 day), *minimal* (2-3 days), *mild* (4-7 days), *moderately serious* (8-28 days), *serious* (>28 days-6 months), or *long-term* (>6 months) (Timpka et al., 2014a). The incidence of each type of health problem was expressed as both the number of cases per athlete per year (52 weeks) and per 1,000 hours of exposure. Exposure was calculated from the weekly training diary data.

To reflect the relative burden of injuries and illnesses as a proportion of the total health burden, severity scores for each health problem were summed and divided by the cumulative severity score for all health problems (Bahr et al., 2018). A risk matrix was created based on the severity and incidence of health problems in all affected injury body areas and illness organ systems, stratified by sex.

7.3.4 Statistical Analysis

For the participant characteristics, the statistical software SPSS (version 26.0; IBM., Chicago, USA) was used to calculate means and standard deviations (SD) for continuous variables. Also, solely in relation to participant characteristics, percentages (%) were calculated for categorical variables, while sex differences were analysed using independent samples t-tests for continuous variables and Chi-squared tests for categorical variables. Statistical significance was set at an alpha level of 0.05 and effect sizes (ES) for mean comparisons were described using Cohen's thresholds (small = 0.2, medium = 0.5, large = 0.8) (Cohen, 1992). For the prevalence and incidence data, the statistical software *R* was used (version 3.6.1; The R Foundation for Statistical Computing., Vienna, Austria).

95% CIs reported for incidence and prevalence data were used to indirectly infer differences between male and female athletes.

7.4 Results

7.4.1 Response Rate and Participant Characteristics

A total of 136 (73 female) adolescent distance runners participated in this study. Throughout the study, a total of 2,969 questionnaires were distributed, and 2,774 responses were received (mean weekly response rate, 91% (range: 85-99%)). During the follow-up period, 97 of the 136 (71%) athletes enrolled in the study completed every weekly questionnaire, while seven athletes dropped out of the study (Figure 7.1). The data collected for these athletes until the time they dropped out were included in the analysis. Responses to the questionnaire were generally received on the Sunday (47%) or Monday (30%) and the median questionnaire completion time was 8 minutes. Participant descriptive characteristics are shown in Table 7.1.

Table 7.1: Participant characteristics of the participants (data presented as mean and SD, unless otherwise stated)

Characteristic	Overall (n = 136)	Female athletes (n = 73)	Male athletes (n = 63)	*p*-Value	Effect Size
Chronological age, years	15.9 (1.3)	15.8 (1.3)	16.1 (1.2)	0.15	0.25
Training age, years	5.2 (2.1)	5.6 (2.1)	4.8 (1.9)	0.04	0.36
Age-group (n, %):				$X^2 = 0.67$	
13-14 years	26 (19%)	19 (26%)	7 (11%)		
15-16 years	72 (53%)	37 (51%)	35 (56%)		
17-18 years	38 (28%)	17 (23%)	21 (33%)		
Stature, cm	171.0 (8.7)	166.1 (6.8)	176.6 (7.1)	<0.01	1.52
Body mass, kg	54.3 (9.1)	50.2 (6.9)	59.0 (9.1)	<0.01	1.10
Maturity timing (n, %)				$X^2 = 0.08$	
Pre-PHV	0 (0%)	0 (0%)	0 (0%)		
At-PHV	7 (5%)	6 (8%)	1 (2%)		
Post-PHV	129 (95%)	67 (92%)	62 (98%)		
Maturity tempo (n, %)				$X^2 = 0.26$	
Early	1 (1%)	1 (1%)	0 (0%)		
Average	128 (94%)	70 (96%)	58 (92%)		
Late	7 (5%)	2 (3%)	5 (8%)		
Injury <12 months				$X^2 = 0.24$	
Yes	100 (74%)	57 (78%)	43 (68%)		
No	36 (27%)	16 (22%)	20 (32%)		
Current performance level (n, %):				$X^2 = 0.98$	
Club	10 (7%)	6 (8%)	4 (6%)		
County	43 (32%)	22 (30%)	21 (33%)		
Regional	16 (12%)	9 (12%)	7 (11%)		
National	60 (44%)	32 (44%)	28 (44%)		
International	7 (5%)	4 (6%)	3 (5%)		

Abbreviations: n, number; cm, centimetres; kg, kilograms; PHV, Peak Height Velocity; X^2, chi squared. NB: Due to rounding, not all numbers add up to stated N.

7.4.2 Number, Incidence, and Severity of Health Problems

In total, 136 athletes reported 213 injuries and 150 illnesses. This translated to 4.0 new injuries and 2.8 new illnesses/athlete/year. The incidence for all health problems (both sexes combined) was 42.6 per 1,000 hours (95% CI, 38.4-47.1). The mean time loss was 4 days/athlete/year (95% CI, 3-5 days), with a mean of five days for injuries (95% CI, 3-7 days) and three days for illnesses (95% CI, 2-4 days) (Table 7.2).

The most frequent injury locations were the lower leg (27%), knee (19%), and foot/toes (13%). For illnesses, the most frequently affected organ systems were upper respiratory (65%), lower respiratory (11%), and non-specific illness (10%). The number and severity of injuries (body region and area) and illnesses (organ system) are summarised in Table 7.3. 61% of injuries had a gradual onset and 39% had a sudden onset. The most frequent injury locations for gradual onset injuries were the lower leg (38%), knee (17%), and thigh (13%). In comparison, the most frequent injury locations for sudden onset injuries were the knee (22%), foot/toes (20%), lower leg (11%), and ankle (11%).

Table 7.2: Incidence, total time loss, and cumulative severity score of all health problems, all injuries, and all illnesses (split by sex)

	Incidence				Total time loss (d)	Cumulative severity score (AU)
	Cases/athlete/year	95% CI	Cases/1,000 hours of exposure	95% CI		
All health problems (n = 363)	**6.8**	**6.13-7.53**	**42.6**	**38.4-47.1**	**1433**	**30218**
Female athletes (n = 227)	4.3	3.7-4.8	50.5	44.1-57.5	813	17623
Male athletes (n = 136)	2.5	2.1-3.0	33.8	28.3-40.0	620	12595
All Injuries (n = 213)	**4.0**	**3.5-4.6**	**25.0**	**21.8-28.6**	**1058**	**21121**
Female athletes (n = 118)	4.0	3.3-4.8	26.2	21.7-31.4	533	10785
Male athletes (n = 95)	4.0	3.2-4.9	23.6	19.1-28.9	525	10336
All Illnesses (n = 150)	**2.8**	**2.4-3.3**	**17.6**	**14.9-20.7**	**375**	**9097**
Female athletes (n = 109)	3.7	3.0-4.4	24.2	19.9-29.2	280	6838
Male athletes (n = 41)	1.7	1.3-2.3	10.2	7.3-13.8	95	2259

Abbreviations: d, days; AU, arbitrary unit; %, percentage; CI, confidence interval; n, number.

Table 7.3: Severity of time loss of all health problems, all injuries (body region and area), and all illnesses (organ system).

Classification / Body region / Body area / organ system	Cases (number)									
	Female athletes					Male athletes				
	0 days	1-7 days	8-28 days	>28 days	Total Time Loss (days)	0 days	1-7 days	8-28 days	>28 days	Total Time Loss (days)
All health problems	**98**	**157**	**11**	**7**	**810**	**50**	**73**	**13**	**6**	**623**
All injuries	**49**	**52**	**5**	**6**	**530**	**36**	**50**	**9**	**6**	**528**
Lower limb	**41**	**45**	**5**	**5**	**490**	**31**	**41**	**8**	**6**	**488**
Foot/toes	2	9	2	1	132	5	4	3	1	84
Ankle	5	2	0	0	6	4	5	2	1	76
Lower leg	11	12	1	3	224	10	18	1	2	172
Knee	12	12	1	1	92	5	7	0	2	116
Thigh	6	8	0	0	20	4	5	1	0	27
Hip/groin	5	2	1	0	16	3	2	1	0	13
Trunk	**6**	**7**	**0**	**1**	**40**	**4**	**6**	**0**	**0**	**18**
Abdomen	0	1	0	0	2	0	0	0	0	0
Lumbosacral	4	4	0	1	36	2	6	0	0	18
Thoracic spine	2	0	0	0	0	0	0	0	0	0
Chest	0	2	0	0	2	2	0	0	0	0
Upper limb	**2**	**0**	**0**	**0**	**0**	**1**	**3**	**1**	**0**	**22**
Wrist	0	0	0	0	0	0	1	0	0	4
Elbow	1	0	0	0	0	0	0	0	0	0
Shoulder	1	0	0	0	0	1	2	1	0	18
All illnesses	**49**	**53**	**6**	**1**	**280**	**14**	**23**	**4**	**0**	**95**
Upper respiratory	33	28	6	0	142	9	18	4	0	80
Lower respiratory	8	5	0	0	9	2	1	0	0	2
Gastrointestinal	2	4	0	0	7	0	1	0	0	2
Neurological	1	1	0	0	1	0	0	0	0	0
Psychological	0	2	0	0	9	1	0	0	0	0
Dermatological	0	0	0	0	0	0	1	0	0	7
Non-specific illness	4	9	0	1	101	0	1	0	0	1
Energy, load management and nutrition	1	4	0	0	11	2	1	0	0	3

7.4.3 Prevalence of Health Problems

The weekly mean prevalence of all health problems, substantial health problems, and time loss health problems are presented in Table 7.4. When compared to all health problems, the mean weekly prevalence was reduced for substantial health problems (approx. 50%), and again for time loss health problems (approx. 33%) across the sample.

Table 7.4: Weekly prevalence of all health problems, substantial health problems, and time loss health problems (in percentages)

	All		Female athletes		Male athletes	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
All health problems	**24**	**21-26**	**27**	**24-30**	**20**	**16-23**
All injuries	16	14-18	16	15-16	16	13-18
All illnesses	8	7-10	12	9-14	4	3-6
Substantial health problems	**11**	**9-12**	**10**	**9-12**	**11**	**9-13**
All injuries	7	6-9	6	5-7	9	7-11
All illnesses	4	3-4	4	3-6	2	1-3
Time loss health problems	**4**	**3-4**	**3**	**3-4**	**4**	**3-5**
All injuries	3	2-4	3	2-4	3	2-5
All illnesses	0	0-1	1	0-1	0	0-1

Abbreviations: CI, Confidence Intervals.

7.4.4 Burden of Health Problems

Using the total number of time loss days as the basis for injury severity when calculating relative burden (Table 7.2), injuries represented 80% of the total burden of health problems, with illnesses representing 20%. This was 66% and 34% for female athletes, compared to 85% and 15% for male athletes, respectively. Using cumulative severity score as the basis for injury severity (Table 7.2), injuries represented 70% of the total burden of health problems, with illnesses representing 30%. This was 61% and 39%, and 82% and 18% for female and male athletes, respectively.

Figure 7.2 illustrates the relationship between severity and incidence for the five most commonly affected body areas (injuries) and organ systems (illnesses), stratified by sex, with supplementary data provided for all other health problems in Appendix K.

Regardless of sex differences, the body areas representing the highest burden of injuries were the lower leg, knee, and foot/toes. For affected organ systems, the highest burden of illnesses was caused by upper respiratory illness, non-specific illness, and lower respiratory illnesses.

7.5 Discussion

To the authors' knowledge, this is the first study to record all injuries and illnesses, including those that did not result in time loss and/or medical attention, exclusively in a population of competitive adolescent distance runners. The key findings were that: (1) the incidence of RRI per 1,000 hours of exposure was markedly higher when compared to previous research; (2) at any time, 24% of athletes reported a health problem, with 11% having experienced a health problem that had substantial negative impact on training and performance; (3) female athletes reported noticeably more illnesses compared with male athletes, including higher prevalence, incidence, time loss, and severity; (4) the most burdensome health problems, regardless of sex, included lower leg, knee, and foot/toes injuries, alongside upper respiratory illnesses; and (5) the mean weekly prevalence of time loss was relatively low, regardless of health problem type or sex.

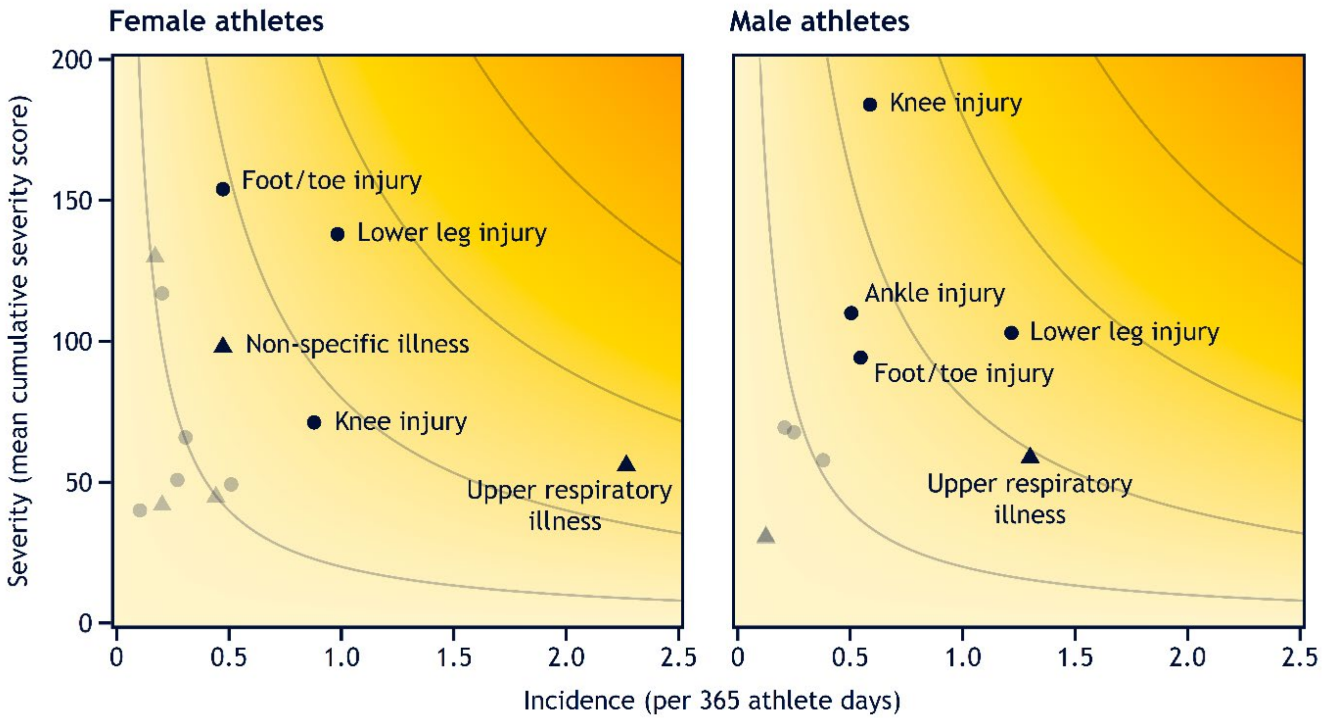


Figure 7.2: Risk matrices illustrating the relationship between severity (consequence) and incidence (likelihood) of all injuries (areas) and illnesses (systems) with three or more reported cases in a population of competitive adolescent distance runners, stratified by sex. The five most commonly affected health problems are labelled. Shading illustrates the relative importance of each health problem; the darker the colour, the greater the overall burden, and the greater the priority should be given to prevention. Supplementary data has been included in Appendix K, excluding means and 95% confidence intervals for health problems with less than three cases.

The first key finding was that the incidence of RRI per 1,000 hours of exposure was markedly higher when compared to previous research. For example, the reported RRI per 1,000 hours for all injuries, including male and female athletes, within this study (25.0) was higher than that reported in similar cohorts of adolescent endurance athletes (range: 4.0-13.1), when using a prospective study design (Rauh et al., 2000, von Rosen et al., 2018a, von Rosen et al., 2017). These differences remain apparent when sex-specific analyses are made. The data from the present study is also higher than that previously reported in novice adult distance runners (Videbaek et al., 2015). Differences between the aforementioned studies may be explained by the fact that the present study included data from the outdoor Track and Field season, whereby athletes regularly reduced their training volume in order to perform to their best ability in races. Likewise, a period of rest (i.e., training break) was usually taken following athletes' final track race of the season, before transitioning into the cross-country season. When combined, this highlights that the reported exposure may have been lower than if the study had captured data throughout an entire calendar year. Further to this, the use of a broad definition of recordable health problems, capturing 'all health problems,' may inflate the reported incidence per 1,000 of exposure.

The mean weekly prevalence of all health problems reported within this study (24%) was lower than that reported in cohorts of adolescent endurance athletes (range: 32.7-38%), as part of sub-group analyses in studies that used similar methods (Moseid et al., 2018, Carragher et al., 2019). Likewise, the reported mean weekly prevalence of substantial health problems within this study (11%) was lower than that reported in comparable cohorts (range: 17.6-22%) (Moseid et al., 2018, Carragher et al., 2019). These studies (Moseid et al., 2018, Carragher et al., 2019), as well as the current study, demonstrate a pattern that approximately half of all health problems are substantial. When only focussing on injuries, the mean weekly prevalence reported within this study (16%) is both similar to (range: 15-19.4%) (von Rosen et al., 2018a, Moseid et al., 2018), and lower than (range: 25.9-32.4%) (von Rosen et al., 2017, Carragher et al., 2019), that reported in similar cohorts of adolescent endurance athletes. For illnesses, the mean weekly prevalence reported within this study (8%) is predominantly lower than that reported in the comparable studies (range: 14-23%) (Moseid et al., 2018, von Rosen et al., 2018a, von Rosen et al., 2017), with the exception being a cohort of elite Irish adolescent endurance athletes (6.9%) (Carragher et al., 2019). Differences between these studies may be explained by the longer follow-up period (52-weeks) used in two of the studies (von Rosen et al., 2017, von Rosen et al., 2018a), thus being representative of a full calendar year, in addition to the possibility that the smaller sample sizes (range: 25 to 76) used in these studies overestimate the prevalence of these health problems (von Rosen et al., 2017, von Rosen et al., 2018a, Moseid et al., 2018, Carragher et al., 2019). The fundamental methodological differences between other studies make any further comparison difficult.

The third key finding was that female athletes reported more illnesses (109 illnesses, 73 participants), compared to male athletes (41 illnesses, 63 participants). They also reported more injuries (118 injuries, 73 participants) than male athletes (95 injuries, 63 participants) too, although this is a less noticeable difference compared to illnesses. In this study, this resulted in higher prevalence, incidence, time loss, and severity data relating to illnesses in female athletes. In the two available studies that report sex differences specific to adolescent distance runners (Carragher et al., 2019, von Rosen et al., 2017), this pattern is consistent. However, in studies that combine sport sub-samples when analysing sex differences (von Rosen et al., 2018a, Moseid et al., 2018), this pattern is not identified. Also, the difference between female and male athletes, in relation to weekly illness prevalence data (8%), is more pronounced in the present study, when compared to others (~3-4%) (Carragher et al., 2019, von Rosen et al., 2017). Nonetheless, this identified sex difference in self-reported illness (and wider health problems) is consistent across general adolescent populations in Europe and North America (Torsheim et al., 2006), and elite adult athletes (Schwellnus et al., 2016). When trying to explain this sex difference, it is apparent that female athletes self-report upper and lower respiratory illnesses, and non-specific illnesses, more often than male athletes do. While the data related to respiratory illnesses are contrary to those sex differences reported in non-athletic populations, including adults and adolescents (Falagas et al., 2007), it does align with research in adult endurance athletes (He et al., 2014). In relation to non-specific illnesses, the higher number self-reported by female athletes is difficult to explain without aetiological information, derived from medical diagnoses. Therefore, future research should look to describe and analyse this sex difference according to specific diagnosis and aetiology (Bahr et al., 2020).

In relation to the burden of health problems (Figure 7.2), results were similar regardless of sex. For example, the body region resulting in the greatest burden from injuries was the lower limb, with the greatest burden according to body area being to the lower leg, knee, and foot/toes. Although comparison to previous research is problematic, these reported body areas are largely consistent with previous adult- and adolescent-based research, irrespective of mode of onset (Rauh et al., 2000, Rauh et al., 2006, van Gent et al., 2007, Jacobsson et al., 2012, Huxley et al., 2014, von Rosen et al., 2017, von Rosen et al., 2018a, Carragher et al., 2019). When combined with the prevalence and incidence data, these results indicate that injury and illness prevention measures for competitive adolescent distance runners should focus on reducing the risk of these specific injuries. Also, as overuse is the usual mode of onset within distance running, any measures should attempt to address this problem. In relation to illnesses, the greatest burden was related to upper respiratory illnesses, in both male and female athletes. While this finding is consistent across the majority of sports (Walsh, 2018), the development of prevention measures in this population may also want to consider this illness system. When combined, these findings demonstrate that a holistic approach to injury and illness prevention is required, whereby a range of different prevention strategies may need to be applied.

As a pattern identified in the data, the mean weekly prevalence of time loss health problems, regardless of type or sex, was relatively low. For example, the mean weekly prevalence of all health problems was 24%, compared to 4% when employing a time loss definition. This means that a large proportion of self-reported health problems did not cause athletes to miss training and competition. Although this could be interpreted as a positive finding in relation to athlete availability, it also worryingly highlights that competitive adolescent distance runners are likely to be training and competing whilst also experiencing a health problem. The potentially adverse consequences of this practice are concerning, representing a “silent issue” in the sport that is largely overlooked by youth sport consensus statements (Bergeron et al., 2015, DiFiori et al., 2014, Mountjoy et al., 2015) and long-term athlete development models (Lloyd and Oliver, 2012). However, this finding may be aligned to the nature of endurance sports, whereby athletes are required to sustain consistent and monotonous training intensities, durations, and frequencies (Seiler, 2010), regardless of health problems.

Therefore, the potentially negative consequences of training and competing when concurrently experiencing a health problem warrants further investigation, while improved access to medical support at the time of initial injury may act to limit this pattern.

7.5.1 Methodological Considerations

Data collection was reliant on athlete self-report outcomes, without any dedicated support from medical professionals. Although this is normal for adolescent distance running in England, it means that recording specific diagnoses for injuries and illnesses was not possible (Bahr et al., 2020) and, as discussed elsewhere (Clarsen et al., 2013), using an 'all health problems' definition can result in overreporting of minor and transient problems (i.e., non-specific symptoms). However, within a homogenous population of distance runners, it is more likely that differences in reporting introduce 'random noise,' rather than systematic bias into the results, whereby some athletes may under-report and others may over-report. Nonetheless, to account for the potential issue of over-reporting, the 'substantial health problems' definition provides additional information on the full impact of injuries and illnesses in this population of adolescent athletes. Also, injuries were not classified based on their mechanism (Bahr et al., 2020). However, based on previous studies (Jacobsson et al., 2012, Huxley et al., 2014, DiFiori et al., 2014, Pierpoint et al., 2016, Moseid et al., 2018, Carragher et al., 2019), and the nature of the sport, it is likely that most injuries in this population have a repetitive mechanism, irrespective of whether the onset was sudden or gradual.

An additional study limitation is the extent to which these findings are generalisable to more recreational adolescent distance runners and different periods of the calendar year. With the emphasis being on competitive athletes, future studies may wish to focus their attention on the wider population of distance runners, allowing for comparison to these data. Likewise, a longer follow-up period (i.e., one year) may better capture seasonal variations related to the incidence, prevalence, and burden of health problems within this population. As internal validity is a prerequisite for generalisability (Rothman et al., 2008b), it is also important to highlight that the proportionately low sample size (representing 22% of the total possible sample), coupled with the rolling enrolment of participants, may have unintentionally made the potential for bias greater. However, this form of baseline self-selection resulted in a group of highly motivated participants, evidenced by the high mean weekly response rate (91%) and small number of participants who dropped out of the study (n = 7). This can be upheld as a methodological strength of this study and, in turn, can be seen to decrease selection bias.

7.6 Practical Implications

Future injury and illness prevention measures within this population should be aimed at reducing the risk of lower limb injuries, with an emphasis on the lower leg, knee, and foot/toes – amply supported by previous research (Rauh et al., 2000, Rauh et al., 2006, Jacobsson et al., 2012, Huxley et al., 2014, von Rosen et al., 2017, von Rosen et al., 2018a, Carragher et al., 2019). The development of prevention measures should also consider how to address the possibility that adolescent distance runners are training and competing whilst concurrently experiencing health problems, including attempting to improve initial access to medical support. This is important to consider in relation to safeguarding the long-term health and wellbeing of these athletes, whereby excelling as an adolescent athlete is unlikely to be necessary for, nor a guarantee of, success as a senior athlete (Kearney and Hayes, 2018). An additional practical implication is that sex differences in the self-reporting of respiratory and non-specific illnesses should be incorporated into the debate surrounding youth athletic development (Bergeron et al., 2015), with further evidence required to explain this difference. Based on the findings of this study, future descriptive epidemiological studies including adolescent athletes should present data for male and female athletes separately.

From a methodological perspective, it is important to reiterate that the response rate during the study was high (91%), with a large proportion of athletes (71%) responding to every weekly questionnaire. Therefore, this study indicates that prospective self-report surveillance methods are feasible in this population, while the questionnaire distribution method can also be advocated for future studies. Finally, the application of the OSTRC-H questionnaire can be recommended, based on its simplicity and capacity to record all health problems (Clarsen et al., 2013, Clarsen et al., 2014). However, future studies should adopt the updated questionnaire (Clarsen et al., 2020), include medical diagnoses, and, where appropriate, extend the length of follow-up.

7.7 Perspectives

This study provides an important insight into the extent of health problems within a population of competitive adolescent distance runners. The incidence of RRI per 1,000 hours of exposure was markedly higher when compared to previous research. At any time throughout the follow-up period, 24% of athletes had a health problem, with 11% having a substantial problem with a negative impact on their training and performance. Regardless of sex, lower leg, knee, and foot/toes injuries were the most burdensome health problems, alongside upper respiratory illnesses, which were a particular problem for female athletes. This study also shows that competitive adolescent distance runners are likely to be training and competing whilst concurrently experiencing health problems, whereby initial access to medical support needs to be improved. Therefore, appropriate management strategies for athletes and coaches should be developed (i.e., return-to-play decision making) for when health problems do occur. These data also support the development of holistic injury and illness prevention measures, that should aim to safeguard the long-term health and wellbeing of competitive adolescent distance runners.

8. KEY FINDINGS, CONTRIBUTION TO KNOWLEDGE, STUDY LIMITATIONS, FUTURE RESEARCH DIRECTIONS, AND CONCLUSION

The primary aim of this PhD thesis was to describe and evaluate the extent of the injury and illness problem in competitive adolescent distance runners in England. As subsidiary aims, this thesis also: (1) investigated the effect of measurement timing and concurrent validity of session rating of perceived exertion (sRPE) and differential ratings of perceived exertion for legs (dRPE-L) and breathlessness (dRPE-B), in order to quantify internal training load (ITL) within this population, and (2) explored potential correlates (risk factors) of running-related injury (RRI). The three studies presented within this thesis (Chapters 4-7) have made a distinct contribution to the existing literature. This chapter will begin by summarising key findings, before explaining how these findings contribute to the existing literature, including comment related to practical research applications. Study limitations will then be discussed, followed by suggestions for future research, and a conclusion.

8.1 Key Findings

8.1.1 Study One

The first study presented within this thesis (Chapter 4) investigated the effects of measurement timing and concurrent validity of sRPE, dRPE-L, and dRPE-B as measures of ITL in adolescent distance runners. The results indicated that sRPE, dRPE-L, and dRPE-B scores were all most likely lower when reported 30 minutes post-session completion, compared with scores reported at session completion (0 minutes). Also, each of these self-reported measures of ITL maintained their largest correlations (r = 0.74 to 0.89) when reported at session completion, when compared to several heart rate-based criteria measures, while these correlations remained consistent (large to very large) across all time points. As a result, it was concluded that sRPE, dRPE-L, and dRPE-B all provide a valid measure of ITL, irrespective of whether the ratings of perceived exertion (RPE) were reported immediately (0 minutes), 15 minutes, or 30 minutes following session completion. This study was the first to validate these measures of ITL in a cohort of adolescent distance runners and, therefore, provide coaches, practitioners, and athletes with both a straightforward and time-efficient means to measure ITL. Furthermore, the validation of these measures supports their inclusion in epidemiological studies, as exhibited in Chapters 5 and 7 of this thesis.

8.1.2 Study Two

The second study provided insight in relation to the typical training practices of competitive adolescent distance runners and established a broad understanding of the RRI problem related to this specific population. Due to the mixed-methods study design, using a combination of quantitative and qualitative approaches, the findings from the second study were split across two chapters. The first element of this study, detailed in Chapter 5, recruited a convenience sample of competitive adolescent distance runners (n = 113) to complete a retrospective questionnaire that aimed to: (1) examine typical training practices and provide descriptive epidemiological data in relation to RRI, and (2) explore potential correlates (risk factors) of RRI. One of the key findings was that the injury incidence rate for 'all RRI' (6.3/1,000 hours of exposure (95% confidence intervals (CI): 5.3 to 7.4)) was slightly higher than that reported in prior studies that included youth endurance athletes (e.g., distance runners, orienteers, and cross-country skiers) (von Rosen et al., 2017, von Rosen et al., 2018a), but lower when compared to studies that only included adult distance runners (Videbaek et al., 2015). Data also highlighted that the incidence proportion for ‘all RRI’ (68% (95% CI: 60% to 77%)) was particularly high, potentially explained by a greater training volume (exposure) in competitive adolescent distance runners, when compared to other youth sports. The knee, foot/toes, and lower leg were the most commonly affected body areas, with overuse being self-reported as the most common cause of RRI. In relation to training practices, this study found that there was a high level of specialisation within this population (i.e., intensive year-round (> eight months) distance running training, having quit other sports), while the total number of training sessions per week (frequency) was shown to increase according to chronological age. In terms of the risk of sustaining RRI, this study applied exploratory univariate analyses to show that a higher level of specialisation was associated with a lower risk of RRI, compared to those with a lower level of specialisation. In relation to sustaining a ‘time loss’ RRI, this study demonstrated that an increased training frequency was associated with a lower risk of RRI.

A sub-sample of the competitive adolescent distance runners who completed the retrospective questionnaire, as reported in Chapter 5, were invited to participate in a semi-structured interview. These interviews were conducted in order to obtain a detailed understanding of adolescent distance runners’ psychosocial response to *serious RRI* (>28 days-6 months of time loss (Timpka et al., 2014a)). This was one of the first studies to have examined this topic in a population of adolescent athletes. Of the 34 athletes who sustained at least one *serious RRI*, 19 athletes were interviewed, as detailed in Chapter 6. A reflexive thematic analysis of the interview transcripts led to the development of 15 codes and three themes. The themes included: (1) *performance uncertainty*, characterised by experiences and expressions of self-doubt related to an athletes’ self-perceived ability to perform at an expected performance level; (2) *injury (mis)management*, whereby athletes typically had to self-navigate their recovery with limited knowledge, resources, and access to medical support; and (3) *contested identity*, representing the idea that a competitive adolescent distance runners' 'athletic identity' is challenged, as a consequence of sustaining a *serious RRI*, thereby requiring a response. These themes were found to support several theoretical relationships presented within Wiese-Bjornstal et al. (1998) 'integrated model of response to sport injury.' When viewed together, the three identified themes framed *serious RRI* as *destabilising athletic identity*, as a psychosocial recovery outcome.

8.1.3 Study Three

The final study included within this thesis (Chapter 7) utilised a prospective cohort study design to describe all health problems (injury and illness) in relation to type, location, incidence, prevalence, time loss, severity, and burden, in a purposively recruited sample of competitive adolescent distance runners. These athletes (n = 136) self-reported all health problems throughout a 24-week period, using the Oslo Sports Trauma Research Center Questionnaire on Health Problems (OSTRC-H), alongside a weekly training diary. The incidence of RRI (25.0 per 1,000 hours of exposure (95% CI: 21.8-28.6)) was considerably higher compared to previous research, including the data reported in Chapter 5. At any time, 24% (95% CI: 21-26%) of participants reported a health problem, with 11% (95% CI: 9-12%) having experienced a health problem that had a substantial negative impact on training and performance. Regardless of sex, lower leg, knee, and foot/toes RRIs were the most burdensome health problems, alongside upper respiratory illnesses. Notably, female athletes self-reported more illnesses, when compared to male athletes, causing a higher prevalence, incidence, time loss, and severity. This study also demonstrated that competitive adolescent distance runners, regardless of sex, are likely to be training and/or competing whilst also experiencing at least one health problem.

8.2 CONTRIBUTION TO KNOWLEDGE

This thesis makes a number of original and important contributions to the existing scientific literature related to the health and wellbeing of competitive adolescent distance runners. This statement is supported by the fact that each study included in this thesis (Chapters 4-7) set out to address gaps in the current evidence-base. Furthermore, the second study presented in this thesis (Chapters 5-6) represents the first time that RRI has been investigated in competitive adolescent distance runners by adopting a sequential mixed methods study design, capturing physical and psychosocial aspects of RRI. This section of this chapter will focus on how the data generated from these studies have directly contributed to knowledge and can be applied in practice. More specifically, this section will consider how this thesis contributes to the first two steps of the six-step Translating Research into Injury Prevention Practice (TRIPP) framework (Finch, 2006): (1) surveillance of health problems, and (2) establishing aetiology and mechanisms. Attention will also be paid to the clinical importance of this thesis, in terms of reducing the risk of RRI or managing RRI in competitive adolescent distance runners.

8.2.1 Surveillance of Health Problems

8.2.1.1 Incidence and Prevalence of Running-Related Injury

As identified throughout the literature review (Chapter 2), there is a lack of data related to the risk of RRI in competitive adolescent distance runners in England. The data from Chapter 5 and Chapter 7 suggest that the incidence of RRI ranges from 6.3/1,000 hours of exposure to 25.0/1,000 hours of exposure, when utilising an inclusive definition of RRI. These figures, despite the difference between them, provide insight in relation to the extent of the RRI problem and are both similar to and higher than those figures reported in prior studies that have included youth endurance athletes (range: 4.0-5.3/1,000 hours of exposure) (von Rosen et al., 2017, von Rosen et al., 2018a), cross-country runners (range: 13.1-17.0/1,000 hours of exposure) (Rauh et al., 2000, Rauh et al., 2006), and track and field athletes (0.84/1,000 hours of exposure) (Pierpoint et al., 2016). These figures are also either comparable to or higher than incidence rates reported across a range of other youth sports (Caine et al., 2008). As a contribution to knowledge, these RRI incidence rates can be applied as an initial 'yardstick' (i.e., point estimates) to which future surveillance research related to competitive adolescent distance runners in England can be compared.

In terms of attempting to explain the difference between the RRI incidence rates presented in this thesis, it is feasible that the different study designs used in each chapter affected these figures. For example, in Chapter 5, the retrospective study design required athletes to report a 'typical training week,' while the prospective study (Chapter 7) involved weekly reporting of their training (encouraged to be logged on a daily basis, immediately following training). Given that an athlete's exposure (i.e., hours of participation) is factored into determining the incidence of RRI, it can be argued that reporting one 'typical training week' might be biased towards a higher reported training volume, due to social desirability bias (Brenner and DeLamater, 2014). As a result, this would result in a lower RRI incidence rate (i.e., 6.3/1,000 hours of exposure). In contrast, the higher RRI incidence rate, as reported in Chapter 7 (i.e., 25.0/1,000 hours of exposure), may well have been influenced by athletes reporting their training throughout the outdoor track and field (athletics) season, whereby athletes regularly reduced their training volume before competitions and took scheduled breaks from training.

Having explained how the denominator (i.e., hours of participation) might affect these RRI incidence rates, it is important to recognise that differences in defining and/or reporting RRI can also influence these figures (Hoeberigs, 1992) – as the numerator. Although both Chapter 5 and Chapter 7 initially applied an inclusive definition of RRI (Section 3.4.1), it is feasible that the retrospective reporting of RRI in Chapter 5 led to overreporting of long-term outcomes (i.e., *serious RRI* (>28 days-6 months of time loss)) and underreporting of more transient outcomes (i.e., *no time loss*). This explanation is shown by the proportions of *serious RRI* (25% vs 6%) and *no time loss RRI* (21% vs 40%) in the retrospective (Chapter 5) and prospective study (Chapter 7), respectively. These data may, therefore, help to explain the lower RRI incidence rate reported in Chapter 5, in addition to some of the differences between previous studies.

Alongside the RRI incidence data, the mean weekly prevalence of RRI reported in Chapter 7 (16%) is both comparable to (range: 15.0-19.4%) (von Rosen et al., 2018a, Moseid et al., 2018), and lower than (range: 25.9-32.4%) (von Rosen et al., 2017, Carragher et al., 2019), figures reported in similar cohorts of adolescent endurance athletes. However, given that the majority of these previous studies only include distance runners as a sub-sample, the data presented in this thesis provide more detailed insight, while offering a point from which to further advance knowledge about RRI in competitive adolescent distance runners. Also, as only one prior study has been found to have included a cohort of UK-based adolescent athletes (D'Souza, 1994), the data from this thesis can be seen as a unique and contemporary contribution to knowledge.

As a further contribution to knowledge, the data presented in Chapters 5 and 7 of this thesis indicated that although female athletes self-reported a greater absolute number of RRIs, when compared to male athletes, these differences were fairly negligible in terms of the incidence of RRI. This is despite the fact that higher RRI incidence rates were reported for female athletes across all definitions of RRI (i.e., 'all,' 'time loss,' and 'medical attention'), supported by the rate ratios reported in Chapter 5. This is somewhat contrary to previous studies, whereby adolescent female cross-country runners (Rauh et al., 2000, Rauh et al., 2006) and track and field athletes (Pierpoint et al., 2016) have been shown to have significantly higher incidence of RRI. However, the data presented in this thesis are similar to those reported in a cohort of adolescent elite Swedish runners (von Rosen et al., 2017), whereby only a slight sex difference in RRI incidence was observed. Specific to Chapter 7, a similar pattern was observed in relation to the weekly prevalence of RRI for all utilised definitions (i.e., 'all,' 'substantial,' and 'time loss'), whereby the data for female and male athletes were relatively similar. This finding is contrary to that found in two relevant previous studies (von Rosen et al., 2017, Carragher et al., 2019), whereby no discernible pattern can be identified due to contrasting results (i.e., a significantly higher prevalence of 'all RRI' in male athletes in one study, while being significantly higher in female athletes in the other). Viewed collectively, these incidence- and prevalence-based sex differences indicate that future RRI prevention measures might not have to be tailored according to sex, assuming that the mechanisms and potential risk factors for RRI are similar.

8.2.1.2 Type, Location, Severity, and Burden of Running-Related Injury

In Chapters 5 and 7, the most commonly injured body region was reported to be the lower limb, while the knee, lower leg, and foot/toes were the most commonly injured body areas. These results align with previous adult- (van Gent et al., 2007, Tonoli et al., 2010, Kluitenberg et al., 2015a) and adolescent-based (von Rosen et al., 2017, von Rosen et al., 2018a, Carragher et al., 2019) distance running studies and can be used to inform the development of prevention measures that aim to reduce the risk of lower limb RRIs.

In relation to the severity of RRI, the proportion of self-reported RRIs that did not incur time loss ranged from 21% (Chapter 5) to 40% (Chapter 7), while no *long-term RRIs* (i.e., >6 months of time loss) were sustained. Due to the study designs used in Chapters 5 and 7 (i.e., length of follow-up), the fact that no *long-term RRIs* were reported is not too surprising. Additionally, data from Chapter 7 showed that the mean weekly prevalence of 'time loss' RRIs (3%) and 'substantial' RRIs (7%) were markedly lower than the mean weekly prevalence of 'all' RRIs (16%). This data contributes to knowledge by indicating that competitive adolescent distance runners are likely to be training and competing whilst concurrently experiencing at least one health problem. This is a concern because, if poorly managed, these relatively minor RRIs could develop into something more serious. For example, in a cohort of semi-professional adult football players, Whalan et al. (2019) have recently demonstrated that the risk of incurring a 'time loss' injury was 3 to 6 times higher when preceded by a 'non-time loss' injury within the previous seven days. Based on this understanding, coaches and sports practitioners need to be aware of this observed trend (i.e., training and/or competing while experiencing at least one health problem), as a practical application, in order to ensure that relatively minor RRIs do not transition into ‘time loss’ and ‘substantial’ RRIs. To extend this point, it is important to recognise that ‘history of previous injury’ is an intrinsic and non-modifiable risk factor for RRI in adolescent distance runners (Krabak et al., 2020). Therefore, appropriate management of ‘non-time loss’ RRIs can be seen as a potentially effective primary prevention strategy. Furthermore, if coaches are aware of this trend, it may help to explain decrements in an athlete’s performance that would have previously been unexplained.

In relation to the burden of RRI, thereby combining severity and incidence data (Bahr et al., 2018), results in Chapter 7 were similar regardless of sex and mirror the data related to most commonly injured body region (i.e., lower limb) and body areas (i.e., knee, lower leg, and foot/toes). While comparison to prior research is difficult, due to the application of different measures of exposure (Martínez-Silván et al., 2020), this data can be used as an initial ‘yardstick’ to compare data from future surveillance research – as aforementioned in relation to the RRI incidence and prevalence data. These data can also be used to inform the development of RRI prevention measures, whereby the focus should be on lower limb RRIs and primary prevention.

In order to facilitate a discussion related to psychosocial responses to *serious RRI*, it is important to highlight that while athletes who had sustained at least one *serious RRI* (i.e., >28 days-6 months of time loss) in Chapter 5 were invited to be interviewed as they were likely to provide information-rich interviews, *serious RRIs* represented 14% (n = 48) of all reported RRIs within Chapters 5 and 7 (n = 355). In comparison to previous research, this proportion of *serious RRI* is likely to be slightly higher that reported in American adolescent cross-country runners (range = 12% to 14%) (Rauh et al., 2000; Rauh et al., 2006), due to the fact that *serious RRIs* were collapsed into a broader ‘15+ days’ severity category. Also, no *serious RRIs* were self-reported in a cohort of elite Irish track and field athletes (Carragher et al., 2019), during a 30-week follow-up period that was comparable to that applied in Chapter 7. Therefore, as the proportion of *serious RRIs* seems to be particularly high in adolescent distance runners, representative of an issue that needs to be addressed, qualitative insight relating to psychosocial responses to *serious RRI* can be viewed as a timely and necessary contribution to existing knowledge.

8.2.1.3 Psychosocial Responses to Running-Related Injury

As argued by Bolling et al. (2018), qualitative research can be utilised to obtain a better understanding of the 'context' in which sport-related injury occurs, aligned to the first step of the TRIPP framework (Finch, 2006). Chapter 6 provided novel insight into how competitive adolescent distance runners in England respond to *serious RRI*, in a psychosocial capacity. Subsumed within each of the identified themes (i.e., *performance* uncertainty, *injury (mis)management*, and *contested identity*), the data generated from these interviews demonstrated several issues that affect competitive adolescent distance runners, including: (1) a willingness to 'push through' pain, (2) limited access to medical support, and (3) defaulting to a negative emotional response having sustained an RRI. Knowledge relating to these issues, typically incorporated within an athlete's psychosocial response to *serious RRI*, provides EA, and other relevant stakeholders, with tangible insight to act on and improve the ability of adolescent distance runners' to cope with and better manage RRI, regardless of severity.

As one of the three themes generated from the reflexive thematic analysis, *injury (mis)management* was also present in the data presented in Chapter 7, thereby further substantiating this finding. To highlight this point, competitive adolescent distance runners were willing to ‘push through’ pain when initially experiencing signs and symptoms of RRI (Chapter 6), while the data from Chapter 7 showed that a similar cohort of adolescent distance runners were likely to be training and competing whilst also experiencing a health problem. Although this willingness to ‘push through’ pain has previously been shown to be prevalent among elite youth athletes (Schnell et al., 2014, Mayer et al., 2018), these data offer sport-specific knowledge related to this issue. For example, Mayer et al. (2018) reported that adolescent endurance athletes were the least likely to experience direct social pressure to ‘play hurt,’ when compared to other popular youth sports. Given this prior knowledge, the data presented within this thesis suggest that this willingness to ‘push through’ pain is most likely to be internalised by competitive adolescent distance runners (i.e., self-administered), interconnected with issues surrounding athletic identity foreclosure (Brewer and Petitpas, 2017), expectations to sustain intense and monotonous training practices (Seiler, 2010), and an ability to directly compare performances using the *Power of 10* database. When applying this knowledge in practice, it is essential that competitive adolescent distance runners are encouraged to make pragmatic decisions in relation to their training practices when initially experiencing pain and/or a minor ‘time loss’ RRI – maintaining long-term athletic development as the priority (Lloyd and Oliver, 2012). As an example, this could be concentrated on coaches and parents stressing that excelling as a youth athlete is not essential for, nor a guarantee of, ‘later success’ (Moesch et al., 2011, Kearney and Hayes, 2018). As a result, successful primary prevention of RRI, combined with sensible decision-making when initially experiencing pain, is likely to improve the chances that competitive adolescent distance runners can maintain a positive performance trajectory (Allen and Hopkins, 2015).

Given that RRIs are still likely to occur, despite evidence-based and/or practice-informed efforts to prevent such outcomes, the identified issues related to limited access to medical support and responding to RRI in a negative capacity can also be upheld as important contributions to knowledge. Based on previous research by Bargoria et al. (2020), it has been shown that receiving medical support allows ‘champion long distance runners’ to sustain excellence in relation to performance and health. Aligned to this finding, Jelvegård et al. (2016) showed that receiving recommendations from medical professionals (or coaches) enabled competitive adult distance runners to focus on rest and recovery, rather than continuing to train through their RRI. Collectively, this evidence indicates that competitive adolescent distance runners require improved access to medical support, in order to negate the default negative emotional response to RRI. In terms of practical application of this knowledge, better access to medical support could be provided via the EA Talented Athlete Pathway programmes (England Athletics, 2020).

As a final point, it is important to highlight that the application of a mixed-methods study design (Chapters 5 and 6) frames discussions about pain, injury, and illness according to quantitative and qualitative lenses. Crucially, this allows the data to be applied in practice in numerous ways, whereby athletes, coaches, and sports practitioners can be made aware of the extent of the injury and illness problem (i.e., the type, location, incidence, prevalence, time loss, severity, and burden of injury and illness), alongside knowing how to best respond to *serious RRI* from a psychosocial perspective. As an extension of this point, Chapter 6 has shown the importance of the ‘athlete voice,’ whereby qualitative research helps to place the needs of the athlete front and centre and move athletes beyond being reduced to a number in a series of statistics (Bekker et al., 2020).

8.2.1.4 Illness

As reported for RRI, there has historically been a lack of data in relation to illness within competitive adolescent distance runners in England. As a result, the data presented in Chapter 7 of this thesis can be seen to address this literature gap, as a novel contribution to knowledge. More specifically, it was reported that the incidence of all illnesses was 17.6/1,000 hours of exposure, while the mean weekly prevalence was 8%. This mean weekly prevalence data was lower than that reported in a number of previous studies that had included a sub-sample of adolescent endurance athletes (range: 14-23%) (von Rosen et al., 2017, Moseid et al., 2018, von Rosen et al., 2018a), with the exception being the data related to a sub-sample of elite Irish adolescent endurance track and field athletes (6.9%) (Carragher et al., 2019). None of these identified studies reported the incidence of illnesses, further highlighting the contribution to knowledge.

Aligned to prior studies that have reported sex differences related to adolescent distance runners (von Rosen et al., 2017, Carragher et al., 2019), the data from Chapter 7 of this thesis showed that female athletes self-reported more illnesses, compared to male athletes. This difference appeared to be due to female athletes self-reporting a higher absolute number of respiratory and non-specific illnesses. Despite lacking medical diagnoses, it seems reasonable to explain this based on female athletes self-reporting symptoms related to the menstrual cycle as 'non-specific symptoms' within the OSTRC-H (i.e., 'pain' and 'feeling tired' (Findlay et al., 2020)). To explain the higher absolute number of respiratory illnesses, this argument could be extended to the fact that low energy availability has been shown to be more prevalent in female track and field athletes, with onset usually occurring throughout adolescence (Melin et al., 2019). As low energy availability can adversely affect the immune system (Mountjoy et al., 2018), it is feasible that this partially explains why female athletes reported a larger number of respiratory illnesses, when compared to male athletes. That said, further research is required to substantiate this argument.

Despite this observed sex difference, it was also observed that upper respiratory illness was the most burdensome type of illness, irrespective of sex. Specific to endurance athletes, it is understood that respiratory illnesses can be caused by the suppression of immune parameters after intense and/or prolonged bouts of training (Gleeson, 2007). In response to this knowledge, it could be argued that little can be done to reduce the burden of respiratory illnesses, whereby reducing the intensity and/or duration of training, as a preventative measure, does not align to the goal of improving athletic performance. While this is a valid point, it may be possible that improved management of ‘broader training practices,’ such as those related to an athlete’s sleeping patterns (Hausswirth et al., 2014, Watson, 2017, Watson et al., 2021), could help to reduce the risk of respiratory illness. Despite the findings reported in Chapter 7 being descriptive, they contribute to knowledge by raising awareness that monitoring illness in competitive adolescent distance runners is as important as monitoring RRI (Schwellnus et al., 2016).

In terms of practical applications, these data should encourage athletes, coaches, and sports practitioners to develop periodised training programmes that intend to optimise endurance performance (Doma et al., 2019), while conceivably reducing the risk of respiratory illness. When coupled with suitable behavioural, lifestyle, and medical practices (Schwellnus et al., 2016), this approach is likely to have a positive influence on the availability of competitive adolescent distance runners, (i.e., competition availability). In turn, sustained periods of training (i.e., those that are unaffected by health problems) are likely to increase the likelihood of attaining successful performance outcomes (Raysmith and Drew, 2016).

8.2.2 Establishing Aetiology and Mechanisms

8.2.2.1 Use of Session and Differential Ratings of Perceived Exertion

When addressing associations between training load and health problems, it is essential that ITL can be measured accurately (Bourdon et al., 2017, Murray, 2017, Nielsen et al., 2020b). As a result, Chapter 4 can be upheld as a significant contribution to knowledge in relation to the fact that the validation of sRPE, dRPE-L, and dRPE-B allow these measures of ITL to be used to explore aetiological questions. From a more practical perspective, the validation of these measures improves the ability of adolescent distance runners to accurately report their ITL, thereby reducing the need for coaches and sports practitioners to adopt complex monitoring systems (Coutts, 2014, Foster et al., 2017). As a contrary point, these measures may actually enable certain coaches to develop an understanding that they had not previously been able to obtain. Furthermore, the validation of sRPE, dRPE-L, and dRPE-B across multiple time points is of benefit to coaches, sports practitioners, and adolescent distance runners – allowing for a degree of flexibility in data collection practices. The ability to accurately record these measures of ITL immediately after session completion (0 minutes) also improves the time efficiency of reporting ITL. In turn, data generated from using these measures will be able to inform training-related decision making practices (West et al., 2020), such as whether an athlete needs extra rest following a particularly intense period of training. As a related point, the fact that dRPE-L and dRPE-B reflect distinct components of exertion, as reported in Chapter 4, enables these measures to be used in conjunction with sRPE during such periods of intense training, thereby enhancing the precision of measuring ITL (McLaren et al., 2016).

It should also be noted that the findings presented within Chapter 4 were recently included in a scoping review Kasai et al. (2020), whereby this study was deemed to be methodologically rigorous. For example, heart rate-based criteria measures were used, instead of a heart rate derived predication equation, while descriptions of the different types of training sessions were provided. Furthermore, this study has already addressed the ‘direction for future research’ proposed in this scoping review, whereby it was recommended that studies are conducted within different sporting subgroups. Due to this external assessment of the methods adopted in Chapter 4, this study can be upheld as a valuable contribution to knowledge.

8.2.2.2 Potential Correlates of Running-Related Injury

Within Chapter 5 of this thesis, exploratory univariate analyses demonstrated that a larger number of training sessions per week (volume) is associated with a lower risk of ‘all’ RRI, while higher specialisation is associated with a lower risk of ‘time loss’ RRI. No other potential correlates (risk factors) of RRI were identified. While causality and temporal relationships cannot be inferred from these data, due to the study design, the (non)identification of potential correlates of RRI contributes to existing knowledge. For example, a consensus statement recently showed that there is limited or conflicting evidence in relation to a number of RRI risk factors in adolescent distance runners (Krabak et al., 2020), including training practices and specialisation.

The finding that a larger number of training sessions per week is associated with a lower risk of ‘all’ RRI is contrary to the limited available evidence. For example, Huxley et al. (2014) showed that, in a cohort of elite adolescent Australian track and field athletes, injured athletes trained at higher intensities and maintained a higher annual training load when aged between 13-14 years, and also completed more high intensity training sessions when aged between 15-16 years. When trying to explain this discrepancy, it is potentially the case that, related to the data in Chapter 5, those athletes who did not sustain an RRI were able to train more frequently, rather than that athletes who trained more frequently sustained fewer RRIs. This suggests that this association may be bidirectional, thereby warranting further research to obtain more comprehensive conclusions in relation to causal associations between training volume and risk of RRI in competitive adolescent distance runners.

In terms of the association between higher specialisation and a lower risk of 'time loss' RRI, the recent youth running consensus statement concluded that there is insufficient evidence that specialisation is a potential correlate of RRI (Krabak et al., 2020). As a result, these data contribute to knowledge by providing an initial degree of sport-specific insight. However, due to the range of chronological ages included in Chapter 5, it is important that this potential correlate is investigated according to different age-groups, whereby the potentially adverse outcomes of single sport specialisation may be more important to address.

8.2.3 Clinical Importance

Having provided a detailed consideration of how the findings presented within this thesis contribute to knowledge, and can be applied in practice, it is also important to examine the clinical importance of these findings. This is related to how these findings are meaningful to different stakeholders, especially in terms of reducing the risk of RRI or managing RRI. Using a socio-ecological perspective, as shown in Figure 2.6 (Chapter 2), the clinical importance of this thesis will be examined in relation to individual, socio-cultural, and environmental/policy levels.

From an individual level, the findings presented in this thesis will be able to benefit competitive adolescent distance runners by improving their knowledge related to the incidence and prevalence of RRI (and illness), alongside the common types, locations, severity, and burden of RRI. This knowledge, likely to be shared via the development of educational resources, will provide athletes with an improved level of education and self-awareness. In turn, it is possible that this knowledge will translate into positive planned behaviours aimed at mitigating the risk of RRI (Finch, 2006, Verhagen et al., 2010). This improved level of education and self-awareness is also supported by the findings reported in Chapter 4, whereby individual athletes will be able to use sRPE, dRPE-L, and dRPE-B as measures of ITL. These measures will directly support their ability to self-regulate training practices, likely to play an important role in reducing the risk of RRI by supporting competitive adolescent distance runners to make better informed decisions and avoid the predominant tendency to simply ‘push through’ pain. Nonetheless, it is important to acknowledge that the responsibility for reducing the risk of RRI does not fully rest upon competitive adolescent distance runners (Emery et al., 2006a). Therefore, it is also important to consider the clinical importance of this thesis in relation to the socio-cultural level (i.e., supporting positive coach-parent-athlete relationships) and environmental/policy level (i.e., improving governance and/or provision of care structures to reduce RRI risk).

From a socio-cultural level, the findings reported in Chapter 6 offer novel insight related to competitive adolescent distance runners’ psychosocial responses to serious RRI. Specifically, the developed themes – (1) *performance uncertainty*, (2) *injury (mis)management*, and (3) *contested identity* – are clinically important in relation to improving management of RRI and developing measures to reduce RRI risk. These findings provide key stakeholders, including coaches, parents, and athletes, with an improved awareness of how RRI can destabilise the athletic identity of adolescent distance runners, thereby supporting their ability to make informed decisions surrounding RRI recovery processes. Improved knowledge of the incidence and prevalence of RRI (and illness), alongside the common types, locations, severity, and burden of RRI, will also be of direct benefit to parents and coaches. As at the individual level, this improved knowledge is likely to translate into a clinically important reduction of RRI risk, especially if the related resources are tailored to the specific needs of the intended end-user.

Lastly, from an environmental/policy level, it is possible for the findings presented in this thesis to support the creation of evidence-based measures to reduce the risk of RRI (see Section 8.4.2), thereby improving the governance and provision of care structures. This is possible due to the fact that Chapters 5-7 offer National Governing Bodies, such as England Athletics, with sufficient evidence to improve their top-down decision making related to reducing RRI risk and managing RRI. Aligned to the TRIPP framework (Finch, 2006), this thesis has addressed the first two steps, whereby completion of the subsequent steps will act to further support clinically important RRI risk reduction (refer to Section 8.4 for a discussion related to addressing these steps). Although not requiring a detailed discussion within the present thesis, it is crucial to highlight that the concept of *return on investment* will need to be considered when creating and implementing such evidence-based measures (Fuller, 2019). This involves the application of a cost-benefit screening process to provide a simple evaluation of the return on athletes' time investment, alongside the financial investment provided from organisations occupying the environmental/policy level (i.e., England Athletics).

8.3 Study Limitations

This section will consider several study limitations that span the original research chapters presented in this thesis (Chapters 4-7), alongside limitations that were not judged to be so when writing specific chapters up for publication. Introduced in rank-order, based on perceived level of importance (most important first), these limitations include: (1) *measurement error,* (2) *sampling methods*, (3) *granularity of epidemiological data*, and (4) *use of magnitude-based inference*. It should be noted that more specific limitations have already been discussed in each original research chapter, while the (dis)advantages related to employing different types of study design have been explained in Section 2.3.2.1.

8.3.1 Measurement Error

Errors in measuring exposure variables within epidemiological studies are usually described as a type of information bias (Rothman et al., 2008b). More specifically, this error can be caused by the measurement tool selected to obtain information on a specific variable and/or self-report bias, whereby data may also be affected by social desirability and recall biases (Coughlin, 1990, Brenner and DeLamater, 2014). Although it is difficult to eliminate all sources of bias from research studies, especially from epidemiological studies, it is important to highlight that sources of information bias were shared across the original research chapters in this thesis (Chapters 4, 5, and 7). This bias was due to a reliance upon self-report and/or surrogate measures. For example, in these chapters, the participant's age at peak height velocity was calculated by applying sex-specific offset equations (Moore et al., 2015), which were subsequently used to estimate maturity timing and tempo (Baxter-Jones et al., 2005). As the participants' stature (to calculate maturity offset) was self-reported in Chapters 5 and 7, any error in measurement could influence the equation output. Furthermore, as stated in Section 3.3.1, concern has been raised in relation to using these offset equations for early- and late-maturing participants (Malina and Kozieł, 2014a, 2014b, 2018), due to measurement inaccuracies, with assessment of skeletal age or secondary sex characteristics (i.e., Tanner Stages) being the preferred measures. Although the majority of participants in Chapters 5 and 7 were ‘average matures,’ allowing this concern to be somewhat negated, the development of these offset equations did not include cohorts of competitive adolescent athletes. Therefore, differences in the characteristics of the study participants conceivably adds to the degree of measurement error.

Other examples of measurement error span Chapters 4, 5, and 7, whereby self-report bias, conflated by social desirability and/or recall biases, can be assumed. Self-reporting weekly training diaries may be affected by adolescent athletes wanting to be seen to be ‘doing more,’ potentially due to the widespread notion that distance running is predominantly about being able to maintain intense and monotonous training practices (Seiler, 2010). Nevertheless, where possible, steps were taken to reduce measurement error. For example, instructions were provided for how to log training, while the validation of sRPE in Chapter 4 was a pragmatic step towards providing adolescent distance runners with a validated tool to record ITL. Due to these steps, the level of measurement error within Chapters 5 and 7 was likely reduced, related to this outcome measure. Likewise, both the baseline and weekly questionnaires included components that had previously been developed and validated, such as the OSTRC-H (Clarsen et al., 2020), thereby helping to reduce measurement error. That said, validation of the OSTRC-H has been limited to adult athletes, with further research required to evidence it's validity in a range of youth sport populations (Clarsen et al., 2020). Yet, due to the relative simplicity of the OSTRC-H (i.e., only requiring a response to four succinct questions), it is likely to translate well to youth sport contexts.

While the concept of measurement error in quantitative research is focussed on sources of bias, comparable (yet contrasting) debates related to the conceptual validity of various theoretical approaches do occur in qualitative inquiry (Mahoney and Goertz, 2006). Therefore, as stated in Chapter 6, use of the 'integrated model of response to sport injury' (Wiese-bjornstal et al., 1998) is one of multiple models that could have been used to analyse the semi-structured interview data (Section 2.3.4.1). Yet, as a widely accepted model (Walker et al., 2007), it can be asserted that it's conceptual validity is suitable for the chosen line of qualitative inquiry.

8.3.2 Sampling Methods

Across each of the four original research chapters in this thesis, non-probability sampling methodologies have been implemented, whereby no attempt has been made to randomise the selection of participants (Teddlie and Yu, 2007). This has included both convenience (Chapters 4 and 5) and purposive (Chapters 6 and 7) sampling methodologies. While this is not necessarily a methodological limitation, whereby *a priori* sample size calculations were determined for the quantitative studies, descriptive epidemiological studies do not require probabilistic sampling methodologies (Tyrer and Heyman, 2016), and qualitative inquiry conventionally recruits participants based upon being 'information-rich cases' (Robinson, 2014, Smith and Sparkes, 2016), the representativeness of findings reported in this thesis can be upheld, in certain instances, as a limitation.

Chapter 5 provides a particularly pertinent example of this limitation. As this study used a convenience sampling technique, whereby participants chose to complete an online questionnaire based upon having received a non-individualised request to do so, and having met a reasonably broad set of inclusion criteria (Vehovar et al., 2016), it was not possible to establish the overall number of athletes that were approached to take part in this study. Therefore, it is not apparent what the ‘entire population’ was before the study, nor the ‘total population’ of potential participants was (i.e., those who received information but did not participate). In turn, this may have contributed to a selection bias (Delgado-Rodriguez and Llorca, 2004), while the generalisability of the data also becomes challenging (Rothman et al., 2008b). That said, it remains difficult to determine the characteristics of this selection bias. Despite this study limitation, it is important to highlight that this sampling method (i.e., study information being distributed via face-to-face meetings, email, and/or social media) was used for pragmatic reasons, as EA did not have a mechanism to recruit a large sample of adolescent distance runners. This limitation was partly addressed when conducting the prospective cohort study (Chapter 7), whereby participants were recruited from a pre-defined pool of athletes, via the *Power of 10* database, and loss to follow-up (including non-response) was negligible.

8.3.3 Granularity of Epidemiological Data

Due to the fact that physicians and/or physiotherapists were not embedded in the data collection procedures related to Chapters 5 and 7, it can be argued that the level of detail (i.e., granularity) reported in the results is limited. To illustrate this point, it is important to highlight that the consensus statement recommendations related to recording and reporting epidemiological data on injury and illness in sport (Timpka et al., 2014a, Bahr et al., 2020) suggest that the classification of health problems can include details related to injury body regions, body areas, tissue types, and pathologies, alongside details of organ system/region and aetiology, for illnesses. However, in Chapters 5 and 7, medical diagnoses were not obtained. Instead, these data were self-reported by participants. As a result, only body regions and body areas were reported for injuries, in addition to the organ system/region for illnesses. Although this is a limitation, this level of detail does align to the most recent consensus statement recommendations (Bahr et al., 2020), based on the notion that self-reporting tissue type and pathology of injuries is considered to be unreliable (Gabbe et al., 2003), due to measurement error. Not being able to make use of physicians and/or physiotherapists during the course of data collection also reflects the reality of participating in track and field (athletics) as an adolescent athlete in England, whereby access to medical support is not usually embedded at this level of participation – as acknowledged in Chapter 6. Therefore, although a lack of granular detail is a limitation, the level of detail achieved is actually far greater than that previously available within this specific sporting context.

8.3.4 Use of Magnitude-Based Inference

Although the use of magnitude-based inference (MBI), as applied in Chapter 4, is not necessarily a limitation, it is important to acknowledge the academic debate related to adopting this statistical approach in Sport and Health Sciences (Barker and Schofield, 2008, Wilkinson, 2014, Welsh and Knight, 2015, Van Schaik and Weston, 2016, Sainani, 2018, Sainani et al., 2019, Batterham and Hopkins, 2019, Lohse et al., 2020). MBI was originally proposed as a more practical approach, when compared to null-hypothesis testing, based on uncertainty in the true value of a statistic (Batterham and Hopkins, 2006). In applied sport and health science journals (i.e., International Journal of Sports Physiology and Performance), MBI has been advocated based on the idea that reporting the clinical or mechanistic (non-clinical) significance of findings in a sport-setting, using established criteria, will help to determine the real-world value and practical application of these data (Wilkinson, 2014, Buchheit, 2016). This was the rationale for utilising qualitative inferences (e.g., 'likely beneficial') in Chapter 4, alongside trying to move beyond relying on 'objective' binary accept/reject decisions based upon *p*-values (Szucs and Ioannidis, 2017), given the subjectivity of self-reporting a rating of perceived exertion. Yet, it has since been argued that MBI, viewed as a hybrid of frequentist and Bayesian statistical approaches, does not necessarily improve the traditional null-hypothesis testing approach (Welsh and Knight, 2015). As a consequence, judgment about whether using MBI is a limitation remains a matter of contention, whereby it is similarly prone to dichotomisation and over-interpretation of findings, when compared to null-hypothesis testing (Lohse et al., 2020).

8.4 Future Research Directions

To further develop the research findings presented throughout this thesis, several different research directions can be suggested. These suggestions align to the first three steps of the TRIPP framework (Finch, 2006): (1) surveillance of health problems, (2) establishing aetiology and mechanisms, and (3) developing preventative measures. Based on these steps, this section will summarise future research directions in terms of: (1) requiring further epidemiological research, (2) developing evidence-based and practice-informed prevention measures, and (3) adopting qualitative research methods to address key questions relating to these steps of the TRIPP framework.

8.4.1 Further Epidemiological Research

It is possible to argue that further research is needed to substantiate and advance the findings reported in the epidemiological studies presented within this thesis (Chapters 5 and 7), due to their exploratory and descriptive nature. For example, it can be maintained that it is important to continue injury and illness surveillance within a cohort of competitive adolescent distance runners, whereby longitudinal (i.e., year-on-year) data collection will allow for an improved understanding of the typical health problems sustained by this regularly overlooked sporting population (Steffen and Engebretsen, 2010, Ekegren et al., 2016). Therefore, based on the effective recruitment and retention of participants shown in Chapter 7, it can be suggested that EA implement a surveillance system for all athletes involved with their talented athlete pathway (i.e., all track and field event-groups). This system should, where possible, include medical diagnoses of injury and illness and apply a more rigorous purposive sampling method. For example, such a system should aim to recruit all athletes enrolled in one or more of the talented athlete pathway programmes, as a 'total population' cohort (Greenland and Rothman, 2008b), in order to address several of the study limitations present in this thesis. To support this approach, future research should validate different RPE-based measures in relation to each track and field event-group, applying a similar approach to that utilised in Chapter 4. This future research direction has recently been advocated in a scoping review of RPE measures in children and adolescents, whereby it was recommended that future research should validate such measures of ITL in sport-specific contexts and field-based settings (Kasai et al., 2020). This would allow such self-reported measures of ITL to be applied as part of the proposed injury and illness surveillance system.

It is also important to build research capacity to answer more complex analytical epidemiological questions, whereby an ability to draw causal inference would be valuable (Shrier, 2007). For example, it would be beneficial to study associations between health problems and different training load parameters (Nielsen et al., 2020a, 2020c), provided that suitable methods are employed (Impellizzeri et al., 2020a, 2020b). Implementing a longitudinal surveillance system would, therefore, allow EA to tailor the delivery of their talented athlete pathway programmes based on this dataset, rather than solely having to rely upon coach-athlete case studies. Additionally, the development of a surveillance system, as proposed, would allow for multivariate modelling to examine the interactions between intrinsic (e.g., sex, chronological age, and maturity timing and tempo) and extrinsic risk factors (e.g., level of specialisation and training volume) and their relationship to specific health problems. This approach would also allow specific risk factors to be identified that explain observed differences between male and female athletes (Krabak et al., 2020), such as that reported for illnesses in Chapter 7. For example, this is what could be achieved with the existing dataset from Chapter 7, whereby the baseline questionnaire, weekly training diaries, and weekly profile of mood states data can be used to inform academic inquiry that seeks to extend the findings presented throughout this thesis.

8.4.2 Development of Preventative Measures

In England, there are currently no evidence-based measures that aim to reduce the risk of injury and/or illness in competitive adolescent distance runners (13-18 years). The development of preventative measures should, therefore, be upheld as a research priority, in an attempt to reduce the risk of injury and/or illness within this population. This is justified based upon the premise that Chapters 5-7 of this thesis have generated novel insights related to the first two steps of the TRIPP framework (Finch, 2006). When combined with other relevant literature (Krabak et al., 2020), there is ample context-specific evidence to inform the development and implementation of preventative measures (Bolling et al., 2018, Tee et al., 2020). More specifically, as proposed throughout Chapters 5-7, such measures should aim to be holistic in their design (i.e., multifaceted), whereby reducing the risk of index RRI occurrence and safeguarding the long-term health and wellbeing of these athletes should be the main objective. While maintaining a holistic design is important, the main focus should be to reduce the risk of lower limb RRI, with an emphasis on primary prevention.

When developing these preventative measures, it is important that a range of key stakeholders (e.g., athletes, coaches, and healthcare practitioners) are involved. The involvement of relevant stakeholders will help to translate the findings from this thesis into effective preventative measures. One way to achieve this is via a 'Knowledge Transfer Scheme,' as proposed by Verhagen et al. (2014). Having combined elements of existing frameworks (Bartholomew et al., 1998, Glasgow et al., 1999), this scheme involves following five consecutive steps when co-developing products within the field of Sports Medicine (i.e., injury and/or illness prevention measures), as illustrated in Figure 8.1. Utilising such an approach can help to develop preventative measures that are simultaneously evidence-based and practice-informed.

8.4.3 Adopting Qualitative Research Methods

Lastly, this thesis has emphasised the suitability of qualitative research methods for examining athletes' psychosocial responses to sport-related injury, as applied in Chapter 6. When coupled with the knowledge that 'qualitative research matters' in relation to safeguarding the long-term health and wellbeing of athletes (Bekker et al., 2020), many different research directions can be supported as an extension of this thesis. As an initial priority, it would be astute to conduct a study that follows adolescent distance runners throughout each phase of the RRI 'continuum.' This approach would align to the implementation of a longitudinal surveillance system, allowing for an examination of the biopsychosocial antecedents of RRI, alongside detailing athletes' immediate psychosocial responses, recovery, and subsequent

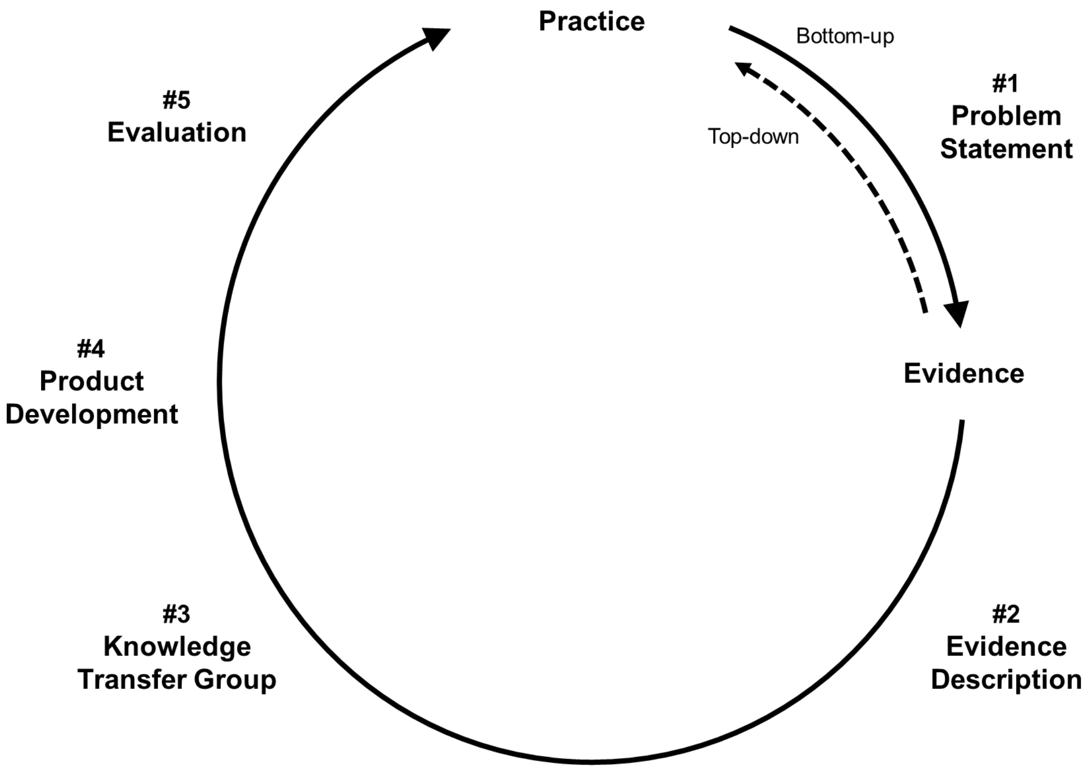


Figure 8.1: A five-step Knowledge Transfer Scheme, initially theorised to support the co-creation of evidence-based and practice-informed products within the field of Sports Medicine (i.e., injury and/or illness prevention measures). Copied from Verhagen et al. (2014), *A Knowledge Transfer Scheme to Bridge the Gap Between Science and Practice: An Integration of Existing Research Frameworks into a Tool for Practice*, British Journal of Sports Medicine, 48(8), p. 699, with permission from BMJ Publishing Group Ltd. (copyright 2014).

return-to-running. As a result, further acknowledgement of ‘complexity’ related to RRI will support the capability of EA to support athletes to cope with RRI, as part of their enrolment in a talented athlete pathway programme. As stated in Chapter 6, this could involve supporting competitive adolescent distance runners to better understand the potential drawbacks of ‘athletic identity foreclosure’ (Brewer and Petitpas, 2017), alongside addressing the potential costs and/or benefits of early sport specialisation (Waldron et al., 2020). Also, evaluating the effectiveness of preventative measures should be directed by qualitative research methods. This should include application of the Reach, Effectiveness, Adoption, Implementation, and Maintenance framework (Glasgow et al., 1999, Finch and Donaldson, 2010, Glasgow et al., 2019), as incorporated within the ‘Knowledge Transfer Scheme’ approach (Verhagen et al., 2014).

8.5 Conclusion

Using a combination of qualitative and quantitative research methods, this thesis contributes a better understanding of the extent of the injury and illness problem in competitive adolescent distance runners (13-18 years) in England. The results presented within this thesis suggest that the incidence of RRI in this population, using an inclusive definition of RRI, is both comparable to and higher than figures reported in relevant previous studies. Potential areas of concern have also been identified, including: (1) commonly injured body regions/areas, (2) sex differences related to self-reported illness, (3) the notion that competitive adolescent distance runners are likely to be training and competing whilst concurrently experiencing health problems, and (4) that *serious RRI* acts to destabilise ‘athletic identity,’ as a psychosocial recovery outcome. This information contributes towards the first step of the TRIPP framework.

As supplementary components of this thesis, sRPE, dRPE-L, and dRPE-B have been shown to provide valid measures of ITL, irrespective of whether reported 0, 15, or 30 minutes following session completion. This finding supported the use of sRPE within the epidemiological components of this thesis and provides coaches, sports practitioners, and athletes with a simple and time-efficient measure of ITL. This thesis also explored potential correlates of RRI, whereby univariate analyses suggested that a larger number of training sessions per week (volume) and higher specialisation might reduce the risk of RRI. This knowledge contributes towards the second step of the TRIPP framework.

Having addressed elements of the first two steps of the TRIPP framework within this thesis, it is important to acknowledge that further research is required in order to substantiate and advance these findings. Where possible, this should include continued surveillance of injury and illness, to enable more complicated analytical epidemiological questions to be addressed. When combining the results from this thesis with other relevant literature (i.e., Krabak et al., 2020), it becomes apparent that context-specific preventative measures should be developed, aligned to the third step of the TRIPP framework.

“Go ahead, Yul Brenner. Go get your Palace.”

Junior Bevil

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10. APPENDICIES

Appendix A: Certificates of Ethics Approval

College of Life and Environmental Sciences
SPORT AND HEALTH SCIENCES

St. Luke's Campus
University of Exeter
Heavitree Road
Exeter
EX1 2LU
United Kingdom

Certificate of Ethical Approval

Proposal Ref No: 170315/B/03

Title: Validity and temporal robustness of the sessional rating of perceived exertion for quantifying training load in adolescent distance runners

Applicants: Robert Mann (PhD Student), Adam Abdul Malik, Emma Cockcroft, Sascha Kranen, Ricardo Oliveira, Owen Tomlinson, Dimitris Vlachopoulous, Max Weston

The proposal was reviewed by the Sport and Health Sciences Ethics Committee.

Decision: This proposal has been approved until December 2017

Signature: Date: 23/3/2017

Name/Title of Ethics Committee Reviewer: Dr Melvyn Hillsdon

Your attention is drawn to the attached paper which reminds the researcher of information that needs to be observed when Ethics Committee approval is given.

College of Life and Environmental Sciences
SPORT AND HEALTH SCIENCES

St. Luke's Campus
University of Exeter
Heavitree Road
Exeter
EX1 2LU
United Kingdom

Certificate of Ethical Approval

Proposal Ref No: 171206/B/02

Title: Adolescent athletes' participation in distance running: training practices, injury and social identity

Applicants: Robert Mann (PhD), Dr Alan Barker, Prof Craig Williams, Bryan Clift (Bath University), Kate Sansum (CHERC Intern Student)

The proposal was reviewed by the Sport and Health Sciences Ethics Committee.

Decision: This proposal has been approved until July 2018

Signature: [signature] Date: 11/1/2018

Name/Title of Ethics Committee Reviewer: Dr Melvyn Hillsdon

Your attention is drawn to the attached paper which reminds the researcher of information that needs to be observed when Ethics Committee approval is given.

College of Life and Environmental Sciences
SPORT AND HEALTH SCIENCES

St. Luke's Campus
University of Exeter
Heavitree Road
Exeter
EX1 2LU
United Kingdom

Certificate of Ethical Approval

Proposal Ref No: 180801/B/02

Title: The relationship between training practices and injury in adolescent distance runners: a six-month prospective cohort study.

Applicants: Robert Mann, Alan Barker, Craig Williams, Bryan Clift, Max Weston

The proposal was reviewed by the Sport and Health Sciences Ethics Committee.

Decision: This proposal has been approved until 01/09/2019

Signature: Date: 13/09/2019

Name/Title of Ethics Committee Reviewer: Dr Melvyn Hillsdon

Your attention is drawn to the attached paper which reminds the researcher of information that needs to be observed when Ethics Committee approval is given.

Appendix B: Example of Participant Information Sheet

UNIVERSITY OF EXETER

Children's Health and Exercise Research Centre, Sport and Health Sciences, University of Exeter.

St Luke's Campus,
University of Exeter,
Heavitree Road,
Exeter, Devon
Telephone: +44 (0)1392 722807
Email: sshs-school-office@ac.uk
Web: sshs.exeter.ac.uk

Participant Information Sheet

Study: The use of sessional rating of perceived exertion as a measure of internal training load in adolescent distance runners.
Researcher: Robert H. Mann
Organisation: University of Exeter
Version: 1/06.03.2017

Thank you for your interest in this study.

Please read this information carefully and discuss the study with your parents/guardians before deciding whether or not to sign the consent form.

What is the purpose of the study?

This study will look at how well session rating of perceived exertion (effort) measures the training load of young distance runners, when compared to other measures, such as heart rate. We also want to know if measures of effort are influenced by the time at which the they are recorded after a training session. This study is being conducted in collaboration with England Athletics and will help us in understanding how to best measure the training load of adolescent distance runners.

Who is taking part?

Local distance runners aged between 13 and 18 years (adolescents), including boys and girls, will be asked to take part in this study. Participants will be training for and/or competing in middle distance running disciplines from the 800 m up to the 3,000 m.

What does this study involve?

You will be asked to make one laboratory visit to the Children's Health and Exercise Research Centre, University of Exeter. The details of this ~ 90 min laboratory visit are outlined below:

- At the start of the visit, we will give you a detailed explanation of the study and tests that we will ask you to complete. We will then ask you to provide us with some basic information about your running, followed by measuring your body weight and height. You will then be introduced to the sessional rating of perceived exertion scales that will be used throughout the study.
- We will ask you to run on the treadmill until you are comfortable with it. We will then ask you to complete a test on the treadmill which involved running until you are exhausted. The exercise test will start at walking speed, with the speed increasing every three minutes, until you are too tired to run for any longer. At the end of each three-minute stage, your blood lactate will be analysed, before returning to the treadmill at a higher speed. During the test, you will wear a facemask so that we can measure the oxygen your body is using to complete the exercise. You will also wear a strap around your chest to measure your heart rate.
- After a little break, the incline of the treadmill will be increased and you will be asked to run at the highest speed you achieved before until you cannot run for any longer. These tests will be used to work out your individual response to training sessions in the following weeks of the study. Also, during these tests, we will be recording your sessional rating of perceived exertion, as explained before the test.
- At the end of the visit, we will explain to you (again) what will happen in the following weeks, including asking you to wear a heart rate monitor for all of your training sessions over a two-week period. Please see the 'what else do I have to do' section for further details.

What else do I have to do?

Following the laboratory visit, you will be asked to record all of your running-related training sessions over a two-week period. This will be done via a heart rate monitor (chest strap and watch) and a training logbook. These will be given out and collected from you at your athletics club. Therefore, you will not have to return to the University after your laboratory visit. We will explain how to use the monitor and logbook when we hand them out. However, the logbook will be where you record any information about your training, including your sessional rating of perceived exertion (overall, legs and breathlessness) at three different time-points: 0 mins, 15 mins and 30 mins after your training session.

Also, during the laboratory visit you will have to run on a treadmill, therefore, you will need to bring suitable kit for exercise (shorts, t-shirt, and suitable trainers). We would also encourage you to ask as many questions as you would like. We hope that your participation in the study inspires you to think about your athletic performance.

What are the possible risks for me if I decide to take part?

All the procedures used in the study are regularly used in research with children and adolescents. The minimal risks include some tiredness after the incremental running test and you may feel light muscle pain in the days after the test. The completion of a health assessment form by you, together with your parents, prior to the study, will ensure that you are safe to participate.

What are the benefits for me if I decide to take part?

This study will look at how well session rating of perceived exertion (effort) measures the training load of young distance runners, when compared to other measures, such as heart rate. As a result of the treadmill test, you will benefit from understanding your maximal exercise capacity. The results from this test can be used to improve your understanding of training and possible race performance. Also, an understanding of the sessional rating of perceived exertion will allow you to monitor your own training load in a very simple way, in order to track the overall intensity of your training sessions.

Finally, we hope that you will enjoy your participation in the project and the chance to be part of a scientific study. At the Children's Health and Exercise Research Centre, we pride ourselves on ensuring that each volunteer has an enjoyable and informative experience throughout every research project. We hope that we can inspire you to take an interest in your health and in the science of exercise, and that this project will be both interesting and fun.

Do I have to take part?

No. You are free to stop participating in the study at any time.

What will happen to the results of the study?

Your data will be stored in coded form to protect anonymity and will be completely confidential. This research will form part of a PhD thesis, and this study will also be submitted to relevant scientific journals for publication. Your information and data will not be identifiable in either of these instances. You will be sent a summary of the research findings once all data have been collected and analysed, as well as your individual data with a full explanation of what it represents should you so wish.

What should I do if I would like to take part?

Please note that your participation must be decided together with your parents. If you would like to take part in the study you and your parents must give your permission by completing the following forms which are included in this information pack:

1. Contact Information Form
2. Parent/Guardian Consent Form
3. Participant Assent Form
4. Health Screen Questionnaire

You should then return these forms to the principal investigator, Robert Mann, who will make himself available to collect these. We will then make contact with your parents to arrange the suitable time to complete the testing.

Taking part is entirely voluntary and it is up to you to decide whether or not you will be involved. If you want to take part you are still free to withdraw at any time, without giving a reason. If you have any questions regarding the nature or purpose of this study, please feel free to contact Robert Mann (primary investigator).

Principal Investigator: Robert Mann ([redacted])
Project Coordinator: Dr. Alan Barker ([redacted])

Appendix C: Example of Consent and Assent Forms

Children's Health and Exercise Research Centre, Sport and Health Sciences, University of Exeter.

St Luke's Campus,
University of Exeter,
Heavitree Road,
Exeter, Devon
Telephone: +44 (0)1392 722807
Email: sshs-school-office@ac.uk
Web: sshs.exeter.ac.uk

PARENT / GUARDIAN CONSENT FORM

Study: The use of sessional rating of perceived exertion as a measure of internal training load in adolescent distance runners.

Researcher: Robert H. Mann

Organisation: University of Exeter

Version: 1/06.03.2017

I have read the information sheet, version 1/06.03.2017, regarding this project and understand the rationale for the study and what my child will be asked to do. I have had the chance to ask questions about the study, and I have received satisfactory answers to any questions I have asked.

Please write your initials in the small boxes to indicate you understand that:

- My child will complete one laboratory visit to the University of Exeter. ☐
- My child will have his/her height and weight measured. ☐
- My child will be asked to complete an incremental running test on a treadmill until exhaustion. ☐
- My child will answer questions about feelings of exertion before, during and after the incremental running test. ☐
- A small amount of blood will be taken from my child's fingertip before,

during and after the incremental running test. ☐

- My child will have to complete a training log book to record his/her running related training over a two-week period. ☐
- My child will be asked to wear a heart rate monitor (and watch) for each of his/her running related training sessions over a two-week period. ☐
- My child is free to withdraw from this study at any time. ☐
- I am free to request further information at any stage. ☐

I know that:

- My child's participation in the project is entirely voluntary and he/she is free to withdraw from the project at any time without giving reason. ☐
- The results will be stored confidentially on a computer for sole use by the Children's Health and Exercise Research Centre, University of Exeter. ☐
- The results of the project may be published but my child's anonymity will be maintained. ☐

Parent / Guardian:

Name: .... Signed: ....

Date: ...../...../...../..... On behalf of my child: ....

Researcher:

Name: .... Signed: ....

Date: ...../...../...../.....

UNIVERSITY OF EXETER

Children's Health and Exercise Research Centre, Sport and Health Sciences, University of Exeter.

St Luke's Campus,
University of Exeter,
Heavitree Road,
Exeter, Devon
Telephone: +44 (0)1392 722807
Email: sshs-school-office@ac.uk
Web: sshs.exeter.ac.uk

PARTICIPANT ASSENT FORM (TO BE COMPLETED BY THE CHILD)

Study: The use of sessional rating of perceived exertion as a measure of internal training load in adolescent distance runners.

Researcher: Robert H. Mann

Organisation: University of Exeter

Version: 1/06.03.2017

I agree to take part in the study as described in the information sheet, version 1/06.03.2017. The study has been clearly explained to me and I have had the opportunity to ask any questions I may have about my involvement in the study.

Please write your initials in the small boxes to indicate you understand that:

- I will complete one laboratory visit to the University of Exeter. ☐
- I will have my height and weight measured. ☐
- I will be asked to complete an incremental running test on a treadmill until exhaustion. ☐
- I will answer questions about feelings of exertion before, during and after the incremental running test. ☐
- A small amount of blood will be taken from my child's fingertip before, during and after the incremental running test. ☐

- I will have to complete a training log book to record my running related training over a two-week period. ☐
- I will be asked to wear a heart rate monitor (and watch) for each of my running related training sessions over a two-week period. ☐
- I am free to withdraw from this study at any time. ☐
- I am free to ask any questions at any time. ☐

I know that:

- I can withdraw from the study at any point with no questions asked. ☐

Participant:

Name: .... Signed: ....

Date: ....../....../....../......

Researcher:

Name: .... Signed: ....

Date: ....../....../....../......

Appendix D: Details of Funded Activities during PhD

SOUTH WEST DOCTORAL TRAINING PARTNERSHIP

Overseas Institutional Visits End of Visit Report for Students and Supervisors

This report is to be submitted to the [redacted] SWDTP Administrator, within two weeks of return to the UK following training.

Applicant Details

Please ensure that we you complete all information required.

Surname	First Name	University
Mann	Robert	University of Exeter
Studentship Award Number / DTC Training Grant Number	**Tel**	**Email**
	[redacted]	[redacted]

Student Report

Please detail below the benefits of your recently completed trip to an overseas university or esteemed research organisation. For example, did the visit meet the aims initially identified in the application for funding? Were there any unexpected benefits?

Do you think your visit made or will make an impact to your PhD research or future career? If so, how?

This visit has made a significant impact on my PhD research. Primarily, this impact can be attributed to the time spent with Prof. Roald Bahr, Prof. Morten Fagerland and Dr. Ben Clarsen, alongside the PhD students within the Oslo Sports Trauma Research Centre (OSTRC). By spending time with these individuals, I have become much more proficient in the application of certain data analysis and management techniques. For example, I have learnt how to effectively manage athlete surveillance data during a prospective cohort study. This has included the development of an Excel spreadsheet that will be utilised in the analysis of my final PhD study. These techniques have become integral to my PhD research.

In addition to these interactions, I have been able to attend the following workshops/seminars:

- IOC Diploma Program in Sports Medicine Workshop (01/04/2019 – 03/04/2019).
- Monitoring Team Sport Athletes: Research and Practice Workshop (07/05/2019).
- Spring Seminar at Kleivstua (20/05/2019 – 22/05/2019).

Attending these workshops/seminars has extended my research network, with direct relevance to the work that I am completing during my PhD. These networking opportunities will be helpful as my academic career progresses, in terms of potential research collaboration. For example, as the OSTRC is one of eleven

International Olympic Committee (IOC) research centres for injury prevention, the network developed during my visit has included academics from some of these different centres. This has included being introduced via email to some relevant academics in these groups. This research network was developed in the first few weeks of the visit, through the use of 'flash meetings' with the OSTRC staff and PhD students. At Kleivstua, I presented an overview of my PhD research and was provided feedback on the content and style. This feedback will be used to improve the way in which I present my work in future conferences. Finally, the content of these workshops/seminars has helped to improve my knowledge of the research field (i.e. athlete surveillance), with a focus on a range of different sporting contexts.

Would you recommend the OIV Scheme to other students? Please give reasons and identify any feedback on the process and forms.

I would highly recommend the OIV Scheme to other students. The primary reason for this is to experience a different research culture to your 'home institution'. During a PhD, you can become a little too familiar with your own research environment. Therefore, an OIV allows you to experience how a different research group operates, spend time with leading academics, and challenge your own academic predispositions. This opportunity also allows you to develop a substantial research network in a different country.

The process of organising this OIV was relatively straightforward. Joanna Williams was extremely helpful in supporting the initial application, with Dr Alan Barker (supervisor) and Prof. Roald Bahr (host academic) providing written statements in support of the trip. In terms of feedback, it was hard to find accommodation for the OIV before having the funds confirmed. It would have helped to have some 'wriggle room' when submitting the application; i.e. if accommodation prices change, then more funds can be requested.

Why did you choose the country you visited?

Norway was chosen because I wanted to visit the Oslo Sports Trauma Research Center (OSTRC), based at the Norwegian School of Sport Sciences (Norges Idrettshøgskole). The aim of OSTRC is to prevent injuries and other health problems in sports through research on risk-factors, mechanisms and prevention methods. This is aligned with my PhD research.

Please note any other comments, feedback and/or additional benefits from the visit:

I have had a thoroughly enjoyable time at the Oslo Sports Trauma Research Center (OSTRC). I am more than thankful for all of the time that has been put aside by OSTRC academics to support my visit. This has included both formal and informal activities. The Spring Seminar at Kleivstua was a personal highlight, whereby I was included in proceedings as if I were a full member of OSTRC. I will always be grateful for this opportunity.

Signed	Robert Mann	Date	24/06/2019

Overseas Institutional Visit End of Visit Report for Students and Supervisors

This report is to be submitted to the [redacted], SWDTP Administrator, within two weeks of return to the UK following training.

Student Surname	First Name	University
Mann	Robert	University of Exeter

Supervisor Report

In addition to the student's comments the SWDTP also seeks the views of their supervisor on the benefits and possible follow up action after completion of the funded studies overseas. This report should be submitted within two weeks of the student's return to the UK.

Supervisor Comments

I'm delighted with the progress Rob has made during his overseas visit to the Oslo Sports Trauma Research Center (OSTRC). The visit has made a significant impact on Rob both from a personal and scientific perspective. On a personal level, Rob is more confident about the quality of his PhD work and in his ability to defend it. This has clearly been developed during the visit through numerous discussions with staff and PhD students at OSTRC, attending bespoke seminar events, and the research retreat in late May. Of particular note for the latter, is that Rob was able to present his work, which was positively received by the audience. In terms of scientific progress, Rob has greatly developed his understanding of research design related issues and how to handle the complex data that are being collected as part of his PhD. Through his interactions with staff members from OSTRC, Rob was able to develop a bespoke spreadsheet to handle and analyse data related to training practices and injury, which will be essential for his prospective study on youth runners.

Did the Overseas Institutional Visit scheme meet your expectations?

Yes. The OIV will be a highlight of Rob's PhD study and the impact will be seen in the quality of his academic work. The scheme is suitably funded to enable the student to spend a significant period of time with the overseas partner – this is essential for their personal and scientific development. This is a real strength to the scheme, as funding for shorter visits will not permit deep and meaningful benefits to occur.

Is there anything the SWDTP could do to improve the OIV scheme?

The scheme appears well run and it is a significant strength that funding can be sought for a long period of stay (12 weeks). As mentioned by Rob in his report, it would be useful if some aspects of the funding had an element of flexibility to support dynamic aspect related to costs– i.e. to secure accommodation. It would also be useful to know if follow-up funding opportunities were possible through this scheme to further develop the student. For example, Rob's research network has widened by a considerable amount and having the opportunity to visit other institutions would further benefit his development. In the context of this visit, OSTRC is one of eleven International Olympic Committee research centres for injury prevention. Whilst being at OSTRC, Rob was able to make contact with numerous staff from these centres, making ideal destinations for other OIV awards.

Signed		Date	1st July 2019

Research Council Policy Internships Scheme

Internship and Funding Permissions Form

This form requires the signature of the applicant, the applicant's lead supervisor and the training grant holder and should be completed and uploaded as part of the online application form. Where necessary electronic signatures (scanned copies, pasted into the relevant box are acceptable).

<u>**Internship permissions**</u>

This section is to be completed by the applicant: I confirm that I am eligible to apply to this opportunity, the content of this application is correct and that I have sought the appropriate permissions from my lead supervisor to undertake this policy internship.	
Name (please print): Robert Mann	
Signature: Robert Mann	**Date:** 08/08/18

This section is to be completed by your lead supervisor: I confirm that the information within this form is correct. If this application is successful, I give my permission for the above applicant to suspend their PhD studies for 3 months.	
Name (please print): Dr. Alan Barker	
Signature: 	**Date:** 10/08/18

Funding permissions

In all cases, this section is to be completed by the training grant holder (the training grant holder is a member of staff at the student's Research Organisation who is responsible for the grant that funds the studentship – normally this will be a contact from a Doctoral Training Partnership or equivalent research council training structure).

Policy Internships are supported using different mechanisms depending on the Research Council which is funding the student. Please read the information relevant to the Research Council which is funding the studentship and complete the appropriate section.

For ESRC students:

I confirm that the above information is correct. I confirm that the stipend and fee costs can be accessed through the student's ESRC Doctoral Training Partnership (DTP). The studentship must be extended by three months to accommodate the internship. Where required, eligible travel and accommodation costs will be supported by the host partner up to a maximum limit of £2,400 for the duration of the internship, with the exception of the Centre for Science and Policy, Parliamentary Office of Science and Technology, National Assembly for Wales Research Service, Northern Ireland Assembly, and the Scottish Parliament Information Centre. Students undertaking internships at one of these host partners will be required to access travel and accommodation costs from other sources, such as their DTP.

Name (please print): Prof. Sally Barnes	**Training Grant Reference Number:** ES/P000630/1
Signature:	**Date:** 09/08/18

[redacted]
Subject: SWDTP Student Impact Funding Confirmation
Date: 19 October 2018 at 15:37:44 BST
To: "Mann, Robert" [redacted]
Cc: [redacted]

Dear Rob

I am writing with reference to your application for Student Impact Funding 'England Athletics: Educational Videos and Infographics for 'Coaching Corner'' (copy attached) which was discussed recently by the SWDTP Student Representative Committee.

Following their recommendation that your application is suitable for funding I am pleased to confirm and approve funding of £993.10
This funding is determined within the limits prescribed by the ESRC for this type of activity and no additional funding will be applied.

By copy of this email, the University of Bristol will arrange for the funds to be transferred to the University of Exeter, under the rules set out in the SWDTP Partnership Agreement. A purchase order number will be sent to finance colleagues, inviting them to send us an invoice for the full amount and this invoice must clearly detail that the funds are for 'Student Impact Funds (Cohort Budget)'. Payment will then be transferred and the monies will be handled by finance colleagues at the University of Exeter. I recommend that you contact [redacted]o make arrangements to draw on the funds or have them moved into your budget code. The University of Bristol finance contact details are as follows: [redacted]

Please note that there are some specific financial requirements in relation to evidencing the spent amount at the end of the project and you will have already received the report and expenditure form that you must complete and return to [redacted]) within two weeks of your activity being completed. No overspend is allowed and any underspend may be re-claimed, where appropriate.

In terms of the activity, please can you keep me informed of your plans and progress so that I can highlight them in the SWDTP Newsletter and website, as and when appropriate. In addition, we may need to meet following your work to discuss the activities so that I can determine how any outputs can be retained for use in other marketing, case study and impact exemplar activities, as determined appropriate by the SWDTP. Information and data collected will be provided to the ESRC as part of our next Annual Report submission.

Finally, if you have any interesting outputs, content, photos, videos or other images, media activity or reports from your impact activity we would appreciate you sharing these with the office so they can be kept for possible future use in SWDTP business.

I think that this covers the initial set-up issues. Please feel free to contact me if you need any additional information.

Very best wishes for a successful impact project.

Appendix E: Training Logbook Completed by Participants (Chapter 5)

Athlete Training Logbook

Study Title: The use of sessional rating of perceived exertion as a measure of internal training load in adolescent distance runners.

Participant: ____

Heart Rate Monitor: __________________________________

Start Date: _____ / _____ / _____ **End Date:** _____ / _____ / _____

Instructions for Reporting your Rating of Perceived Exertion (RPE)

What is effort (exertion)?

Effort is the feeling of how hard, heavy, and strenuous an exercise is.

Measuring perceived exertion:

We want to measure your perceived exertion (i.e., effort) during different types of running-related training sessions and competitions. This can depend on the strain and fatigue in your muscles (e.g., leg muscles) and on your overall feelings of breathlessness. To measure your perceived exertion, a 10-point scale will be used (see p.3). When reporting your rating of perceived exertion (RPE), you must only think about your subjective feelings and not the physiological signals and/or other sensations (e.g., discomfort).

How to use the RPE scale:

When using the RPE scale (see p.3), 10, 'maximal effort,' is the main anchor. This is the strongest perception of effort that you have ever experienced. When using the RPE scale, start with a 'verbal descriptor' and then choose a 'rating.' For example, if your perception of effort is 'easy', select rating #2; if it is 'hard', select rating #5, and so on.

It is very important that you answer what you perceive and not what you believe you should answer. Please be as honest as possible when reporting your ratings and try not to overestimate or underestimate them.

Examples:

- **#1** is 'very light', like walking slowly at your own pace for several minutes.
- **#3** is not very hard; it feels fine, and it is no problem to continue.
- **#5** you are tired, but you don't have any great difficulties.
- **#7** you can still go on, but you have to push yourself. You are very tired.
- **#10** is as hard as most people have ever experienced before: maximal.

0-10 RPE Scale

Rating	Verbal Descriptor
0	Rest
1	Very, very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	
10	Maximal
•	

Instructions for Reporting Training

Use of the training logbook:

1. Each page of the training logbook is the same, with a number of sections for you to complete after your training session. Please make sure that you only use this to record running-related training and competition, such as athletics club sessions, normal training runs, track races, etc.
2. Please report as much information about your training session as possible, this will help with the analysis of the data.
3. You need to report your rating of perceived exertion for three different measures of perceived exertion:
   a) **Overall** – how hard was the session (whole-body)?
   b) **Leg Exertion** – only for your legs, how hard was the session?
   c) **Breathlessness** – only for your breathing, how hard was the session?
4. Each of the three measures of perceived exertion (i.e. overall, leg exertion and breathlessness) need to be recorded at three different time points after your training session or race: **0min** (i.e., straight after your session or race has finished), **15min** and **30min**.

Use of the heart rate monitor:

1. Apply a splash of water to the electrode areas of the heart rate monitor strap. This is the part that will sit just below your chest muscles.
2. Without attaching the heart rate transmitter, adjust the strap length to fit tightly around your chest. Attach the hook to the other end of the strap to fix in place. The strap should feel comfortably tight and rest just below your chest muscles.
3. Now attach the heart rate transmitter to the chest strap, making sure that the Polar logo is in a central and upright position.
4. Once attached, the heart rate transmitter will start to flash green and will make one 'beep' when your heart rate has been identified. You can start training once this has happened.
5. After training, detach the heart rate transmitter from the strap. You will hear two 'beeps' when the transmitter has turned off.

Training Logbook: Session #1

Today's date: ____ / ____ / ____ **Time at start of session:** ____:____:____

Total duration of session (minutes)*: ____

Total distance covered during session (miles or km (please specify))*: __________________

*Please include the duration and distance covered during any warm up/cool down activities.

Type of session (e.g. easy run, intervals, race, etc.): ________________________________

____

____

Session description (e.g. number/type of interval repetitions, duration of recovery, inclusion of warm a up or cool down, etc.): ____

____

____

____

Using the **RPE scale** (see p.3), please complete the following table:

	0 min	**15 min**	**30 min**
sRPE: Overall			
sRPE: Leg Exertion			
sRPE: Breathlessness			

General Comments: ____

____

____

Other Sporting Activity: ____

____

____

Appendix F: Retrospective/Baseline Questionnaire (Chapters 5 and 7)

DISTANCE RUNNING STUDY
Retrospective/Baseline Questionnaire

N.B. Those sections that are shaded in blue were ommitted from the baseline questionnaire in Chapter 7, in order to reduce the total amount of time that the questionnaire would take each participant.

SECTION #1: Demographics

Full Name:	**Date of Birth:** ____ / ____ / ____ (Day, Month, Year)
Sex: ☐ Male ☐ Female	
Height: ____ feet ____ inches or ____ cm	**Is distance running your main sport?** ☐ Yes ☐ No*
Weight: ____ stone or ____ kg	**How many years have you participated in distance running?**
Age Group: ☐ 13-14 y ☐ 15-16 y ☐ 17-18 y	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Are you a member of an Athletics Club? ☐ Yes ☐ No	☐ 6 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12 ☐ 13 ☐ Other ____
If you answered 'yes', which Athletics Club(s)?	**What is your current level?** ☐ Recreational (for fun) ☐ Competitive
*If distance running is not your main sport, what is?	**How long have you participated at this level?** ____ years ____ months

SECTION #2: Performance History

Which distance running event is your main event? *Tick one.* ☐ 800 m ☐ 1,500 m ☐ 3,000 m ☐ 5,000m ☐ 10,000m ☐ Other If 'other', which event? ____	**Which other events do you compete in?** *Tick all that apply.* ☐ 800 m ☐ 1,500 m ☐ 3,000 m ☐ 5,000m ☐ 10,000m ☐ Other If 'other', which events? ____
What is your personal best time for your main event? ____ : ____ (Minutes, Seconds)	**Do you currently have a Coach?** ☐ Yes ☐ No **If 'yes', do they set your training plan?** ☐ Yes ☐ No **If 'no', who sets your training plan?**
At what level are you currently competing? *Tick all that apply.* ☐ Club ☐ County ☐ Regional ☐ National ☐ International	
What is the highest level that you have competed at? *Tick one.* ☐ Club ☐ County ☐ Regional ☐ National ☐ International	

1

SECTION #3.1: Training Practices

How many months of the past year (12 months) did you participate in distance running?

☐ None ☐ 1 ☐ 2 ☐ 3 ☐ 4
☐ 5 ☐ 6 ☐ 7 ☐ 8
☐ 9 ☐ 10 ☐ 11 ☐ 12

How many weeks per month did you participate in distance running? *For the months where you did participate.*

☐ None ☐ 1 ☐ 2 ☐ 3 ☐ 4

How many days per week did you participate in distance running? *For the weeks where you did participate.*

☐ None ☐ 1 ☐ 2 ☐ 3 ☐ 4
☐ 5 ☐ 6 ☐ 7

How many minutes per day did you participate in distance running?

☐ None ☐ less than 1 hour ☐ 1-2 hours ☐ 3-4 hours
☐ 5-6 hours ☐ 7-8 hours ☐ Other: ____________

How long does a normal training session last for you? *Round up to the nearest hour.*

☐ less than 30 mins ☐ between 30 mins - 1 hour ☐ between 1 - 2 hours ☐ More than 2 hours

What surface do most of your training sessions take place on?

☐ Athletics Track ☐ Tarmac / Road ☐ Grass / Cross Country ☐ Other: ____________

What footwear / shoes do you wear when running on the following surfaces? *Complete table below.*

	Type of surface	Brand of shoe	Model of shoe	Duration of use (i.e. months)?
1	Athletics Track			
2	Tarmac / Road			
3	Grass / Cross Country			
4	Other: ____________			

Do you include a warm-up as part of your training sessions? ☐ Yes ☐ No

In 'yes', please describe your typical warm-up: ____________________________

Do you include a cool-down as part of your training sessions? ☐ Yes ☐ No

In 'yes', please describe your typical cool-up: ____________________________

Do you do any strength and conditioning (physical preparation), in addition to your distance running? ☐ Yes ☐ No

In 'yes', please describe what this typically involves and who sets this training: ____________________

How many times did you compete in distance running events in the past year (12 months)?

☐ None ☐ Less than 10 ☐ Between 10 and 20 ☐ Other: ____________

SECTION #3.2: Training Diary

Thinking about the last seven days of your distance running training (i.e. a typical week), please complete the following training diary. When entering session duration and distance covered, please estimate as best as possible. For session intensity, please choose a number on the CR-10 Borg Scale (on back of questionnaire), by answering the following question: 'how hard was your workout?'.

Day of week	Session number	Total session duration (min)	Total distance covered (km)	Type of training session	Session intensity	Specific details about the training session
Example	1	*45*	*7*	*6 x 800 m (2 min recovery)*	*7 = very hard*	On an atheltics track, in spikes. Started the session at 9am
	2	*30*	*6*	*30 minute easy run*	*2 = easy*	*On tarmac, in regular trainers.* Started the session at 6pm.
Monday	1					
	2					
Tuesday	1					
	2					
Wednesday	1					
	2					
Thursday	1					
	2					
Friday	1					
	2					
Saturday	1					
	2					
Sunday	1					
	2					

SECTION #4: Athletic Identity Measurement Scale

For each statement, please circle <u>one number</u> from 1 (strongly disagree) to 7 (strongly agree) that best represents your answer.

	Strongly Disagree						Strongly Agree
I consider myself an athlete.	1	2	3	4	5	6	7
I have many goals related to sport.	1	2	3	4	5	6	7
Most of my friends are athletes.	1	2	3	4	5	6	7
Sport is the most important part of my life.	1	2	3	4	5	6	7
I spend more time thinking about sport than anything else.	1	2	3	4	5	6	7
I need to participate in sport to feel good about myself.	1	2	3	4	5	6	7
Other people see me mainly as an athlete.	1	2	3	4	5	6	7
I feel bad about myself when I do poorly in sport.	1	2	3	4	5	6	7
Sport is the only important thing in my life.	1	2	3	4	5	6	7
I would be very depressed if I were injured and could not compete in sport.	1	2	3	4	5	6	7

SECTION #5: Injury and Medical History

In the past year (12 months), have you had an injury that resulted from distance running participation, irrespective of the need for medical attention or time loss from the sport? This includes training and conditioning for distance running.

☐ Yes ☐ No If 'yes', please list in table below:

Injury Date	Injury Type	Session Type	Surface	Body Part	Time loss	Treatment (if any)	How were you injured?
i.e. month and year	*Sprain, bruise, etc.*	*Intervals, race, etc.*	*Track, grass, etc.*	*Left elbow, ankle, etc.*	*1 day, 3 weeks, etc.*	*None, first aid, Doctor, physio, massage, etc.*	*fall, repetitive overuse, strenuous move, etc.*

Were any of these injuries the same injury happening again? This can include injuries beyond the previous 12 months.

☐ Yes ☐ No If 'yes', please list (#'s): ______________________________

Do you have any injuries that are ongoing?

☐ Yes ☐ No If 'yes', please describe these injuries: ______________________________

Are you currently receiving treatment for any of these injuries?

☐ Yes ☐ No If 'yes', please describe these injuries: ______________________________

Are you currently taking medication for any of your injuries?

☐ Yes ☐ No If 'yes', please list medication: ☐ Paracetemol ☐ Ibuprofen ☐ Other: ____________

Do you currently take any medication on a regular basis?

☐ Yes ☐ No If 'yes', please list medication: ☐ Paracetemol ☐ Ibuprofen ☐ Asthma inhaler ☐ Other: ____________

Are you currently taking any supplements for performance and/or health reasons (vitamins, minerals, protein powder, etc.)?

☐ Yes ☐ No If 'yes', please list supplements, the dose and how long you have been taking the supplement: ____________

Have you ever been diagnosed by a physician with a bone fracture, arthritis, and/or other muscle or bone related condition?

☐ Yes ☐ No If 'yes', please describe (include year): ____________

Have you had surgery in the past year?

☐ Yes ☐ No If 'yes', please describe: ____________

In the past year (12 months), have you had any pain, discomfort, or physical problems during running that you did not list as an injury?

☐ Yes ☐ No If 'yes', please list in the table below.

Date	Session Type	Surface	Body Part	Time loss	Treatment (if any)	Description
i.e. month and year	*Intervals, race, etc.*	*Track, grass, etc.*	*Left elbow, ankle, etc.*	*1 day, none, 3 weeks, etc.*	*None, first aid, Doctor, physio, massage, etc.*	*Provide short overview*

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SECTION #6: Specialisation

N.B. These questions were combined in Section #1 when applied as a baseline questionnaire (Chapter 7).

Is distance running more important to you than any other sport?	☐ Yes	☐ No
Have you quit other sports in order to focus on distance running?	☐ Yes	☐ No
Do you train or participate in distance running for more than 8 months of the year?	☐ Yes	☐ No

In the past year, how many months, weeks and hours per week (on average) did you participate in a school PE class?

_______ number of months _______ number of weeks _______ hours per week

Based on the past year, did you participate in any sports on a weekly basis (NOT including PE class or running)?

☐ Yes ☐ No If 'yes', please estimate the average number of hours per week you participated in each sport:

SPORT	hrs/wk, mo/yr	SPORT	hrs/wk, mo/yr	SPORT	hrs/wk, mo/yr
Aerobics	,	Floor hockey	,	Speed skating	,
Athletics	,	Football	,	Swimming	,
Badminton	,	Golf	,	Tennis	,
Baseball	,	Gymnastics	,	Ultimate Frisbee	,
Basketball	,	Hiking/ Scrambling	,	Triathlon	,
Boxing (incl. kick)	,	Horse riding	,	Volleyball	,
Canoeing	,	Kayaking	,	Waterpolo	,
Caving	,	Lacrosse	,	Weight training	,
Climbing	,	Martial arts	,	Wrestling	,
Cycling - Mountain	,	Rafting	,	*Other:	,
Cycling - Road	,	Rugby	,		,
Dance	,	Skateboarding	,		,
Dirt biking	,	Skiing - Downhill/Alpine	,		,
Diving	,	Skiing - Cross-country	,	*Please describe other:	
Field hockey	,	Snowboarding	,		
Figure skating	,	Squash	,		

Section #8: Further Research

Are you be willing to take part in any further research studies?	☐ Yes	☐ No
Are you be willing to take part in any further research studies?	☐ Yes	☐ No

Thank you for completing this questionnaire

7

Appendix G: Weekly Questionnaire (Prospective) (Chapter 7)

Start of Block: Introduction

Questionnaire Week: _____

The following questionnaire should not take you longer than 10 minutes to complete. However, please take your time and answer the questions in an honest and detailed manner.

When answering these questions, you are **reflecting on the training week that you have just completed**, i.e. from Monday [insert date] until Sunday [insert date].

Please enter your full name below:

____

End of Block: Introduction

Start of Block: OSTRC 1.1

Q1. Have you had any difficulties participating in normal training and competition due to injury, illness or other health problems during the past week?

- Full participation without health problems
- Full participation, but with injury/illness
- Reduced participation due to injury/illness
- Cannot participate due to injury/illness

Page Break

Q2. To what extent have you reduced your training volume due to injury, illness or other health problems during the past week?

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

Page Break

Q3. To what extent has injury, illness or health 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

Page Break

Q4. To what extent have you experienced symptoms/health complaints during the past week?

- No symptoms/health complaints
- To a mild extent
- To a moderate extent
- To a severe extent

Page Break

Display the following question:
If – Response to Q1 is anything other than "Full participation without health problems."
Or – Response to Q2 is anything other than "No reduction."
Or – Response to Q3 is anything other than "No effect."
Or – Response to Q4 is anything other than "No symptoms/health complaints."

Q5. Is the health problem referred to in the four questions above an injury or an illness?

- Injury
- Illness

Page Break

Display the following question:
If – Response to Q5 is "injury."

Q6. Please select the box that best describes the location of your injury. If the injury involves several locations, please select the main area. If you have multiple injuries, please complete a separate registration for each one.

- Head/Face
- Neck
- Shoulder (including Clavicle)
- Upper Arm
- Elbow
- Forearm
- Wrist
- Hand/Fingers
- Chest/Ribs
- Abdomen
- Thoracic Spine
- Pelvis/Buttock
- Hip and Groin
- Thigh
- Knee
- Lower Leg
- Ankle
- Foot/Toes
- Other

Page Break

Display the following question:
If – Response to Q6 is "other."

Q6.1. If 'other', please provide details below:

____

Page Break

Display the following question:
If – Response to Q5 is "illness."

Q7. Please select the boxes corresponding to the major symptoms you have experienced during the past 7-day period. You may select several alternative; however, in the case that you have several unrelated illnesses please complete a separate registration for each one.

- Fever
- Fatigue/Malaise
- Swollen Glands
- Sore Throat
- Blocked Nose/Running Nose/Sneezing
- Cough
- Breathing Difficulties/Tightness
- Headache
- Nausea
- Vomiting
- Diarrhoea
- Constipation
- Fainting
- Rash/Itchiness
- Irregular Pulse/Arrhythmia
- Chest Pain/Angina
- Abdominal Pain
- Numbness/Pins and Needles
- Anxiety
- Depression/Sadness
- Irritability
- Eye Symptoms
- Ear Symptoms
- Symptoms from Urinary Tract/Genitalia
- Other

Display the following question:
If – Response to Q7 is "other."

Q7.1. If 'other', please provide details below:

____

Page Break

Display the following question:
If – Response to Q5 is either "injury" or "illness."

Q8. Please state the number of days over the past 7-day period that you have had to completely miss training or competition due to this problem.

- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7

Page Break

Display the following question:
If – Response to Q5 is either "injury" or "illness."

Q9. Is this the first time you have registered this problem through this monitoring system?

- Yes, this is the first time
- No, I have reported the same problem in one of the previous four weeks
- No, I have reported the same problem previously, but it was more than four weeks ago

Page Break

Display the following question:
If – Response to Q5 is either "injury" or "illness."

Q10. Who have you reported this to?

- Nobody
- Doctor
- Physiotherapist
- Other

Page Break

Display the following question:
If – Response to Q10 is either "Doctor" or "Physiotherapist."

Q10.1. Please provide their name and workplace below:

____

Page Break

Display the following question:
If – Response to Q10 is "Other."

Q10.2. If 'other', please provide details below (including their job title, name and workplace):

____

Page Break

Display the following question:
If – Response to Q5 is either "injury" or "illness."

Q11. Please use this section to record any additional information that may be of interest:

____

____

Page Break

Display the following question:
If – Response to Q5 is either "injury" or "illness."

Q12. Have you experienced any other injuries, illnesses or other health problems during the past seven days?

- Yes
- No

If response to Q12 is "Yes," the participant will be required to complete another round of questions (Q1-Q12) about their second health problem. This will be repeated a 3rd and 4th time, if necessary. If more than four health problems were experienced, the participant will be prompted to contact the principal investigator via email.

End of Block: OSTRC 1.1

Start of Block: OSTRC 1.2

End of Block: OSTRC 1.2

Start of Block: OSTRC 1.3

End of Block: OSTRC 1.3

Start of Block: OSTRC 1.4

End of Block: OSTRC 1.4

Start of Block: Training Diary

Q13. Training Diary

Please complete the following training diary (see below), reflecting on the last seven days, i.e. Monday [insert date] to Sunday [insert date].

The training you include here should be specific to distance running, including any competitions/races that you take part in.

When entering 'session duration' (min) and 'distance covered' (miles), please estimate as best as possible. For 'type of session', please include details about intervals completed, recovery, or whether it was just an easy run, etc. The more detail, the better!

For session intensity, please choose a number from the modified CR10 scale, as below. When choosing a number, you need to be answering the following question: 'How hard was your workout?'. Please record this immediately following your training session.

In table form, the training diary allows two sessions to be included per day (extra pages can be requested, if required), with the following information:

- *Session duration (minutes).*
- *Distance covered (miles).*
- *Type of session (intervals/recovery/etc.).*
- *Session intensity (RPE value).*
- *Specific details (open textbox).*

Q13.1. Please add any additional information below:

For example, you may want to provide information about any additional training (i.e. strength and conditioning) and competition outcomes (i.e. race results).

____

____

____

____

End of Block: Training Diary

Start of Block: Profile of Mood States

Q14. Profile of Mood States

Below is a list of words that describe feelings that people have. Please read each word carefully and select the answer which best describes how you feel right now. Make sure you answer every question!

In table/matrix form, the Profile of Mood States lists 24 words and requires participants if they currently feel like the word/descriptor. Responses include: (1) Not at all, (2) A little, (3) Moderately, (4) Quite a bit, or (5) Extremely. Only one answer for each word/descriptor can be selected. The words/descriptors included are as follows:

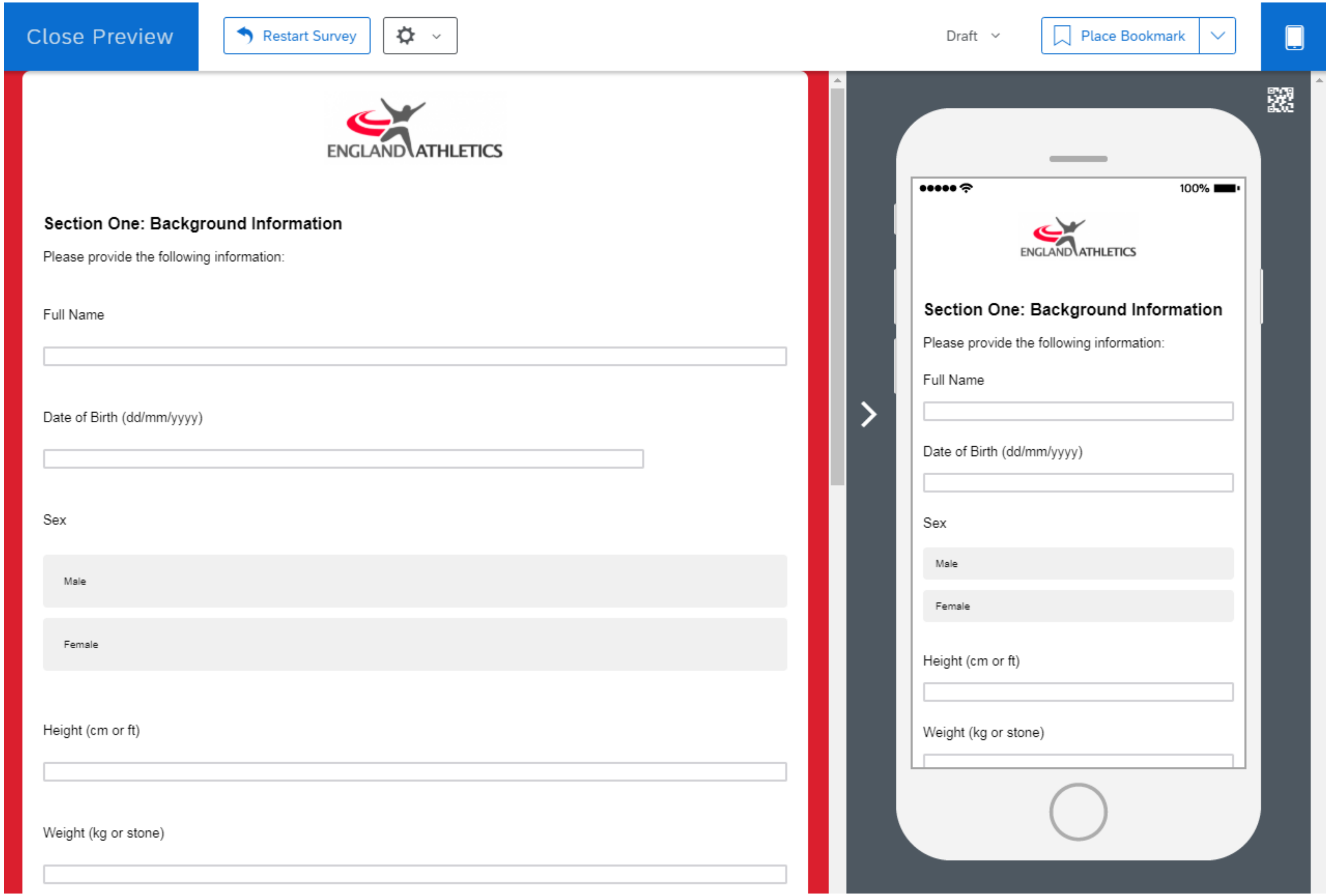
- *Panicky.*
- *Lively.*
- *Confused.*
- *Worn out.*
- *Depressed.*
- *Downhearted.*
- *Annoyed.*
- *Exhausted.*
- *Mixed-up.*
- *Sleepy.*
- *Bitter.*
- *Unhappy.*
- *Anxious.*
- *Worried.*
- *Energetic.*
- *Miserable.*
- *Muddled.*
- *Nervous.*
- *Angry.*
- *Active.*
- *Tired.*

- *Bad tempered.*
- *Alert.*
- *Uncertain.*

End of Block: Profile of Mood States

End of Questionnaire

Appendix H: Screenshot of Qualtrics Online Questionnaire Platform



Appendix I: Semi-Structured Interview Guide (Chapter 6)

Semi-Structured Interview:

Running-Related Injury in Competitive Adolescent Distance Runners

Interviewer:

Date of interview: _____ / _____ / _____

Time of interview: ___________ am / pm

Location of interview: __________________________

Interviewee (code): ____________________________

Interviewee (pseudonym): ______________________

Safety Check Complete: Yes / No

Notes:
Total Duration of Interview: __________ min

At this point, turn on the dictaphone / audio recorder and test with interviewee.

Purpose:

The purpose of this interview is to discuss your experiences of running-related injury. The first part of the interview is based on your typical training practices, aims and ambitions, athletic identity, and what you most like/dislike about distance running. The second part of the interview is about your injury experiences and how you responded to these. The final element is based on what you believe are the common causes of RRI.

Key Terms:

1. *Athletic Identity:* The degree to which you identify with the athlete role.
2. *Injury Experiences:* How you respond to running-related injury, including details about time loss, pain, and how you cope with injury (i.e., support received).

General Information:

Make sure that the following points are explained to the interviewee, having explained purpose and key terms.

1. You have previously provided informed assent to be a participant in this project. Please could you confirm that you are willing to be involved with this project?
2. I am recording this interview, so that we can transcribe this into text at a later date. You will be allowed to review the interview transcription, once complete.
3. You do not have to answer any question which you do not feel comfortable with. Also, you can stop the interview at any time, without having to justify. Please feel free to ask for a break at any time.
4. Do you have any questions?

Semi-Structured Interview Guide

Please note that this guide only provides an overview of the main questions and probes. As each interview interaction was unique, question ordering and probes differed between interviews. In "section two," reference to a questionnaire is in relation to the retrospective questionnaire that was completed prior to interview.

Section One: Background Information

How is training going for you at the moment?

- Regularity of training at athletics club.
- Supplementary training: gym, other sports, etc.
- Enjoyment?

Describe a typical training week:

- Any changes to training since injury?
- Who sets this training?

Are you training for any specific events or competitions?

- Aims and ambitions for these events or competitions?

What other sports and hobbies do you take part in?

- Level of participation?
- How long have you participated in these other activities?

Would you say that distance running is your main sport/hobby?

- How much time commitment does this require?

When talking to other people, would you refer to yourself as a distance runner?

- Ask participant to provide examples.
- How would other people be able to identify you as a distance runner?

Completion of the athletic identity measurement scale (attached at end of interview guide):

- Discussion based around responses to questionnaire.

What is it that you most enjoy about distance running?

- Ask participant to list a minimum of three points.

What is it that you most dislike about distance running?

- Ask participant to list a minimum of three points.

Provide Summary of Section One

Section Two: Injury Experiences

Based on your questionnaire responses, please can you provide more details regarding the injuries that you have experienced as a result of distance running?

- Encourage participant to provide in-depth descriptions.

Have you experienced any more injuries since the completion of the questionnaire?

- Gather information about site and severity of injuries.
- What was the most recent injury?
- Were any of these reoccurring injuries?

Which of these injuries caused the most amount of time loss from the sport?

- Are any of these injuries still ongoing?

Focussing on the most severe injuries (>28 days of time loss):

- What was running like for you just before these injuries occurred?
- Did you experience any initial signs or symptoms of these injuries?
- How did you know that you were injured?
- How did you initially respond to these injuries?
- What were you thinking and/or feeling when these injuries happened?
- How did these injuries initially make you feel about yourself?
- How did these injuries influence your athletic identity?
- Did you receive any kind of support when injured?
- Did you receive any medical treatment for these injuries?
- When injured, what were your biggest concerns?
- How do you look back on these injury experiences now?
- What did you learn from these injuries?
- Did these injuries change your view of sports participation?
- Have your aims and ambitions related to distance running changed as a result of these injuries?
- Did these injuries cause you to miss out on other activities (i.e., school, other sports, etc.)?
- What do you think could have prevented these injuries?

In your opinion, what are the three most common factors that cause injury in distance running?

- Gather information about why they believe these factors cause injury.
- Try to get participation to list these causes in rank order.

Provide Summary of Section Two

End of Interview

Interview Notes:

Try to consider how the interview went. Include details about the interviewee's body language, how engaged they were, and whether they offered detailed responses to the questions — provide an honest commentary on how the interview went. What kind of relationship do I feel developed with the participant? How did I feel and respond to their experiences? How did they react to my questions? Did they appear nervous or open and at ease answering questions? What was the interview context like, and how did it influence the conversations?

Athletic Identity

Please complete the following section about your athletic identity, i.e., the level to which you identify with the role of being an athlete/distance runner. For each statement, please circle one number (from 1 to 7) that best represents your answer:

	Strongly Disagree						**Strongly Agree**
I consider myself an athlete.	1	2	3	4	5	6	7
I have many goals related to sport.	1	2	3	4	5	6	7
Most of my friends are athletes.	1	2	3	4	5	6	7
Sport is the most important part of my life.	1	2	3	4	5	6	7
I spend more time thinking about sport than anything else.	1	2	3	4	5	6	7
I need to participate in sport to feel good about myself.	1	2	3	4	5	6	7
Other people see me mainly as an athlete.	1	2	3	4	5	6	7
I feel bad about myself when I do poorly in my sport.	1	2	3	4	5	6	7
Sport it the only important thing in my life.	1	2	3	4	5	6	7
I would be very depressed if I were injured and could not compete in sport.	1	2	3	4	5	6	7

Appendix J: Finalised Themes and Codes, including Quotes (Chapter 6)

Theme #1: Performance Uncertainty

This theme represents the idea that while injured, adolescent distance runners believe that they are losing their ability to perform at their normal/expected competitive level. This results in anxiety, worry, and a sense of loss (grief) about their 'return-to-play' and 'return-to-competition', typically in a transient manner. This is heightened due to the ability to compare (tangible) their current and previous levels of performance, alongside how other athletes are performing relative to themselves (Po10). Injury also leads to altered training practices, seen as a subsidiary to performance, which subsequently shifts their attention and timeframes – causing uncertainty. These alterations are often perceived as both disruptive and non-preferable to the athlete, resulting in frustration and missed opportunity.

Representativeness: 15 out of 19 participants

Code	Supporting Quotations
Worry, anxiety, uncertainty, and loss n = 16	***Losing fitness. Because I know that. Um. Anaerobic fitness is the hardest to get. Once you've lost. It's the easiest to lose. […] So, that was my biggest concern. Because I knew that every day not running, I knew that it was, like, slowly ebbing away.*** **[AD05]**
	Probably just how long it would last for, because I didn't go to the doctors or physio for quite a long time. Until. And then, when I went, they said that I would be alright, as long as I make sure that it doesn't get so bad and you just rest it. [OL07]
	It made me feel worse as I couldn't do the one thing I loved and I knew I was losing fitness and everything, because a rule of thumb in athletics is however long you take off, it takes double to get back to where you were. **[LHS08]**
	Because of the injury being last winter, I've missed a cross-country season last year. So, I'm not too sure how my performances like cross-country wise and where I should be. [NB09]
	As soon as I've kind of done one [a race] that like sets my benchmark and I don't feel like I'm ready to get my own, kind of, to do one [a race] by myself yet because I don't feel fit enough and stuff like that. [NB09]
	I think that the fact that I have no idea how well I would do is what puts me off doing it [a race]. [NB09]
	And obviously with running, if I miss like a week of training, that's me. My fitness is gone. And it takes. I think I read in like a magazine, that it took six weeks to get back to fitness. [ES10]
	I don't know how long I'm going to be doing. Not running for. And I. Um. I feel like something has been taken away from you. And you feel

	like it's your fault, again. Yeah. And it's also. You can't just do the simple. You can't do. You can't run. It seems so simple to do, but you can't do it. [AR11]
	When will I get back? Um. When will it go away? Will it come back? Will it still be there? And, like, how long am I going to be running in pain for? Yeah. And how much of an impact will it have on my fitness? And, how long would it take to get back to where I was? **[AR11]**
	It probably is me exaggerating a bit, but it is still a concern. Or, not running to the same standard that I have before, that's a big worry for me. Yep. Because that is what I have dedicated my time to and I don't want to lose that. [JG13]
	I was worrying that I wasn't going to, like, make it into the Uni team. And that I wasn't going to make mates at the Uni athletics club because I couldn't turn up to the first, like, few weeks of training, where everyone was getting to know each other and things like that. I was thinking, like, what if this means I can't run from, like, now until forever. **[JG13]**
	So, I was worried about the track season and also just, like, not being able to get back to sport for a while, as well. And also missing out on, like, quite a big block of training so I would be a lot behind, like, other people. [NF14]
	Worried about when I'm able to get back. Whether it's going to affect my, like, running career and stuff like that. Because, obviously it's been a lot longer time and it's, kind of, becoming clear that it's not going to be a very quick fix at all. Um. So, I think that's probably what I'm most concerned about right now. **[MO15]**
	I was just worried about not being able to get back to where I was really. [LW18]
	I was quite worried, and I didn't know what was going to happen. Um. It [the injury] made me feel quite bad because I knew that if I couldn't run, I wouldn't have a lot else, because. Um. I've taken so much time to do running and just not having a chance to do it would really annoy me. [FB19]
	Not being able to perform at the same level I had previously. That was a big concern. Um. Not being able to. Um. Train. Um. Train at the same level as before and having, like, my form completely drops. [FB19]
Comparison n = 9	*At first, I was just, like. I was just happy to be back. I wasn't really expecting to be the best. But I was just, like, happy to be back. But*

	when it, like, got to racing. Yeah. I didn't. I think that I was just expecting to do better than I did. [OM03]
	I guess that there are quite a lot of comparison to. Especially when you are getting to the point when people are comparing how many miles they've done and at what speed. Um. You've got to try and cut away from that. [AD06]
	I know I shouldn't care about how people look at my, like, Power of 10, and stuff like that. But I feel like because I haven't done one [a race] in so long, if I now do one and it doesn't go well, it's more of. It looks like more of a reflection on, like, me as an athlete rather than, like, just currently what form I'm in, as I don't have a form from last year. **[NB09]**
	I feel slightly embarrassed that, like, I used to be ranked, like, second in the UK when I was like twelve. And now I'm more down towards the, like, thirty. And that. It just makes me feel like not talking about it so much. [NB09]
	I feel like I care too much about what other people think of me, but I can't help it. So, I just kind of I just don't talk about it [current performance level]. [NB09]
	It just puts you way behind everyone else, that you're thinking that you want to beat. Like, even within my running training group, even though we were all really close and we were all really good friends with each other. You still have people that you wanted to, like, beat in training. **[ES10]**
	Turning up to races and seeing people race and getting places that you think you should be able to get at that point in time, but you can't because you've been injured is definitely one of the worst things. [JG13]
	You can see, like, everyone else improving and getting better and you're, like, that could be me, but I can't get better. I can't improve because I am injured. And I'm not able to do it. Especially with social media because you have everyone putting up photos of them doing a race and you're looking at the photos of them doing races and doing really well, and thinking, wow, I could have been there. **[FB19]**
	You can see everyone that, like, you used to target yourself against and used to pace yourself when running, doing so well. And it is frustrating, but then you always have to think that you'll get there. You'll get back. [FB19]
Frustrated and annoyed	*I was upset when I couldn't compete, when I did have my injury. I did get really annoyed and it was frustrating because knowing that other*

n = 5	*people were running who I. It's going to sound really. But knowing who I could be beat in races, like, seeing them race. It was very upsetting.* [RN04]
	I just felt that I couldn't do anything. I just felt really bad because, obviously, knowing what I could do, what I am capable of doing, I just couldn't do. Like, you see people running around and you think I could do that, like running at races and just normal training, like. You think that you can do it. But obviously, you can't. It was very. It did make me feel like, feel a bit, it did put me back. **[RN04]**
	I felt annoyed because I just wanted to carry on with my sport, but I stopped because I knew that it would be a lot better. It would get a lot better, and I wouldn't have to run, like, with the pain. Eventually. [OL07]
	One of the things that we always do in our training group is if you're injured you turn up and you cycle next to the group. You help out. You help with the training and things like that. And me doing that is so painful, like, having to turn up and watch everyone else doing what you want to be doing and just like. You're there but you're not really doing it. That is one of the worst things because you know that it's so close, so yet far. **[JG13]**
	Well, I guess, when I was injured, like, last year, that was for quite a while. I got quite frustrated after a while that I couldn't really do anything because I'd so much, like, more time. I just didn't know what to do really. [NF14]
Missed opportunity and disappointment n = 4	***I was really disappointed and down for, like, probably a day or two afterwards. I was really pissed off because it was national indoors at the weekend. The weekend coming. And I knew that all I had to do was stay fit for that week. And then the, like, the dying moment. Just coming. Just tapering up into it, I'd managed to injure myself at the worst possible time, like. So, I was quite annoyed and down about it.*** **[AD05]**
	Quite disappointed because I had National race coming up. And that I had to miss out of. So, I didn't start. And yeah. That was quite annoying because I reckon, I could have got second or third in that race. Looking at how, like, other people did who I had been racing against that season. Yeah. I reckon I would have meddled. So, that was quite annoying. Frustrating. [AW12]
	With all the goals I had set before. I slightly lowered them and realised that I probably wouldn't be able to do as well as I wanted to. And I didn't want to get disappointed about not being able to as well. So, I kind of like lowered the goals. [AW12]

I felt like I was letting the club down a bit. Because, like, obviously, during the track season we've got, like, this massive thing about everyone taking part and doing as much as they can and, obviously, I was having to do less. So, I didn't. Like, every time, like, the manager would be like, can you do an eight-hundred, I would have to turn them down. Just, obviously, that doesn't feel great because I don't want to let the club down. But, yeah. It wasn't great. **[LW18]**

Theme #2: Injury (Mis)Management

This theme represents the idea that while injured, adolescent distance runners often have to navigate the recovery process with limited knowledge, resources, and medical support. Therefore, the management of the injury is not often optimal, with the adoption of a trial and error approach that perpetuates their 'loss of control.' This theme is also linked to the notion that identifying the cause/diagnosis of an injury is often delayed in adolescent distance runners, without the adopting of preventative interventions, i.e., dependence on a reactionary intervention (post-injury), instead of using a proactive approach (injury prevention). The delay in determining a cause/diagnosis stems from adolescent distance runners perception of pain, whereby differentiating between initial pain/niggles and 'more severe' injuries becomes a problem. This is perpetuated by an over-reliance on self-diagnosis and wanting themselves to return to running too soon after injury.

Representativeness: 16 out of 19 participants

Code	**Supporting Quotations**
Pushing through the pain n = 10	*And, with running. Sort of. You get sore and you get niggles all the time. Sort of. And you just put your trainers on and run through it.* [AD05]
	As soon as it started hurting a little bit, I kind of, like, carried on. So, maybe if I'd, like, stopped as soon as it started hurting up a little bit. [AH06]
	It was not too bad to run on, but it was. I had slight pains in my knee, but I just thought that it would be nothing and that it would be alright. And you can get through it. But it would keep. It kept on building, and building, until the point when I just couldn't run on it. Um. Because it was just so painful. **[OL07]**
	And you just think to yourself, is this just a niggle? Like, is it just something bad that I'm just going to have to sort out tonight, or is this actually something that's going to take out a lot of my time? [ES10]
	I started to get, like, pain in my left leg. Um. I didn't think much about it and kind of kept running through it. It kind of kept easy off, getting worse. And then, I raced. I carried on racing. And then in December, it really flared up. Like, I remember trying to run and it was like, agony. Like, I couldn't run. **[AR11]**
	I kept running through it for so long. So now, I know as soon as I get a niggle, I'll back off for a week and then for a few days, and hopefully we'll go. Whereas before I would just keep running through it, keep going through it. But now I know how to back off. [AR11]
	It was like a build-up of pains that had started off really mild and I just carried on training through it because I didn't really realise it was there, because it was so small. And I thought was like tiny thing and it'll go away. […] But then those few sessions would have made the pain a lot

	worse. So, had I stopped as soon as I felt with the tiniest thing, then I would have been a lot better off. [AW12]
	I had a bit of an ache for a week or two, but I could still run on it and it wasn't bad, it wasn't preventing me from anything. But then, within two weeks of that first ache, I was finding it hard to walk. [JG13]
	And, so I had, like, consistent pain on the side of my foot. Um. Which I didn't really think about, because I don't like the idea of not training. [AP16]
	I can feel my injuries coming and I just ignore them and I'm like, they'll just sort themselves out, but I need to stick to my training plans and what I need to do. And I think that that just makes it worse. It's not going to make it any better. **[AS17]**
Return to running n = 7	*I still ran, but every time I ran, it would be painful afterwards. So, I went back to have more physio, for that. And then, eventually I got rid of that with exercises and rest.* [MW01]
	I was just in a lot of pain all of the time. Um. And then, obviously, getting better, a bit. Err. It was. You know. I did just want to start running again, after a while. Because. You know. Once you have got on top of the pain, a bit. And, I was getting better. I just, kind of, did want to go back to running. But, you just can't. **[OM03]**
	I would try to increase it. And I could adjust, and I felt it again. So, I went back down to just basic. And the, obviously, I did get better. [RN04]
	When I was injured, the first thing I was. Like. How am I going to get back? How am I going to get back fit? […] And made sure all the physio and all the little strength and rehab stuff that I had to do; I did. And did it to the best of my ability all the time. And made sure that I was really disciplined with. Yeah. I was just quite positive. Like. If something goes wrong, I am always looking. Like. Glass half full. **[AD05]**
	I think that I have been a lot more sensible. That is the main thing, I think. I listen to my body a little bit more. And, sometimes you do need to cut off the pace a little bit. [AD05]
	I kept trying, which I think was partly the problem, but I kept basically going out, psyching myself up to do it, putting my trainers on, starting. Running for like ten seconds, having to stop and then I walked for a bit and I try and stretch, and I kept thinking to myself, I can make it better. [NB09]
	Whenever I'd see my coach and they'd be like, oh, the best thing to do is rest it and be like, no it's not. I can rest it my whole life and I'll still go back to running and it will still be there. [ES10]

Self-diagnosis and treatment n = 4	***I was YouTubing how to tape. I was Googling stretches and trying to Google where the pain was and what was. Kind of trying to diagnose it, really, because I didn't know what I had. I feel like once you've got something you can Google how to treat it and you can find a lot of stuff on it.* [NB09]**
	***It was all too like generic and it was like a bull in a china shop. Whereas, I went to physio and we kind of isolated stuff and worked out exactly where my weaknesses were and it was more like precise and also like controlled.* [NB09]**
	When it was really bad, before I saw the Physio, I was really upset because I thought I'd. I thought I was having a stress fracture. Um. And then when I saw the physio, I was kind of a bit relieved, because I was like, oh, I'm glad it wasn't a stress fracture. [AR11]
	I've got. I know I've got some friends, now, who've got injuries. And they've had, like, special, like, specialised programmes for them. I didn't have any of that. I just remember using internet a lot. [AP16]
Access to medical support	*No. Not as soon. Err. So, probably a month into it, I went to see a physio. Um. Err. They gave me some exercises. And, like, foam rolling. I got a sports massage as well.* [NB02]
n = 4	*I used a resistance band as well. That was one of my exercises that I did every day. It was tough. It was painful almost a bit, but it did help. It did feel as if I was getting stronger. The physio did say it was getting stronger. So, it was doing something good anyway.* [RN04]
	My physio and coach were quite supportive. Because they both know each other. So, I was getting physio a couple of times a week. Um. My coach was looking out for me. [AD05]
	I went to the doctors and had some physio done on it. Okay. But I mainly got told to rest, which is the main thing that helped. [OL07]
	Well with the physio I had to have quite a lot of time at school because my mum had to pick me up and we had to go to Physio, like because sometimes the only time that they had free was like in middle of the day, so I'd have to miss quite a lot school. [ES10]
	***I just wish as soon as I felt the tiny pain. I wish I'd just stopped and gone to see the Physio as soon as I did. And he could have said. Um. Tell me what to do then and I reckon, had I done that, I wouldn't have been out for as long and would have been fine for fine to like to keep going after maybe a week, instead of four or five weeks.* [AW12]**
	Get an appointment with the GP and then get the GP to refer me to the specialist. Which took a long time. I had to put it all on the NHS. Um.

	Which was quite annoying because it is something that should have taken two weeks, but it took a couple of months. [JG13]
	Sometimes at the Physios, it's been kind of confusing, because they've, kind of, contradicted each other, or said things and it's not really done anything and it feels, kind of, frustrating, but. Um. I would say that my main, like, support network has been, kind of, coaches and family. **[MO15]**
Injury prevention n = 4	*Because I got physio on it, I still have got a load of exercises to do. And, I mean, I still do them. So, I know. I mean, I know what it would feel like, as well. Because that was my first, like, real injury. I guess. So, I think that I would know what to expect.* [MW01]
	Like, now I do it every day. Even if I don't train I do it. It's something I didn't do before that I just think everyone should be doing but they won't until they get injured. **[NB09]**
	And it's quite a depressing thought when you go to the physio and they give you a pile of exercises that you need to do every day for the rest of your life. And it just gets bigger and bigger and bigger. [ES10]
	Well, I do my physio exercises every day now just to make sure, like, it doesn't happen again, and I'll always be careful type warm-up and stuff, and. If something feels sore, I stop. **[NF14]**

Theme #3: Contested Identity

This theme represents the idea that while injured, the athletic identity of an adolescent distance runner is contested – directly challenged. This is represented by athletes questioning of their own commitment to distance running, which results in recognition that they will return as a 'better' athlete (confirmatory) or casts further doubt over their suitability to the sport of distance running (questioning). As part of this theme, an athlete's ability to cope with injury is associated with access to different forms of support – physical, emotional, and social – from coaches, parents, and medical practitioners, etc.

Representativeness: 16 out of 19 participants (84%)

Code	**Supporting Quotations**
Confirming identity n = 8	***It made me realise, like, how much I love running, and how much I missed it, when I couldn't do it. I guess. It's like, if I couldn't do it. Because I put so much time into it, it just wouldn't feel normal.*** **[MW01]**
	I didn't really think that it changed much of what I thought. Because I never thought that I was going to change from running. I was always sticking to it. [MW01]
	It's happened before and I have come back. So, like, I knew I would come back again. So, I never questioned it, basically. [NB02]
	Hopefully, I'll never get it again because it was, obviously, it was very. It was a horrible place to be at, but I just view it as something that made me stronger, like obviously, if I didn't have I wouldn't have realised that I can be stronger, and to improve and to do well and to prevent getting injured again. **[RN04]**
	I knew that I was going to get back to it. I knew. Like. People get injured. People get injured all the time. I knew I would come back to it. [AD05]
	It probably made me more determined. Um. It probably just made me more determined to be back stronger. Knowing what I want to do, maybe more. That that's what I want to do. Because when I couldn't run it made me realise that that's what I wanted to do. **[AR11]**
	I don't really think so. No. I think I'd, like, still view myself as an athlete and it's not. It's not like I ever thought of, like, stopping. I just thought, like, when this ends, I just want to get back to what I was doing. [AW12]
	Didn't demotivate me. Um. Maybe when I came back, I was like more motivated because I was like, right. Okay. I really need to catch up the time I've lost. But, like, I wouldn't say it changed my aims or anything. [AS17]

Questioning identity n = 7	*I've not been doing too well in, like, my races and things, for quite a long time. So, I am taking a bit of a break from running, for a bit. And looking into doing something else.* [OM03]
	I care about it a lot more now and I spend a lot more time doing it now, but because I don't perform as well. I don't. [pause] I wouldn't call myself. Err. Like, an athlete or maybe runner I would say. [NB09]
	I have almost stopped running completely because I got so badly injured. Just constant injury, all the time. I was just thinking, like, I'm not getting anywhere. I need to, like, go back and, like, restart almost. Like, fix everything and then go forward. [ES10]
	You don't talk about it because it's like how can you enjoy not doing sport? But, like, when it's getting really stressful and then you get injured sometimes it's like, oh, great. I can just lie on the sofa a bit. [ES10]
	I can't rely on sport to be the centre of my life, because otherwise I will just lose out on different part of my social life and I will just become too focused. And when things do go wrong, I will just spiral down and get depressed or something. And that just won't be good for me. So, I have to make sport important in my life, but I also have to prioritise other things around it to keep my life balanced, so I know that I am okay, and I do have, like, different options in the future. **[JG13]**
	I think that sport does make you feel good about myself and it does me feel better. But I don't need it. I think that being injured recently has given me that, like, outlook. Before I would have said, 'oh, I do need sport to feel good', but then. Um. Now. Just, I've found more other things that also make things. Um. Seeing other things is more important. Well, not more important, but equally important, as my sport. **[JG13]**
	It made you, me, think, 'is running the right thing for me?'. Um. 'Is this what I want to spend my time on?', and things like that. Um. Yeah. It made me worry a lot about it. [JG13]
Self-presentation n = 4	*I guess that the image of it is quite. Um. It is quite a good thing to be. Like. Able to say. Like. Most people can't do it and can't sustain it, really. And then to be able to. [MW01]*
	I suppose if someone asks what you do. I suppose. Like. My first thing is. Like. I run. Like. At a national level. And just, that's my thing, I suppose. Yeah. If people ask, that's what. That's like the main thing I do. Yeah. [AD05]
	I feel like the running set me apart from everyone else because I. I've never. Um. Until like really recently, I've never thought of myself as

	being massively academic. Um. That's kind of only become like apparent after GCSE results and stuff. Before that, I was never. I didn't feel like I was like I was the smartest or like the most outgoing person. So, the running has always been like something extra I've had. Which I guess other people haven't. [NB09]
	It's nice to have something, like, specific to me. Rather than just being, like, the same as everyone else. [LW18]
Injury as an excuse n = 3	***I think it's lasted so long, I kind of get a bit sick and tired of saying oh, but I've been injured. And I feel like it sounds so like oh, yeah, of course she's been injured. I don't feel like. Um. I didn't want to seem like I'm using the whole, like, knee thing or like just before with my knee thing I was like anaemic. And I don't want to seem like I'm using, like, excuses.*** **[NB09]**
	I think at that point, I felt a lot better about my, like, athlete identity than I do now because I could say pretty, like, black and white I'm injured. Yeah. So, like, I can say like I've done this in the past. I've been at a decent level in the past, but at the moment I am injured, so I am not running, I'm not training or competing. Um. So, I feel as if I had more of an identity then than I do now just because. Um. I guess when you're seeing a physio and stuff like that. Now I'm not seeing a physio. It's kind of like, no physio, not injured. [NB09]
	Sometimes it's normally just a confidence thing. Like, I've got some tape on, so it won't hurt but sometimes it's like I'm injured it's just showing, like, maybe if you. If you don't do very well, it's, like, okay, I've got tape on. **[ES10]**
Unidimensional identity n = 7	***Not really. Um. I don't really do too much outside of running. It, sort of, takes up. I fully committed to that a couple of years ago. And, it pretty much takes up all my time. That. Um. I don't really do a lot other than run and recover, really.*** **[AD05]**
	Yeah, it is the only thing I do really. I much prefer that, to doing other stuff. [OL07]
	Like, people see, like, the sport and not the person. So, if someone that I don't know just kind of comes out to me and be like, oh, are you going to the Olympics? Like, yeah. If you go to Nationals, and they're like, did you win? It's like, no, of course I didn't win. It was Nationals. I came like a hundredth and I'm pleased with that, but it's so annoying when people just like. They don't, like, look any further than your sport and they just think, like. Oh. And if they say what do you do on weekends? I was, like, oh, I was just training. They are just like, oh, that's the only thing you do isn't it? It's like, no. I do other stuff. [ES10]

	***I dedicate a lot of my time to. Um. Being an athlete and I think about it a lot. Um. I'm always trying to think of ways of what I could do better. What isn't going well, or, like, I keep a training journal. So, half the time I am writing stuff down in there. If I'm not doing schoolwork, I'll probably be thinking about what I can do to do better.* [AR11]**
	Well, I've put quite a lot of time into my training and my racing and that commitment towards the sport. And yeah. I yeah. So, I'd say like through commitment, I consider myself an athlete. [AW12]
	There's not a lot to be honest. Um. I mean, like, I try and do some of this summer sports at school. Such as? Rounders. Yeah. Um. But that's really it. Like, on top of homework, there's not really a lot of time. [FB19]
	***I base everything around running. So, not being able to do it would leave a lot of gaps and I wouldn't be able to look forward to doing a race or being able to have big aims.* [FB19]**
Forms and types of support	*I think the main support was from my coaches. Like, they kept an eye on me quite closely to see that I was actually doing it [rehabilitation exercises] properly.* [LHS08]
n = 7	*I think it would make me worse, so it is better for me to just stay away and like think of the long-term, instead of, like, constantly being, like, looking behind to see what everyone else is doing. Because, I think I'm better at just like doing my own thing and then doing other stuff.* [ES10]
	***When it was quite bad at the start, my Mum was quite kind. You know, she was there. Um. Because I get quite upset when I'm injured. I'm not the best person to be around. And when I couldn't run, she was quite. She was there to talk to. But I didn't. I kind of keep myself to myself when I'm injured. I don't really talk to other people.* [AR11]**
	***My coach at home, she kept on checking up on me. Texting me at least a couple of times a week, just to see how I was doing. She was really good like that. Also, the University coach, he kept on checking up on me, even though I wasn't turning up to anything. It's like, 'are you okay?', 'when am I going to see you next?', like, 'can you volunteer at this fun run?', and things like that. Still getting me involved when he could. And the University Cross Captain, was. He kept on, like, trying to get me involved and things. And getting me out on socials, and things like that. Just to get me into everything, which was good. So that helped me a lot.* [JG13]**

I've just started at [University] and the running there is, like, a big thing and I'm kind of missing out on meeting people and doing all the social side, because obviously I can't really train with people, because it's kind of mainly gym based on my own. Um. But it's fine. At least I can do a bit of running. Because if I can do anything, I'd be pretty annoyed, but it's obviously quite frustrating. [MO15]

My coach was, like, good at just, kind of, constantly, like, texting me to check that I was okay. And, like, kind of, trying to get updates and stuff. Which I think helped because it, kind of, made me know that she was there, in a way, that she was not just going to forget about me. [MO15]

They were a big support because. Um. My family definitely, because they would often. Um. They'd like help buy tape for my knee and they'd. Um. They'd, like, support me when it was really bad, and they tried to take my mind off it. [FB19]

Appendix K: Supplementary Data for Figure 7.2 (Chapter 7)

Original data used to create risk matrix for male athletes, excluding means and 95% confidence intervals for health problems with less than three cases.

Outcome	Cases (n)	Incidence	95% CI (-)	95% CI (+)	TL	TL mean	95% CI (-)	95% CI (+)	CSS	CSS mean	95% CI (-)	95% CI (+)
Injury: Lower leg	29	1.2168	0.832	1.7212	170	5.86	2.17	11.1	2982	103.0	53.1	174.0
Injury: Knee	14	0.5876	0.338	0.962	116	8.29	1.29	17.7	2569	184.0	42.2	405.0
Illness: Upper respiratory	31	1.3	0.8996	1.82	80	2.58	1.52	3.81	1824	58.8	45.2	73.8
Injury: Ankle	12	0.5044	0.2756	0.8528	76	6.33	1.5	13.5	1323	110	42.3	216.0
Injury: Foot/toes	13	0.546	0.3068	0.9048	84	6.46	2.08	12.2	1224	94.2	39.5	173.0
Injury: Shoulder (including Clavicle)	2	0.0832	0.0156	0.2704	17				521			
Injury: Thigh	9	0.3796	0.1872	0.6916	27	3.0	1.0	5.67	520	57.8	32.9	87.4
Injury: Lumbar spine	6	0.2496	0.104	0.52	12	2.0	0.833	3.17	406	67.7	40.2	98.3
Injury: Hip and groin	5	0.208	0.078	0.4576	13	2.6	0.4	5.8	347	69.4	40.6	100.0
Injury: Pelvis/buttock	2	0.0832	0.0156	0.2704	6				205			
Injury: Wrist	1	0.0416	0.0052	0.1976	4				160			
Illness: Dermatological	1	0.0416	0.0052	0.1976	7				100			
Illness: Lower respiratory	3	0.1248	0.0364	0.338	2	0.667	0.0	2.0	92	30.7	16.0	60.0
Illness: Energy, load management, and nutrition	3	0.1248	0.0364	0.338	3	1.0	0.0	3.0	91	30.3	16.0	59.0
Illness: Non-specific illness	1	0.0416	0.0052	0.1976	1				86			
Injury: Chest/ribs	2	0.0832	0.0156	0.2704	0				79			
Illness: Gastrointestinal	1	0.0416	0.0052	0.1976	2				44			
Illness: Psychological	1	0.0416	0.0052	0.1976	0				22			

Abbreviations: n, number; %, percentage; CI, confidence interval; -, lower; +, upper; TL, time loss; CSS, cumulative severity score.

Original data used to create risk matrix for female athletes, excluding means and 95% confidence intervals for health problems with less than three cases.

Outcome	Cases (n)	Incidence	95% CI (-)	95% CI (+)	TL	TL mean	95% CI (-)	95% CI (+)	CSS	CSS mean	95% CI (-)	95% CI (+)
Injury: Lower leg	29	0.9828	0.6708	1.3884	226	7.79	1.48	17.8	3997	138.0	50.6	268.0
Illness: Upper respiratory	67	2.2672	1.7732	2.8652	142	2.12	1.33	3.04	3755	56.0	45.1	69.5
Injury: Foot/toes	14	0.4732	0.2704	0.7748	132	9.43	2.71	19.7	2163	154.0	60.0	300.0
Injury: Knee	26	0.8788	0.5876	1.2688	92	3.54	0.923	7.23	1850	71.2	36.7	118.0
Illness: Non-specific illness	14	0.4732	0.2704	0.7748	101	7.21	1.21	18.1	1372	98.0	37.9	208.0
Injury: Thigh	15	0.5096	0.2964	0.8164	20	1.33	0.467	2.47	738	49.2	33.5	69.1
Injury: Lumbar spine	6	0.2028	0.0832	0.4212	34	5.67	0.167	16.3	703	117.0	21.8	300.0
Illness: Energy, load management, and nutrition	5	0.1716	0.0624	0.3692	11	2.2	1.0	3.2	648	130.0	33.8	292.0
Injury: Hip and groin	9	0.3068	0.1508	0.5564	16	1.78	0.222	4.0	593	65.9	24.0	123.0
Illness: Lower respiratory	13	0.442	0.2444	0.7332	9	0.692	0.231	1.23	583	44.8	27.6	70.2
Injury: Ankle	8	0.2704	0.13	0.5096	6	0.75	0.125	1.75	406	50.8	28.4	87.2
Illness: Gastrointestinal	6	0.2028	0.0832	0.4212	7	1.17	0.5	1.83	251	41.8	32.7	51.7
Illness: Psychological	2	0.0676	0.0156	0.2184	9				169			
Injury: Pelvis/buttock	3	0.104	0.026	0.2704	2	0.667	0.0	1.0	120	40.0	28.0	47.0
Injury: Chest/ribs	2	0.0676	0.0156	0.2184	2				74			
Illness: Neurological	2	0.0676	0.0156	0.2184	1				60			
Injury: Shoulder (including Clavicle)	2	0.0676	0.0156	0.2184	1				50			
Injury: Thoracic spine	2	0.0676	0.0156	0.2184	0				44			
Injury: Abdomen	1	0.0364	0.0052	0.156	2				25			
Injury: Elbow	1	0.0364	0.0052	0.156	0				22			

Abbreviations: n, number; %, percentage; CI, confidence interval; -, lower; +, upper; TL, time loss; CSS, cumulative severity score.