Training Volume, Heart Rate Variability, and Injury Risk in CrossFit Athletes: Identifying Risk Factors and Intervention Strategies

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A dissertation submitted to the Department of Human Kinetics and Ergonomics, Rhodes University, Makhanda, in fulfilment of the requirements for the degree of Master of Science

Makhanda, 2025

DECLARATION

I, Kieran Skae, declare that this dissertation is my own work.
It is being submitted for the degree of Master of Science in the Department of Human Kinetics and Ergonomics at Rhodes University, Makhanda.

It has not been submitted before for any degree or examination at this or any other university.

Signature

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Kieran Skae

29 April 2025

DEDICATION

To my family. Owen, Vera, and Shannon.

For your continuous support, encouragement and belief in me throughout this journey.

ABSTRACT

CrossFit, a high-intensity functional fitness program, has increased in popularity worldwide. Yet, systematic research into injury risk among non-elite participants and studies on interventions to reduce injury rates and mitigate risk factors remain limited. Reported injury rates and preventative strategies vary widely, leaving a critical evidence gap, particularly in under-studied regions such as South Africa. This dissertation addresses this gap through two complementary phases guided by the Translating Research into Injury Prevention Practice (TRIPP) framework.

Study one, a sixteen-week, observational study, included 33 non-elite CrossFit athletes who completed weekly online injury surveys using the adapted Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire. Participants' training volume (TV) was monitored using acute to chronic training volume ratios (A:C ratios), where acute training volume was the sum of session rating of perceived exertion (sRPE) and session duration over the most recent week, and chronic training volume was the three-week rolling average. Heart rate variability (HRV) was assessed daily via the HRV4Training application. Although no statistically significant findings were identified between TV, HRV, and injury risk, the relatively small sample size and exploratory nature of the study warrant cautious interpretation of these findings. Injury was, however, significantly associated with demographic and behavioural factors (age, male sex, training frequency, and commitment), and injury likelihood progressively increased over the study period.

Study two (scoping review) was conducted according to the PRISMA Extension for Scoping Reviews (PRISMA-ScR) and Joanna Briggs Institute guidelines. The literature search was performed across seven databases: MEDLINE, Academic Search Complete, and Health Source – Consumer Edition (via EBSCO), PubMed, SCOPUS, Science Direct, and Web of Science. Findings revealed limited structured interventions, predominantly focusing on warm-up and cool-down protocols, nutritional supplementation, protective exercise gear, mobility programmes, HRV monitoring, and education approaches. The findings also highlighted inconsistent injury definitions, high methodological variability, and underrepresentation of specific athlete populations.

Collectively, these findings emphasise the need for advanced CrossFit injury research beyond risk identification (TRIPP stages one and two), shifting towards structured and inclusive investigations of preventative strategies (stages three to six). Future research should prioritise methodologically robust studies, standardise data collection methods, and evaluate multifactorial injury prevention strategies to enhance the safety and sustainability of CrossFit participation.

SUMMARY OF RESEARCH CONTEXT AND KEY FINDINGS

CrossFit's increasing growth has outpaced our understanding of how best to keep non-elite participants safe, especially in under-studied regions like South Africa. Therefore, this dissertation combined an observational cohort (Study one) with a scoping review (Study two) to establish progression beyond merely cataloguing injury research and moving on to actively developing, implementing, and assessing structured, evidence-informed intervention strategies.

Study one (Chapter Three) found that, in a univariate analysis, neither TV nor HRV were significantly associated with injury risk. Instead, other factors such as demographic and behavioural factors, including participants over the age of 51 years, male sex, training frequency (2-3 sessions per week), and a moderate commitment level, were more closely aligned to injury risk. Furthermore, injury risk progressively increased over the study duration, suggesting cumulative effects related to ongoing participation.

Study two (Chapter Four) revealed limited literature on CrossFit injury prevention interventions, predominantly focused on warm-up and cool-down protocols, protection exercise gear, nutritional supplementation, mobility programme, HRV monitoring, and educational factors. The review highlighted significant gaps, such as methodological inconsistencies, a lack of structured intervention-based studies, inconsistent injury definitions, and underrepresentation of specific populations, including females, youth, advanced-level athletes, and athletes from African and Asian contexts.

Collectively, identifying risk factors is only the first step. To truly advance CrossFit safety, research must now design, implement, and rigorously evaluate context-specific interventions, moving into stages four to six of the TRIPP framework (intervention effectiveness, implementation, and real-world evaluation). This progression is necessary to inform the development of an evidence-informed protocol. Thus, such efforts will contribute significantly to creating safer, more effective, and sustainable CrossFit training environments.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisors, Candice Christie and Candice MacMillan, for their unmatched guidance, support, and encouragement throughout the course of this research. Their insight, patience, and thoughtful feedback were instrumental in shaping this dissertation's direction and overall quality.

I am also grateful to the Department of Human Kinetics and Ergonomics at Rhodes University for providing the academic foundation and resources that made this work possible.

A special thank you to the CrossFit gym owners in Makhanda and the CrossFit athletes who participated in the study. Your time, trust, and commitment were essential to making this research a reality.

Thank you to the statisticians who assisted during the analysis process. Your input helped bring clarity to the data.

Finally, to my family and close friends. Thank you for your love, patience, and endless encouragement through every high and low. Your support gave me endless strength every step of the way, and I could not have done this without you.

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LIST OF ABBREVIATIONS

A:C ratios – acute:chronic ratios

ACWR – acute:chronic workload ratio

ACL – anterior cruciate ligament

ARSS – Acute Recovery and Stress Scale

EWMA – exponentially weighted moving average

GPS – Global Positioning System

HR – heart rate

HRV – heart rate variability

HIFT – high-intensity functional training

Ln – logarithmically transformed

$Ln(RMSSD_{week})$ – seven-day rolling average of the root mean square of successive differences between normal heartbeats, which has been logarithmically transformed

PEP programme – Prevent Injury and Enhance Performance programme

RPE – rating of perceived exertion

RMSSD – root mean square of successive differences between normal heartbeats

sRPE – session rating of perceived exertion

TRIPP – translating research into injury prevention practice

TV – training volume

$\dot{V}O_2$ max – maximum rate of oxygen consumption

WOD – workout of the day

OPERATIONAL DEFINITIONS

Athlete:

1. Someone who engages vigorously in sports training to enhance sport-specific skills, performance, or results, whether technical, physical, or tactical, in preparation for competition.[1]
2. Someone who engages actively in sports competitions unless injured or during a competition break.[1]
3. Someone who is formally registered with a local, regional, or national sports federation.[1]
4. Someone who prioritises sports training and competition as their primary physical activity, dedicating several hours per week or more depending on the phase of the season or competition, in accordance with their interests.[1]

JOURNAL SUBMISSIONS AND CONFERENCE PRESENTATIONS EMANATING FROM THIS DISSERTATION

Kieran SKAE, Nicola SEWRY, Candice CHRISTIE, Licinda PIENAAR, Candice MACMILLAN (2025). Intervention strategies to reduce and mitigate injury risk factors among CrossFit athletes: A scoping review *(German Journal of Exercise and Sport Research) (Submitted)*

Kieran SKAE, Candice CHRISTIE, Licinda PIENAAR, Candice MACMILLAN (2024). Are training volume and heart rate variability injury risk factors among CrossFit Athletes in South Africa? (*Accepted for presentation at the ECSS Rimini 2025 conference).*

CONTRIBUTIONS OF AUTHORS TO THIS PROJECT

As part of the declaration of this dissertation, I acknowledge contributions by various individuals to this work, as detailed below:

The conceptual design, methodology development, and data collection for both studies were carried out by myself in collaboration with my supervisors, Prof Candice Christie and Dr Candice MacMillan.

Drafting of all the written work, including the literature review, observational study, scoping review, and integration of findings, was completed by myself. Both supervisors provided critical feedback and revision support on all the draft chapters and final submissions.

Statistical guidance and support were provided by independent statisticians, who assisted with the interpretation and presentation of the quantitative data from the observational study.

All contributors have reviewed the relevant sections of the dissertation and approved the final subscript.

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CONFLICT OF INTEREST

The author was employed as a coach at the CrossFit gym where the data collection phase was conducted. All aspects of the study were independently designed, analysed, and reported. Also, manuscripts and data were reviewed by academic supervisors and peer reviewers with no affiliation to the athlete populations or training environments involved. Nonetheless, the dual role presents an inherent risk of social desirability bias. Participants may have under-reported injuries or over-reported training adherence to align with perceived expectations of the coach (author). Although the adapted OSTRC questionnaire and weekly online reporting format were intended to minimise interviewer influence, future studies should consider fully anonymised reporting and/or independent data collectors to mitigate this potential bias.

CHAPTER ONE: BACKGROUND

1.1. Introduction

CrossFit is a sport and training methodology combining high-intensity exercise with functional movements,[2] primarily including resistance training paired with short-duration cardiovascular workouts.[3,4] Since its inception in the early 2000s, CrossFit has rapidly become one of the world's fastest-growing fitness trends, attracting participants globally,[5,6] and offering numerous benefits, including psychological enhancements (e.g., increased motivation),[7,8] physiological adaptations (e.g., improved cardiovascular fitness),[9–11] biomechanical improvements,[3] and a range of physical performance gains (e.g., strength, flexibility and endurance).[3] This growth has extended to South Africa, although research exploring its effectiveness and impact within this region remains limited.[6,14]

Despite these clear benefits, CrossFit is associated with disproportionately high injury rates.[2,4–6,12–16] While injuries are common in any sport, CrossFit's combination of complex movements, constantly varied durations, high-intensity, and minimal rest periods may increase the risk, particularly among non-elite athletes. Additionally, current research on injury prevention in CrossFit remains limited, with existing literature primarily focused on identifying injury risk factors rather than developing structured prevention strategies.[12,15] Consequently, a critical gap remains regarding structured, evidence-based intervention strategies designed to reduce the likelihood of injury.

To address these gaps, this dissertation adopted a two-part methodological approach, incorporating, an observational, longitudinal study to investigate injury risk factors among non-elite CrossFit athletes, and a structured scoping review of existing injury prevention strategies. This integrated approach aims to bridge the gap between risk identification and intervention development, setting the stage for practical and evidence-based advancements in CrossFit injury prevention. The following sections elaborate on the problem statement, research questions, aims and objectives, and the significance of the study.

1.2. Problem Statement

Injury rates among CrossFit athletes are high. Identifying injury risk factors and intervention strategies to minimise these factors are necessary to ensure the general well-being and longevity of CrossFit athletes. Training volume and HRV have been identified as potential risk factors for injury among elite and competitive CrossFit athletes. However, limited literature with respect to the non-elite status of CrossFit athletes in South Africa, specifically in the Eastern Cape, has been analysed. Literature on non-elite athletes' TV, particularly regarding sRPE, duration, and frequency to calculate the acute to chronic training volume ratios (A:C ratios), has yet to be fully explored among individuals living in South Africa. Similarly, research on daily HRV monitoring using the HRV4Training application has not yet been analysed among this population. Furthermore, the incidence of both acute and overuse injuries within the framework of an observational, longitudinal cohort study has not been investigated, leaving a gap in understanding these critical factors among non-elite athletes in South Africa. It is crucial to recognise the variability in CrossFit culture across different countries. While the core principles of the sport may be the same globally, how non-elite athletes structure their day-to-day training routine in South Africa could differ significantly from how their counterparts in other regions structure their routines.

Although injury rates among CrossFit athletes are notably high, and while several risk factors for injury have been identified, intervention strategies specifically designed to reduce these rates and minimise injury risk factors remain limited. Additionally, there is a need to address existing evidence gaps concerning the effectiveness and limitations of the available interventions. Therefore, a thorough review is essential to assess the extent, range, and nature of research on intervention strategies to minimise injury risk factors among CrossFit athletes. Hence, a scoping review is particularly suitable for providing a comprehensive overview of existing intervention studies, mapping key knowledge domains, and identifying gaps in the current literature.

1.3. Research questions, aims, and objectives of the study

Based on the problem statement formulated in the preceding section, this research endeavours to address the following questions:

Research Question 1 (Study 1):

Are TV and HRV associated with injury risk among non-elite CrossFit athletes in the Eastern Cape, South Africa?

Aim 1 (Study 1):

To determine if TV and HRV are associated with injury risk among non-elite CrossFit athletes in the Eastern Cape, South Africa.

Objectives related to Aim 1 (Study 1):

1. To determine individual athletes' TV, encompassing sRPE, duration, and frequency to analyse the A:C ratios;
2. To determine individuals' daily HRV utilising the HRV4Training application; and
3. To determine the incidence of injuries over 16 weeks.

Research Question 1 (Study 2):

Which intervention strategies aimed to reduce injury rates and/or minimise musculoskeletal injury risk factors in CrossFit athletes have been explored?

Research Question 2 (Study 2):

What are the evidence gaps concerning the effectiveness or limitations of these specific intervention strategies?

Aim 1 (Study 2):

To survey the extent, range, and nature of research on intervention strategies intended to minimise injury risk factors among CrossFit athletes.

Objectives related to Aim 1 (Study 2):

1. To provide a comprehensive scoping review of studies exploring intervention strategies to minimise injury risk factors among CrossFit athletes;
2. To map out specific knowledge domains; and
3. To identify gaps in the existing literature.

1.4. Significance of the study

Firstly, this study will be one of the first studies in South Africa to investigate risk factors associated with injury among non-elite CrossFit athletes. If associations are found, the results can be used in injury prevention strategies, explicitly focusing on TV, HRV and injury risk monitoring among non-elite CrossFit athletes. In particular, coaches may be able to identify the early onset of injuries among athletes and address possible preventable causes, thereby reducing athletes' injury risk. Therefore, the outcomes of this study may be used to make recommendations to CrossFit coaches regarding exercise prescription and monitoring of athletes' HRV and TV. This study's data collection methods are simple, user-friendly, and cost-effective. If associations are found, athletes will also be able to track and monitor their own TV and HRV using the same methods.

Secondly, the scoping review component could be a pivotal approach in identifying various studies that have assessed intervention strategies to minimise injury risk factors among CrossFit athletes. This approach can highlight specific knowledge gaps, identify inconsistencies, and underscore the need for a more comprehensive exploration of injury prevention within the exercise regime of CrossFit. By mapping and elucidating the findings, a broader understanding of the importance of targeted injury prevention strategies for individuals engaged in CrossFit training could emerge, thereby confirming the need for future research endeavours. Such valuable insights could guide CrossFit coaches to explore in greater depth these prevention methods, and to incorporate them into their coaching practices to ensure a safe and effective training environment.

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

CrossFit combines high-intensity training with functional movements to deliver varied workouts that challenge strength, cardiovascular fitness, and mobility.2 Since its early-2000s inception, CrossFit has become one of the fastest-growing fitness regimes worldwide, exposing participants to musculoskeletal demands and associated injury risks.[2,5,6,13,15,16] This review outlines the sport's fundamentals and history, examines injury prevalence and incidence rates, identifies key risk factors (including TV and HRV monitoring), and surveys existing injury prevention strategies in the CrossFit literature.

2.2. History of CrossFit Internationally and in South Africa

2.2.1. International footprint

CrossFit, an exercise regime that was developed in 2000 by Greg Glassman, is one of the world's most rapidly growing sports.[5,6] In 1999, a website for the sport was first developed.[17] The plan and start-up of CrossFit.com went public on 10 February 2001, where unique programming was distributed daily.[17] By December 2005, despite the fact that no money had been spent on advertising, marketing, or promotion, the website CrossFit.com had over 75,000 regular unique visitors from around the world, over one million visits so far that year, and over a terabyte of data delivered monthly.[17]

In 2007, CrossFit initiated the first CrossFit Games. A small group of 70 athletes gathered at a ranch in northern California for the inaugural CrossFit Games.[18] The founder of CrossFit, Greg Glassman, believed the fittest athletes would be able to handle the unknown and unknowable, so the first event of the 2007 CrossFit Games was chosen randomly.[18] With coach Glassman presiding, coloured balls labelled with different exercises were pulled from a hopper, and a workout was created on the spot.[18] CrossFit started a new era of fitness competitiveness.[18] Each year, the CrossFit Games are more challenging, raising the level of competition to new heights.[18]

CrossFit was initially designed to train individuals whose work requires physical fitness and muscle strength (e.g., police officers and members of the military special forces), so that workers could go from low to high levels of effort in seconds.[19] The demand for the sport among the public has increased, with 11,000 CrossFit-affiliated gyms worldwide as of 2015,[20] which grew exponentially to a total of 15,000 as of 2018.[21]

2.2.2. CrossFit affiliate mapping in Africa

There is limited research captured on the history of CrossFit in South Africa. However, the mappings (see Figures 2-1, 2-2, and 2-3) give us insight into how many CrossFit gyms use the CrossFit® trademark and provide training at a physical location in Africa, South Africa, and the Eastern Cape in South Africa, respectively.[22] The Affiliate Finder Map established the following landmarks:[22]

Figure 2 - 1: CrossFit Affiliates in Africa.

Figure 2 - 2: CrossFit Affiliates in South Africa.

Figure 2 - 3: CrossFit Affiliates in the Eastern Cape.

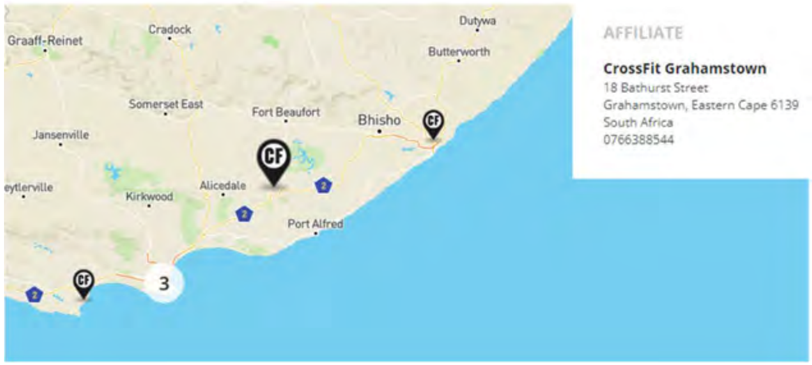

Figure 2-1 shows that Africa, particularly Southern Africa, provides some CrossFit training gyms. Cape CrossFit, in the Western Cape, was the first CrossFit-affiliated gym to be opened in South Africa, in 2008/09.[23] Since then, South Africa's affiliation has grown,[23] and it now has 114 CrossFit gyms.[22] The Eastern Cape hosts seven of these affiliates.[22]

2.3. The fundamentals of CrossFit

CrossFit advocates a high-intensity, functional form of exercise, which utilises a unique style of programming, specialising in maximising the neuroendocrine response, increasing power, utilising multiple training modalities and functional forms of movement, and incorporating diet strategies.[3]

It is a sport that combines resistance training with short high-intensity cardiovascular exercises into a "workout of the day" (WOD), which is predominantly completed in a class setting, supervised by a coach in an exercise space known in the CrossFit community as a "box".[3,4] Typical workouts in gyms and health clubs worldwide involve isolation movements and extended aerobic sessions.[3] CrossFit programmes incorporate a warm-up, a strength or skill development segment, the WOD, and a cool-down.[24–26]

The key focus of the WOD is to have different weekly exercises and limited or no rest periods between activities, which makes the workouts intensive.[25,27] Either of two levels of training difficulty can be used during CrossFit classes: "Rx", where the workout weights and movement standards should be accomplished as prescribed, or "scaled", where the weights and movement standards are scaled down to suit the athlete's capabilities, for those that cannot perform to the Rx standards.[4]

One of the fundamentals of CrossFit is that despite the level of difficulty of the WOD, every movement involved in the class can be modified for the individual(s) participating in the session, which ensures inclusivity.[4,13] The underlying principle is to prevent anyone from feeling excluded, which cultivates an environment where all participants can actively take part in the sessions according to their unique capabilities and fitness levels.[4,13] The scalability of CrossFit is one of the reasons for its popularity, as it is suitable for a diverse range of individual capabilities, including those of the elderly and pregnant and disabled individuals.[4,14]

Each CrossFit gym registered with CrossFit Inc. may use the trademark in naming their gym, after paying the yearly affiliation fee.[14] The names and locations of registered CrossFit gyms are posted on the CrossFit webpage.[14,28] Although thousands of CrossFit gyms use the CrossFit® trademark, CrossFit does not follow a franchising model.[14] Unlike most large fitness corporations, the CrossFit head office does not supervise their registered affiliates, which gives owners and coaches the freedom to run their gyms however they want.[14] The quality of the gyms might vary based on the experience of the owners and coaches, but the facilities still follow the core methodology of CrossFit's strength and conditioning.[14] CrossFit maintains that in a free market economy, the CrossFit gyms with experienced coaching and management will grow, while those with poor management and coaches will struggle.[14,15]

CrossFit is considered a competitive sport, where the start of the CrossFit Games season, namely the CrossFit Open, a three-week international event, is claimed to be one of the most prominent annual fitness competitions.[18] The Open is the first qualifying stage of the CrossFit Games, and individuals who want to compete in the games must qualify at the Open in their region.[29] While the primary purpose of the CrossFit Open is to find the best CrossFit athletes in each region to move on to the regionals, it is also an opportunity for any athlete, at any level, to participate in the competition.[29]

During the 2023 season, 322,000 individuals participated in the Open, driven by a range of motivations, from the sheer enjoyment of the challenge to earnest aspirations of securing a coveted spot in the subsequent qualifying stage for the CrossFit Games.[18] Following the Open, the top 10% of individual athletes and the top 25% of teams who have distinguished themselves earn an exclusive invitation to the Quarterfinals.[18] Subsequently, those who have excelled in the Quarterfinals proceed to the Semifinals, which is a multifaceted event spanning 10 challenges, and which is held across six continents.[18] This setup ensures representation from each continent, with at least one athlete and team securing qualification for the Games.[18] This culminates in the finest athletes from different divisions, including 40 women; 40 men; 36 teams; 140 masters;[1] 40 teens;[2] and 30 adaptive athletes from the Neuromuscular, Upper Extremity, and Lower Extremity[3] categories, emerging as elite qualifiers for the prestigious CrossFit Games.[18,30]

2.4. The demands of CrossFit

2.4.1. Integrated activities

CrossFit is a diverse fitness regimen that integrates various activities designed to push athletes to their limits and help them adapt physically.[4,5] These encompass psychological elements such as improved motivation;[7,8] physiological changes involving reduced exercising heart rate, reductions in blood lactate, and improved maximum rate of oxygen consumption ($\dot{V}O_2$ max);[10,11,31] advanced biomechanical shifts affecting functional movement patterns;[3] and a range of improved physical enhancements including cardiovascular and respiratory endurance, stamina, strength, flexibility, power, speed, coordination, agility, balance, and accuracy.[3]

CrossFit's specific styles of exercise include power/Olympic weightlifting (i.e., squats, "cleans", deadlifts, bench presses, and presses), gymnastics (i.e., pull-ups, lunges, "knees to elbows", handstand push-ups, push-ups, and sit-ups), and aerobic exercise/metabolic conditioning (i.e., swimming, running, and rowing).[5,15,19] These functional movements are executed frequently, with constantly varied durations, and they are completed at high intensity, often involving minimal to no rest.[15,32]

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[1] Masters: 35–65+ years[30]

[2] Teens: 14–17 years[30]

[3] Neuromuscular, Upper Extremity, and Lower Extremity: Vision, Intellectual, Seated With Hip Function, Seated Without Hip Function, and Short Stature categories[30]

Constant variation, functional movements, and high intensity are the three definitive elements that make up CrossFit's movement demands and programming, which the CrossFit website specifically elaborates on, as follows:

2.4.2. Constant variation[4]

CrossFit aims to build a broad, general, and inclusive fitness.[33] This type of strength and conditioning programme does not elicit specialism in one physical task. The goal is to be good at activities of daily living, sport, and combat, everywhere, at any time, for any duration, and in any environment.[33] The CrossFit website explains this by stating that if we do not train to vary as many factors as possible, we will find ourselves inadequate in the face of life's challenges, whether those challenges are excelling at sports or day-to-day living.[33]

2.4.3. Functional movements

CrossFit places a premium on functional movements derived from everyday activities.[34] The term "functional" in CrossFit parlance denotes movements considered "natural", which means that they are not movements used only at the gym.[34] Instead, these movements are found everywhere in human behaviour, and they arise spontaneously as a response to daily living.[34] To illustrate, rising from a chair requires an air squat; lifting groceries from the floor, a deadlift; hoisting a 20-litre water jug onto a table, a power clean; and placing items on a high shelf, a shoulder press.[34]

An important aspect underscored by CrossFit is the essential nature of these functional movements, as explained on its official website.[34] For example, these same movements, such as standing up from a chair or picking up groceries, are deemed essential for the demands of everyday life.[34] The website clarifies this by asserting that loss of the ability to move corresponds functionally to the loss of capacity to live independently.[34]

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[4] Definitions in Sections 2.4.2–2.4.4 are drawn directly from CrossFit, Inc.'s official website to capture the sport's self-described fundamentals. These are not independent academic definitions but represent the terminology used by the governing organisation.

2.4.4. High intensity

For CrossFit, intensity is a measure of power (power = work/time).[35] The faster the work is completed, the more intense the effort.[35] Intensity is the independent variable most associated with maximising the rate of return on favourable adaptation to exercise, that is, training with higher intensities will produce faster positive adaptations of the body.[35]

While CrossFit emphasises the importance of intensity in training, the CrossFit website underscores the individualised nature of intensity requirements.[35] It acknowledges that each person's capacity for intensity varies, which necessitates a tailored approach aligned with their physical and psychological capabilities.[35] The website explains this by asserting that "the intensity at which someone should work is always and only relative to that individual".[35] Furthermore, it states that as long as one is working near the limits of one's capacity, one will derive the same increased benefits from the programme, whether one is an elite athlete or is someone who is "simply trying to maintain functional capacity for independent living".[35]

2.5. Definition of injury in CrossFit

Part of the reason for the high discrepancy in injury rates reported (i.e., 19% to 74%) is the lack of consistency in the definition of injury in CrossFit, which makes pooling of data and comparison of results difficult. For example, Szeles et al.[4] employing a "one-session-missed" criterion, reported a high injury rate of 18.9 per 1,000 training hours (up to a 73% injury rate). In contrast, studies employing the Weisenthal et al.[15] criteria (requiring ≥ 1 week removal or ≥2 weeks modification or medical consultation) found rates closer to 3.2 and 0.27 injuries per 1,000 hours,[2,6] yielding much lower and more comparable injury percentage estimates: 19%,[15] 31%,[2] 38%,[6] and 56%.[13]

It must be noted that there is no generally accepted theoretical definition for injury in CrossFit. Researchers investigating injuries in CrossFit have either defined injury by what they thought should be classified as an injury in CrossFit[4,12] or used injury criteria from another sport and modified them to reflect specific factors that they thought should be measured in CrossFit participants.[2,6,13,15]

The definition that has been found to be most popular in studies that have analysed injuries in CrossFit is as follows:

> "Injury encompassed any new musculoskeletal pain, feeling, or injury that results from a CrossFit workout and leads to 1 or more of the following options: 1. Total removal from CrossFit training and other outside routine physical activities for >1 week 2. Modification of normal training activities in duration, intensity, or mode for >2 weeks 3. Any physical complaint severe enough to warrant a visit to a health professional".[2,6,13,15]

This definition is similar to the consensus definition for an injury in powerlifters, which also defines injuries according to missed or modified training sessions or competition.[36]

The studies that have used this definition[2,6,13,15] have followed a structured threefold injury criterion survey, which was developed by Weisenthal et al.[15] The injury criterion was based on a survey that was used to identify injuries in track and field,[37] but then, through a series of semi-structured interviews with CrossFit gym owners, coaches, physicians, and participants, the survey was modified to reflect specific factors that should be measured in CrossFit participants[15]. The survey was then piloted with multiple CrossFit athletes (five groups of three) and adjusted according to feedback.[15] From this, the authors established the threefold injury criterion, which encompassed various injuries that can occur with CrossFit workouts.[15]

The criterion established an injury through three options:

1. Total removal from training for >1 week; or
2. Modification of training intensity, duration, or mode for >2 weeks; or
3. Any physical complaint which is severe enough to consult a healthcare professional.

2.6. Injury prevalence and incidence rates of CrossFit

CrossFit-related injury prevalence and incidence rates have been investigated in many countries, including the United States,[2,5,15,38] Brazil,[4,6] Puerto Rico,[5] and the Netherlands.[13] In South Africa, only one study, conducted in Johannesburg, describes injury incidence.[14] The areas of the body most injured are the shoulders (19% to 39%), the back (13% to 36%), and the knees (8% to 16%).[2,5,6,13–16]

Despite widespread concern over injury rates associated with CrossFit, the existing literature has inconsistencies and biased evidence on CrossFit-related injuries.[6,12] A systematic review thoroughly examined scientific findings related to CrossFit, and it revealed a prevailing issue of low-quality literature marked by high rates of bias.[39] While specific studies highlight the positive aspects of CrossFit,[10,11,25,26,40] others indicate disproportionately high injury rates, ranging from 19% to 74% over periods ranging from 3 to 12 months.[2,4–6,12–16] When the injury rates are expressed as a number of injuries per 1,000 training hours, the results vary considerably, between 0.27 and 18.9.[2,4,6,12,16]

While these reports suggest disproportionately high injury rates, the injury rates for CrossFit are lower than those of contact sports such as rugby union. A study by Kerr et al.[41] found that rugby union players, on average during matches, experience injury rates of 23%, and that the difference between males (16.9/1,000 hours) and females (17.1/1,000 hours) was fairly similar. However, the study acknowledged that injury rates in rugby increase with higher standards of play, where factors like increased ball-in-play time and physical contact events (e.g., tackles) significantly impact injury incidence.[41] This distinction in play dynamics likely explains rugby's higher injury rate than CrossFit, weightlifting, and powerlifting.

2.7. Internal and external risk factors for injury in CrossFit

Globally, several studies have investigated the epidemiology and injury risk factors among CrossFit athletes.[4,6,13–16,38] Injury risk factors are classified as internal or external risk factors.[42] Training volume relates to the combined external and internal stress, that is, biochemical and biomechanical stress, imposed on athletes.[43] External stressors include objectively measured TV prescription (duration, intensity, and type of activity), resulting in mechanical and locomotive stress.[44] Internal stressors are physiological and psychological responses to the externally objective stressors,[44] most commonly quantified via sRPE multiplied by session duration. Monitoring both types of stress may provide insights into specific adaptations to training, which may be positive and anticipated (e.g., result in improved performance and fitness levels) or adverse (e.g., result in injury or illness).[45]

Internal risk factors associated with increased injury risk include sex, specifically males;[14,15] increased height, weight, and body mass index;[16] and previous injury.[4,6,13,14,38] External risk factors associated with increased injury risk include greater weekly training frequency and hours[16], more years of experience participating in CrossFit,[6,13,16] lack of coaching supervision,[13,15,38] lifting weights that are too heavy ("ego lifting"),[13,14,38] improper form/technique,[13,38] and a lack of skill and awareness.[4] Also, heightened fatigue levels are a risk factor from internal and external factors.[13,14,38]

2.8. The association between TV, HRV and injury risk monitoring in CrossFit participants

Exercise monitoring is an important part of an athlete's training process, whether they are an elite athlete or a regular exerciser.[46] It serves to confirm whether programmed TVs are effectively executed by the athlete, which can be used to improve athletic performance and detect the risk of possible injury.[46] Consequently, it has been suggested that poor TV management is a risk for injury in sport settings, which is why exercise monitoring has become such a valuable tool used in the sporting world.[47,48]

Several different monitoring tools have been devised to follow the progression of individuals, including the measurement of both external and internal loads.[46,49] In simple terms, external loads are observational exercise behaviours,[46] which relates to the objective quantification of the work done during the training or competition undertaken.[49] For example, the external load in resistance training is expressed as the work completed or the velocity generated during lifting,[50] which can be measured in standard units, such as kilograms, metres, seconds, metres per second, and kilojoules per second.[46] Many coaches that use workload monitoring base their training prescriptions on external load to achieve the desired psychophysiological response.[49]

This external response is closely tied to the internal training load.[49] Assessments of internal load serve as indicators that mirror the actual psychophysiological responses of the body to cope with the demands imposed by external loads.[49] Athletes and coaches can monitor these responses through metrics such as heart rate (HR), blood lactate, or session rating of perceived exertion (sRPE), for example.[46]

As technology advances, so do tools designed for athlete monitoring. These instruments range from straightforward metrics, such as quantifying TV load in resistance training sessions or calculating the mean heart rate reserve during endurance workouts, to more advanced approaches.[46] Examples include the use of Global Positioning System (GPS) technology in sports such as soccer, which is able to analyse total distance, low-intensity distance, high-speed running distance, sprint distance, and accelerations and decelerations during a match.[51] Advancements extend to measuring HRV upon waking, which can help assess recovery status.[52–54] This shows the diverse and complex nature of contemporary athletic performance tracking.[46]

Two monitoring tools have gained widespread attention for injury risk management: the acute:chronic workload ratio (ACWR) formula[47] and HRV monitoring using a mobile application.[46]

While some emerging evidence suggests that the ACWR is an accurate method to identify increased injury risk,[55] other scholars have pointed out several limitations and even questioned its accuracy in detecting possible risks.[56] In other words, the ACWR helps identify critical windows regarding elevated injury risk based on imbalanced training loads, such as sudden load spikes.[51] However, Wang et al.[56] demonstrate that the ACWR and related models are flawed, especially if interpreted casually and used to design or alter training programmes. For instance, a single study conducted in the sport of swimming found the Acute Recovery and Stress Scale (ARSS) to be a more accurate way to monitor recovery stress than the ACWR.[57] However, another recent study, which analysed junior tennis players, suggests that ACWR and injury history are the best predictors of injuries.[58] Another popular method is the exponentially weighted moving average (EWMA) approach. The traditional ACWR equally weights all sessions over a fixed seven- and 28-day windows, making it an incentive to sudden load spikes. In contrast, the EWMA approach applies exponential decay to prioritise recent sessions, yielding stronger injury risk associations in team sport athletes.[76] However, it is more complex to calculate for practitioners.

Scholars are divided on the accuracy of the ACWR in identifying increased injury risk, and additional research on this method is needed. Nonetheless, for this study, the ACWR approach was deemed a preferred option to the ARSS and EWMA approaches for assessing injury risk. This preference is based on the fact that ACWR is derived from sRPE and duration of the session.[59] Session rating of perceived exertion has been established as a reasonable method for gauging exercise intensity, which is particularly suitable for this study, given the diverse nature of CrossFit movements, encompassing weightlifting, gymnastics, and aerobic exercises.[5]

Heart rate variability monitoring has some positive results in terms of its accuracy in sports such as running,[60] soccer,[61] and swimming,[54] where all three of the studies cited acknowledge that it may help manage TV and predict individual adaptations to training. In short, HRV is measured by technology (e.g., a smartphone or a smartwatch) that can measure the beat-to-beat variations of heart rate, whether with a high or low variation or limited change and how between-beat variation changes daily (smartphones and smartwatches can detect these changes).[53] Analysis of this data provides insight into the state of the nervous system and whether there is a dominance of sympathetic ("fight-or-flight" stress system) or parasympathetic ("rest-and-digest" recovery system) activity.[52–54] This information can be valuable for assessing fatigue and early signs of overreaching in athletes.[52–54] For instance, studies on collegiate sprint swimmers undergoing overload training reported reduced and more variable parasympathetic activity and increased fatigue and muscle soreness.[54]

Regarding CrossFit athletes, few studies have investigated the association between TV and injury risk. Internationally, two recent studies identified a possible relationship between high TV and injury risk in competitive and elite CrossFit athletes, where the studies yielded conflicting findings.[59,62] Specifically, the ACWR, well-being, HRV, and sRPE were examined.[59,62]

In these two studies, training load was expressed in arbitrary units (AUs).[59,62] This metric encompasses the cumulative value of both the sRPE and the duration of the training sessions.[59,62,63] From this training load data, the ACWR is calculated. "Acute" refers to one training session or one week of training, while "chronic" refers to a rolling average of the last four weeks.[59,62] Among CrossFit athletes, ACWRs of between 0.8 and 1.3 are considered in the "sweet spot", which suggests that this is where injuries are at their lowest risk.[59,62,64] If ratios are lower than 0.8 or higher than 1.3, it is considered a higher risk for injury.[59,62,64]

Tibana et al.[59] and Williams et al.[62] both investigated HRV using the HRV4Training smartphone application. This application employs photoplethysmography (PPG) through the smartphone's camera to measure HRV.[59,62,65] PPG detects changes in blood volume during a cardiac cycle, by illuminating the skin and assessing alterations in light absorption.[65] Using smartphones, HRV4Training extracts PPG data from an individual's fingertip placed on the camera, subsequently determining autonomic nervous system activity markers.[65] In both international studies cited, participating athletes were instructed to perform a one-minute HRV reading each morning in a supine position upon waking.[59,62] The root mean square of successive differences between the athletes' normal heartbeats (RMSSD) served as the HRV measurements. In both studies, the RMSSD data was then logarithmically transformed (Ln) to resolve non-uniformity errors, and it was expressed as a weekly HRV score (Ln($rMSSD_{week}$)) for analysis.[59,62]

Tibana et al.[59] analysed an elite female CrossFit athlete for 38 weeks. Her total weekly training load was 2092 AU, and her mean sRPE and ACWR were 1.1, where her ACWR for 50% of the weeks was outside the recommended safe zone (0.8–1.3).[59,64] The sRPE could distinguish different internal loads during the 38 weeks of periodisation.[59] Still, no correlations between subjective variables (well-being, fatigue, sleep, pain, stress, and mood) and injuries were found, and neither were any associations found between training load variables (weekly training load, monotony, and ACWR), weekly heart rate variability (Ln($rMSSD_{week}$)), and recuperation subjective variables.[59] However, the authors mentioned that the fact that the athlete's ACWR for 50% of her training weeks was outside of the safe zone could be a concern for injuries, and that this should be controlled by coaches during training season to prevent injury.[59]

Williams et al.[62] studied six competitive CrossFit athletes over 16 weeks, and they established that a reduction in HRV (a low Ln($rMSSD_{week}$)) combined with a high ACWR predicted a significantly higher risk of overuse injury. Four out of the six athletes reported some form of overuse injury throughout the study period, with one athlete experiencing multiple overuse injuries.[62] The parts of the anatomy that were affected by overuse problems were the knee (two cases), the wrist (two cases), the lower back (two cases), and the elbow (one case). By contrast, high ACWRs were tolerated when HRV (Ln($rMSSD_{week}$)) stayed normal or was high.[62] Williams et al.[62] state that HRV monitoring has the potential to help detect and accommodate strategies to prevent overuse injuries, and to ensure training loads without rapid spikes in workloads (greater than 1.3). This is considered the best training approach for optimising performance whilst minimising the risk of injury. There was no evidence to suggest that sex would affect the trends of the variability measures.[62,66] However, it is acknowledged in this research that this could be a potential limitation.

Due to the lack of research on correlations between risks, such as TV and HRV, this study, therefore, investigates these potential risk factors among non-elite CrossFit athletes (see Chapter 3 Study 1).

2.9. Injury prevention strategies in CrossFit

Over the past two decades, exercise-based injury prevention strategies in sports have been frequently assessed.[67,68] Individual studies investigating injury prevention strategies of various sports, ranging from individual sports, such as running,[69–71] to team sports, such as soccer[72] and basketball,[73] have been published.

To ensure relevance to CrossFit's blend of endurance, power and multidirectional demands, the selection of these five prospective studies in running, basketball and soccer cohorts was purposeful. Despite being very different, these sports do, however, approximate CrossFit's varied stimulus. Running models sustained metabolic load;[69–71] basketball's emphasis on rapid changes of direction, plyometrics and explosive efforts;[73] and soccer's combined endurance with agility and power.[72] All five studies utilised different prevention strategies, which makes comparisons difficult. However, what must be noted is the effectiveness of interventions and whether they can minimise injury risk.

All three running studies reported no significant reduction in injury rates.[69–71] The running injury prevention strategies that were used were a four-week preconditioning programme utilising walking and hopping exercises;[69] a 16-week graded training programme based on the 10% training rule (increasing TV by no more than 10% each week);[70] and a 16-week intervention focused on warm-up, cool-down, and stretching exercises[71].

The soccer study found that improving strength and reducing muscle imbalance between the quadriceps and the hamstrings decreased the incidence of anterior cruciate ligament (ACL) injuries, due to the functions that these muscles perform on the knee joint and in motion control.[72] The injury prevention strategy was a 24-week intervention which followed the Prevent Injury and Enhance Performance (PEP) programme.[72]

The basketball study established a statistically significant reduction of 81% in the occurrence of ankle sprains from the first biennium (2004–2006) to the third biennium (2008–2010); lower back pain showed a reduction of 78%; and the reduction in knee sprains was 65%, but it was not statistically significant.[73] In the first biennium (2004–2006), the injury prevention programme consisted of typical proprioceptive exercises.[73] In the second biennium (2006–2008), the proprioceptive training became quantifiable and interactive through electronic proprioceptive stations, and in the third biennium (2008–2010), the intensity and TV increased, while the session duration decreased.[73] The authors' findings suggest that improvements in proprioceptive control in single-stance stability may be a key factor for effectively reducing ankle sprains, knee sprains, and lower back pain.[73]

With regard to CrossFit athletes, very few studies have investigated intervention strategies to reduce injury rates or risk factors. The studies that have analysed prevention strategies have conflicting findings. Martínez-Gómez et al.[74] investigated the effects of utilising mobility and stability exercises, which participants performed before all CrossFit sessions during the warm-up with foam rollers and elastic resistance bands. The results, however, show no benefits in terms of reducing injury rates.[74] Kaczorowska et al.[75] assessed the effects of a MobilityWOD intervention programme on functional movement patterns, and, as in the study by Martínez-Gómez et al.[74], exercises were derived from physiotherapy and functional training (foam rollers, lacrosse balls, and resistance bands). However, the findings differ, as the use of the MobilityWOD intervention brought about a significant improvement in the mobility of the participants and a reduced risk of sustaining an injury.[75]

Due to the lack of research on injury prevention strategies among CrossFit athletes, a scoping review (see Chapter 4 Study 2) is conducted in this dissertation to provide a more constructive and in-depth search for possible injury prevention strategies, and therefore to establish that injury prevention strategies are something that needs further evaluation in CrossFit.

2.10. Summary

Despite the fact that CrossFit has proved itself to be a feasible strength and conditioning programme,[10,11,25,26,40] disproportionate injury rates have been found with the sport,[2,5,6,12–16] with some studies reporting very high injury rates.[4,12]

Also, few studies have investigated the association between TV and injury risk among CrossFit athletes. Of the studies that have investigated this association, one study found that where the

ACWR for 50% of the training weeks was outside the recommended safe zone (0.8–1.3), this could be a concern for injuries,[59] and another study found that a reduction in HRV (a low Ln($RMSSD_{week}$)) combined with a high ACWR predicted a significantly higher risk of overuse injury.[62]

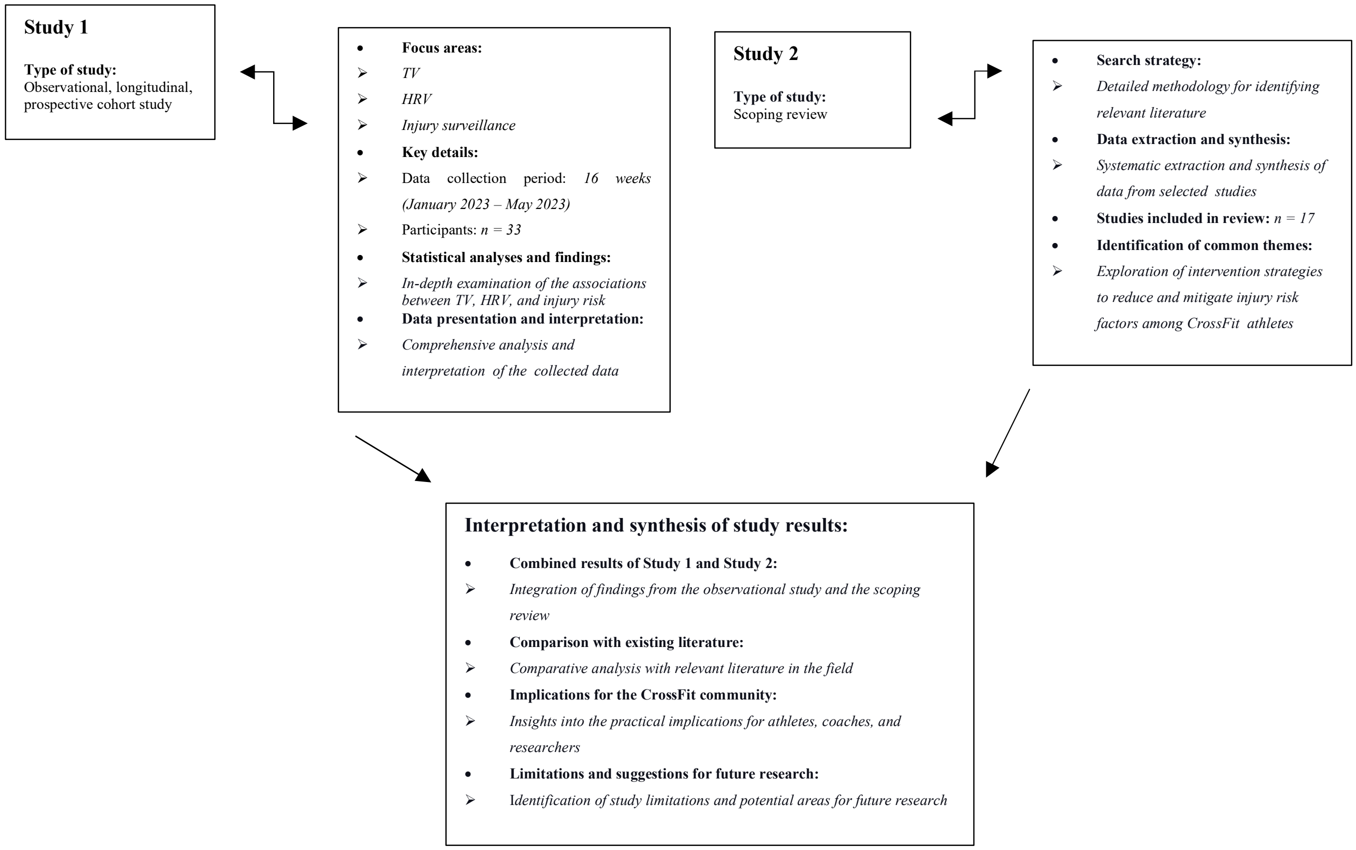
More research needs to be conducted on injury prevention strategies in CrossFit. Numerous studies have acknowledged specific risk factors,[4,6,13–16,38] but most of them have only established risk factors or provided possible recommendations that could potentially help prevent injury risk, and they have not specifically prioritised the analysis of injury prevention strategies. The studies that have analysed prevention strategies have conflicting findings, with one study successfully reducing the risk of injury[75] and the other being unsuccessful.[74] Further studies are needed to provide an in-depth analysis of injury prevention in CrossFit.

The purpose of the studies included in this dissertation is, therefore, (a) to investigate risk factors associated with injury among non-elite CrossFit athletes in the Eastern Cape, South Africa (see Chapter 3 Study 1) and (b) to provide a scoping review of the time, nature, and characteristics of studies investigating intervention strategies to reduce or minimise injury risk factors among CrossFit athletes, in order to (1) map specific knowledge domains, including key concepts, and (2) identify gaps in the literature (see Chapter 4 Study 2).

2.11. Outline of dissertation

This dissertation comprises two studies. The first study investigates the interplay between TV, HRV, and injury among the non-elite CrossFit athlete population. The second study is a comprehensive scoping review of relevant literature on injury prevention strategies. The synthesis of the findings offers valuable implications for the CrossFit community, with a critical examination of limitations of the studies and suggestions for future research. The methodology of each study is explained in detail in dedicated chapters, and Figure 2-4 depicts the sequence of the studies.

Figure 2 - 4: Sequence of studies included in this dissertation



TV = training volume; HRV = heart rate variability; n = number

CHAPTER THREE: STUDY ONE

Are training volume and heart rate variability injury risk factors among CrossFit Athletes in South Africa?

Kieran SKAE, Candice CHRISTIE, Licinda PIENAAR, Candice MACMILLAN (2024). Are training volume and heart rate variability injury risk factors among CrossFit Athletes in South Africa? (*Accepted for presentation at the ECSS Rimini 2025 conference).*

Study One was accepted for presentation at the *European College of Sport Science* in Rimini at the time of this dissertation submission in 2025. Within this thesis, figures, tables, and their respective captions have been strategically integrated into the text according to the journal's formatting guidelines. However, the reference style has been maintained to align with the overall document's consistency.

ABSTRACT

Background: Reported CrossFit injury rates are high; however, there is a paucity of research on injury risk factors. This study investigated if training volume (TV) and heart rate variability (HRV) are injury risk factors among CrossFit athletes.

Methods: This observational longitudinal study included 33 non-elite CrossFit athletes who completed weekly online injury surveys, and daily TV and HRV over a sixteen-week period. Training volume was calculated as session duration multiplied by the session perceived exertion (sRPE) rating and expressed in arbitrary units (AU). The A:C ratio “safe zone” was set at (0.8-1.3 AU). Acute (total TV over seven days) and chronic (three-week rolling average of the acute TV) TV ratios (A:C ratios) were also calculated. Heart rate variability was assessed using the "HRV4Training" mobile application. Injuries were surveyed using the Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire, adapted to include data on acute injuries. The study used descriptive statistics, skewness and kurtosis to analyse data and t-tests, ANOVAs, and linear regressions to examine the relationship between A:C ratios, HRV, and injury risk. The study used Cohen's d to calculate effect sizes (ES), with ES values of 0.20, 0.50, and 0.80 indicating small, medium, and large effects.

Results: Mean weekly TV was 1299 ± 675.4 AU, session duration 55.2 ± 32.4 minutes and sRPE 7.4/10. Of the 33 participants, 66% had A:C TVs, which were outside the "safe zone.” Thirteen participants (41%) sustained injuries, and 51 injuries were reported, of which 69% were overuse and 31% acute injuries. The shoulder and ankle were the most common sites of acute and overuse injuries. In the univariate model, TV and HRV were not associated with injury risk. Injury rates were higher among participants aged ≥ 51 years, males, with commitment levels of between four and five (medium), and who were training two to three times per week. Non-competing CrossFit Open participants had a higher overall injury count with a more significant percentage of injuries than competing participants. Injury probability increased from 11% in week one to 31% in week 16, peaking in those with two years of training experience.

Conclusions: Training volume (A:C ratios) and HRV were not associated with injury risk. Injury rates were higher among males, participants older than 51 years, with medium training commitment, medium to high frequency of training, and less experience. Although TV and

HRV were not identified as individual injury risk factors, they might be related to an increased risk of injury when considered with other variables. Future studies with larger sample sizes should investigate these variables using a multivariate model.

Keywords: High-intensity functional training; physiological adaptations; exercise monitoring; injury prevention

INTRODUCTION

CrossFit is a rapidly growing sport[5,61] and multi-billion-dollar industry[20] with more than 13,000 gyms worldwide,[5] including 143 in South Africa and six in the Eastern Cape.[22] The 2023 CrossFit Games season saw participation from over 300,000 individuals, underscoring its widespread appeal and competitive fervour.[76] The sport combines the fundamentals of high-intensity training and functional exercise,[77] which is multifaceted, resulting in multiple adaptations,[4,5] including psychological,[8,10] physiological,[9–11] biomechanical,[3] and physical.[3] CrossFit movements include power/Olympic lifting, gymnastics, and aerobic/metabolic conditioning.[5,15,19]

Defining participation levels in CrossFit poses challenges owing to its relative infancy. Studies classify participants as beginners (just started solo training), intermediates (attend group training multiple times weekly), and advanced (ready for CrossFit Games).[5] Limited research contrasts elite (advanced) and non-elite (beginner/intermediate) CrossFit athletes. However, higher training hours are noted among competitive athletes compared to non-competitive ones.[16]

CrossFit-related injuries have been studied across various countries, including the United States,[2,5,15] Brazil,[4,6] District of Columbia,[5] Puerto Rico,[5] and the Netherlands.[13] In South Africa, only one study in Johannesburg has investigated injuries.[14] Despite discrepancies in injury definitions among studies, the shoulders (19% to 39%), back (13% to 36%), and knees (8% to 16%) are commonly affected.[2,5,6,13–16] Reported injury prevalence ranges from 19% to 74%,[2,5,6,12–16] while injury rates per 1000 training hours vary from 0.27 to 3.24.[2,6,12,16] CrossFit injury rates are comparable to sports such as powerlifting and Strongman[78] but lower than rugby union.[41]

Multiple studies have explored injury risk factors in CrossFit athletes,[4,6,13–16] categorising them into internal and external factors.[42] External risks include workload,[16] years of experience,[6,13,16] and lack of coaching supervision.[13,15] Internal factors include height, weight, body mass index,[16] and prior injuries. Few studies have investigated the association between TV and injury risk in CrossFit athletes.[4,6] Findings suggest that competitive and elite CrossFit athletes face a higher risk of injury due to increased TV.[59,62] Specifically, the acute-to-chronic workload ratio (ACWR), well-being, HRV, and sRPE have been examined among CrossFitters.[59,62]

Workloads, measured in AU, were calculated by multiplying subjective sRPE with objectively measured TV, measured in minutes during a session.[59,62] Competitive CrossFit athletes' average weekly TVs have been found to vary between 2092 and 2591 AU.[59,62] The ACWR, calculated by dividing the acute load by the chronic load, showed that an ACWR between 0.8 and 1.3 was optimal for minimising injury risk.[24] However, in these studies, individual athletes spent 32%[62] and 50%[59] of their time outside the optimal range.

Heart rate variability (HRV) reflects an athlete's recovery level and can be assessed using the "HRV4Training" smartphone application (https://www.hrv4training.com).[59,62] Monitoring HRV may signal early signs of tissue overload before pain or injury onset, which can be helpful in tracking recovery and training adaptation.[62,79] Tibana et al.[59] found no links between workload, HRV, and subjective factors, possibly because of the small sample size of one athlete. Conversely, Williams et al.[62] noted a higher risk of overuse injury with reduced HRV and high ACWR in six competitive CrossFit athletes.

This study addressed prior research limitations by examining associations between TV and HRV among non-elite CrossFit athletes in the Eastern Cape, South Africa, over sixteen weeks with a larger sample size than previously published research. Specifically, the study aimed to determine if TV and HRV are associated with injury risk. If associations are found, the results can be used as part of injury prevention strategies, specifically volume and recovery monitoring, among non-elite CrossFit athletes.

MATERIALS AND METHODS

Research Participants and Setting

Setting

Data were collected at the CrossFit facility in Makhanda, Eastern Cape, South Africa.

Sample Size and Selection

Approximately 160 athletes are members of the CrossFit facility in Makhanda, South Africa.

A sample size of 34 participants yielded a priori power of 80%.[80] This number was calculated as follows: Effect sizes (ES) were calculated using Cohen's d, where ES of 0.20, 0.50 and 0.80 were interpreted as small, medium, and large.[80] A priori power analysis, using G-power related to the medium effect size (ES=0.5), was used for the sample size calculation.[80] Forty-five participants initially volunteered to participate in the study. Two (4%) were excluded because one was under 16, and the other did not partake in the prescribed CrossFit training regimes. Ten participants (22%) withdrew from the study. Therefore, a total of 33 participants (73%) were included. A convenience sample was selected based on the geographical proximity to the CrossFit facility.

Inclusion/Exclusion Criteria

The study included male and female CrossFit athletes aged 16 years and older. For participants aged 16-17, parental or guardian consent and participant assent were obtained. Athletes of all levels of participation, except professional athletes, were included. Athletes who could not participate in any or all of the exercises included in the daily workout routine at the start of the data collection period were not eligible for participation in the study.

Instruments and Data Collection Procedures

Before commencing the study, ethical approval (2022-5925-7235) was obtained from the Rhodes University Human Research Ethics Committee (RU-HREC).

Data was collected over 16 weeks (January 2023 to May 2023). During the observational period, standard daily training programmes referred to as the "workout of the day" (WOD), competitions, and any additional training data were captured. To ensure sustained compliance of all participants, a WhatsApp group was created, and daily reminders were sent out.

A pilot study was conducted to test and troubleshoot the data collection procedures related to injury surveillance, TV questionnaires, and using the HRV4 application. Five participants who met the inclusion criteria were included in this pilot study. Participants suggested changes related to the user-friendliness and layout of the questionnaires, which were subsequently incorporated. Data from the pilot study were not included in the statistical analysis of the main study.

Three days before the commencement of the study (20th of January 2023), the researcher conducted a briefing session at the CrossFit facility. The session included handing out an instructional manual (Appendix K), an in-depth explanation of the study, and a demonstration of the use of all data collection procedures. Participants completed a short questionnaire that gathered information on age, sex, CrossFit commitment, training regularity, participation in CrossFit Open, and years of CrossFit experience (Appendix G and I). An electronic version of the manual was provided for those unable to attend in person.

Training Volume

Session RPE is a well-established subjective measure of the intensity of effort,[62] showing strong validity and reliability across diverse exercise modalities.[65,66] Participants' sRPE was gauged on a scale of zero to ten, with zero being rest and ten being maximal effort.[63] Each participant was requested to complete an online self-reporting questionnaire via Google Forms 20-30 minutes after their training sessions/competitions, recording the duration of the session and sRPE. Participants' TV was then calculated by multiplying session duration (minutes) by participants' sRPE and expressed in AU.

The A:C ratio was calculated by dividing the acute and chronic volumes. Ratios between 0.8 and 1.3 were considered in the "sweet spot".[64] It has been reported that ratios lower than 0.8 resulted from undertraining, and ratios above 1.5 resulted from overtraining and were referred to as the “danger zone”.[64,81] Therefore, values between 0.8 and 1.3 were considered the “safe zone”.[59,62] The total days spent outside the recommended safe area were also captured.

A three-week rolling average was chosen for the chronic volume rather than the traditional four-week window or an exponentially weighted moving average (EWMA) to reflect CrossFit’s shorter programming cycles better. While a four-week average smooths fluctuations more effectively, it can lag in representing recent training changes; EWMA offers increased sensitivity but requires selecting a decay constant.[81] The three-week window provides balance, sufficiently responsive to recent volume shifts while providing enough steadiness to minimise false week-to-week variability.

Heart Rate Variability

Participants utilised the "HRV4Training" (see http://www.hrv4training.com) smartphone application to measure HRV through photoplethysmography (PPG).[59,62,65] The application uses PPG to detect changes in blood volume by illuminating the skin and measuring light absorption during a cardiac cycle.[65] By placing a fingertip on the smartphone camera, participants allowed the application to extract PPG, enabling the determination of markers for autonomic nervous system activity.[65] Validation work in the CrossFit athletic population has demonstrated strong agreement between PPG-derived R-R interval (rMSSD) measures, supporting the HRV4Training’s field validity.[59,62] The HRV4Training application calculates HRV as the square root of the mean sum of the squared differences between R-R intervals (rMSSD), which is used to assess the strength status of the parasympathetic nervous system.[62,65] The rMSSD is then log-transformed (Ln) and placed on a scale of one to ten.[62]

During the study, upon waking, participants had to open the HRV4Training application and perform a one-minute HRV measurement in a relaxed supine position, breathing normally.[59,62] This involved each athlete placing their index finger on their phone camera so that the application could measure their scores. During the procedure, participants were requested to remain immobile and breathe freely without forcing unnatural breathing.[65] A seven-day rolling average of the participants' measurements (Ln $rMSSD_{week}$) was then calculated and used as the weekly HRV score in this study.[59,62] This provided better methodological validity than taking single scores daily.[62,82]

Injury Surveillance

An injury was defined as "any new musculoskeletal pain, feeling or injury that resulted from a CrossFit workout and led to one or more of the following: 1. Total removal from CrossFit training and other outside routine physical activities for >1 week; 2. Modification of normal training activities in duration, intensity, or mode for >2 weeks; 3. Any physical complaint severe enough to warrant a visit to a health professional".[15]

Regardless of injury status, participants completed the weekly injury surveillance questionnaire every Sunday via Google Forms on their mobile devices. The participants could access the injury surveillance questionnaire online via Google Forms on their mobile phones or suitable devices. The OSTRC Overuse Injury Questionnaire[62,83] was adapted to suit the specific requirements of this investigation. While the OSTRC questionnaire was initially intended for collecting overuse injury-related data and was validated in previous studies,[62,83,84] the authors adjusted the questionnaire to include elements for capturing acute injuries in this study. Criterion three of the injury definition ensures that acute injuries, resulting in medical consultation but possibly requiring <7 days of training removal, are still captured, while criteria 1 and 2 record longer-term removal or modification events. The questionnaire consisted of four key questions assessing the severity of a health problem based on its effect on sports participation, TV, performance, and symptoms, with responses scored on a 0–25 scale.[62,83] Two expert reviewers conducted independent assessments to ensure the face and content validity of the adapted questionnaire.

Overuse or chronic injuries occur due to repetitive submaximal loading of the musculoskeletal system when rest is insufficient to allow for structural adaptations.[62,85] Acute injuries occur suddenly and are caused by a specific incident.[86] The questionnaire consisted of four questions for each anatomical region.[62,83] The responses to the four questions were allocated a numerical value from 0 to 25 and used to calculate a severity score from 0 to 100 for each overuse and acute injury.[62,83] Questions one and four were assigned values 0-8-17-25. In contrast, questions two and three were assigned values of 0-6-13-19-25.[62,83] The response values were allocated such that 0 represents no injuries, whilst higher values represented increasing severity of injury for each question.[62,83]

Statistical Analyses

Data were collected using the HRV4Training app (developed by Marco Altini, The Netherlands) and Google Forms (developed by Google LLC, United States), and the results were exported to Microsoft Excel (developed by Microsoft Corporation, United States). Statistical analyses were conducted in R (version 4.2.0) using a 95% confidence interval (CI) and a significance threshold of $p < 0.05$. The normality of the data were determined using skewness and kurtosis. Data met the assumption of normality if skewness values ranged between -2 and +2 and kurtosis values between -7 and +7.[87]

Descriptive statistics for continuous variables (e.g., age, participant's training duration, sRPE variation, weekly TV expressed as AU, and HRV patterns) included mean and standard deviation (SD) for parametric data or median and interquartile range (IQR) for non-parametric data. Depending on normality, descriptive statistics, including the mean and SD or median and IQR, were utilised to analyse these variables.

Categorical variables (e.g., sex, training regularity, participation in the CrossFit Open, frequency of injuries by body region, and average injury severity scores) were presented as frequencies and percentages. Also, frequencies and percentiles were computed to determine participants' adherence to the recommended "safe zone" for the A:C ratios and their compliance with daily HRV measurement using the HRV4Training app. Additionally, cross-tabulation and descriptive statistics examined the relationship between injury status and variables of interest. An independent samples t-test was conducted to compare the number of weeks spent in the safe zone range (0.8-1.3) between the injured and uninjured groups, and a one-sample t-test was used to assess statistically significant differences between participants' actual A:C ratio scores and the lower and upper safe zone range. Analysis of variance (ANOVA) with repeated measures was used for HRV patterns across the weeks to assess how HRV measures changed over time, and a two-tailed t-test for independent samples was used to assess HRV differences between injured and uninjured participants. The Chi-square and Fisher's exact tests were conducted for the variables of interest to evaluate the relationships and assess the statistical significance of any variables linked to injury risk. Additionally, symmetric measures such as Phi and Cramer's V determined the strength and magnitude of these associations.[88]

For correlations between TV, HRV, and injury risk, the A:C ratios and HRV values were transformed into z-scores to facilitate comparison and interpretability.[89] A two-tailed Pearson correlation coefficient test was used to assess linear associations between the A:C ratios and HRV z-scores, with correlation coefficients classified as follows: 0.1 (Trivial), 0.3 (Small), 0.5 (Moderate), 0.7 (Large), and 1.0 (Very large).[90,91] Logistic regression further explored whether the A:C ratios and HRV z-scores could predict injury risk, treating injury status as a binary outcome (injured or not injured).

RESULTS

Participant characteristics

Of the 33 participants aged between 16 and 60 years, 22 (67%) were female, and 11 (33%) were male. The age data were normally distributed. The average age for women was 39 years (SD = 13), and for men, 42 years (SD = 13).

Training Characteristics

Descriptive statistics of participants' training characteristics are presented in Table 3-1. Skewness and Kurtosis showed that all the variables were normally distributed.

Table 3 - 1**:** Descriptive statistics related to participants' experience, commitment to training, training regularity, and participation in the CrossFit Open competition.

Experience and commitment to training	Total (n=33)	Female (n=22)	Male (n=11)
	Mean ± SD	Mean ± SD	Mean ± SD
Years of CrossFit Training	4 ± 3	4 ± 3	4 ± 3
Commitment to training [where 1 = low commitment & 7 = high commitment]	5 ± 1	5 ± 1	4 ± 1
Training regularity	**Total (n=33)**	**Female (n=22)**	**Male (n=11)**
	n (%)	n (%)	n (%)
<2 days/week	1 (3%)	1 (5%)	0 (0%)
2 days/week	1 (3%)	0 (0%)	1 (9%)
3 days/week	10 (30%)	7 (32%)	3 (27%)
4-6 days/week	20 (61%)	13 (59%)	7 (64%)
Daily	1 (3%)	1 (5%)	0 (0%)
Participation in CrossFit Open competition	**Total (n=33)**	**Female (n=22)**	**Male (n=11)**
	n (%)	n (%)	n (%)
Yes	18 (55%)	11 (50%)	7 (64%)
No	15 (45%)	11(50%)	4 (36%)

n = number; SD = Standard deviation

TV

All data pertaining to TV were normally distributed. Participants' average weekly TV was 1299 ± 675 AU, with individual sessions lasting an average of 55 ± 32 minutes with a perceived exertion rating of 7.4. Of the 398 weekly A:C ratio observations, 261 (66%) were outside the "safe zone" (0.8 - 1.3). No participants remained within the "safe zone" for all sixteen weeks.

HRV

All data relating to HRV were normally distributed. The response rate of the HRV questionnaire was 95%, and seven of the 33 participants (21%) had a compliance rate of 100% throughout the 16-week data collection period.

Injury incidence

Twelve participants (36%) sustained 49 injuries, of which 31/49 (63%) were overuse injuries and 18/49 (37%) acute injuries. Overuse injuries mainly affected the shoulder (20 and 12%), and the acute injuries affected the foot/toe (10 and 6%). The average severity score for the reported acute injuries was 39, and for overuse injuries was 32. The number of injuries per body region and average severity score are summarised in Table 3-2.

Table 3 - 2: Descriptive statistics for injury cases per body region and average severity score.

Body region	Number of athletes			Number of injuries			Average severity scores*	
	Total	Acute	Overuse	Total	Acute	Overuse	Acute	Overuse
Shoulder	4	2	2	20	2	18	0	39
Lower leg	3	2	2	15	3	12	42	47
Foot/toe	2	2	0	10	10	0	40	0
Thigh	1	1	0	1	1	0	48	22
Elbow/arm	2	1	1	3	2	1	64	53

*0 represents no injuries, whilst higher values represented increasing severity of injury with 100 being the highest

Relationship between participant A:C values, A:C safe zone and injury

The injured group (M = 4, SD = 3) spent fewer weeks in the safe zone compared to the uninjured group (M = 5, SD = 3). However, this difference was not statistically significant t (31) = -0.71, p = 0.486, 95% confidence interval [CI] [-3.15, 1.53]. The effect size was small (Cohen's d = 0.29), indicating a negligible difference between the groups.

Table 3-3 summarises the relationship between participants' actual A:C ratio values and the lower (0.8) and upper (1.3) "safe zone" values. A statistically significant difference was observed between the mean actual A:C ratio (M = 1) and the safe zone values ($p < 0.05$). A range was calculated within the samples using a 95% bootstrap CI for the safe zone's lower (0.8) and upper (1.3) values. From this, a one-sample t-test revealed that the actual A:C ratios were 0.2 higher than the lower safe zone, t (397) = 6.18; $p < 0.001$ and 0.3 lower than the upper safe zone, t (397) = -9.27; $p < 0.001$. However, the high variability in ratios (SD = 1) suggests inconsistencies in TV despite the mean falling within the safe zone.

Table 3 - 3: One sample t-test on the differences between participants' actual A:C ratios and the "safe zone" values.

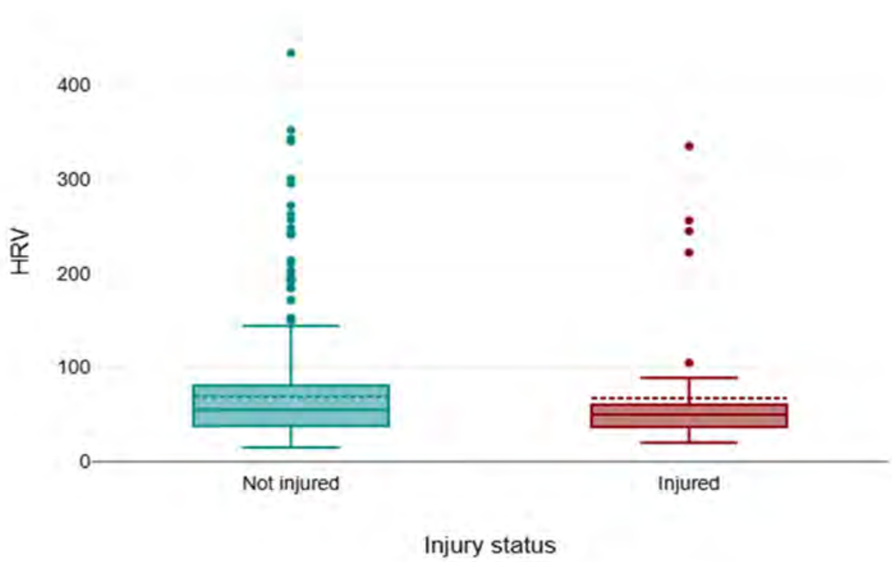
TV	Mean ± SD	95% CI	
Participants' actual A:C ratios (n = 398)	1 ± 1	0.94 - 1.05	
Parameter	t-test	Bootstrap 95% CI	*p*-value
Safe zone value = 0.8 (lower)	6.18	0.14 - 0.26	<0.001*
Safe zone value = 1.3 (upper)	-9.27	-0.36 - -0.24	<0.001*

*Statistically significant. TV = training volume; SD = standard deviation; CI = confidence intervals; A:C ratios = acute-to-chronic training volume ratios; n = numbers

HRV patterns and injury across the 16 weeks

There was no statistically significant variance in HRV across the study weeks (p = 0.987), indicating that HRV remained relatively stable over time. The within-group variance (M = 2898) was greater than the between-group variance (M = 1098), suggesting that most of the variability in HRV was due to individual participant differences rather than weekly fluctuations. When comparing HRV between injured and uninjured participants, the two-tailed t-test for independent samples showed no statistically significant difference, t (526) = 0.24, p = 0.813, 95% CI [-14.04, 17.87]. This result indicates that HRV levels did not meaningfully differ between those who sustained injuries and those who did not. Figure 3-1 presents a box plot illustrating HRV distribution by injury status.

Figure 3 - 1: Box plot of HRV by injury status.



HRV = heart rate variability

Correlations between AC ratios, HRV, and injury risk

There were no linear associations between the A:C ratios and HRV z-scores (r = 0.04; p = 0.404), so the variations in TV did not appear to have a meaningful alignment with the changes in HRV. The regression analysis for A:C ratios and HRV and injury risk is summarised in Table 3-6. Neither A:C ratios nor HRV demonstrated statistically significant associations with injury risk in this study. The A:C ratios showed a weak negative association with injury risk (odds ratio [OR] = 0.90, 95% CI [0.76 - 1.27], p = 0.886). HRV had a weak positive association with injury risk (OR = 1.22, 95% CI [0.95 - 1.75], p = 0.128). However, both A:C ratios (W = 0.02; p = 0.886) and HRV (W = 2.31; p = 0.886) displayed low Wald statistics, confirming their minimal impact on the model.

Other injury risk factors identified

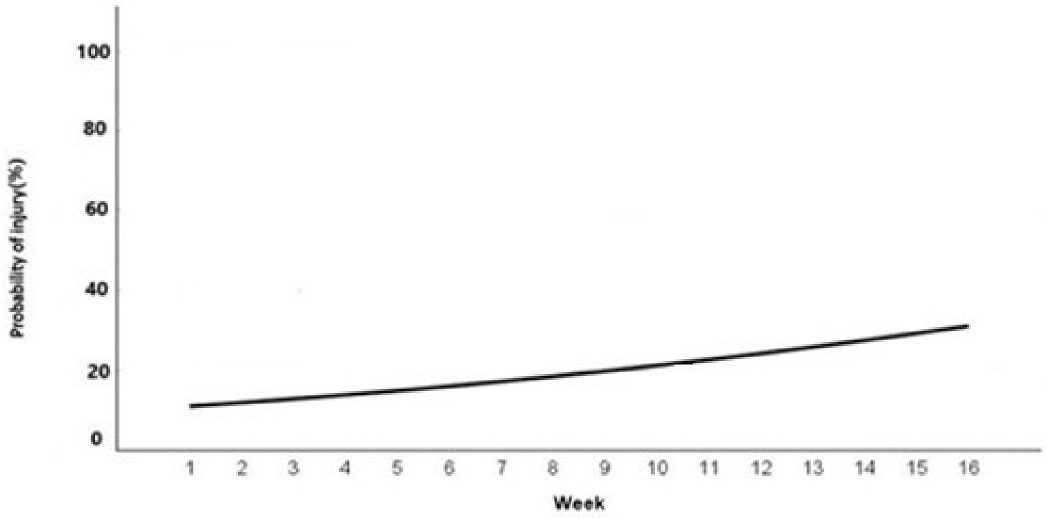
There were significant associations between age, training commitment level, training regularity, and years of CrossFit experience ($p < 0.05$). Table 3-4 summarises these associations. Among the statistically significant findings, age showed a strong association with injury (Pearson Chi-Square = 292.73, $p < .001$; Cramer's V = 0.74), with the 51+ age group reporting the highest number of injuries (51 injuries). Similarly, training duration was significantly associated with injury risk (Pearson Chi-Square = 344.27, $p < .001$; Cramer's V = 0.81). Athletes with two years of experience reported the highest number of injuries (29 injuries), whereas those with four years had the fewest. Additionally, injury risk increased from 11% in week one to 31% by week 16 (Figure 3-2). These figures reflect injuries defined according to the Wiesenthal et al.[15] three-fold injury criteria (>1 week removal, >2 weeks modification, or medical consultation), which yields more conservative estimates than definitions based on any missed session.

Table 3 - 4: Strength of injury associations between the different analysed variables.

Variable	Pearson Chi-Square	ES (Cramer's V)	*p*-value
Age	297.73	0.74	<0.001*
Sex	4.96	0.09	0.026
Commitment level	51.71	0.31	<0.001*
Training regularity	34.20	0.25	<0.001*
Competition participation	4.46	0.09	0.035
Years of CrossFit	344.27	0.81	<0.001*

*Statistically significant. ES = Effect size

Figure 3 - 2: Estimated probability of injury per week



DISCUSSION

This study explored correlations between TV, HRV, and injury risk among non-elite CrossFit athletes in South Africa. The key findings indicated that TV and HRV were not associated with injury risk. There were, however, other variables associated with increased injury risk. Notably, participants older than 51 years, males, individuals with a commitment level of four to five (medium), those training two to three times per week, and athletes with two years of experience exhibited a heightened risk of injury.

Training volume

The study found an average weekly TV of 1299 AU, with notable participant variability. This variability may be attributed to the small sample size of 33. In contrast, previous studies involving elite athletes reported higher TVs of 2092 AU[59] and 2591 AU,[62] highlighting the different training volumes between elite and non-elite CrossFit participants.

Participants' average training session duration was less than an hour (55 minutes), which might align with their non-elite status, as competitive athletes often train longer.[59,62] Despite the shorter sessions, the perceived exertion rating of 7.4 indicates that CrossFit is physically demanding. Sustained high exertion levels could potentially increase the risk of injury when experienced consistently. However, further research is required to better understand the relationship between perceived exertion in CrossFit training and injury risk.

The number of weeks spent within the "safe zone" did not significantly differ between injured and uninjured participants. While the injured group had slightly fewer weeks in the safe zone on average, the non-significant result indicates that A:C ratio fluctuations alone may not be the primary determinant of injury risk. Furthermore, despite the overall average A:C ratio being within the safe zone, 66% of participants fell outside this range. This study's actual A:C ratio range was 0.5-1.5, which overlaps with the broader "safe zone" of 0.3-1.8, yet injuries still occurred, indicating that being within the safe zone does not guarantee injury prevention. The inconsistencies in TV among the non-elite participants may have played a role in these findings, suggesting that factors beyond just A:C ratio fluctuations, such as individual differences among the participants, may have contributed to injury risk. This finding reinforces the need to consider multiple factors when assessing injury risk in CrossFit athletes.

HRV

Heart rate variability trends remained relatively similar throughout the study, with no significant week-to-week changes observed. While some studies suggest that reduced HRV may indicate an increased risk of injury,[62] this study found that injured participants did not have significantly lower HRV than those who remained injury-free. This suggests that the injured participants' HRV levels were not low enough to elicit a physiological response associated with increased injury risk.

However, individual HRV variability differences were notable, highlighting the unique nature of each participant's responses. Also, the occasional abnormally high HRV spikes in some participants may have resulted from technical errors in the HRV4Training application, potentially linked to power outages (load-shedding) in South Africa during the study period or delayed measurements after getting out of bed. Despite these challenges, the study demonstrated the feasibility of using PPG smartphone technology for HRV recordings, achieving a high compliance rate of 95%, comparable to the 94% reported by William et al.[26] Notably, regular reminders to participants were necessary to sync recordings. Without this intervention, data loss could have impacted the study's outcomes. Future research should explore methods to optimise HRV measurement accuracy in larger sample sizes.

Injury incidence

The most reported injury sites, shoulder, lower leg, and foot/toe, align with findings from other studies on injury risk factors among CrossFit athletes.[4,6,13–16] Notably, this study did not report any injuries to the lumbar spine, a common injury identified in previous research.[4,6,13–16] This difference may be explained by the strong emphasis placed by coaches on lumbar care and supervision at the CrossFit facility in Makhanda.

Correlations between TV, HRV, and injury risk

No significant association between A:C ratios and HRV was found, nor were there any substantial changes in A:C ratios associated with variation in HRV. Additionally, neither variable was individually associated with injury risk. This contrasts with the findings of Williams et al.[62], who reported that combining a 'low' HRV value with a 'high' ACWR significantly increased the risk of overuse injuries. However, their study assessed these variables in combination, whereas our analysis examined them separately. The study's multi-variable model could have yielded similar results, but sample size limitations prevented it. Future research should explore larger cohorts to better understand A:C ratios, HRV, and injury risk interactions.

Another possible explanation for this finding could be differences in TV and structure. Given their elite status, the Williams et al.[62] participants engaged in significantly higher weekly TVs (total and per day). In contrast, the non-elite athletes in this study likely had lower overall TVs and potentially less structured programmes. While elite athletes typically follow progressive and periodised training plans to balance stress and adaptation, non-elite athletes may experience fluctuating and unstructured TVs. The inconsistency in HRV may cause physiological stress without necessarily triggering the same adaptive responses observed in elite athletes.

Future research should explore whether these relationships hold across different populations, including elite and non-elite athletes and those in other sports. Understanding whether HRV and A:C ratios interact differently at varying levels of athletic performance could provide valuable insight into how best to monitor and reduce injury risk.

Other injury risk factors identified

The were significant differences between injured and non-injured participants' age, commitment to training, training regularity, the CrossFit Open Competition, and years of CrossFit training. There was a strong association between age and injury status, with older athletes (51+ years), experiencing higher injury rates. However, studies such as those by Feito et al.[2] and Weisenthal et al.[15] found no significant effect of age on injuries, likely due to their smaller sample sizes compared to this study. Age-related physiological changes, such as decreased muscle mass and joint degeneration, could explain the increased injury risk among older athletes.[92]

Additionally, the percentage of males who got injured was higher than that of females. This observation aligns with other studies suggesting that males tend to experience injuries more frequently, potentially due to differences in training behaviours.[14,15] For example, other research indicates that males tend to lift heavier loads and are more likely to take greater risks (let their egos get to them), which may increase injury susceptibility.[14] Also, it has been found that females are significantly more prone to seeking coaching supervision as opposed to males.[15]

The study also found a significant relationship between CrossFit commitment levels and injury status. Commitment levels four to five exhibited the highest injury count, possibly indicating a transition where athletes push their limits without adequate recovery. Understanding athletes' behaviours and training patterns at this level could provide insights into the increased injury risk.

An association was also noted between the frequency of training and injury status. Participants who trained "2 to 3 times per week" reported the highest injury count. This observation is similar to findings from previous research, suggesting that less frequent training may correlate with a higher risk of injury.[2] Factors such as the "constantly varied" nature of CrossFit's training style may be a possible reason for those with less experience being more prone to injuries.[2] Strength and flexibility issues or lack of efficiency in the diverse range of movements may hinder their ability to correctly complete some of the more basic exercises.[2]

A statistically significant association was also found between injury status and participation in the CrossFit Open competition. This could be attributed to higher movement proficiency and better training routine management from the CrossFit Open participants, which reduce athletes' injury risk. In contrast, non-competitors, potentially including more beginner athletes, were more susceptible to injuries.

One of the most important findings was increased injury probability throughout the study. The likelihood of injuries increased from 11% in the first week to 31% in the final week. This pattern may reflect participants' growing familiarity with reporting injuries, possibly influenced by becoming more aware of their "aches and pains", which influenced individuals' reporting behaviour.[93] Additionally, cumulative TVs over time may have contributed to increased fatigue, elevating the injury probability later in the study. This has been observed in collegiate sprint swimmers undergoing overload training, with increased fatigue and muscle soreness reported.[54]

Finally, a strong association was identified between years of CrossFit training and injury status. Athletes with two years of experience reported the highest injury count, potentially indicating that they are attempting more challenging movements without fully mastering proper techniques. In contrast, those with four or more years of experience had significantly fewer injuries, suggesting improved technique and awareness of their physical limits.

These findings highlight the importance of targeted injury prevention strategies tailored to different stages of training. The modified OSTRC-O questionnaire proved effective in capturing both acute and overuse injuries, emphasising its potential as a valuable tool for monitoring injuries in this population.

Limitations and strengths of this study

The first limitation of this study is that it was conducted at a single CrossFit gym with a relatively small sample size and, as such, the generalisability of the findings is limited. However, a single CrossFit facility allowed the research to be conducted over sixteen weeks with consistent training conditions for all athletes, and the sample size was relatively large compared to other studies on TV and HRV in CrossFit athletes. Despite this, the local training environment, coaching styles, and participant characteristics may differ elsewhere; future studies should replicate these methods across multiple facilities to enhance external validity. The second limitation was that the researcher could not control the participants' adherence to the HRV protocol as required. However, automated daily reminders were sent to participants to encourage adherence. Thirdly, participants occasionally submitted delayed HRV measurements, likely due to regional power outages (loadshedding), which affected mobile connectivity. Nevertheless, the researcher's efforts to recover missing data ensured its integrity throughout the study. Fourthly, the researcher did not collect participants' anthropometry data (weight and height), which is a known internal risk factor for musculoskeletal injury. For this reason, the ability to examine how anthropometry might have influenced injury risk and HRV responses was absent. Future research should include these measures to study interactions between anthropometrics, TV, and HRV. Lastly, injuries were self-reported by the participants and not verified by a medical professional.

The strengths of this study include: This is the first observational study in South Africa to examine the correlation between TV and HRV on non-elite CrossFit athletes' injuries.

Secondly, it was a longitudinal study conducted over sixteen weeks. This provided more in-depth research, capturing changes over time, and offering a more nuanced understanding of the correlation between TV, HRV, and injuries. Thirdly, most of the participants were female, whereas in previous studies, they were mainly males, providing additional insights into female-specific risk factors.

Practical application

The complexity of injury occurrence in CrossFit training is evident, and this study underscores the multifaceted nature of injury risk. Hence, it is imperative that coaches within the CrossFit community consider TV and HRV as interdependent factors rather than isolated risks when monitoring athletes and devising training programmes. Coaches must remain mindful of the escalating risk of injuries associated with prolonged athlete participation. Future researchers should consider study designs that would allow for multifactorial models when investigating injury risk among CrossFit athletes to attain a more profound comprehension of the intricate dynamic injury risks.

CONCLUSION

This study offers valuable insights into TV and HRV as injury risk factors among non-elite CrossFit athletes in South Africa. While no significant correlations were found between TV, HRV, and injury risk, these results contrast with previous research on elite athletes, where these factors may play a more substantial role. Additionally, factors including age (51 and older), male sex, training commitment level, frequency and years of experience were associated with injury risk. Therefore, despite TV and HRV having no link to injury, they may contribute to injury when considered alongside other variables. This highlights the complexity of injury risk, and future research should explore how these variables interact. These findings suggest that training demands, and recovery may vary with experience levels, highlighting the need for further exploration across diverse athletic populations. Future research with larger sample sizes should use multivariate models to investigate the combined influence of TV and HRV on injury risk and develop targeted interventions to mitigate injury risk among non-elite CrossFit athletes.

Conflicts of interest

The authors certify that there is no conflict of interest with any financial organisation regarding the material discussed in the manuscript.

Funding

The authors report no involvement in the research by the sponsor that could have influenced the outcome of this work.

Authors' contributions

Kieran Skae and Candice MacMillan have made substantial contributions to the design of the manuscript; Kieran Skae and Candice Christie to the acquisition, analysis and interpretation of the data. All authors have participated in drafting the manuscript; Kieran Skae, Candice Christie, Lucinda Pienaar, and Candice MacMillan revised it critically. All authors read and approved the final version of the manuscript.

OTHER INFORMATION

Table 3 - 5: Cross-tabulation injury differences across the different analysed variables.

Category	Subcategory	Non-Injured	Injured	Total
Age	16–20	16	0	16
	21–30	120	26	235
	31–40	81	16	124
	41–50	111	13	64
	51+	97	51	76
	Total	425	106	531
Sex	Female	293	61	354
	Male	132	45	177
	Total	425	106	531
Commitment level	Low (1–3)	84	12	96
	Medium (4–5)	251	88	339
	High (6–7)	90	6	96
	Total	425	106	531
Training regularity	Daily	16	0	16
	4–6 times per week	267	51	318
	2–3 times per week	109	55	164
	2 or less per week	33	0	33
	Total	425	106	531
Competition participation	No	184	58	242
	Yes	241	48	289
	Total	425	106	531
Weekly variations	Weeks 1–4	116	10	126
	Weeks 5–8	106	26	132
	Weeks 9–12	101	31	132
	Weeks 13–16	102	39	141
	Total	425	106	531
Years of CrossFit	< 1	150	27	177
	1–2	68	45	113
	3–4	129	16	145
	5+	78	18	96
	Total	425	106	531

ADDITIONAL NOTES

In addition to variables directly related to TV and HRV, factors such as age (>51 years), male sex, training commitment, frequency, and experience were associated with an increased risk of injury. There were a few cases where several other variables affected TV and HRV. However, no direct association with injury risk was identified. Therefore, the findings discussed here are speculative and intended for future research to explore these potential associations with injury. The normality of all results was assessed using skewness and kurtosis, confirming that the data were normally distributed.

Significant differences were observed between individuals training less than twice a week and those training more frequently, with the former group exhibiting significantly lower A:C ratios compared to the latter ($p < 0.001$) (Tables 3-6 and 3-7). However, while this finding is noteworthy, it should be interpreted cautiously due to the small sample size (n = 7) for those training less than twice a week (Table 3-6). Nevertheless, the significantly lower A:C ratios in this group may suggest an increased risk of injury, potentially stemming from inadequate preparation for physical demands. Conversely, athletes who train more frequently and maintain balanced TVs may be better equipped to handle physical stress, potentially mitigating their injury risk. These results emphasise the importance of structured training programmes that encourage consistent participation and gradual increases in TV. Future research with larger sample sizes is recommended to validate these associations and further elucidate the relationship between training frequency and injury risk.

Table 3 - 6: Descriptive statistics of A:C ratios for training regularity.

Training regularity	N	Mean ± SD	95% CI
Daily	13	1 ± 1	0.81 - 1.56
4 to 6 times per week	242	1 ± 1	0.92 - 1.07
2 to 3 times per week	124	1 ± 1	0.92 - 1.18
2 times per week	17	1 ± 1	0.60 - 1.26
Less than 2 times per week	7	0 ± 0	0.00 - 0.00
Total	403	1 ± 1	0.94 - 1.06

N = Number; SD = Standard deviation; CI = Confidence interval

Table 3 - 7: Multiple comparison post-hoc analysis of A:C ratios for training regularity.

Training regularity	Comparisons	Mean difference	95% CI	*p*-value
Tamhane				
Daily	4 to 6 times per week	0	-0.40 - 0.78	0.972
	2 to 3 times per week	0	-0.46 - 0.74	0.998
	2 times per week	0	-0.45 - 0.96	0.963
	Less than 2 times per week	1	0.59 - 1.77	<0.001*
4 to 6 times per week	Daily	-0	0.40 - -0.78	0.972
	2 to 3 times per week	-0	0.16 - -0.26	0.999
	2 times per week	0	0.58 - -0.46	1.000
	Less than 2 times per week	1	1.10 - 0.89	<0.001*
2 to 3 times per week	Daily	-0	0.46 - -0.74	0.998
	4 to 6 times per week	0	0.26 - -0.16	0.999
	2 times per week	0	0.64 - -0.41	0.999
	Less than 2 times per week	1	1.23 - 0.85	<0.001*
2 times per week	Daily	-0	0.45 - -0.96	0.963
	4 to 6 times per week	-0	0.46 - -0.58	1.000
	2 to 3 times per week	-0	0.41- -0.64	0.999
	Less than 2 times per week	1	1.45 - 0.41	<0.001*
Less than 2 times per week	Daily	-1	-0.59 - -1.77	<0.001*
	4 to 6 times per week	-1	-0.89 - -1.10	<0.001*
	2 to 3 times per week	-1	-0.85 - -1.23	<0.001*
	2 times per week	1	-0.41 - -1.45	<0.001*
Dunnet T3				
Daily	4 to 6 times per week	0	0.77 - -0.39	0.947
	2 to 3 times per week	0	0.73 - -0.45	0.996
	2 times per week	0	0.95 - -0.45	0.945
	Less than 2 times per week	1	1.76 - 0.60	<0.001*
4 to 6 times per week	Daily	-0	0.39 - -0.77	0.947
	2 to 3 times per week	-0	0.16 - -0.26	0.999
	2 times per week	-0	0.57 - -0.45	1.000
	Less than 2 times per week	1	1.10 - 0.89	<0.001*
2 to 3 times per week	Daily	-0	0.45 - -0.73	0.996
	4 to 6 times per week	0	0.26 - -0.16	0.999
	2 times per week	0	0.64 - -0.41	0.997
	Less than 2 times per week	1	1.23 - 0.85	<0.001*
2 times per week	Daily	-0	0.45 - -0.95	0.945
	4 to 6 times per week	-0	0.45 - -0.57	1.000
	2 to 3 times per week	-0	0.41 - -0.64	0.997
	Less than 2 times per week	1	1.44 - 0.42	<0.001*
Less than 2 times per week	Daily	-1	-0.60 - -1.76	<0.001*
	4 to 6 times per week	-1	-0.89 - -1.10	<0.001*
	2 to 3 times per week	-1	-0.85 - -1.23	<0.001*
	2 times per week	-0	-0.42 - -1.44	<0.001*

Games-Howell				
Daily	4 to 6 times per week	0	-0.37 - 0.75	0.815
	2 to 3 times per week	0	-0.43 - 0.71	0.941
	2 times per week	0	-0.42 - 0.93	0.801
	Less than 2 times per week	1	0.64 - 1.74	<0.001*
4 to 6 times per week	Daily	-0	-0.75 - 0.37	0.815
	2 to 3 times per week	-0	-0.26 - 0.16	0.961
	2 times per week	0	-0.43 - 0.55	0.994
	Less than 2 times per week	1	0.89 - 1.10	<0.001*
2 to 3 times per week	Daily	-0	-0.71 - 0.43	0.941
	4 to 6 times per week	0	-0.16 - 0.26	0.961
	2 times per week	0	-0.39 - 0.62	0.954
	Less than 2 times per week	1	0.86 - 1.23	<0.001*
2 times per week	Daily	-0	-0.93 - 0.42	0.801
	4 to 6 times per week	-0	-0.55 - 0.43	0.994
	2 to 3 times per week	-0	-0.62 - 0.39	0.954
	Less than 2 times per week	-0	0.45 - 1.42	<0.001*
Less than 2 times per week	Daily	-1	-1.74 - -0.64	<0.001*
	4 to 6 times per week	-1	-1.10 - -0.89	<0.001*
	2 to 3 times per week	-1	-1.23 - -0.86	<0.001*
	2 times per week	-1	-1.42 - -0.45	<0.001*

*Statistically significant. CI = Confidence interval

Additionally, a significant difference in HRV was observed between age groups ($p < 0.001$) (Tables 3-8 and 3-9). Notably, individuals aged 36–45 years showed a decline in HRV, followed by recovery in the 50+ age group (Tables 3-8 and 3-10). This trend may reflect the combined impact of training demands and external stressors, such as work and family responsibilities, which could reduce recovery capacity and increase the potential for injury risk. However, this interpretation is speculative, as factors like cumulative fatigue and stress management were not directly measured. Conversely, the higher HRV values among younger and slightly older athletes may suggest better recovery strategies or fewer external stressors, although this remains speculative. Further research is required to understand better the influence of training demands and external stressors on recovery and injury risk across age groups in CrossFit athletes.

Table 3 - 8: Descriptive statistics of HRV values by age group.

Age groups	N	Mean ± SD	95% CI
25 years or less	76	4 ± 0	4.09 - 4.31
26 - 35 years	102	4 ± 1	4.00 - 4.20
36 - 45 years	185	4 ± 0	3.82 - 3.96
Older than 50 years	141	4 ± 1	3.98 - 4.22
Total	504	4 ± 1	3.99 - 4.08

N = Number; SD = Standard deviation; CI = Confidence interval

Table 3 - 9: ANOVA analysis of HRV values by age group.

Source	Sum of Squares	Mean square	*p*-value
Between Groups	6.94	2	<0.001*
Within Groups	158.79	0	
Total	165.73		

*Statistically significant

Table 3 - 10: Multiple comparison post-hoc analysis of HRV for the different age groups.

Age groups	Comparisons	Mean difference	95% CI	*p*-value
		LSD		
25 years or less	26 – 35 years	0	-0.07 - 0.27	-0.07
	36 – 45 years	0	0.16 - 0.46	<0.001
	Older than 50 years	0	-0.60 - 0.26	0.224
26 – 35 years	25 years or less	-0	-0.27 - 0.70	0.254
	36 – 45 years	0	0.07 - 0.36	0.003*
	Older than 50 years	0	-0.14 - 0.14	0.997
36 – 45 years	25 years or less	-0	-0.46 - -0.16	<0.001*
	26 - 35 years	-0	-0.35 - -0.07	0.003*
	Older than 50 years	-0	-0.33 - -0.09	<0.001*
Older than 50 years	25 years or less	-0	-0.26 - 0.06	0.224
	26 - 35 years	-0	-0.14 - 0.14	0.997
	36 - 45 years	0	0.09 - 0.33	<0.001*
		Tamhane		
25 years or less	26 - 35 years	-0	-0.10 - 0.30	0.726*
	36 - 45 years	-0	0.13 - 0.48	<0.001*
	Older than 50 years	-0	-0.12 - 0.32	0.808*
26 - 35 years	25 years or less	-0	-0.30 - 0.10	0.726
	36 - 45 years	-0	0.05 - 0.37	0.004
	Older than 50 years	0	-0.21 - 0.21	1.000*
36 - 45 years	25 years or less	-0	-0.48 - -0.13	<0.001*
	26 - 35 years	-0	-0.37 - -0.05	0.004*
	Older than 50 years	-0	-0.40 - -0.02	0.019*
Older than 50 years	25 years or less	-0	-0.32 - 0.12	0.808
	26 - 35 years	-0	-0.21 - 0.21	1.000
	36 - 45 years	0	0.02 - 0.40	0.019*

*Statistically significant

Furthermore, training regularity significantly impacted HRV, with higher frequencies associated with better HRV values (Tables 3-11 and 3-12). Athletes training daily or 4 to 6 times per week demonstrated significantly higher HRV compared to those training 2 times per week or less ($p < 0.001$) (Tables 3-11 and 3-13). Higher HRV values correlated with consistent training, while those who trained less frequently had lower HRV values. Consistent training and competition positively impacted HRV, potentially reflecting enhanced recovery and autonomic function. Conversely, less frequent training could reduce the adaptive response to exercise, potentially leading to greater exercise-induced muscle damage per session and negatively impacting HRV. This decline in HRV suggests that athletes training less often might be more susceptible to injuries due to insufficient adaptation to TVs and inadequate stress management when exposed to high-intensive training. Therefore, promoting regular training could be crucial in minimising injury risk and improving overall performance. However, further research is necessary to determine the optimal training frequency for non-elite CrossFit athletes.

Table 3 - 11: Descriptive statistics of HRV for training regularity.

Training regularity	N	Mean ± SD	95% CI
Daily	16	4 ± 0	4.16 - 4.42
4 to 6 times per week	302	4 ± 0	3.98 - 4.10
2 to 3 times per week	157	4 ± 0	4.04 - 4.24
2 times per week	13	3 ± 0	3.15 - 3.39
Less than 2 times per week	16	3 ± 0	3.32 - 3.60
Total	504	4 ± 0	3.99 - 4.09

N = Number; SD = Standard deviation; CI = Confidence interval

Table 3 - 12: ANOVA analysis of HRV values for training regularity.

Source	Sum of Squares	Mean square	*p*-value
Between Groups	15.70	4	<0.001*
Within Groups	150.03	0	
Total	165.73		

*Statistically significant. CI = Confidence interval

Table 3 - 13: Multiple comparison post-hoc analysis of HRV for training regularity.

Training regularity	Comparisons	Mean difference	95% CI	*p*-value
		LSD		
Daily	4 to 6 times per week	0	-0.02 - 0.53	0.073
	2 to 3 times per week	0	-0.13 - 0.4	0.288
	2 times per week	1	0.62 - 1.43	<0.001*
	Less than 2 times per week	1	0.45 - 1.21	<0.001*
4 to 6 times per week	Daily	-0	-0.53 - 0.02	0.073
	2 to 3 times per week	-0	-0.21 - 0.01	0.288
	2 times per week	1	0.47 - 1.08	<0.001*
	Less than 2 times per week	1	0.30 - 0.86	<0.001*
2 to 3 times per week	Daily	-0	-0.44 - 0.13	0.073
	4 to 6 times per week	0	-0.01 - 0.21	0.065
	2 times per week	1	0.56 - 1.18	<0.001*
	Less than 2 times per week	1	0.40 - 0.96	<0.001*
2 times per week	Daily	-1	-1.43 - -0.62	0.288*
	4 to 6 times per week	-1	-1.08 - -0.47	0.065*
	2 to 3 times per week	-1	-1.18 - -0.56	<0.001*
	Less than 2 times per week	-0	-0.59 - 0.21	<0.001
Less than 2 times per week	Daily	-1	-1.21 - -0.45	<0.001*
	4 to 6 times per week	-1	-0.86 - 0.30	<0.001*
	2 to 3 times per week	-1	-0.96 - -0.40	<0.001*
	2 times per week	0	-0.21 - 0.59	0.353
		Tamhane		
Daily	4 to 6 times per week	0	0.05 - 0.46	0.010*
	2 to 3 times per week	0	-0.08 - 0.38	0.440
	2 times per week	1	0.78 - 1.27	<0.001*
	Less than 2 times per week	1	0.57 - 1.10	<0.001*
4 to 6 times per week	Daily	0	-0.46 - -0.05	0.010*
	2 to 3 times per week	-0	-0.27 - 0.07	0.612
	2 times per week	1	0.57 - 0.97	<0.001*
	Less than 2 times per week	1	0.36 - 0.80	<0.001*
2 to 3 times per week	Daily	-0	-0.38 - 0.08	0.440
	4 to 6 times per week	0	-0.07 - 0.27	0.612
	2 times per week	1	0.65 - 1.09	<0.001*
	Less than 2 times per week	1	0.44 - 0.92	<0.001*
2 times per week	Daily	-1	-1.27 - -0.78	<0.001*
	4 to 6 times per week	-1	-0.97 - -0.57	<0.001*
	2 to 3 times per week	-1	-1.09 - -0.65	<0.001*
	Less than 2 times per week	-1	-0.45 - 0.06	0.271
Less than 2 times per week	Daily	-1	-10.10 - -0.57	<0.001*
	4 to 6 times per week	-1	-0.80 - -0.36	<0.001*
	2 to 3 times per week	-1	-0.92 - -0.44	<0.001*
	2 times per week	0	-0.06 - 0.45	0.271

*Statistically significant. CI = Confidence interval

Finally, those with fewer years of training experience had significantly higher HRV values than those with more years ($p < 0.001$) (Tables 3-14 and 3-15). The lowest HRV was observed in the 4 to 6 years group, followed by the 6+ years group, while the highest values were found in the 3 years or less group (Tables 3-14 and 3-16). This may suggest that newer athletes undergo rapid physiological adaptation, leading to improved autonomic nervous system function. In contrast, athletes with more training experience may have reached a plateau where the body has adapted to the sustained intensity, resulting in lower HRV scores. However, this lower HRV could also suggest an increased injury risk, as reduced autonomic nervous system recovery may impair the body's ability to handle continued high training volumes. These findings align with broader research suggesting that more frequent and consistent training and competition involvement may enhance cardiovascular health and HRV.[94] However, it may also suggest that as athletes advance in their training careers, they may require more sophisticated recovery strategies to maintain high HRV while mitigating the risk of injury.

Table 3 - 14: Descriptive statistics of HRV for years of CrossFit training.

Years	N	Mean ± SD	95% CI
3 years or less	76	4 ± 0	4.09 - 4.24
4 to 6 years	102	4 ± 1	3.78 - 3.95
More than 6 years	185	4 ± 1	3.92 - 4.12
Total	504	4 ± 1	3.99 - 4.09

N = Number; SD = Standard deviation; CI = Confidence interval

Table 3 - 15: ANOVA analysis of HRV values for years of CrossFit training.

Source	Sum of Squares	Mean square	*p*-value
Between Groups	7.846	4	<0.001*
Within Groups	157.881	0	
Total	165.73		

*Statistically significant

Table 3 - 16: Multiple comparison post-hoc analysis of HRV for years of CrossFit training.

Years	Comparisons	Mean difference	95% CI	*p*-value
		LSD		
3 years or less	4 to 6 years	0	0.18 - 0.41	<0.001*
	More than 6 years	0	0.02 - 0.27	0.022*
4 to 6 years	3 years or less	-0	-0.41 - -0.18	<0.001*
	More than 6 years	-0	-0.28 - -0.02	0.026*
More than 6 years	3 years or less	-0	-0.27 - -0.02	0.022*
	4 to 6 years	0	0.018 - 0.28	0.03*
		Tamhane		
3 years or less	4 to 6 years	0	0.15 - 0.43	<0.001*
	More than 6 years	0	-0.01 - 0.30	0.069
4 to 6 years	3 years or less	-0	-0.43 - -0.15	<0.001*
	More than 6 years	-0	-0.31 - 0.01	0.066
More than 6 years	3 years or less	-0	-0.29 - 0.01	0.069
	4 to 6 years	0	-0.01 - 0.31	0.066

*Statistically significant

Linking notes for Chapters 1, 2, 3 and 4

This section contains information to clarify the link between Chapter 1 (Background), Chapter 2 (Literature review), Chapter 3 (Study 1: Are training volume and heart rate variability injury risk factors among CrossFit Athletes in South Africa?) and Chapter 4 (Study 2: Intervention strategies to reduce and minimise injury risk factors among CrossFit athletes: A scoping review). In-depth discussions of the findings of individual papers are in the discussion sections, while an overall discussion follows in Chapter 5.

As argued in the previous chapter (Study 1), no significant correlations were found between A:C ratios, HRV, and injury risk. Also, neither TV nor HRV were identified as individual risk factors for injury. However, specific groups in the study were associated with increased injury risk. Notably, age (>51 years), training commitment level, frequency and experience were associated with increased injury risk. Given the absence of a significant association between TV, HRV and injury risk, as established in Chapter 3 (Study 1), it is possible to make a link between this chapter and the broader research argument. The first step in answering the research question (Are TV and HRV associated with injury risk among non-elite CrossFit athletes in the Eastern Cape, South Africa?) was to conduct a critical review of the literature. This helped refine the research questions and guided the methodological approach.

In this Chapter, the authors examined individual athletes' TV, encompassing sRPE, duration, and frequency, to analyse the A:C ratios. Secondly, the individuals' daily HRV was analysed utilising the HRV4Training application. Lastly, the incidence of injuries of the participants over 16 weeks was assessed. Questionnaires were utilised to gather data on training volume and injury surveillance, with detailed information provided in Appendices A and C. Additionally, Appendix K provides instructions for athletes on accessing and utilising the HRV4Training application. Moreover, Appendix B delineates the procedures for author-added participant inclusion into the HRV4Training coach panel, along with grouping and analysis protocols.

In Chapter 4 (Study 2), a scoping review was undertaken to identify intervention strategies to reduce and minimise injury risk factors among CrossFit athletes. This review explores the existing literature to provide a comprehensive overview of available methods. See Tables 4-2 and 4-3 for a detailed overview of the intervention strategies identified in the review.

CHAPTER FOUR: STUDY TWO

Strategies to reduce and mitigate injury risk factors among CrossFit athletes: A scoping review

> **Kieran SKAE, Nicola SEWRY, Candice CHRISTIE, Licinda PIENAAR, Candice MACMILLAN (2024). Intervention strategies to reduce and mitigate injury risk factors among CrossFit athletes: A scoping review *(German Journal of Exercise and Sport Research) (Submitted)***

Study Two was submitted as a scoping review in the *German Journal of Exercise and Sport Research* at the same time as this dissertation submission in 2025. Throughout this thesis, figures, tables, and accompanying captions have been seamlessly integrated into the text per the journal's formatting standards. Nevertheless, the reference style has been preserved to maintain consistency throughout the document.

ABSTRACT

Objectives: Despite the high injury rates among CrossFit athletes and extensive research on injury risk factors, studies on interventions to reduce injury rates and mitigate risk factors are limited. This scoping review aimed to survey the existing literature on strategies to decrease injury occurrence and reduce injury risk factors in CrossFit athletes.

Design: A scoping review.

Methods: Following PRISMA-ScR and Joanna Briggs Institute guidelines, a search was conducted using multiple databases for studies involving CrossFit athletes of any age and skill level. The reviewers independently screened titles, abstracts and full texts against predefined inclusion criteria, extracted data on study design, intervention characteristics and outcomes, and resolved discrepancies by consensus. Extracted data were then charted and synthesised descriptively to map intervention strategies and highlight evidence gaps. The terms "CrossFit", "high-intensity functional training", "high-intensity intermittent training", and "injury prevention" were used.

Results: Seventeen articles were eligible for inclusion; four (24%) focused on intervention strategies to decrease injury rates, while thirteen (76%) focused on intervention strategies to minimise injury risk factors. Most studies (59%) were conducted in Europe. Risk factors for which interventions were sought included overtraining, insufficient recovery, muscle damage, shoulder mobility deficiencies, compromised functional movement patterns, biomechanical risk factors related to knee injuries and pain, recovery levels, and absence of coaching supervision. The intervention strategies included nutritional supplementation, warm-up and cool-down/post-exercise recovery strategies, mobility and flexibility training programmes, protective exercise gear, monitoring heart rate variability (HRV) and training load, educational interventions, and coaching involvement.

Conclusions: This review highlights research aimed at minimising injury risk in CrossFit athletes and emphasises a notable research gap in Africa and Asia. Additionally, there has been limited research on female, advanced-level, and young (<18 years) athletes. This review highlights the inconsistencies in injury definitions and reporting rates, data collection methods, and sample sizes. These findings warrant further research on nutritional supplementation, mobility and flexibility training, protective training gear, HRV monitoring and training load, CrossFit-related education, and coaching. Intervention strategies that effectively minimise injury risk factors in other sports similar to CrossFit should also be explored.

Keywords: CrossFit; high-intensity functional training; high-intensity intermittent training; injury rate; injury prevention; intervention strategies

INTRODUCTION

CrossFit is an exercise regimen characterised by constant exercise variation performed at high intermittent intensities, aimed at cultivating physical competency across various fitness domains. These encompass cardiovascular endurance, stamina, strength, flexibility, power, speed, coordination, agility, balance, and accuracy.[13,39,95] The sport promotes a holistic approach to fitness development, emphasising a balanced integration of diet, gymnastics, weightlifting, and various aerobic and anaerobic exercises.[13,39,95] To this day it is considered one of the world's most rapidly growing exercise regimes, gaining widespread popularity since the launch of CrossFit.com in 2001, with more than 15,000 affiliated gyms worldwide.[5,6,96–98] CrossFit's highly intensive functional training (HIFT) nature can be modified for various fitness levels, attracting participants from many age groups and physical condition levels.[5] Participation levels range from beginners starting individual training to intermediates engaged in group sessions multiple times weekly and advanced athletes competing in prestigious events like the CrossFit Games.[5] All CrossFit participants are called "athletes"[4] and will, therefore, also be referred to as "athletes" throughout this scoping review.

Despite the benefits of CrossFit training, which has been demonstrated to be a feasible and effective programme for improving health-related fitness,[99] high injury rates are associated with the sport.[2,5,6,13,15,16] With the growth in popularity, there has been an increase in the number of studies investigating CrossFit-related injury prevalence and incidence internationally.[5,6,13,15]

Injury prevalence rates are between 32% and 38% in periods between six and twelve months, and when expressed as injury rate per 1,000 training hours, results vary from 2.3 to 3.2.[5,6,16] The body areas most injured are the shoulders, back, and knees.[2,5,6,13,16] These results are similar to a systematic review that aimed to identify the safest type of resistance training, which included seventeen CrossFit/HIFT studies, three powerlifting, three strength training, three weightlifting and one Strongman competition.[78] Mean injury rates of 46-57% and 3.2-4.2/1,000 hours for weightlifters and powerlifters have been reported.[78] CrossFit injury rates are similar to these sports, with a mean injury incidence of 4.2/1,000 hours and an injury prevalence of 53%. The high injury rate among CrossFit and similar sports warrants research investigating injury risk factors and intervention strategies to reduce injury rates and minimise risk factors.[78]

Extrinsic risk factors associated with increased injury risk include level of recovery,[15,16,17] overtraining/diminished recovery,[100–103] and absence of coaching supervision.[15] Intrinsic risk factors associated with increased injury risk include sex, specifically males,[15] anthropometric variables (height and body composition),[16] decreased joint mobility or compromised functional movement patterns,[75,104] and previous injury.[15]

CrossFit includes components of cardiorespiratory training (including running and agility drills) and plyometric and strength exercises that resemble weightlifting and gymnastics.[4] Injury prevention programmes that improve stability, balance and strength have proven effective in reducing injuries in elite and recreational athletes participating in cardiorespiratory dominant sports such as basketball and soccer.[73,105] Physiotherapists treating gymnasts reported that, in their experience, prescribing strength programmes that incorporate weight training and recovery strategies, including foam rolling, ice, massage, and ensuring good sleep and nutrition, were associated with reduced risk of injury.[106] While intervention strategies among sports, some of which are evident in CrossFit, have been investigated, few studies have investigated intervention strategies to reduce injury rates or minimise injury risk factors (e.g., joint mobility) among CrossFit athletes.

A preliminary search of MEDLINE, the Cochrane Database of Systematic Reviews, and JBI Evidence Synthesis was conducted. Systematic reviews of CrossFit injury rates and risk factors were found.[19,97,107] However, no current or in-progress reviews were identified on intervention strategies to reduce CrossFit or HIFT-related injury incidence. Therefore, this scoping review aimed to survey the literature on intervention strategies to reduce and minimise injury risk factors among CrossFit athletes.

METHODOLOGY

This review was conducted according to the PRISMA Extension for Scoping Reviews (PRISMA-ScR)[108] and Joanna Briggs Institute guidelines[109] and was registered on Open Science Framework.

Framework Registration DOI: https://doi.org/10.17605/OSF.IO/AZDFV

Review question/objective

This review aimed to survey the extent, range, and nature of research on intervention strategies intended to reduce and minimise injury risk factors among CrossFit athletes with the following specific questions:

1) Which intervention strategies have been investigated to reduce injury rate and minimise musculoskeletal injury risk factors among CrossFit athletes?
2) What are the research gaps in these fields?

Eligibility criteria

A detailed description of the eligibility criteria is summarised in Table 4-1. In short, male and female athletes of any age participating in CrossFit-type training at any level (beginner, intermediate, and advanced) were considered. CrossFit is defined as strength and conditioning exercise programmes with constantly varied, multi-joint, functional movements and high-intensity intermittent exercise sessions designed to improve fitness and health.[4,13,110] Studies investigating intervention strategies to reduce CrossFit-related injury rates or minimise CrossFit-specific injury risk factors were analysed. Intervention strategies included, but were not limited to, the level of coaching supervision, specific warming-up routines, recovery techniques, and improving flexibility and mobility. All experimental studies conducted in any language and country were considered.

Search strategy

The search strategy was developed by KS and CM using the Peer Review of Electronic Search Strategies standard.[111] In addition, the search strategy was peer-reviewed by a research librarian with expertise in review searching and was not otherwise associated with the project. A sequential three-step search strategy was used in this review to identify published and unpublished studies published before June 2024. First, the researchers conducted a targeted exploration of PubMed, followed by an analysis of the text words in the title and abstract, and the index terms used to describe the article. Subsequently, a second search was performed across all included databases using all identified keywords and index terms. Third, the researchers used the reference lists of all the identified studies to identify other relevant studies. Initial keywords used were terms related to "CrossFit", "high-intensity functional training", "high-intensity intermittent training", and "injury prevention". The current review consisted of articles published since the database's inception, and the researcher included articles published in any language. The complete search algorithm for PubMed is illustrated in Figure 4-1.

Figure 4 - 1: PubMed Search Strategy.

History and Search Details Download Delete

Search	Actions	Details	Query	Results	Time
#3	...	>	Search: (((CrossFit[Title/Abstract]) OR (High-intensity functional training[Title/Abstract])) OR (High-intensity intermittent training[Title/Abstract])) AND ((((((((((Injury prevention[Title/Abstract]) OR (Mitigating[Title/Abstract])) OR (Recovery[Title/Abstract])) OR (Stretching[Title/Abstract])) OR (Warm-up[Title/Abstract])) OR (Cool-downs[Title/Abstract])) OR (Strength training[Title/Abstract])) OR (Mobility[Title/Abstract])) OR (Flexibility[Title/Abstract])) OR (Protective exercise equipment[Title/Abstract])) OR (Education[Title/Abstract]))	132	03:12:25
#2	...	>	Search: ((((((((((Injury prevention[Title/Abstract]) OR (Mitigating[Title/Abstract])) OR (Recovery[Title/Abstract])) OR (Stretching[Title/Abstract])) OR (Warm-up[Title/Abstract])) OR (Cool-downs[Title/Abstract])) OR (Strength training[Title/Abstract])) OR (Mobility[Title/Abstract])) OR (Flexibility[Title/Abstract])) OR (Protective exercise equipment[Title/Abstract])) OR (Education[Title/Abstract])	1,525,982	03:12:04
#1	...	>	Search: ((CrossFit[Title/Abstract]) OR (High-intensity functional training[Title/Abstract])) OR (High-intensity intermittent training[Title/Abstract])	512	03:09:14

Showing 1 to 3 of 3 entries

Source of Evidence

The databases searched included MEDLINE, Academic Search Complete, and Health Source – Consumer Edition via EBSCO, PubMed, SCOPUS, Science Direct, and Web of Science. All search results were uploaded and stored in a systematic review management platform (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia) and were accessible to all reviewers. Covidence automatically removed duplicates by reviewing the following fields: title, year, volume, and authorship. Two reviewers (KS and CM) independently reviewed duplicates removed by Covidence to verify their accuracy.

Selection of studies

The titles and abstracts of the articles found in the databases were screened for eligibility by two independent reviewers (KS and NS). Thereafter, the full text (where indicated) was reviewed by two independent reviewers. Reasons for excluding sources of evidence in the full text that did not meet the inclusion criteria were recorded and reported in the scoping review. Disagreements between two reviewers at any stage were resolved through discussion or with a third reviewer (CC). All three reviewers had previous experience with evidence synthesis. Additionally, although systematic reviews often include quality assessment, the PRISMA-ScR guidelines[108] consider formal quality assessment optional for scoping reviews, which focus on mapping the nature of evidence rather than synthesising effect sizes. Consequently, no formal risk of bias or study quality assessment was conducted, allowing for comprehensive study inclusion in alignment with the scoping-review methodology.

Data extraction

Three independent reviewers (KS, CM, and NS) extracted the data from the papers included in the scoping review. A standard data extraction template designed in the Covidence software was used for data extraction. The data extracted included specific details about the (a) study characteristics (i.e., design, location, study aim, type of sport), (b) participant characteristics (i.e., level of participation, age, sex), and (c) context characteristics (i.e., injury, risk factors investigated, and intervention strategies aimed at minimising specific risk factors or reducing specific types of injury) (Tables 4-2 and 4-3). Disagreements between the two reviewers were resolved through discussion or with a third reviewer (CC).

Data presentation

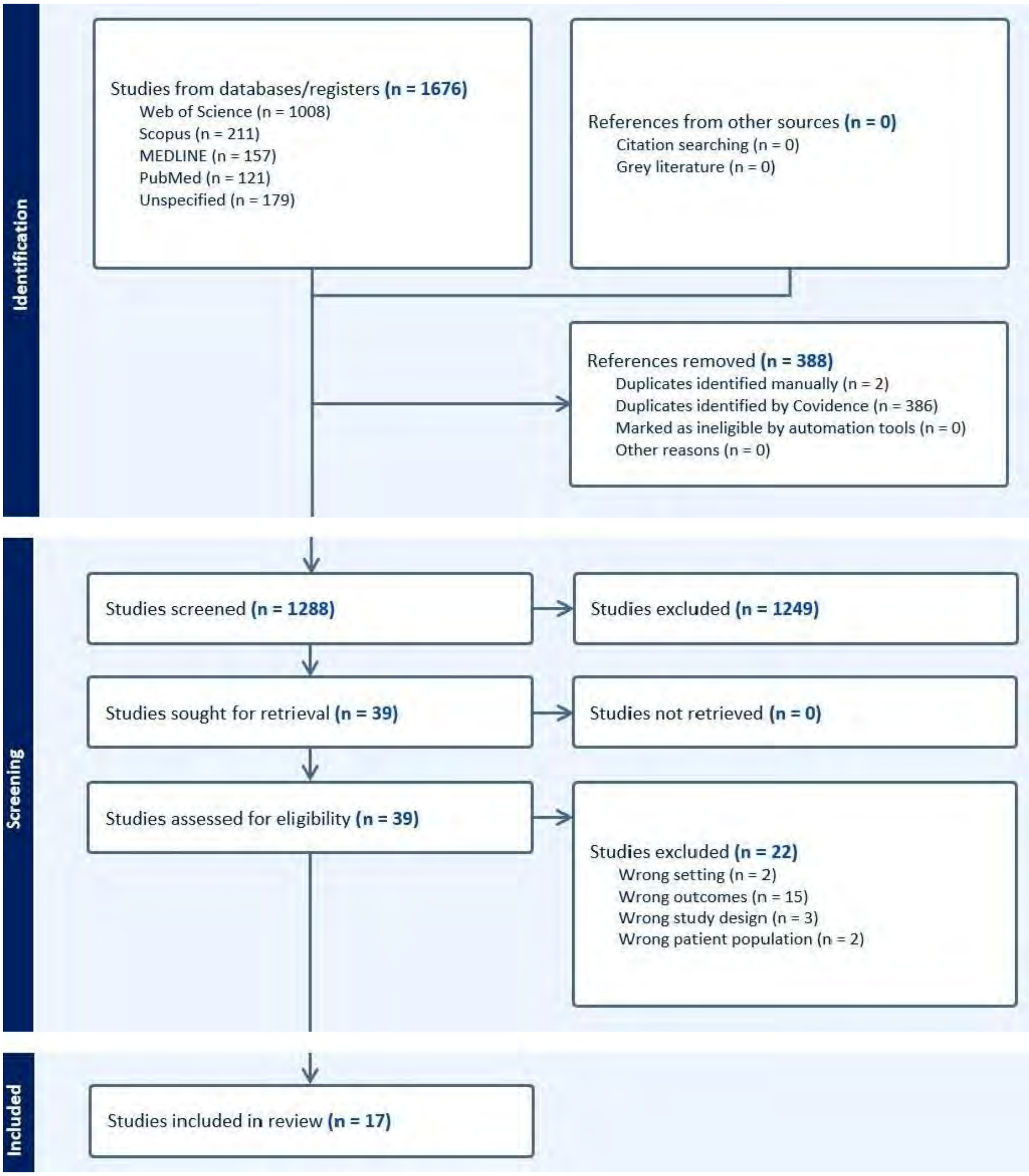
The results are presented numerically and thematically. A numerical analysis maps the data in tabular form, showing the distribution of studies by theme (injury rates and injury risk factors), year of publication, country of origin, and data that answered each question in this scoping review. A descriptive summary accompanies the tabular results and explains how they relate to the scoping review's questions and objectives.

RESULTS

Studies selected

The initial search was performed in December 2023 and updated in February 2025. Seventeen articles were eligible for inclusion in this review, with no unique records being found in grey literature. The PRISMA Extension for Scoping Reviews (PRISMA-ScR) flow diagram is displayed in Figure 4-2.[108] The study, participant, and context characteristics of the studies investigating intervention strategies to reduce injury incidence are summarised in Table 4-2, while studies investigating intervention strategies to minimise injury risk factors are summarised in Table 4-3. Although it is not the purpose of this paper to review the studies' results or assess their methodological quality, the main findings are summarised in the respective tables.

Figure 4 - 2: PRISMA 2020 flow diagram of the inclusion process of the articles in the scoping review.



Study characteristics

Most studies (n = 14; 82%) investigated CrossFit,[15,74,75,102,104,110,112–118] while two (12%) investigated high-intensity functional training (HIFT),[100,103] and one (6%) looked at Tactical Fitness (TACFIT).[101] Most studies were published between 2020 and 2024 (n = 13; 76%),[74,75,100,102–104,110,113–118] while four (24%) were published between 2014 and 2018,[15,62,101,112] Six of the seventeen studies (35%) included were conducted in Spain,[74,102–104,116,117] four (24%) in Brazil,[100,113,115,118] two (12%) in Italy,[101,114] two (12%) in Poland,[75,110] two (12%) in the United States of America,[15,112] and one (6%) in the United Kingdom.[62] Ten (59%) studies had a randomised controlled trial (RCT) design,[74,100,102–104,112–114,116,117] four (24%) had a cross-sectional design,[15,101,115,118] two (12%) had a longitudinal, cohort study design[62,75] and one (6%) had a retrospective study design.[110]

Participant characteristics

Nine (53%) studies only analysed male participants,[75,100–103,113,116–118] and eight (47%) analysed male and female participants.[15,62,74,104,110,112,114,115] Sixteen (94%) of the studies investigated participants eighteen years and older (ranging from eighteen to 60 years)[15,62,75,100–104,110,112–118], and one study did not specify the age investigated[107]. Some studies categorised participants as regular,[104] recreational,[113] or non-professional CrossFit athletes,[114] while others included individuals across all levels of participation.[15] However, nine (53%) studies outlined inclusion criteria regarding participants' CrossFit experience but did not specify whether they were regular, recreational or elite.[74,75,102,110,112,115–118] Additionally, two studies (12%) analysed HIFT athletes,[100,103]18,21 one (6%) examined elite competitive CrossFit athletes,[62] and one (6%) did not specify the level of participation.[101]

Context characteristics

CrossFit injury rates

Four (24%) studies investigated the association between different intervention strategies, injury incidence,[74] and prevalence rates[15,62] or a mixture of both.[110] All four studies investigated a range of different injuries, and three (75%) reported the types of injuries sustained.[15,62,110] Two

(50%) reported injury incidence/1000 athlete training hours[74,110] and one (25%) reported the average prevalence rates of overuse injury.[62]

CrossFit injury risk factors

Thirteen (76%) studies investigated CrossFit/HIFT injury risk factors.[75,100–104,112–118] Of the thirteen studies, one investigated more than one risk factor i.e. two risk factors.[102] Eight investigated the effect of specific intervention strategies on recovery,[100–103,112–114,117] one muscle damage,[116] two on biomechanical risk factors related to compromised functional movement patterns[75] or knee injuries and pain,[118] one on body composition[102] and two on mobility[104] or flexibility.[115]

Intervention strategies

Four studies (18%) investigated the effects of nutritional supplementation.[102,112,116,117] Eight (48%) assessed the impact of warm-up,[74,104,110] cool-down/post-exercise recovery strategies,[100,101,103,114] or a mixture of both.[113] One (8%) investigated the effects of instrument-assisted soft tissue mobilisation techniques and post-isometric horizontal adduction stretches on shoulder mobility.[104] One (8%) investigated the effects of the MobilityWOD training program.[75] One investigated the effects of Pilates method (PM) exercises on flexibility.[115] One (6%) investigated the effects of tracking and monitoring heart rate variability (HRV) and training load trends.[62] Two (12%) investigated the impact of educational factors related to CrossFit,[15,110] and one (6%) investigated the impact of coaching involvement.[15]

DISCUSSION

This scoping review aimed to survey the literature on intervention strategies to reduce injury rates (incidence and/or prevalence) and mitigate injury risk factors among CrossFit athletes. Despite broad inclusion criteria, only thirteen studies were eligible for inclusion, highlighting the scarcity of literature on intervention strategies to mitigate injury risk in CrossFit. Intervention strategies included nutritional supplementation, warm-up and cool-down/post-exercise recovery strategies, mobility and flexibility training programmes (e.g., MobilityWOD), protective training gear, monitoring HRV and training load, educational factors, and coaching involvement. Although most of the studies found an association between intervention strategies aimed at reducing injury incidence and prevalence or the reduction of injury risk factors, there were several methodological differences.

Study characteristics

Most of the studies were published between 2020-2024[74,75,100,102–104,110,113–118], while others were published between 2014-2018[15,62,101,112]. There is an apparent gap between 2019-2020, possibly due to the lockdowns during the Covid-19 pandemic, which may have affected participation in CrossFit or HIIT, data collection, and the publication of numerous studies because of its impact on community interactions. However, recent publications indicate that there is further intention to research injury prevention among CrossFit athletes.

Most studies were conducted in North America, South America, and Europe. However, a discernible gap in research is evident for Africa and Asia. This lack of evidence from low- to middle-income countries is a common thread among many sports medicine and sports science research areas and might be due to a lack of resources and funding for research in these regions. Considering that these are the largest continents globally and that CrossFit is a popular training modality in countries across both continents,[22] there is a need for additional research in African and Asian contexts. This would contribute to a more comprehensive understanding of CrossFit practices on a global scale.

Most of the studies included investigated participants training at an official CrossFit-affiliated facility[15,62,74,75,102,104,110,112–118], however, as CrossFit is a sport of high-intensity functional and intermittent training[4,13,110], a few other studies were considered eligible for this review[100,101,103]. While these eligible studies might have been conducted outside an official CrossFit affiliate, they were considered because of the similarities in training regimes. This review acknowledges that HIIT has characteristics similar to CrossFit and is often practised outside a dedicated affiliate facility. Consequently, it emphasises the importance of awareness when generalising findings about injury risk in the broader context of CrossFit. The influence of the training environment and specific training approaches on injury risk should be considered.

Most of the articles used an RCT study design.[74,100,102–104,112–114,116,117] The remainder of the studies used either a cross-sectional[15,101,115,118], cohort[62,75], or retrospective study design[110]. Cross-sectional and cohort studies are limited in injury risk research because they cannot establish causal relationships. Cross-sectional studies provide only a snapshot in time, while cohort studies are observational and prone to confounding.[119] While cross-sectional and cohort studies are commonly used in sports injury research, they have limitations, including those that make them less ideal for establishing causal relationships between risk factors and injury rates. No qualitative studies were identified. Qualitative research can add significant value to studies investigating injury risk factors and injury rates by providing deeper insights into the context, perceptions, and lived experiences of athletes, coaches, and medical professionals and should, therefore, be considered for future research.

Participant characteristics

Most studies that included both sexes pooled the results instead of presenting the results for males and females separately.[62,74,104,110,112,114,115] There are several anatomical and physiological differences between sexes. Therefore, the effectiveness of intervention strategies may differ between males and females. Studies investigating both sexes should, therefore, report results separately. Nine of the studies only included males,[75,100–103,113,116–118] limiting the generalisability of their findings for females. Given the widespread participation of female athletes in CrossFit, there is a clear need for female-specific data analysis. This highlights an ongoing gap in CrossFit research focused on female athletes.

Most of the studies investigated participants eighteen years and older[15,62,75,100–104,110,112–117,120], establishing that future research should also focus on investigating CrossFit athletes under the age of eighteen years. Currently, no studies have examined risk factors related to adolescents in CrossFit. Adolescent recovery in CrossFit might differ from adults, especially considering hormonal profiles, developing musculoskeletal systems, growth-related vulnerabilities (e.g., open growth plates), and different movement mechanics. Previous high-intensity interval training (HIIT) research showed no age-based recovery differences.[121] However, due to CrossFit's constantly varied nature of movements, future research is essential to determine whether injury risks vary in younger athletes, as this could inform the development of age-specific preventative strategies.

The participation level was not restricted to a particular group. Apart from one study that included six elite CrossFit competitors,[62] most studies outlined their inclusion criteria regarding participants' CrossFit experience. However, they did not specify whether they were regular, recreational or elite.[10,74,75,110,112,115–118] Some studies categorised participants as regular,[104] recreational,[113] non-professional CrossFit athletes,[114] or HIFT athletes.[100] While others included individuals across all participation[15] or did not specify the level of participation.[101] These inconsistencies challenge comparisons across studies, as training demands, injury risks, and performance levels differ between groups. Without clear classifications, findings may be misinterpreted, limiting their relevance for both researchers and practitioners. Standardised definitions would improve comparability and ensure that injury trends and prevention strategies are accurately assessed. Future research should also explore injury prevention strategies tailored to advanced athletes, using consistently defined sample groups to enhance the reliability of findings.

Context characteristics

CrossFit injury incidence and prevalence

There were notable inconsistencies in the measurement and reporting among the studies included[15,62,74,110], making the comparison of injury incidence and prevalence of results among studies difficult. Consensus regarding future research methodology and reporting standards should be considered to allow for comparison of findings.

CrossFit injury risk factors

Overtraining, diminished recovery, muscle damage, shoulder mobility deficiency, compromised functional movement patterns, biomechanical risk factors related to knee injuries and pain, level of recovery, absence of coaching supervision, anthropometric variables (height and body composition), previous injury, and sex have been acknowledged as injury risk factors. The only risks addressed were overtraining, diminished recovery, muscle damage, shoulder mobility deficiency, biomechanical risk factors and level of recovery. Therefore, there are gaps in the literature related to research investigating the efficacy of intervention strategies to minimise risk factors, such as anthropometric variables and sex. Also, notably, there are various methods employed by studies to measure these risk factors. However, this has made it difficult to compare the study results. It is recommended that similar reporting standards, according to published consensus statements, be used in the future to enable comparisons of relevant findings.[122]

Intervention strategies

Four studies investigated the effects of nutritional supplementation on participants' recovery rates[102,112,117] or muscle damage.[116] Among these, only one study reported a significant impact on recovery.[116] Two studies found a relationship between supplement intake and recovery,[102,112] however, the results lacked significance, while one study found no effect at all.[117] Further research is required to understand the role of supplementation as a viable and sustainable method to facilitate recovery in CrossFit athletes. There is an absence of investigation on other forms of supplementation, such as creatine monohydrate, which is considered one of the most used nutritional supplements among active individuals to enhance muscle mass, exercise performance and recovery.[123,124]

In the studies that investigated the impact of warm-up[74,104,110], cool-down/post-exercise recovery strategies[100,101,103,114] or a mixture of both[113], all eight utilised different intervention strategy styles to influence risk factors for injury, making comparisons of results and definite inferences difficult. However, most found that warm-up and cool-down routines effectively promote recovery, potentially reducing injury risk. It is worth noting which forms of warm-up, cool-down/post-exercise recovery, or both were considered the most effective in promoting recovery. Collaborative efforts to research the same intervention strategy constructs may portray more valuable and insightful results.

The studies investigating mobility[75,104] and flexibility[115] successfully improved these parameters. However, limited research on these intervention strategies made direct comparisons challenging. One study examining a physical therapy intervention for the shoulder found it effectively promoted horizontal adduction (HADD) and internal rotation (IR) mobility, reducing injury risk.[104] Despite these positive findings, further research is needed to establish its effectiveness. The study assessing the MobilityWOD training programme reported various benefits, including enhanced recovery,[75] though more research is required to confirm its reliability. Similarly, the study that used Pilates exercises demonstrated improved flexibility in participants performing the wall ball exercise, an extreme conditioning program (ECP) exercise involving high-repetition squats.[115] This suggests a potential for injury risk reduction in this movement. Future research should explore whether Pilates-based flexibility training can enhance mobility and injury prevention in other exercises, such as barbell back squats and lunges. Ultimately, prospective studies are necessary to determine whether these training programmes effectively reduce injuries among CrossFit athletes. Additionally, collaborative efforts should also focus on identifying the optimal duration and frequency of these interventions.

One study investigated the effects of tracking and monitoring HRV and training load trends, establishing that HRV monitoring can be utilised as a tool to help adjust training load prescriptions to reduce overuse injury risk.[62] However, one of the significant limitations of the study was the relatively small sample size (six subjects).[62] Future research should explore the utility of HRV and training load monitoring with a more prominent sample size to magnify more reliable, comprehensive results. Also notable is the need to differentiate between sexes, as HRV may differ throughout the menstrual cycle for females.[121] However, studies have stated that no evidence has shown that sex could affect the trends in HRV in elite triathletes[66] and CrossFitters.[62]

Two studies assessed the impact of CrossFit-related educational factors[15,110], with one of the studies also evaluating coaching involvement[15]. Coaching guidance relating to the form and technique of movements performed by participants was established to have a positive impact on the injury rate reduction.[15] Educational factors, such as how athletes should approach return to exercise after sustaining an injury[15] or how coaches and athletes distinguish between different types of pain (e.g., soreness from acute pain)[110], were both, however, mentioned as possible recommendations that could reduce the likelihood of injury or re-injury. Considering that both studies stated that education could potentially minimise injury risk factors and that coaching involvement has shown a positive contribution to injury risk reduction, more investigation is warranted.

Strengths and limitations

Some strengths to be considered are that this is the first known study to survey literature on intervention strategies to reduce injury rates and minimise risk factors among CrossFit athletes. Secondly, eight databases were searched, thereby ensuring a comprehensive search. One noticeable limitation was that although this review considered studies in any language, only studies published in English were found relevant to the study's aim.

CONCLUSION

This review identified intervention strategies for reducing injury risk among CrossFit athletes. This reveals a lack of literature and identifies several knowledge gaps. These include the underrepresentation of studies in Africa and Asia and limited exploration among female, advanced-level, and young (<18 years) athletes. The review also highlights inconsistencies in injury definitions, rates, and data collection methods, making comparisons difficult. Most research has focused on interventions related to overtraining or diminished recovery as risk factors. Intervention methods investigated were limited to nutritional supplementation, mobility and flexibility training programmes, HRV monitoring, CrossFit-related educational factors, and coaching involvement. Further research is essential to refine and validate these existing interventions and explore new, evidence-based strategies that could more effectively reduce injury risk. Addressing these gaps is crucial for advancing injury prevention strategies and for promoting the safety of CrossFit athletes.

Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Authors' contributions

Kieran Skae and Candice MacMillan have given substantial contributions to the design of the manuscript; Kieran Skae and Nicola Sewry to acquisition, analysis and interpretation of the data. All authors have participated to drafting the manuscript, Kieran Skae, Nicola Sewry, Candice Christie, Licinda Pienaar and Candice MacMillan revised it critically. All authors read and approved the final version of the manuscript.

Acknowledgements

None

OTHER INFORMATION

Table 4 - 1: Detailed description of eligibility criteria.

Inclusion criteria
Population   ▪ The definition of CrossFit was based on the definitions of the following studies: ➢ Mehrab et al.[13]: “Constantly varied, high intensity, functional movement strength and conditioning programme”.   ➢ Szeles et al.[4]: “CrossFit is a strength and conditioning exercise programme with constantly varied multi-articular functional movements and high-intensity intermittent exercise sessions designed to improve fitness and health”.   ➢ Szajkowski et al.[110]: “CrossFit is a physical activity programme and sport based on functional movements performed at high intensity and with high variability of exercises”.   ▪ According to CrossFit's philosophy, all participants, regardless of their fitness proficiency, are universally addressed as 'athletes’.[4]   ▪ This review examined individuals across all levels of participation: ➢ Beginner athletes who have recently embarked on individual training without engaging in competitive events, intermediate athletes involved in group training sessions multiple times per week but not yet at a competitive level and advanced athletes capable of competing in prestigious events such as the CrossFit Games.[5]   ▪ Any age was considered.   ➢ CrossFit and HIFT can be adjusted for any fitness level, attracting participants from a widespread distribution of ages.[5] The youngest age for competing in the CrossFit Games season is 14. However, most studies investigating CrossFit injuries analyse participants 18 years and older.   ***Concept of interest***   ▪ Studies investigating intervention strategies (e.g., coaching supervision, specific warming-up and cool-down routines, strength training programmes, recovery techniques, improving flexibility and mobility, and heart rate variability monitoring) were included to reduce CrossFit-related injury incidence/prevalence and/or mitigating injury risk factors.   ➢ Risk factors include level of recovery, overtraining/diminished recovery, absence of coaching supervision, deficiency of bodily mobility or compromised functional movement patterns, and previous injury.   ***Context***   ▪ Studies conducted in settings, regardless of the facility’s official CrossFit affiliate status, where CrossFit-type training is offered were considered.   ▪ Research articles from all countries were considered.   ***Types of studies***   ▪ Quantitative and qualitative research studies, cohort studies, case-control studies, cross-sectional studies, experimental and quasi-experimental study designs, and longitudinal study designs were included in this scoping review.

Table 4 - 2: Summation of studies investigating intervention strategies aimed at reducing injury incidence.

Author and Year	**Study Characteristics**	**Participant Characteristics**	**Context**		**Findings**
	Design / Location / Aim / Type of sport	Level of Participation / Age / Sex	Injury	Intervention strategies	
Weisenthal et al. (2014)	Design: A cross-sectional study Location: United States of America (USA) Aim: To establish an injury rate among CrossFit participants and to identify trends and associations between injury rates and demographic categories, gym characteristics, and athletic abilities among CrossFit participants. Sport: CrossFit	Level of participation: All levels included. Age: 18+ years Sex: Male and female	Injury rate: 75/386 participants (19%) had experienced at least one injury. Of the 386 participants, 63 experienced one injury (84%), ten experienced two injuries (13%), and two experienced three injuries (3%). The shoulders (21/84), lower back (12/84), and knees (11/84) were the most affected.	Increased supervision by CrossFit coaches. Coaching staff educating athletes on the skills, risks, and correct techniques needed to perform CrossFit exercises. Coaches' education related to return to exercise post-injury.	The injury rate was significantly decreased with coaching involvement. However, male athletes tended to injure themselves more frequently than female athletes. This may be because females were more likely to seek help from a coach than males, which may account for their decreased injury rate. If athletes are not experienced, it is recommended that they evaluate the skill and attentiveness of the coaches and must be made aware of risks and the correct technique required to perform different exercises included in a workout.
Szajkowski et al. (2023)	Design: A retrospective analysis Location: Poland Aim: Investigate the number and location of injuries and possible preventative strategies to reduce injury incidence in CrossFit athletes using a self-report questionnaire. Sport: CrossFit	Level of participation: CrossFitters; Participating for > 6 months. Age: 18–60 years Sex: Male and female	Of the 424 participants in the study, 204 people (48%) were injured, and 220 (52%) were not. Incidence/1000 athlete training hours: Shoulders (0.73), lower back (0.7) and knees (0.46).	Performing isometric exercises included in the warm-up. Education related to different types of pain (acute pain vs. delayed-onset muscle soreness (DOMS)).	The injury rate was significantly lower for participants who said they included isometric exercises in the warm-up than those who did not. Most participants who exercised despite experiencing acute pain (other than DOMS) were significantly more vulnerable to sustaining an injury. Therefore, it is advised to stop exercising if experiencing acute pain to reduce the risk of injury.

Martínez-Gómez et al. (2021)	Design: A randomised controlled trial Location: Spain Aim: Assess the effects of an injury-prevention programme on injury rate in CrossFit athletes. Training load and perceptual response (i.e., pain and fatigue) were also determined. Sport: CrossFit	Level of participation: Practicing CrossFit ≥ 2 times per week during the preceding year Age: Unknown Sex: Male and female	Overall injury incidence rate: 0.04/1000 training hours with a total of 101 548 hours reported.	Intervention group: Participants performed mobility and stability exercises incorporating foam rollers and elastic bands, which were done before all CrossFit sessions during the warm-up. Control Group: Participants maintained their usual warm-up routine.	Joint mobility and stability exercises did not adjust injury rate, fatigue, or pain perception in recreational CrossFit athletes.
Williams et al. (2017)	Design: A longitudinal, cohort study Location: United Kingdom Aim: Investigate the interaction between heart rate variability (HRV), training loads, and risk of overuse injuries in competitive CrossFit athletes. Sport: CrossFit	Level of participation: Competitive, elite CrossFit athletes. Age: 26-27 years Sex: Male and female	Sample size = six participants. Injured = 4 (67%) and non-injured = 2 (33%). The average prevalence of overuse injury problems in any anatomical location was 9%, and the average prevalence of substantial overuse injuries was 3%. Overuse problems affected the following anatomical areas: Knee (two cases); wrist (two cases); lower back (two cases); elbow (one case). The substantial overuse problem was to the elbow.	Tracking and monitoring HRV and training load trends.	Reductions in HRV concurrent with workload spikes were associated with an increased risk of developing overuse injuries. In contrast, high workloads were well-tolerated when HRV trends remained ‘normal’ or ‘high.

Table 4 - 3: Summation of studies investigating intervention strategies aimed to influence risk factors for injury.

Author and Year	**Study Characteristics**	**Participant Characteristics**	**Context**		**Findings**
	Design / Location / Aim / Type of sport	Level of Participation / Age / Sex	Injury risk factors and measurement	Intervention strategies	
De Oliveira et al. (2023)	Design: A randomised controlled trial Location: Brazil Aim: Investigate the effects of different recovery modalities on delayed onset muscle soreness (DOMS) and recovery perceptions following a bout of high-intensity functional training in trained men. Sport: High-intensity functional training (HIFT)	Level of participation: HIFT athletes practising the modality at least twice weekly; participating for >1 year. Age: 25-35 years Sex: Male	Risk factor: Diminished recovery Outcome measures: The Visual Analog Scale (VAS) was used to assess DOMS. The Total Quality Recovery (TQR) scale was used to assess recovery perceptions. The feeling scale (FS) was used to answer possibilities to the question "How are you feeling right now?" to evaluate the affective response to exercise.	Three recovery modalities which aimed to promote recovery were conducted following ("post") the HIFT session: Foam rolling group (FR): 45s bout of FR followed by 15s rest twice, alternating left and right sides. Static stretching group (SS): 45s bout of SS followed by a 15s rest twice, alternating left and right sides. Muscle groups for the FR and SS: hamstrings, gluteus, quadriceps, pectoralis, and latissimus dorsi. Control group (CONT) Sit quietly on a bench. Time of intervention: 20 minutes after every workout session.	Neither FR nor SS were more effective than passive rest, as participants appeared to attain similar short-term recovery after the HIFT session. The FR protocol seemed to provide better recovery perceptions, while the group performing SS as a modality showed a better magnitude of recovery represented by their pain perception and their effective response that may be related to the sum of the relaxation caused by the stretching protocol.
Di Blasio et al. (2018)	Design: A cross-sectional pilot study Location: Italy Aim: Investigate if cool-down typology can affect hormonal responses related to overtraining. Sport: Tactical Fitness (TACFIT) – Combination of high-intensity interval training and functional training.	Level of participation: Not specified. Mean Age: 34.22 +/- 7.42 years Sex: Male	Risk factor: Overtraining/Diminished recovery Outcome measures: Salivatory testosterone (T) and cortisol (C) levels to calculate cortisol: testosterone ratio. Salivary samples were measured after warm-up, training sessions, +/-4 hours after training sessions, the	Two cool-down strategies aimed to promote recovery were compared: Experimental group: Asanas poses – yoga intervention (TACFIT® workout + Asanas protocol). Control group: TACFIT® workout without Asanas poses at the end.	The addition of the Asanas at the end of a TACFIT® workout seems to determine lower salivary cortisol and cortisol to testosterone ratios and higher testosterone with respect to a traditional TACFIT® workout.

			morning of the next training session and once on none-training days.	Time of intervention: 10 minutes after every workout session.	
Fernández-Lázaro et al. (2021)	Design: A randomised, single-blind, placebo-controlled trial Location: Spain Aim: Evaluate the effects of Tribulus terrestris L. (TT) supplementation on body composition and hormonal responses regarding testosterone and cortisol when performing a CrossFit training program. Sport: CrossFit	Level of participation: CrossFitters with at least 20 months of CrossFit experience and previous completion of "Fran" (benchmark workout of the day - WOD). Age: 18-50 years Sex: Male	Risk factors: Body composition Diminished recovery Outcome measures: Body composition was determined by body mass, fat mass, and fat composition. Recovery was determined by testosterone and cortisol levels. Total testosterone was assessed by enzyme-linked immunosorbent assay (ELISA). Cortisol concentration was assessed by enzyme-linked fluorescence assay (ELFA)-based technology using ready-to-use reagents with a compact multiparametric immunoanalyzer Minividas.	Supplementation intervention group: Participants consumed two capsules (770 mg) daily of TT on an empty stomach for six weeks. Control group: Did not consume the TT capsules.	TT supplementation did not impact body composition in CrossFit male athletes. However, TT supplementation may act as a testosterone booster, helping the recovery after physical loads and mitigating fatigue.
Martínez-Gómez et al. (2022)	Design: A crossover randomised controlled trial Location: Spain Aim: Compare the effects of three different recovery strategies [active recovery (voluntary exercise), surface neuromuscular electrical stimulation (NMES), or total rest] following a high-intensity functional training session. Sport: High-intensity functional training (HIFT)	Level of participation: HIFT athletes with previous training experience with HIFT (≥ one year, ≥3 training sessions/week). Mean age: 29 years Sex: Male	Risk factor: Overtraining/Diminished recovery Outcome measures: Delayed onset of muscle soreness (DOMS) was assessed through a 0–10 Visual Analog Scale (VAS), which was measured at four-time points (baseline, immediately post-WOD, post-recovery, and 24h post-exercise). Blood lactate concentration was quantified using a portable analyser, which was analysed at	Following the HIFT session, participants recovered for 15 minutes with one of the three recovery strategies: Low-intensity leg pedalling group: RPE of 6 out of 10 on a cycle ergometer. NMES group: An electrical stimulator with surface electrodes was used to evoke involuntary muscle contractions in the lower limbs (quadriceps, hamstrings, and calves).	Findings suggest comparable effectiveness of NMES, low-intensity leg pedalling or total rest for enhancing recovery, with the former tending to lower perceived fatigue immediately after recovery compared with total rest. NMES group: Results show a slightly quasi-significant improvement in the subjective perception of recovery immediately after its application, although a potential placebo effect should not be disregarded.

			baseline (before warm-up) and at several time points during the recovery phase (0, 7.5, and 15 min, respectively, after the WOD). Muscle oxygen saturation (SmO2) of the right vastus lateralis muscle was determined continuously during the 15 min of the recovery phase. A chest strap continuously monitored heart rate (HR) during the recovery phase.	Control group: Participants remained seated (total rest).	However, no additional benefits were found with NMES for other perceptual (DOMS) or physiological indicators (blood lactate, HR, muscle oxygen kinetics).
Triviño et al. (2024)	Design: A randomised, triple-blind, placebo-controlled, crossover design Location: Spain Aim: investigate the effect of acute carbohydrate (CHO) intake during a CF session on the delayed onset muscle soreness (DOMS), the perceived exertion (RPE), performance, recovery, and metabolic markers (capillary lactate and glucose) in CrossFit athletes. Sport: CrossFit	Level of participation: Having a minimum of 3 years of experience in CrossFit, with at least 6 hours of training per week for the last 3 months. Age: 18-35 years Sex: Male	Risk factor: Diminished recovery Outcome measures: Exercise-induced muscle damage (EIMD) was assessed using a validated visual analogue scale (0–100 mm), where 0 indicated no pain, and 100 was unbearably painful, administered 24 and 48 hours post-test. RPE was recorded after each block using the Borg scale (0–10), while emotional sensations were evaluated via the Feeling Scale (FS). Gastrointestinal distress was assessed using the Gastrointestinal Distress Scale (GDS) following carbohydrate consumption. Heart rate was measured post-block with a Quirumed OXYM4000 pulse oximeter,	CHO intervention: Participants consumed either 5 g placebo (PLA) or 65 g CHO (60 g CHO in a 2:1 maltodextrin-to-fructose ratio) dissolved in 750 ml of water during the session, with identical flavour and appearance. Supplements were randomly assigned. The session began with a CMJ warm-up and three CMJ trials, followed by the AST70 test (max squats at 70% body weight in 30sec). After a 3–5 min rest, participants completed a snatch warm-up, then performed five high box jumps and one snatch every 1:15 min, progressing from 60% 1RM to max load. After a 10min rest, they did three sets of back squats (1 rep at 90% 1RM, 8 reps at 70% 1RM, 3min rest). Another 10min rest preceded a 16min EMOM (20-s	The ingestion of 60 g of CHO during a two-hour CF session did not enhance DOMS, perceived effort, performance, recovery, and metabolic variables in CrossFit athletes.

			while capillary glucose and lactate were assessed via finger prick using the GlucoMen Areo 2K and YST blood lactate meter, respectively, at key workout stages.	assault bike sprint, 40-s rest; 40-s thrusters, 20-s rest; 1 min rest). After a final 10min rest, they completed a 9-min AMRAP (starting with 10 double-unders, increasing by 5 reps each round, plus 6 burpees and a 7-m shuttle run).	
Outlaw et al. (2014)	Design: A randomised open-label study Location: United States of America (USA) Aim: Investigate if a six-week pre-workout and post-workout supplementation can aid recovery of high-intensity exercise in trained CrossFit individuals by analysing VO2 max, Wingate peak (WPP) and mean power (WMP). Sport: CrossFit	Level of participation: CrossFitters practising CrossFit three times a week; participating for >6 months minimum. Mean age: 31.87 years Sex: Male and female	Risk factor: Level of recovery Outcome measures: VO2max was assessed using the Bruce protocol treadmill test to determine anaerobic capacity. The VO2max value in mL/kg/min was recorded after the completion of the test. WPP and WMP were assessed using the Excalibur Sport V2 bicycle, which was recorded in Watts to determine aerobic capacity.	Supplement group: Participants received a pre-workout supplement (containing pomegranate fruit extract, tart cherry extract, beetroot extract, green tea extract, and black tea extract) and a whey-protein and carbohydrate supplement mixed with water (F = 1 serving; 20 g protein; 40 g carbohydrate and M = 2 servings; 40 g protein; 80 g carbohydrate). Time of consumption: Pre-workout sup = consumed 30 mins before each workout, and post-workout sup = consumed immediately after each workout. Control group: Participants consumed only water one hour before and one hour after each CrossFit workout. Both groups performed two workouts of the day (WODS) before and after the six weeks. Testing (T1 & T2) was done within 48 hours of completing WOD1 and WOD2.	The pre-workout supplement that was taken 30 minutes before each CrossFit workout possibly assisted the participants in recovering from the previous exercise bout, and this might be reflected in the better recovery of VO2max, WPP and improvement from T1 to T2. It seems logical that if one can recover more quickly from exercise, they will be more prepared to handle the physical stress of the subsequent workout.
Tonlorenzi et al. (2021)	Design: A randomised controlled trial	Level of participation: Non-professional CrossFit athletes.	Risk factor: Level of recovery	Experimental group (MS): Participants were instructed to	Mandibular stretching, stimulating the trigeminal-

	Location: Italy Aim: To see whether regularly practised mandibular (mouth) stretching at submaximal jaw opening can facilitate post-workout recovery as measured by cardiovascular parameters and blood lactate levels. Sport: CrossFit	Age: 20-30 years Sex: Male and female	Outcome measures: High heart rate, blood pressure and blood lactate. Blood pressure and heart rate were taken with a digital sphygmomanometer immediately before and after the two workouts and after 5 minutes from the end of the exercises. Blood lactate levels were measured with a portable blood lactate meter Accutrend Plus Roche using reflectance photometry. Blood samples were collected with blood lancet Accu-check immediately before and after the workout and 30 and 60 minutes after.	perform ten minutes of mandibular stretching twice daily for one week, immediately after the training session and in the evening before bed. Dosage: Ten minutes of stretching for each session, which had to be completed over eight days. Control group (C): Did not perform mandibular stretching. Both groups performed two high-intensity CrossFit workouts seven days apart while training as usual on the days between.	cardiac reflex and central oxygen-conserving mechanisms could help relieve post-training stress and improve training recovery. Also, the data presented suggested that in athletes subjected to high-intensity physical exercise, daily application of a mandibular stretching procedure results in a significant improvement in the time of recovery as measured by blood lactate levels.
Pinto et al. (2022)	Design: A randomised, triple-blind, placebo-controlled crossover trial Location: Brazil Aim: Investigate the effects of photobiomodulation therapy combined with a static magnetic field (PBMT-sMF) applied at different time points (before, after, or before and after the workout of the day (WOD)) on recovery in CrossFit athletes by analysing muscle damage, inflammation, and oxidative stress. Sport: CrossFit	Level of participation: Recreational CrossFitters who have been practising CrossFit for at least one year. Age: 18-35 years Sex: Male athletes	Risk factors: Level of recovery. Outcome measures: Muscle damage, inflammation, oxidative stress, and antioxidant activity were measured by assessing blood samples. Blood samples measuring 5 ml were collected from the anterior cubital vein to analyse muscle damage, inflammation, and oxidative stress before (baseline) and 1, 24, and 48 hours after the WOD.	Randomisation and blinding of the participants were used in the study, and each participant recruited was assigned to receive one of the four possible recovery interventions: Placebo before and after WOD (placebo), PBMT-sMF before and placebo after WOD (PBMT-sMF before), placebo before and PBMT-sMF after WOD (PBMT-sMF after), and PBMT-sMF before and after WOD (PBMT-sMF before and after). These possible recovery strategies were completed before or after the prescribed WOD, which participants performed at the same hour of the day for each of the four interventions.	PBMT-sMF decreased the levels of biochemical markers of muscle damage and inflammation, reduced oxidative stress, and increased antioxidant activity in CrossFit athletes when applied before or after the WOD (PBMT-sMF before and after). PBMT-sMF applied before or after WOD significantly decreased the creatine kinase, catalase, and superoxide dismutase activities and interleukin-6, thiobarbituric acid, and carbonylated protein levels compared to the other three interventions.

				However, each intervention was performed on a separate week (intervals of seven days between them, for a total of four weeks).	
Vicario-Merino et al. (2024)	Design: Experimental repeated measures, controlled and randomised, double-blind pilot study Location: Spain Aim: Investigate the impact of high-intensity activity (Karen – CrossFit benchmark workout) on athletes' creatine kinase (CK) levels and the effects of branched-chain amino acid supplementation (BCAA) on pain, fatigue, and recovery indicators. Sport: CrossFit	Level of participation: 6 months of experience in high-intensity training (CrossFit), with a minimum frequency of 3 times per week. Age: 34 years Sex: Male	Risk factor: Muscle damage Outcome measures: Blood samples were collected before the Karen test at 24, 48, and 72 hours, with CK values in blood analysed. The rate of perceived exertion (RPE Scale 0–10) was recorded at each sampling point using the Visual Analog rating scale.	Supplementation intervention: The participant received the BCAA supplementation in either an 8:1:1 or 2:1:1 ratio (with L-leucine as the predominant amino acid) or a placebo containing maltodextrin and rice flour. 15 g per day was consumed, starting 72 hours before the first blood sample and the initial Karen workout. Supplementation continued for seven consecutive days, with intake occurring at the same time each day. This protocol followed the recovery time study framework for trained athletes performing the CrossFit Karen routine, ensuring supplementation began one week before data collection.	The BCAA supplementation with the ratio of 8:1:1 proved to have a protective effect on muscular damage, as seen in the CK values and in the RPE, allowing the participant to reach a perception of no pain 72 hours later.
Maynart et al. (2024)	Design: A cross-sectional exploratory study Location: Brazil Aim: Investigate whether wearing 7 mm neoprene knee sleeves during the front squat and box jump CrossFit exercises reduces the biomechanical risk factors related to knee injuries and pain. Sport: CrossFit	Level of participation: Practicing CrossFit for at least six months and three times a week. Age: 18-45 years Sex: Male	Risk factor: Biomechanical risk factors related to knee injuries and pain Outcomes measures: Kinematic and kinetic data of the knee in the sagittal, frontal and transverse planes were obtained for the two tasks and under the two experimental situations. The maximum load lifted on 1 rep max test was recorded under knee sleeves (KS) and without knee sleeves (WKS) conditions. The GROC	Knee sleeve intervention: Participants performed five repetitions of the front squat movement at 70% of 1RM and five repetitions of the box jump exercise on a twenty-four-inch box for KS and WKS conditions. In KS conditions, the participants wore 7 mm neoprene knee sleeves made of polymer material, without a patellar hole (Slim liPing brand). This knee-sleeve model was chosen due to its popularity with CrossFit athletes.	The neoprene KS had little impact on the biomechanics of the knee joint during CrossFit. However, participants reported that the neoprene KS model promoted knee stability and were willing to use it to prevent knee injuries.

			scales were applied after each exercise and condition to assess participants' self-reported perception of stability.		
Kaczorowska et al. (2020)	Design: A longitudinal, cohort study Location: Poland Aim: Assess the effect of the Mobility Workout of the Day (WOD) training program on functional movement patterns related to the risk of injury in adult male CrossFit practitioners. Sport: CrossFit	Level of participation: Practising CrossFit five times a week; participating for >1 year minimum. Age: 20-35 years Sex: Male	Risk factor: Biomechanical risk factors (Compromised functional movement patterns) Outcome measures: Functional Movement Screen (FMS) tests (FMS= 3 marks per test, seven tests) (obtaining 14 points or less on the test shows dysfunctional movement patterns = injury is significantly increased).	MobilityWOD intervention: Comprised of exercises derived from physiotherapy and functional training. Dosage: Eight weeks total, done once a week, lasting 45 minutes. Experimental group: Participants performed exercises with foam rollers, lacrosse balls and resistance bands. Control group: Not created due to the club's small number of CrossFit participants.	MobilityWOD training improved the quality of functional movement patterns and reduced the risk of injury. Before MobilityWOD training, 26% of the group achieved an equal or lower score (14 points) on the FMS, thus indicating an increased risk of injury. After performing the exercises according to the MobilityWOD training methodology, only 6% of the respondents achieved results of 14 points or below on the FMS test.
Jusdado-Garcia et al. (2021)	Design: Randomised, single-blind pilot study Location: Spain Aim: Determine the effectiveness of a physical therapy intervention through instrument-assisted soft tissue mobilisation and horizontal adduction shoulder stretches in CrossFitter's shoulder mobility. Sport: CrossFit	Level of participation: Regular CrossFitters who exercise two days/week. Age: 18-40 years Sex: Male and female	Risk factor: Shoulder mobility (glenohumeral internal rotation deficit and posterior shoulder stiffness). Outcome measures: Shoulder internal rotation (IR) and horizontal adduction (HADD) (digital inclinometer). Posterior shoulder stretch per Caption (Park scale).	Physical therapy intervention: Experimental group: Instrument-assisted soft tissue mobilisation techniques and post-isometric horizontal adduction stretches. Control group: Only soft tissue mobilisation was performed. Dosage: 2-5 min, two days/week, over four weeks, before each workout.	Experimental group: All variables improved. Control group: Improvement in right HADD and left IR. Instrument-assisted soft tissue mobilisation can improve shoulder HADD and IR. An instrument-assisted soft tissue mobilisation technique yields the same results as those achieved combined with post-isometric stretch with shoulder adduction.
Pires et al. (2024)	Design: An observational cross-sectional study Location: Brazil Aim: The aim of this study was to evaluate the acute effects of Pilates	Level of participation: Practicing an ECP (CrossFit) for at least three months, not being inserted in another training program, without previous contact with the Pilates method, and being sufficiently physically healthy to	Risk factor: Flexibility Outcome measures: The Wells bench test was used to measure flexibility in the posterior spine and thigh chain of an individual. The volunteer	Flexibility intervention: The study involved participants in a 50-minute Pilates intervention class, focusing on the main joints involved in performing the Wall Ball exercise. The exercises were performed using the Universal	A single session of PM exercises was able to significantly improve flexibility immediately after the exercises. Lower flexibility was observed before the intervention (19.8

	method (PM) exercises on the flexibility of an extreme conditioning program (ECP) involving the movement known as the wall ball CrossFit exercise). Sport: CrossFit	perform the procedures. Age: 18 years or older Sex: Male and female	was barefoot, sitting on a mat with the plantar fascia resting on a 20 cm high bench. They performed three movements, followed by trunk flexion without knee flexion.	Reformer device, with verbal commands given to improve performance. Participants performed footwork exercises, stomach massage, and front splits. The exercises involved supine positions, pushing the Reformer, and maintaining fluid movements. The participants were encouraged to maintain axial elongation and avoid "plumbing" postures.	±4.46 cm), compared to the measurement performed afterwards (24.3 ±10.46 cm). For the repetitions of the Wall Ball exercise, the initial data (21.3 ±9.0) were lower than the final data (23.7 ±13.0), showing that the PM exercises significantly improved the participants' flexibility after the intervention.

Figure 4 - 3: Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	2-3
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	5
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	6 and Supp Table 1
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	6
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	6
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	7
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	7
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	7-8
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	8
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	8
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	N/A
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	8

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	9 and Figure 1
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	9-10
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	N/A
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	10-11
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	10-11
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	11-16
Limitations	20	Discuss the limitations of the scoping review process.	17
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	17
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	18

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

Figure 4 - 4: Proof of submission to German Journal of Exercise and Sport Research

German Journal of Exercise and Sport Research

Strategies to reduce injury rates and mitigate injury risk factors among CrossFit athletes: a scoping review

--Manuscript Draft--

Manuscript Number:	
Full Title:	Strategies to reduce injury rates and mitigate injury risk factors among CrossFit athletes: a scoping review
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Linking notes for Chapters 1, 2, 3, 4 and 5

This section clarifies the link between Chapter 1 (Background), Chapter 2 (Literature Review), Chapter 3 (Study 1: Are Training Volume and Heart Rate Variability Injury Risk Factors Among CrossFit Athletes in South Africa?), Chapter 4 (Study 2: Intervention Strategies to Reduce and Minimise Injury Risk Factors Among CrossFit Athletes: A Scoping Review), and Chapter 5 (Discussion). In-depth discussions of the findings of individual papers are presented in their respective discussion sections, while an overall discussion follows in Chapter 5.

As argued in Chapter 3 (Study 1), no significant correlations were found between A:C ratios, HRV, and injury risk. Additionally, neither TV nor HRV were identified as individual risk factors for injury. However, certain demographic and training-related factors, such as age (>51 years), training commitment level, frequency, and experience, were associated with increased injury risk. Given the absence of a significant association between TV, HRV, and injury risk, Chapter 4 (Study 2) builds upon these findings by identifying intervention strategies that may mitigate injury risk factors. Tables 4-2 and 4-3 provide a detailed overview of the intervention strategies identified in the scoping review.

Chapter 5 integrates the literature review (Chapter 2) with the findings from Chapters 3 and 4 to highlight the broader implications of this dissertation. Furthermore, it informs future research and practice in the sport.

CHAPTER FIVE: DISCUSSION

Despite high injury rates, 19% to 74% from 2013–2018[2,12,13,15,16] and 32% to 60% from 2019 to 2023,[4–6,14,110,125] few intervention studies have been conducted, leaving prevention strategies underdeveloped. Applying the TRIPP framework, a structured, six-stage approach to sports injury prevention,[126] it is evident that CrossFit injury research primarily remains at stage two, which focuses on establishing injury causes and mechanisms.[126] Few studies have advanced to stage three, which involves introducing and assessing preventive interventions.[126] This study addressed this gap by investigating injury risk factors, specifically TV and HRV, among non-elite CrossFit athletes and identifying existing prevention strategies through a scoping review. By combining insights from both studies, this research aims to contribute toward progressing CrossFit injury prevention strategies beyond risk identification and towards effective, evidence-based interventions, ultimately supporting the long-term health and performance of CrossFit athletes.

A key finding from study one (observational study) was that TV and HRV were not significantly associated with injury risk among non-elite CrossFit athletes. Instead, demographic and training-related factors, such as being 51 years and older, training two to three times per week, having two years of experience, and maintaining medium commitment levels, were more closely associated with injury occurrence. These findings challenge the assumption that physiological markers alone can predict injury risk in non-elite populations, suggesting that behavioural patterns and training history may play a more significant role.

Study two (scoping review) reinforces this perspective by highlighting the limited research on structured injury prevention strategies in CrossFit, especially in Africa and Asia, and among female, advanced-level, and younger athletes. Inconsistencies in injury definitions, data collection methods, and sample sizes further complicate comparisons across studies, reducing the reliability of current findings. The review identified several key intervention areas, with warm-up and cool-down protocols emerging as the most frequently studied strategies[74,100,101,103,104,110,113,114]. However, differences in specific protocols across these studies limit direct comparisons and generalisations. Other interventions investigated less extensively include nutritional supplementation,[102,112,116,117] mobility and flexibility training programmes,[75,115] protective exercise gear,[118] monitoring HRV and training load,[62] educational factors,[15,110] and coaching involvement[15]. Nevertheless, the effectiveness of these approaches in reducing injuries remains inadequately explored, underscoring the necessity for further research. Numerous potentially valuable interventions, such as targeted strength and conditioning programmes, psychological strategies, educational factors focusing on technique modifications, tailored recovery strategies (e.g., sauna and ice baths), and nutritional supplements like creatine monohydrate, are underexplored or entirely unexamined. Future robust intervention studies are, therefore, essential to address these critical research gaps.

To clearly illustrate how this research fits within the TRIPP framework described by Finch et al.[126] Each of the six stages can be described as follows: Stage one involves injury surveillance. Stage two corresponds to understanding the aetiology of why the injuries occurred. Stage three involves the identification of potential preventative strategies to minimise the injury problems found. Stage four corresponds to assessing the effectiveness of the interventions. Stage five involves assessing the effectiveness of the preventative strategies in a real-world context. Finally, stage six involves implementing these strategies broadly, evaluating their real-world effectiveness, and refining approaches to ensure sustainability and broader adoption.

The observational study aligns primarily with stages one and two, through injury surveillance and exploration of associated injury risk factors among non-elite CrossFit athletes. Specifically, it identified demographic and training characteristics that were more strongly associated with injury risk than physiological markers alone (TV and HRV). The scoping review aligns with stage three, by mapping existing injury-preventative strategies and highlighting significant gaps in structured interventions. Stages four to six represent critical future research directions, including rigorous testing of preventive interventions (stage four), studies focused on practical implementation strategies (stage five), and real-world effectiveness evaluations (stage six), as emphasised in the scoping review findings. Figure 5-1 visually summarises this alignment, clearly demonstrating how the current findings and recommendations relate to each TRIPP stage. Adopting this structured approach illustrates how future CrossFit injury research can methodically advance towards meaningful improvements in injury prevention, necessitating more innovative and effective methods for capturing and mitigating injury risks.

Figure 5 - 1: Applying the TRIPP Framework to CrossFit Injury Research

Model stage	TRIPP
Stage 1: Injury surveillance	**Definition:** Identify injury prevalence and incidence. **Findings:** - Twelve (36.4%) out of 33 participants sustained 49 injuries. - Injury rate aligns with the previous research range of 32.2%-60.2% (2019-2023). - 63.2% of the injuries were overuse, and 36.7% were acute. - Most affected areas: shoulder, foot/toe.
Stage 2: Establishing risk factors	**Definition:** Understand the causes and mechanisms for injury. **Findings:** - Key risk factors: age = 51, training frequency (2/3 sessions/week), moderate commitment and two years of CrossFit experience. - Physiological markers (TV, HRV) were less predictive of injury.
Stage 3: Introducing preventative strategies	**Definition:** Identify and propose interventions to address injury risks. **Findings:** - The scoping review identified inconsistently applied strategies (e.g., warm-ups, cool-downs). - Significant gaps were noted in structured preventative interventions.
Stage 4: Assessing intervention effectiveness	**Definition:** Test preventative measures under controlled conditions. **Recommendations:** - Conduct robust trials evaluating identified preventative strategies (e.g., mobility/flexibility training programmes and HRV monitoring) and underexplored strategies (e.g., sauna, ice bath, creatine monohydrate intake).
Stage 5: Describe intervention context and implementation	**Definition:** Evaluate the practicality and feasibility of implementing preventative strategies. **Recommendations:** Implement studies assessing the real-world feasibility of preventative strategies in CrossFit gym settings.
Stage 6: Evaluate effectiveness in practice	**Definition:** Assess broader implementation, effectiveness, sustainability, and refinement of interventions. **Recommendations:** - Perform long-term effectiveness evaluations, refine interventions based on findings, and encourage widespread adoption of proven strategies.

The integrated findings from this dissertation emphasise the multifaceted nature of injury risk in CrossFit, highlighting the necessity of an all-inclusive, practical approach to injury prevention. Although previous research has typically investigated interventions targeting single injury risk factors independently, an integrated approach addressing multiple risk factors simultaneously, despite methodological complexities, may be more beneficial, as athletes function as interconnected systems within broader environmental contexts. Researchers, coaches and practitioners in the CrossFit community should adopt a holistic view of athlete management, considering physiological metrics like TV and HRV, as well as demographic and behavioural factors. To facilitate practical implementation and guide future research, specific recommendations for coaches and researchers are summarised in Table 5-1. Ultimately, the TRIPP framework provides a valuable tool for systematically advancing CrossFit injury research from surveillance and risk factor identification to effective real-world interventions. Future research can translate evidence-based knowledge into intervention by progressing through each TRIPP stage, enhancing athlete safety, performance, and overall well-being. This structured approach sets the stage for targeted recommendations and future research opportunities to reduce injury risk in CrossFit athletes.

Table 5 - 1: Recommendations for coaches and researchers for injury prevention

Recommendations for Coaches	Recommendations for Researchers
• **Holistic Athlete Management** - Adopt a holistic management approach. - Prioritise demographic and behavioural profiling (age, sex, training frequency, experience, athlete commitment). - Regularly monitor athlete progress and adapt accordingly.	• **Standardisation and Clarity** - Adopt standardised guidelines to enhance clarity and reliability across studies. - Clarify injury definitions and standardise research methodologies.
• **Intervention Strategies** - Implement structured warm-up and cool-down protocols with mobility and flexibility exercises. - Encourage the use of protective gear. - Enhance coaching involvement through education, mentorship, and supervision.	• **Intervention Development and Evaluation** - Shift research from injury risk monitoring to developing and testing proactive interventions. - Conduct further research on structured warm-up/cool-downs, supplementation, mobility, protective gear, HRV, education, and coaching roles.
• **Culture and Education** - Promote a gym culture prioritising injury prevention. - Provide regular workshops focusing on technique, recovery strategies and injury awareness. - Design and implement user-friendly injury reporting systems for members.	• **Emerging Areas of Research** - Investigate other interventions such as strength and conditioning programmes, psychological strategies, recovery techniques (e.g., sauna, ice baths), and nutritional supplements (e.g., creatine monohydrate).

Collectively, these integrated findings advocate for a multifactorial injury prevention framework, blending demographic insights, behavioural trends, and structured educational and coaching interventions alongside physiological metrics to foster a safer, more sustainable CrossFit training environment. Given the integrated insights from both studies, several avenues for future research emerge. Researchers should investigate structured intervention strategies identified in the scoping review through experimental or quasi-experimental designs, mainly targeting understudied populations such as female, advanced-level, and young CrossFit athletes. Additionally, conducting a systematic review on frequently explored intervention strategies identified in the scoping review would provide deeper insights into the quality of existing research, enabling more concrete recommendations for practice. Longitudinal studies comparing elite and non-elite CrossFit athletes should be conducted to identify specific TV thresholds associated with increased injury risk. Additionally, the effectiveness of multifactorial injury prevention programmes incorporating physiological markers (TV, HRV) and behavioural factors and assessing the interaction between these domains should be explored. Future research should also focus on the practical implementation of standardised injury definitions and data collection methods across diverse geographic and demographic contexts within the CrossFit community, prioritising studies within underrepresented regions such as Africa and Asia to ensure the global applicability of injury prevention strategies. Addressing these areas will substantially contribute to a safer, more effective, and sustainable CrossFit training environment.

CHAPTER SIX: CONCLUSION

This dissertation set out to explore if TV and HRV were associated with injury risk among non-elite CrossFit athletes in the Eastern Cape, South Africa, and surveyed research on intervention strategies to minimise injury risk factors through a structured scoping review. These aims were addressed through two complementary studies, each guided by specific research questions that focused on identifying injury risks and researching the current state of injury prevention strategies within CrossFit.

The guided research questions were as follows:

Study One (Observational Study):

1. To what extent are TV and HRV associated with injury risk among non-elite CrossFit athletes in the Eastern Cape, South Africa?

Study Two (Scoping Review):

1. Which intervention strategies have been explored to reduce injury rates and/or minimise musculoskeletal injury risk factors in CrossFit athletes?
2. What evidence gaps exist regarding the effectiveness or limitations of these intervention strategies?

To provide a clear overview of how this dissertation addressed its core research questions and aims, Table 6-1 summarises the key findings and practical implications of both studies. This included outcomes related to the association between TV, HRV, and injury risk, as well as identifying intervention strategies and existing research gaps in CrossFit injury prevention.

Table 6 - 1: Summation of findings and implications of studies included in this dissertation

Study	Findings	Implications
Study one (observational study)	- TV and HRV were not associated with injury risk. - Demographic and training characteristics (e.g., age ≥ 51, 2-3 sessions/week, two years of experience, moderate commitment) showed stronger associations with injury. - The likelihood of injuries increased from 11% in the first week to 31% in the final week.	- Injury risk may be more influenced by athlete behaviours and training habits than physiological trends in non-elite athletes. - Monitoring demographic and training patterns in non-elite athletes may help prevent injuries by considering factors like TV and HRV alongside other variables. - Highlights the importance of tracking injury trends over time.
Study two (scoping review)	- Warm-up and cool-down protocols were the most studied interventions. - Other strategies (e.g., nutritional supplementation, mobility programmes, protective gear, HRV monitoring, coaching involvement) were less explored. - Research inconsistencies in definitions, methods, and populations were evident. - Gaps identified in structured research and inclusion of underrepresented groups.	- Need for consistent and standardised injury definitions to improve comparability. data collection methods - Broaden research to include diverse regions and athlete groups. - Further research is required to refine existing interventions and explore new evidence-based strategies.

The research process offered valuable learning opportunities and aligned well with the study's aims. Choosing a two-part method approach, an observational study alongside a scoping review, allowed for a deeper understanding of injury risk and prevention in CrossFit by combining participant-reported data with a broader analysis of existing literature. This integration proved a strength, offering context-specific insights and a more expansive view of how CrossFit is evolving. Collecting real-time data over 16 weeks highlighted the challenges and importance of consistent participant engagement and accurate self-reporting. It also emphasised the difficulties of tracking physiological and behavioural variables in a community-based sports setting. Simultaneously, the scoping review process highlighted how varied the literature remains, reinforcing the value of evidence mapping in under-researched or emerging disciplines like CrossFit. Although certain limitations, such as self-reporting bias, data completeness, and variability in injury definitions, posed challenges, they also offered important lessons about the practical genuineness of sports injury research. The process prompted new questions about how commitment, experience, and training habits might interact with injury risk and exposed the need for more standardised and inclusive approaches to data collection and intervention evaluation. Overall, the research design facilitated meaningful insights, and the experience of navigating two distinct methodologies contributed to a richer understanding of the subject matter and the research process itself.

This dissertation contributes to the advancement of CrossFit injury research by reinforcing the need to move beyond identifying injury risk factors and developing effective prevention strategies. Much of the existing literature remains focused on documenting injury rates and associated risk variables, while structured, evidence-informed interventions remain scarce. By integrating real-world athlete data with a comprehensive review of current preventive approaches, this research offers a clearer understanding of where the field currently stands and what is needed to reduce injury risk more effectively. Through applying the TRIPP framework, this study helps position CrossFit research within a structured model for injury prevention, bridging the gap between identifying risks (Stage two) and informing intervention development (Stage three). It highlights specific gaps in population representation, intervention consistency, and methodological accuracy, issues researchers should address to advance injury prevention practice in the CrossFit community.

Based on these conclusions and the practical recommendations outlined in Chapter Five (Table 5-1), it is evident that both practice and research must continue to evolve to prevent injuries in CrossFit more effectively. Coaches and practitioners should focus on applying structured, evidence-based interventions, while researchers should prioritise advancing the field beyond risk identification and toward proactive injury prevention. Future research should explore these approaches through applied research designs that assess real-world outcomes, particularly among underrepresented populations such as female, advanced-level, and younger CrossFit athletes. Efforts should also be directed at enhancing injury definitions and data collection methods to improve study comparability. Additionally, investigating the interaction between physiological metrics (e.g., TV, HRV) and behavioural or demographic factors can help inform more comprehensive injury prevention models. Research conducted within African, Asian, and other underrepresented contexts will be essential to ensure the global applicability of future injury prevention strategies. Supporting these research efforts with the later stages of the TRIPP framework (stages four to six) will be essential to progress from theory to practice in the CrossFit injury prevention field.

In conclusion, this research contributes to the evolving understanding of injury risk and prevention in CrossFit. Integrating observational data with a scoping review of existing interventions highlights the complexity of injury risk factors and the urgent need for evidence-based, context-specific strategies. Instructed in the TRIPP framework, this research lays the foundation for future work prioritising structured prevention, standardisation, and inclusivity. As CrossFit continues to grow globally, these findings and recommendations are a meaningful step toward promoting safer and more sustainable training environments for athletes at all levels.

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APPENDICES

APPENDIX A: TRAINING VOLUME

Please answer the questions as accurately as you can. The results depend on how you feel each day, so you must give your best possible answer.

NB: PLEASE ANSWER 20/30 MINUTES AFTER EACH TRAINING/COMPETITION SESSION HAS BEEN COMPLETED

Your initials and study number (e.g. KS17)

Question 1

What training/competition session is this?

- ☐ I did not train/compete
- ☐ 1st of the day
- ☐ 2nd of the day
- ☐ 3rd of the day
- ☐ 4th of the day

Question 2

What time did you commence the training/competition session?

- ☐ 5:00 am - 7:00 am
- ☐ 7:00 am - 9:00 am
- ☐ 9:00 am - 11:00 am
- ☐ 11:00 am - 13:00 pm
- ☐ 13:00 pm - 15:00 pm
- ☐ 15:00 pm - 17:00 pm
- ☐ 17:00 pm - 19:00 pm

Question 3

What was the duration of this training/competition session today? (including warm-up + cooldown)

Minutes:

- ☐ 5
- ☐ 10

- ☐ 15
- ☐ 20
- ☐ 25
- ☐ 30
- ☐ 35
- ☐ 40
- ☐ 45
- ☐ 50
- ☐ 55
- ☐ 60
- ☐ 65
- ☐ 70
- ☐ 75
- ☐ 80
- ☐ 85
- ☐ 90
- ☐ 95
- ☐ 100
- ☐ 105
- ☐ 110
- ☐ 120
- ☐ 130
- ☐ 130+ (N.B., please send the researcher a private message if you go over this).

Question 4
What was your rating of perceived exertion (intensity level) for this training/competition session today?

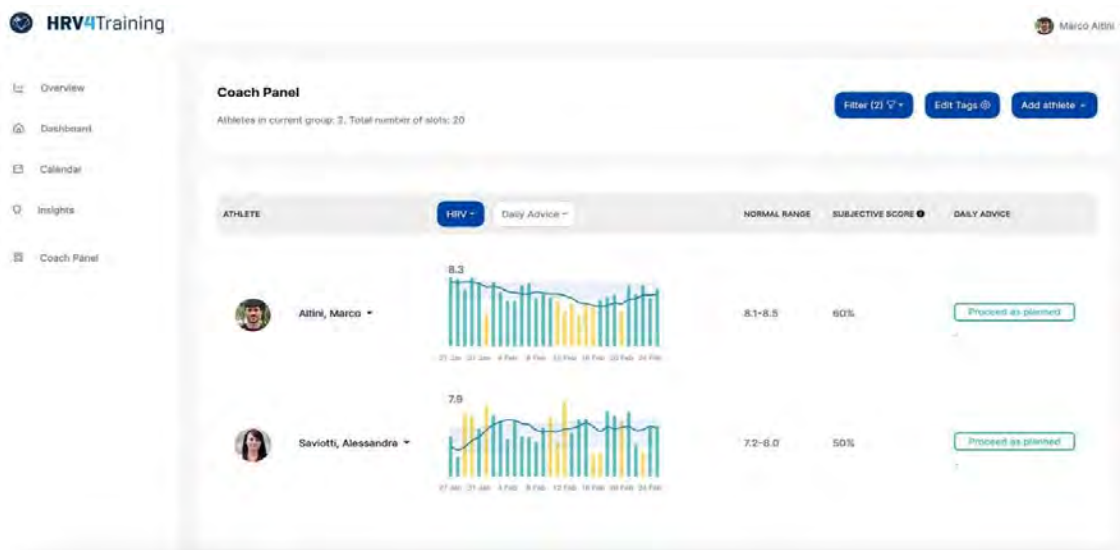
On a scale of 0-10, with 0 being rest and 10 being maximal effort:

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 8
- ☐ 9
- ☐ 10

APPENDIX B: HRV4TRAINING COACH

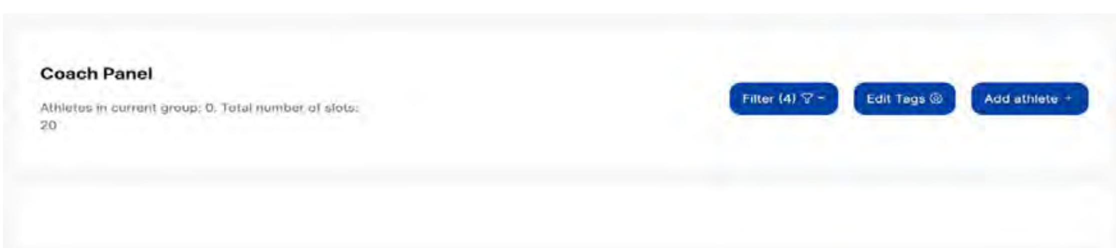
Coach panel:

HRV4Training Pro has several functionalities, one of which allows coaches to monitor their athletes individually and compare their trends as a group. Coaches can receive and sync their athletes' data right after taking their morning HRV measurement with either their iPhone or Android so that they can analyse their data remotely.

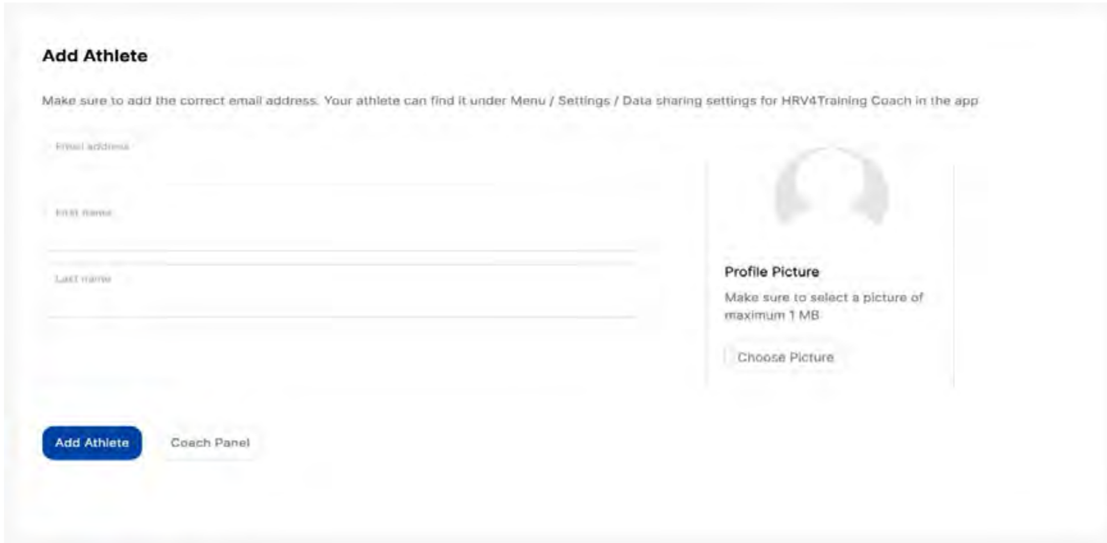


Adding athletes:

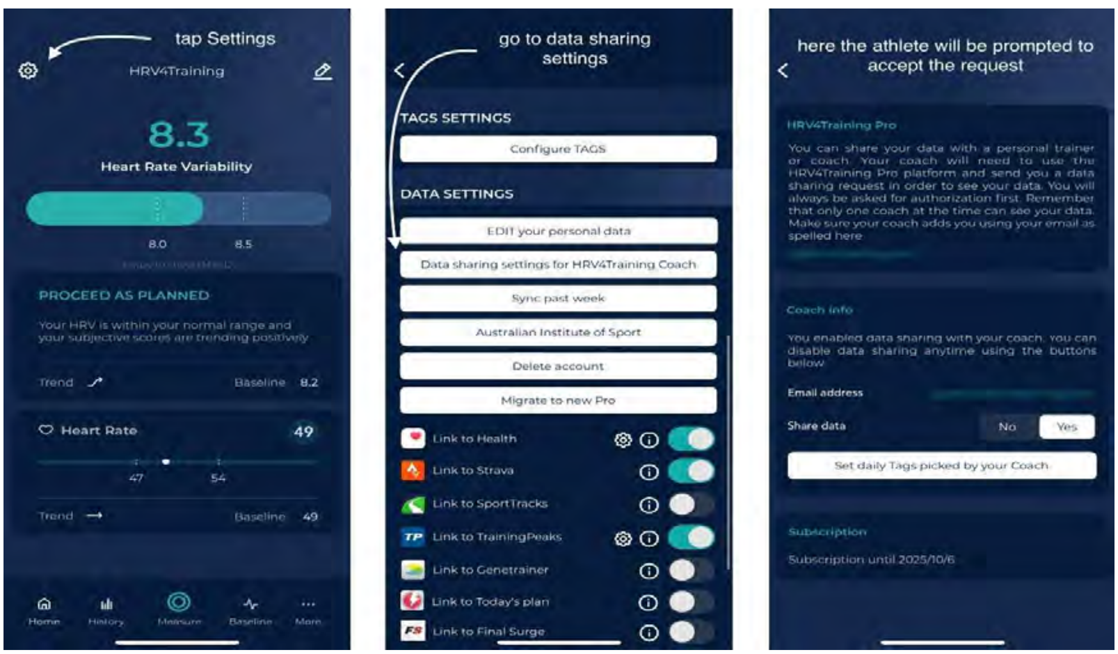
When you first start using HRV4Training Pro, no athletes will be added yet. To add athletes, click Add Athlete on the top right corner, which will bring you to the following page.



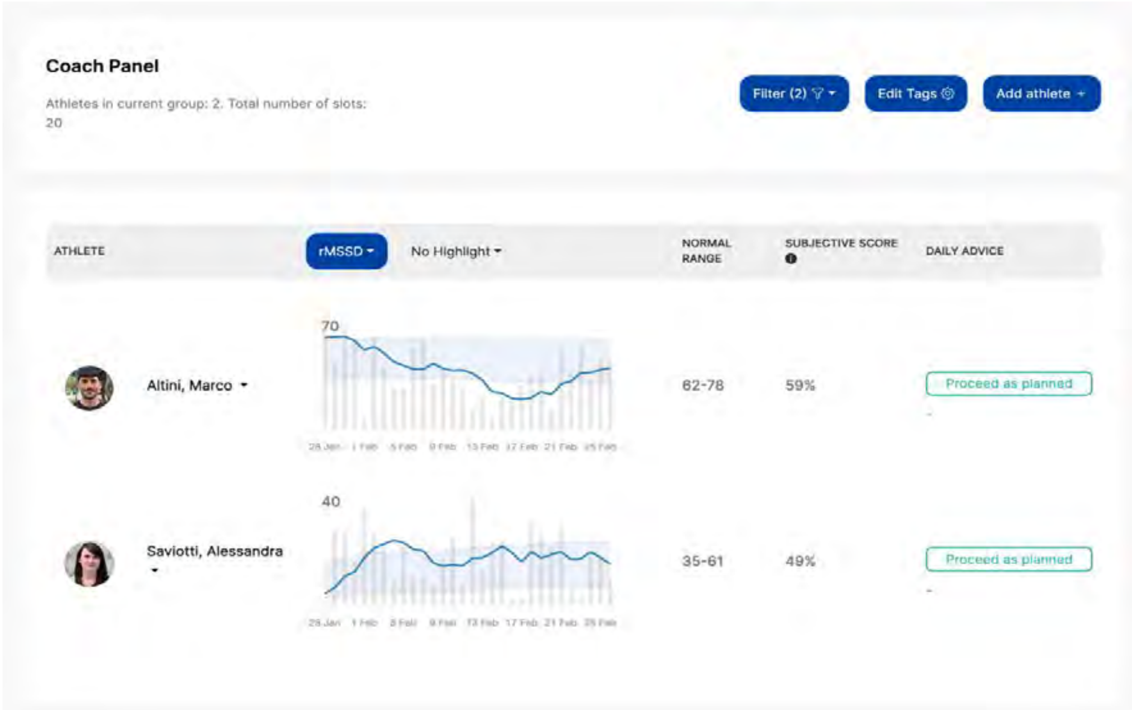
This will redirect you to a new page, where you can invite your athlete to monitor their daily HRV trends. The coach must enter the athlete's email, first name, and last name. The athlete will receive the request when registered in the HRV4Training app.



Once your athletes are registered on the app, they must go to the data-sharing settings for HRV4Training Coach. Here, they will be able to accept the request from the coach.



As soon as the athletes have accepted the request, the coaching panel will start populating with athletes' names. From here, as soon as the athletes start doing their HRV measurements upon waking, their data will automatically sync through to the coach's device. The platform displays each athlete's daily HRV, normal range (represented as a shaded area), and 7-day moving average (shown as a blue line), allowing coaches to monitor trends over time.



Selecting your athletes individually:

When you want to look at specific athletes individually, you can click on their names, redirecting you to a new page showing a more in-depth analysis of the selected athlete.

APPENDIX C: INJURY SURVEILLANCE

Based on the modified Oslo Sports Trauma Research Centre (OSTRC-O) over-use injury questionnaire.[84]

Your initials and study number (e.g. KS17)

INSTRUCTIONS

Injury definition[15]
Any new musculoskeletal pain, feeling or injury resulting from a CrossFit workout and leads to one or more of the following:
1. Total removal from CrossFit training and other outside routine physical activities for more than one week.
2. Modification of normal training activities in duration, intensity, or mode for more than two weeks.
3. Any physical complaint severe enough to warrant a visit to a health professional.

INJURY STATUS

Since the study commenced (23rd of January 2023), have you incurred an injury due to CrossFit training/competition?
If you indicate "Yes", you proceed to the next section for injury assessment.
If you indicate "No", thank you for your submission.

☐ Yes
☐ No

INJURY INCIDENCE

Has an injury caused difficulty participating in regular training, a reduction in your training volume and/or had a negative effect on your performance this week?

☐ Yes
☐ No

Is this the first time you are reporting this injury during the injury surveillance period?

☐ Yes
☐ No

KNEE INJURY

I have incurred a KNEE injury

☐ Yes
☐ No (you will be redirected to the next section)

Nature of injury

How did you sustain the injury?

☐ Acute injury (injuries that happen suddenly and are caused by a single, identifiable incident).[86]
☐ Overuse injury (injuries occur due to repetitive loading of the musculoskeletal system when rest is insufficient to allow for healing).[62,85]

Participation

Have you had difficulties participating in regular training and competition due to this injury problem during the past 7 days?
☐ Full participation without injury problems
☐ Full participation, but with injury problems
☐ Reduced participation due to injury problems
☐ Could not participate due to injury problems

Modified training/competition

To what extent have you modified your training or competition due to these injury problems during the past 7 days?
☐ No modification
☐ To a minor extent (the load and/or number of reps and/or sets of an exercise was reduced during a training session)
☐ To a moderate extent (the load and/or number of reps and/or sets of more than one exercise was reduced during most training sessions)
☐ To a major extent (no exercises which predominantly involve the lower limbs could not be performed)
☐ Cannot participate at all

Performance

To what extent have these injury problems affected your performance during the past 7 days?

[Note: one such performance is Range of Motion (ROM) defined as how much you can move the injured area]

☐ No effect
☐ To a minor extent (the quality, in terms of technique and ROM, in which one exercise was performed was hindered during a training session)
☐ To a moderate extent (the quality, in terms of technique and ROM, of one or more exercises was hindered during most training sessions)
☐ To a major extent (the quality, in terms of technique and ROM, all exercises involving the lower limbs were hindered during training sessions)
☐ Cannot participate at all

Pain

To what extent have you experienced pain in the injured area related to CrossFit training/competition during the past 7 days?
☐ No pain

- ☐ Mild pain (1-4 out of 10)
- ☐ Moderate pain (5-7 out of 10)
- ☐ Severe pain (8-10 out of 10)

LOWER LEG INJURY

I have incurred a LOWER LEG injury

- ☐ Yes
- ☐ No (you will be redirected to the next section)

Nature of injury

How did you sustain the injury?

- ☐ Acute injury (injuries that happen suddenly and are caused by a single, identifiable incident).[86]
- ☐ Overuse injury (injuries occur due to repetitive loading of the musculoskeletal system when rest is insufficient to allow for healing).[62,85]

Participation

Have you had difficulties participating in regular training and competition due to this injury problem during the past 7 days?

- ☐ Full participation without injury problems
- ☐ Full participation, but with injury problems
- ☐ Reduced participation due to injury problems
- ☐ Could not participate due to injury problems

Modified training/competition

To what extent have you modified your training or competition due to these injury problems during the past 7 days?

- ☐ No modification
- ☐ To a minor extent (the load and/or number of reps and/or sets of an exercise was reduced during a training session)
- ☐ To a moderate extent (the load and/or number of reps and/or sets of more than one exercise was reduced during most training sessions)
- ☐ To a major extent (no exercises which predominantly involve the lower limbs could not be performed)
- ☐ Cannot participate at all

Performance

To what extent have these injury problems affected your performance during the past 7 days?

[Note: one such performance is Range of Motion (ROM) defined as how much you can move the injured area]

- ☐ No effect
- ☐ To a minor extent (the quality, in terms of technique and ROM, in which one exercise was performed was hindered during a training session)
- ☐ To a moderate extent (the quality, in terms of technique and ROM, of one or more exercises was hindered during most training sessions)
- ☐ To a major extent (the quality, in terms of technique and ROM, all exercises involving the lower limbs were hindered during training sessions)
- ☐ Cannot participate at all

Pain

To what extent have you experienced pain in the injured area related to CrossFit training/competition during the past 7 days?

- ☐ No pain
- ☐ Mild pain (1-4 out of 10)
- ☐ Moderate pain (5-7 out of 10)
- ☐ Severe pain (8-10 out of 10)

THIGH INJURY

I have incurred a THIGH injury

- ☐ Yes
- ☐ No

Nature of injury

How did you sustain the injury?

- ☐ Acute injury (injuries that happen suddenly and are caused by a single, identifiable incident).[86]
- ☐ Overuse injury (injuries occur due to repetitive loading of the musculoskeletal system when rest is insufficient to allow for healing).[62,85]

Participation

Have you had difficulties participating in regular training and competition due to this injury problem during the past 7 days?

- ☐ Full participation without injury problems
- ☐ Full participation, but with injury problems
- ☐ Reduced participation due to injury problems
- ☐ Could not participate due to injury problems

Modified training/competition

To what extent have you modified your training or competition due to these injury problems during the past 7 days?

- ☐ No modification
- ☐ To a minor extent (the load and/or number of reps and/or sets of an exercise was reduced during a training session)

- ☐ To a moderate extent (the load and/or number of reps and/or sets of more than one exercise was reduced during most training sessions)
- ☐ To a major extent (no exercises which predominantly involve the lower limbs could not be performed)
- ☐ Cannot participate at all

Performance

To what extent have these injury problems affected your performance during the past 7 days?

[Note: one such performance is Range of Motion (ROM) defined as how much you can move the injured area]

- ☐ No effect
- ☐ To a minor extent (the quality, in terms of technique and ROM, in which one exercise was performed was hindered during a training session)
- ☐ To a moderate extent (the quality, in terms of technique and ROM, of one or more exercises was hindered during most training sessions)
- ☐ To a major extent (the quality, in terms of technique and ROM, all exercises involving the lower limbs were hindered during training sessions)
- ☐ Cannot participate at all

Pain

To what extent have you experienced pain in the injured area related to CrossFit training/competition during the past 7 days?

- ☐ No pain
- ☐ Mild pain (1-4 out of 10)
- ☐ Moderate pain (5-7 out of 10)
- ☐ Severe pain (8-10 out of 10)

ANKLE INJURY

I have incurred an ANKLE injury

- ☐ Yes
- ☐ No (you will be redirected to the next section)

Nature of injury

How did you sustain the injury?

- ☐ Acute injury (injuries that happen suddenly and are caused by a single, identifiable incident.[86]
- ☐ Overuse injury (injuries occur due to repetitive loading of the musculoskeletal system when rest is insufficient to allow for healing).[62,85]

Participation

Have you had difficulties participating in regular training and competition due to this injury problem during the past 7 days?

- ☐ Full participation without injury problems
- ☐ Full participation, but with injury problems
- ☐ Reduced participation due to injury problems
- ☐ Could not participate due to injury problems

Modified training/competition

To what extent have you modified your training or competition due to these injury problems during the past 7 days?

- ☐ No modification
- ☐ To a minor extent (the load and/or number of reps and/or sets of an exercise was reduced during a training session)
- ☐ To a moderate extent (the load and/or number of reps and/or sets of more than one exercise was reduced during most training sessions)
- ☐ To a major extent (no exercises which predominantly involve the lower limbs could not be performed)
- ☐ Cannot participate at all

Performance

To what extent have these injury problems affected your performance during the past 7 days?

[Note: one such performance is Range of Motion (ROM) defined as how much you can move the injured area]

- ☐ No effect
- ☐ To a minor extent (the quality, in terms of technique and ROM, in which one exercise was performed was hindered during a training session)
- ☐ To a moderate extent (the quality, in terms of technique and ROM, of one or more exercises was hindered during most training sessions)
- ☐ To a major extent (the quality, in terms of technique and ROM, all exercises involving the lower limbs were hindered during training sessions)
- ☐ Cannot participate at all

Pain

To what extent have you experienced pain in the injured area related to CrossFit training/competition during the past 7 days?

- ☐ No pain
- ☐ Mild pain (1-4 out of 10)
- ☐ Moderate pain (5-7 out of 10)
- ☐ Severe pain (8-10 out of 10)

FOOT/TOE INJURY

I have incurred a FOOT/TOE injury
- ☐ Yes
- ☐ No (you will be redirected to the next section)

Nature of injury

How did you sustain the injury?
- ☐ Acute injury (injuries that happen suddenly and are caused by a single, identifiable incident).[86]
- ☐ Overuse injury (injuries occur due to repetitive loading of the musculoskeletal system when rest is insufficient to allow for healing.[62,85]

Participation

Have you had difficulties participating in regular training and competition due to this injury problem during the past 7 days?
- ☐ Full participation without injury problems
- ☐ Full participation, but with injury problems
- ☐ Reduced participation due to injury problems
- ☐ Could not participate due to injury problems

Modified training/competition

To what extent have you modified your training or competition due to these injury problems during the past 7 days?
- ☐ No modification
- ☐ To a minor extent (the load and/or number of reps and/or sets of an exercise was reduced during a training session)
- ☐ To a moderate extent (the load and/or number of reps and/or sets of more than one exercise was reduced during most training sessions)
- ☐ To a major extent (no exercises which predominantly involve the lower limbs could not be performed)
- ☐ Cannot participate at all

Performance

To what extent have these injury problems affected your performance during the past 7 days?

[Note: one such performance is Range of Motion (ROM) defined as how much you can move the injured area]

- ☐ No effect
- ☐ To a minor extent (the quality, in terms of technique and ROM, in which one exercise was performed was hindered during a training session)
- ☐ To a moderate extent (the quality, in terms of technique and ROM, of one or more exercises was hindered during most training sessions)

- ☐ To a major extent (the quality, in terms of technique and ROM, all exercises involving the lower limbs were hindered during training sessions)
- ☐ Cannot participate at all

Pain

To what extent have you experienced pain in the injured area related to CrossFit training / competition during the past 7 days?
- ☐ No pain
- ☐ Mild pain (1-4 out of 10)
- ☐ Moderate pain (5-7 out of 10)
- ☐ Severe pain (8-10 out of 10)

HIP/GROIN INJURY

I have incurred a HIP/GROIN injury
- ☐ Yes
- ☐ No (you will be redirected to the next section)

Nature of injury

How did you sustain the injury?
- ☐ Acute injury (injuries that happen suddenly and are caused by a single, identifiable incident).[86]
- ☐ Overuse injury (injuries occur due to repetitive loading of the musculoskeletal system when rest is insufficient to allow for healing).[62,85]

Participation

Have you had difficulties participating in regular training and competition due to this injury problem during the past 7 days?
- ☐ Full participation without injury problems
- ☐ Full participation, but with injury problems
- ☐ Reduced participation due to injury problems
- ☐ Could not participate due to injury problems

Modified training/competition

To what extent have you modified your training or competition due to these injury problems during the past 7 days?
- ☐ No modification
- ☐ To a minor extent (the load and/or number of reps and/or sets of an exercise was reduced during a training session)
- ☐ To a moderate extent (the load and/or number of reps and/or sets of more than one exercise was reduced during most training sessions)
- ☐ To a major extent (no exercises which predominantly involve the lower limbs could not be performed)

☐ Cannot participate at all

Performance

To what extent have these injury problems affected your performance during the past 7 days?

[Note: one such performance is Range of Motion (ROM) defined as how much you can move the injured area]

☐ No effect
☐ To a minor extent (the quality, in terms of technique and ROM, in which one exercise was performed was hindered during a training session)
☐ To a moderate extent (the quality, in terms of technique and ROM, of one or more exercises was hindered during most training sessions)
☐ To a major extent (the quality, in terms of technique and ROM, all exercises involving the lower limbs were hindered during training sessions)
☐ Cannot participate at all

Pain

To what extent have you experienced pain in the injured area related to CrossFit training/competition during the past 7 days?
☐ No pain
☐ Mild pain (1-4 out of 10)
☐ Moderate pain (5-7 out of 10)
☐ Severe pain (8-10 out of 10)

PELVIS/SACRUM/BUTTOCK INJURY

I have incurred a PELVIS/SACRUM/BUTTOCK injury
☐ Yes
☐ No (you will be redirected to the next section)

Nature of injury

How did you sustain the injury?
☐ Acute injury (injuries that happen suddenly and are caused by a single, identifiable incident).[86]
☐ Overuse injury (injuries occur due to repetitive loading of the musculoskeletal system when rest is insufficient to allow for healing).[62,85]

Participation

Have you had difficulties participating in regular training and competition due to this injury problem during the past 7 days?
☐ Full participation without injury problems
☐ Full participation, but with injury problems
☐ Reduced participation due to injury problems

☐ Could not participate due to injury problems

Modified training/competition

To what extent have you modified your training or competition due to these injury problems during the past 7 days?

- ☐ No modification
- ☐ To a minor extent (the load and/or number of reps and/or sets of an exercise was reduced during a training session)
- ☐ To a moderate extent (the load and/or number of reps and/or sets of more than one exercise was reduced during most training sessions)
- ☐ To a major extent (no exercises which predominantly involve the lower limbs could not be performed)
- ☐ Cannot participate at all

Performance

To what extent have these injury problems affected your performance during the past 7 days?

[Note: one such performance is Range of Motion (ROM) defined as how much you can move the injured area]

- ☐ No effect
- ☐ To a minor extent (the quality, in terms of technique and ROM, in which one exercise was performed was hindered during a training session)
- ☐ To a moderate extent (the quality, in terms of technique and ROM, of one or more exercises was hindered during most training sessions)
- ☐ To a major extent (the quality, in terms of technique and ROM, all exercises involving the lower limbs were hindered during training sessions)
- ☐ Cannot participate at all

Pain

To what extent have you experienced pain in the injured area related to CrossFit training/competition during the past 7 days?

- ☐ No pain
- ☐ Mild pain (1-4 out of 10)
- ☐ Moderate pain (5-7 out of 10)
- ☐ Severe pain (8-10 out of 10)

LUMBAR SPINE INJURY

I have incurred a LUMBAR SPINE injury

- ☐ Yes
- ☐ No (you will be redirected to the next section)

Nature of injury

How did you sustain the injury?

- ☐ Acute injury (injuries that happen suddenly and are caused by a single, identifiable incident).[86]
- ☐ Overuse injury (injuries occur due to repetitive loading of the musculoskeletal system when rest is insufficient to allow for healing).[62,85]

Participation

Have you had difficulties participating in regular training and competition due to this injury problem during the past 7 days?

- ☐ Full participation without injury problems
- ☐ Full participation, but with injury problems
- ☐ Reduced participation due to injury problems
- ☐ Could not participate due to injury problems

Modified training/competition

To what extent have you modified your training or competition due to these injury problems during the past 7 days?

- ☐ No modification
- ☐ To a minor extent (the load and/or number of reps and/or sets of an exercise was reduced during a training session)
- ☐ To a moderate extent (the load and/or number of reps and/or sets of more than one exercise was reduced during most training sessions)
- ☐ To a major extent (no exercises which predominantly involve the lower limbs or upper limbs could not be performed)
- ☐ Cannot participate at all

Performance

To what extent have these injury problems affected your performance during the past 7 days?

[Note: one such performance is Range of Motion (ROM) defined as how much you can move the injured area]

- ☐ No effect
- ☐ To a minor extent (the quality, in terms of technique and ROM, in which one exercise was performed was hindered during a training session)
- ☐ To a moderate extent (the quality, in terms of technique and ROM, of one or more exercises was hindered during most training sessions)
- ☐ To a major extent (the quality, in terms of technique and ROM, all exercises involving the lower limbs or upper limbs were hindered during training sessions)
- ☐ Cannot participate at all

Pain

To what extent have you experienced pain in the injured area related to CrossFit training/competition during the past 7 days?

- ☐ No pain
- ☐ Mild pain (1-4 out of 10)
- ☐ Moderate pain (5-7 out of 10)
- ☐ Severe pain (8-10 out of 10)

SHOULDER INJURY

I have incurred a SHOULDER injury

- ☐ Yes
- ☐ No (you will be redirected to the next section)

Nature of injury

How did you sustain the injury?

- ☐ Acute injury (injuries that happen suddenly and are caused by a single, identifiable incident).[86]
- ☐ Overuse injury (injuries occur due to repetitive loading of the musculoskeletal system when rest is insufficient to allow for healing).[62,85]

Participation

Have you had difficulties participating in regular training and competition due to this injury problem during the past 7 days?

- ☐ Full participation without injury problems
- ☐ Full participation, but with injury problems
- ☐ Reduced participation due to injury problems
- ☐ Could not participate due to injury problems

Modified training/competition

To what extent have you modified your training or competition due to these injury problems during the past 7 days?

- ☐ No modification
- ☐ To a minor extent (the load and/or number of reps and/or sets of an exercise was reduced during a training session)
- ☐ To a moderate extent (the load and/or number of reps and/or sets of more than one exercise was reduced during most training sessions)
- ☐ To a major extent (no exercises which predominantly involve the upper limbs could not be performed)
- ☐ Cannot participate at all

Performance

To what extent have these injury problems affected your performance during the past 7 days?

[Note: one such performance is Range of Motion (ROM) defined as how much you can move the injured area]

- ☐ No effect
- ☐ To a minor extent (the quality, in terms of technique and ROM, in which one exercise was performed was hindered during a training session)
- ☐ To a moderate extent (the quality, in terms of technique and ROM, of one or more exercises was hindered during most training sessions)
- ☐ To a major extent (the quality, in terms of technique and ROM, all exercises involving the upper limbs was hindered during training sessions)
- ☐ Cannot participate at all

Pain

To what extent have you experienced pain in the injured area related to CrossFit training / competition during the past 7 days?

- ☐ No pain
- ☐ Mild pain (1-4 out of 10)
- ☐ Moderate pain (5-7 out of 10)
- ☐ Severe pain (8-10 out of 10)

ELBOW/ARM INJURY

I have incurred an ELBOW/ARM injury

- ☐ Yes
- ☐ No (you will be redirected to the next section)

Nature of injury

How did you sustain the injury?

- ☐ Acute injury (injuries that happen suddenly and are caused by a single, identifiable incident).[86]
- ☐ Overuse injury (injuries occur due to repetitive loading of the musculoskeletal system when rest is insufficient to allow for healing).[62,85]

Participation

Have you had difficulties participating in regular training and competition due to this injury problem during the past 7 days?

- ☐ Full participation without injury problems
- ☐ Full participation, but with injury problems
- ☐ Reduced participation due to injury problems
- ☐ Could not participate due to injury problems

Modified training/competition

To what extent have you modified your training or competition due to these injury problems during the past 7 days?

- ☐ No modification

- ☐ To a minor extent (the load and/or number of reps and/or sets of an exercise was reduced during a training session)
- ☐ To a moderate extent (the load and/or number of reps and/or sets of more than one exercise was reduced during most training sessions)
- ☐ To a major extent (no exercises which predominantly involve the upper limbs could not be performed)
- ☐ Cannot participate at all

Performance

To what extent have these injury problems affected your performance during the past 7 days?

[Note: one such performance is Range of Motion (ROM) defined as how much you can move the injured area]

- ☐ No effect
- ☐ To a minor extent (the quality, in terms of technique and ROM, in which one exercise was performed was hindered during a training session)
- ☐ To a moderate extent (the quality, in terms of technique and ROM, of one or more exercises was hindered during most training sessions)
- ☐ To a major extent (the quality, in terms of technique and ROM, all exercises involving the upper limbs were hindered during training sessions)
- ☐ Cannot participate at all

Pain

To what extent have you experienced pain in the injured area related to CrossFit training/competition during the past 7 days?

- ☐ No pain
- ☐ Mild pain (1-4 out of 10)
- ☐ Moderate pain (5-7 out of 10)
- ☐ Severe pain (8-10 out of 10)

ELBOW/ARM INJURY

I have incurred an ELBOW/ARM injury

- ☐ Yes
- ☐ No (thank you for your submission)

Nature of injury

How did you sustain the injury?

- ☐ Acute injury (injuries that happen suddenly and are caused by a single, identifiable incident).[86]
- ☐ Overuse injury (injuries occur due to repetitive loading of the musculoskeletal system when rest is insufficient to allow for healing).[62,85]

Participation

Have you had difficulties participating in regular training and competition due to this injury problem during the past 7 days?

- ☐ Full participation without injury problems
- ☐ Full participation, but with injury problems
- ☐ Reduced participation due to injury problems
- ☐ Could not participate due to injury problems

Modified training/competition

To what extent have you modified your training or competition due to these injury problems during the past 7 days?

- ☐ No modification
- ☐ To a minor extent (the load and/or number of reps and/or sets of an exercise was reduced during a training session)
- ☐ To a moderate extent (the load and/or number of reps and/or sets of more than one exercise was reduced during most training sessions)
- ☐ To a major extent (no exercises which predominantly involve the upper limbs could not be performed)
- ☐ Cannot participate at all

Performance

To what extent have these injury problems affected your performance during the past 7 days?

[Note: one such performance is Range of Motion (ROM) defined as how much you can move the injured area]

- ☐ No effect
- ☐ To a minor extent (the quality, in terms of technique and ROM, in which one exercise was performed was hindered during a training session)
- ☐ To a moderate extent (the quality, in terms of technique and ROM, of one or more exercises was hindered during most training sessions)
- ☐ To a major extent (the quality, in terms of technique and ROM, all exercises involving the upper limbs was hindered during training sessions)
- ☐ Cannot participate at all

Pain

To what extent have you experienced pain in the injured area related to CrossFit training/competition during the past 7 days?

- ☐ No pain
- ☐ Mild pain (1-4 out of 10)
- ☐ Moderate pain (5-7 out of 10)
- ☐ Severe pain (8-10 out of 10)

APPENDIX D: RHODES ETHICAL CLEARANCE

RHODES UNIVERSITY
Where leaders learn

Rhodes University Human Research Ethics Committee
PO Box 94, Makhanda, 6140, South Africa
t: +27 (0) 46 603 7727
f: +27 (0) 46 603 8822
e: ethics-committee@ru.ac.za
NHREC Registration number: RC-241114-045

https://www.ru.ac.za/researchgateway/ethics/

16 November 2022

Kieran Skae

Email:
g17s4347@campus.ru.ac.za
kieranskae16@gmail.com

Review reference: 2022-5925-7235

Dear Kieran Skae

Title: The association between training volume, heart rate variability and injury among non-elite CrossFit athletes in South Africa
Researcher: Kieran Skae
Supervisor(s): Professor Candice Christie

This letter confirms that the above research proposal has been reviewed and **APPROVED** by the Rhodes University Human Research Ethics Committee (RU-HREC). Your Approval number is: 2022-5925-7235 Approval has been granted for 1 year. An annual progress report will be required in order to renew approval for an additional period. You will receive an email notifying you when the annual report is due.

Please ensure that the ethical standards committee is notified should any substantive change(s) be made, for whatever reason, during the research process. This includes changes in investigators. Please also ensure that a brief report is submitted to the ethics committee on the completion of the research. The purpose of this report is to indicate whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the ethical standards committee should be aware of. If a thesis or dissertation arising from this research is submitted to the library's electronic theses and dissertations (ETD) repository, please notify the committee of the date of submission and/or any reference or cataloguing number allocated.

Sincerely,

Janet Hayward

Dr. Janet Hayward

Chair: Rhodes University Human Research Ethics Committee, RU-HREC

cc: Ethics Coordinator

APPENDIX E: INFORMATION LEAFLET – GYM FACILITY OWNERS

RHODES UNIVERSITY
Where leaders learn

Department of Human Kinetics and Ergonomics
73 African Street, Grahamstown, 6139 • Tel: 046 603 8471 • e-mail: g17s4347@campus.ru.ac.za

Dear Sir/Ma'am,

My name is Kieran Skae. I am currently enrolled for a Master's degree in Human Kinetics and Ergonomics at Rhodes University. I am researching whether there is an association between training volume, heart rate variability and injury among non-elite CrossFit athletes in South Africa. I am a member of the CrossFit gym and an instructor (coach) at the CrossFit facility in Makhanda. I would be most grateful if you would allow me to conduct this research at your CrossFit facility.

Why is this study critical?

This study will be one of the first studies in South Africa to investigate risk factors associated with injury among non-elite CrossFit athletes. If an association between exercise volume, heart rate variability (HRV) and injury is confirmed, CrossFit coaches might be able to identify athletes at risk of sustaining injuries and address the possible preventable causes, thereby minimising athletes' injury risk. The outcomes of this study may be used to make recommendations to CrossFit coaches with regard to exercise prescription and monitoring of athletes' HRV and training volume. The methods used for data collection in this study are simple, user-friendly and cost-effective. If associations are established, athletes would also be able to track and monitor their own training volume and HRV using the same methods. The results of this study will also be helpful should a follow-up survey be undertaken on a longitudinal basis, especially at other CrossFit facilities in different regions in South Africa. Their results may then be used to enable comparisons and other measures.

What would the members/participants be expected to do?

Data will be collected for 16 weeks (January 2023 – April 2023). Standard daily training programmes, the "workout of the day" (WOD), and any additional training each individual do will be observed. Participants will be asked to complete a series of questions and procedures during these 16 weeks relating to training volume, heart rate variability, and injuries they may have sustained during the week. HRV and training volume data will be collected daily, while the injury surveillance questionnaire will be completed weekly. Data for training volume and injuries will be collected using an electronic online questionnaire constructed on google forms, and HRV will be collected using the available smartphone application called "HRV4Training". None of the procedures are invasive and will not inflict any pain or discomfort. Participation is entirely voluntary, and they may withdraw at any time. The members/participants will not suffer any consequences and do not have to provide a reason for not wanting to participate.

What are the benefits and risks to the members/participants?

Injury prevention recommendations can be developed based on the results of this study. These recommendations can then be given to the owners of the CrossFit facility. If a member/participant consented to share their information, a report of their analysis results could be provided to the affiliate owners. This will enable them to provide better coaching according to their needs to improve their training performance.

The risk factors of this study are deemed to be very low. The researcher is only observing and recording what you would normally be doing. In fact, it is essential to the success of the researcher's study that you do not deviate from what you would have done if you were not a participant in this study. In addition, no social group, institution or community members are being investigated other than CrossFit members who are voluntarily participating in the study. The participants are generally realistic about what they can and cannot do. However, there is a risk that you may encounter a physical injury simply due to you not warming up properly, or over-exerting yourself in the process of your training performance being measured and analysed in the lead-up to the competition. In this regard, you are strongly encouraged to maintain your regimen as if you were not participating in the study.

How will feedback be provided to participants/parents of participants?

Upon request, participants/parents of participants will receive feedback in the form of an email that contains the research results and practical recommendations. The researcher also intends to publish the research results in the form of a Master's Research report as well as a presentation at the end-of-year departmental seminar. However, confidentiality and anonymity of records will be maintained, and participants' names and identities will not be revealed to anyone who has not been involved in the conducting of the research.

Will information be handled as confidential?

The names of participants will only be written on the consent form and not on the questionnaires. Consent forms will be kept separately from the questionnaires. All information will be confidential and only be used for this research study. All members/participants will be given a study number and kept in possession of the researcher only.

Hard copies of the data collection tools and the electronic versions and spreadsheets will be held on the researcher and supervisor's computer, which will be password protected and saved in a cloud.

Ethical clearance to conduct this study has been obtained from the Rhodes Human Research Ethics Committee (Ethical clearance number: 2022-5925-7235).

For more information, or if you have any queries, please don't hesitate to contact us. Contact details are provided below.

If you are interested in participating in this study, please fill in and sign the attached consent form.

Kind regards,

Kieran Skae, BA (Hons)
Phone: (073) 716-0984
Email: g17s4347@campus.ru.ac.za

Prof. Candice Christie

Phone: +27 (0)46 603 8470

Email: c.christie@ru.ac.za

Rhodes University Research Ethics Committee contact details:

Dr Janet Hayward

Phone: 046 603 8232

APPENDIX F: INFORMED CONSENT – GYM FACILITY OWNER

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73 African Street, Grahamstown, 6139 • Tel: 046 603 8471 • e-mail: g17s4347@campus.ru.ac.za

- I,___________________________________(full name) hereby agree that the researcher can approach the members of my CrossFit gym to see if they want to participate in this study as described in the information leaflet. The following has been made clear to me:
- The goals and methods of the study.
- That ethical approval of the study has been obtained by the Rhodes University research ethics committee.
- That all results will be treated with the strictest confidentiality.
- That there will be no consequences should participants choose to withdraw from the study.

By signing this form, I agree that the selected members/participants can participate in the study and go forward with all the questions and procedures the members/participants will have to do weekly to collect the data/information needed for this research study.

I understand that there are no monetary rewards for their participation, and I am not obliged to let them take part, and it is entirely up to the members/participants' choices if they want to partake or not.

Signature _________________________ Witness __________________________

Date ______________________________

APPENDIX G: INFORMATION LEAFLET – PARTICIPANT

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Department of Human Kinetics and Ergonomics

73 African Street, Grahamstown, 6139 • Tel: 046 603 8471 • e-mail: g17s4347@campus.ru.ac.za

Dear potential participant

My name is Kieran Skae. I am currently enrolled for a Master's degree in Human Kinetics and Ergonomics at Rhodes University. I am researching whether there is an association between training volume, heart rate variability and injury among non-elite CrossFit athletes in South Africa. I am a member of the CrossFit gym and an instructor (coach) at the CrossFit facility in Makhanda. I would be most grateful if you would be willing to participate in this study.

Why is this study critical?

This study will be one of the first studies in South Africa to investigate risk factors associated with injury among non-elite CrossFit athletes. If an association between exercise volume, heart rate variability (HRV) and injury is confirmed, CrossFit coaches might be able to identify athletes at risk of sustaining injuries and address the possible preventable causes, thereby minimising athletes' injury risk. The outcomes of this study may be used to make recommendations to CrossFit coaches with regard to exercise prescription and monitoring of athletes' HRV and training volume. The methods used for data collection in this study are simple, user-friendly and cost-effective. If associations are established, athletes would also be able to track and monitor their own training volume and HRV using the same methods. The results of this study will also be helpful should a follow-up survey be undertaken on a longitudinal basis, especially at other CrossFit facilities in different regions in South Africa. Your results may then be used to enable comparisons and other measures.

What would you be expected to do?

Data will be collected for 16 weeks (January 2023 – April 2023). Standard daily training programmes, the "workout of the day" (WOD), and any additional training you do will be observed. You will be asked to complete a series of questions and procedures during these 16 weeks relating to training volume, heart rate variability, and injuries you may have sustained during the week. HRV and training volume data will be collected daily, while the injury surveillance questionnaire will be completed weekly. Data for training volume and injuries will be collected using an electronic online questionnaire constructed on google forms, and HRV will be collected using the available smartphone application called "HRV4Training". None of the procedures are invasive and will not inflict any pain or discomfort. Your participation is entirely voluntary, and you may withdraw at any time. You will not suffer any consequences and do not have to provide a reason for not wanting to participate.

What are the benefits and risks to the members/participants?

Injury prevention recommendations can be developed based on the results of this study. These recommendations can then be given to the affiliate owners of the CrossFit gym. If you consent to share your information, a report of your analysis results could be provided to the affiliate owners. This will enable them to provide better coaching according to your needs to improve your training performance

The risk factors of this study are deemed to be very low. The researcher is only observing and recording what you would normally be doing. In fact, it is essential to the success of the researcher's study that you do not deviate from what you would have done if you were not a participant in this study. In addition, no social group, institution or community members are being investigated other than CrossFit members who are voluntarily participating in the study. The participants are generally realistic about what they can and cannot do. However, there is a risk that you may encounter a physical injury simply due to you not warming up properly, or over-exerting yourself in the process of your training performance being measured and analysed in the lead-up to the competition. In this regard, you are strongly encouraged to maintain your regimen as if you were not participating in the study.

How will feedback be provided to participants?

Upon request, participants will receive feedback in the form of an email that contains the research results and practical recommendations. The researcher also intends to publish the research results in the form of a Master's Research report as well as a presentation at the end-of-year departmental seminar. However, confidentiality and anonymity of records will be maintained, and participants' names and identities will not be revealed to anyone who has not been involved in the conducting of the research.

Will information be handled as confidential?

The names of participants will only be written on the consent form and not on the questionnaires. Consent forms will be kept separately from the questionnaires. All information will be confidential and only be used for this research study. All members/participants will be given a study number and kept in possession of the researcher only.

Hard copies of the data collection tools and the electronic versions and spreadsheets will be held on the researcher and supervisor's computer, which will be password protected and saved in a cloud.

Ethical clearance to conduct this study has been obtained from the Rhodes Human Research Ethics Committee (Ethical clearance number: 2022-5925-7235).

For more information, or if you have any queries, please don't hesitate to contact us. Contact details are provided below.

If you are interested in participating in this study, please fill in and sign the attached consent form.

Kind regards,

Kieran Skae, BA (Hons)
Phone: (073) 716-0984
Email: g17s4347@campus.ru.ac.za
Prof. Candice Christie

Phone: +27 (0)46 603 8470

Email: c.christie@ru.ac.za

Rhodes University Research Ethics Committee contact details:

Dr Janet Hayward

Phone: 046 603 8232

APPENDIX H: INFORMED CONSENT – PARTICIPANT

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I,____(full name) hereby agree to participate in this study as described in the information leaflet. The following has been made clear to me:

- The goals and methods of the study.
- That ethical approval of the study has been obtained from the Rhodes University research ethics committee.
- That all results will be treated with the strictest confidentiality.
- That there will be no consequences should participants choose to withdraw from the study.

By signing this form, I agree to provide any information related to injuries I sustained during the 16 weeks of this research analysis. Furthermore, I agree to input my daily Heart Rate Variability measurement via the dedicated app, as well as my actual activity Training Volume and the weekly Injury Surveillance via the dedicated questionnaires.

I understand that there are no monetary rewards for participation. My participation is voluntary and I can withdraw from the research study at any time.

Signature:_________________________**Witness**:__________________________

Date:____/__________/2023

--

PLEASE PROVIDE THE INFORMATION BELOW. All information will be treated with the strictest confidentiality.

DATE OF BIRTH ____________________AGE _________GENDER _______________

How long have you been a member of CrossFit? ______________

How would you classify your current commitment to CrossFit training on the scale below,
where 1 = Gentle and 7 = Intense? (Circle applicable number).

GENTLE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**INTENSE**

How regularly do you do CrossFit Training? (Tick applicable box).

DAILY	**4 to 6 times per week**	**2 to 3 times per week**	**2 times per week**	**Less than 2 times per week**

Thank you for completing the above. Please fold it and insert in the box provided.

APPENDIX I: INFORMATION LEAFLET – PARENT OF PARTICIPANT

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73 African Street, Grahamstown, 6139 • Tel: 046 603 8471 • e-mail: g17s4347@campus.ru.ac.za

Parent of Participant

My name is Kieran Skae. I am currently enrolled for a Master's degree in Human Kinetics and Ergonomics at Rhodes University. I am researching whether there is an association between training volume, heart rate variability and injury among non-elite CrossFit athletes in South Africa. I am a member of the CrossFit gym and an instructor (coach) at the CrossFit facility in Makhanda. I would be most grateful if your child would be willing to participate in this study.

Why is this study critical?

This study will be one of the first studies in South Africa to investigate risk factors associated with injury among non-elite CrossFit athletes. If an association between exercise volume, heart rate variability (HRV) and injury is confirmed, CrossFit coaches might be able to identify athletes at risk of sustaining injuries and address the possible preventable causes, thereby minimising athletes' injury risk. The outcomes of this study may be used to make recommendations to CrossFit coaches with regard to exercise prescription and monitoring of athletes' HRV and training volume. The methods used for data collection in this study are simple, user-friendly and cost-effective. If associations are established, athletes would also be able to track and monitor their own training volume and HRV using the same methods. The results of this study will also be helpful should a follow-up survey be undertaken on a longitudinal basis, especially at other CrossFit facilities in different regions in South Africa. Their results may then be used to enable comparisons and other measures.

What would your child be expected to do?

Data will be collected for 16 weeks (January 2023 – April 2023). Standard daily training programmes, the "workout of the day" (WOD), and any additional training each individual do will be observed. They will be asked to complete a series of questions and procedures during these 16 weeks relating to training volume, heart rate variability, and injuries they may have sustained during the week. HRV and training volume data will be collected daily, while the injury surveillance questionnaire will be completed weekly. Data for training volume and injuries will be collected using an electronic online questionnaire constructed on google forms, and HRV will be collected using the available smartphone application called "HRV4Training". None of the procedures are invasive and will not inflict any pain or discomfort. Participation is entirely voluntary, and they may withdraw at any time. Your child will not suffer any consequences and does not have to provide a reason for not wanting to participate.

What are the benefits and risks to the members/participants?

Injury prevention recommendations can be developed based on the results of this study. These recommendations can then be given to the owners of the CrossFit facility. If a member/participant consented to share their information, a report of their analysis results could be provided to the affiliate owners. This will enable them to provide better coaching according to their needs to improve their training performance.

The risk factors of this study are deemed to be very low. The researcher is only observing and recording what you would normally be doing. In fact, it is essential to the success of the researcher's study that you do not deviate from what you would have done if you were not a participant in this study. In addition, no social group, institution or community members are being investigated other than CrossFit members who are voluntarily participating in the study. The participants are generally realistic about what they can and cannot do. However, there is a risk that you may encounter a physical injury simply due to you not warming up properly, or over-exerting yourself in the process of your training performance being measured and analysed in the lead-up to the competition. In this regard, you are strongly encouraged to maintain your regimen as if you were not participating in the study.

How will feedback be provided to the parents of participants?

Upon request, the parents of participants will receive feedback in the form of an email that contains the research results and practical recommendations. The researcher also intends to publish the research results in the form of a Master's Research report as well as a presentation at the end-of-year departmental seminar. However, confidentiality and anonymity of records will be maintained, and participants' names and identities will not be revealed to anyone who has not been involved in the conducting of the research.

Will information be handled as confidential?

The names of participants will only be written on the consent form and not on the questionnaires. Consent forms will be kept separately from the questionnaires. All information will be confidential and only be used for this research study. All members/participants will be given a study number and kept in possession of the researcher only.

Hard copies of the data collection tools and the electronic versions and spreadsheets will be held on the researcher and supervisor's computer, which will be password protected and saved in a cloud.

Ethical clearance to conduct this study has been obtained from the Rhodes Human Research Ethics Committee (Ethical clearance number: 2022-5925-7235).

For more information, or if you have any queries, please don't hesitate to contact us. Contact details are provided below.

If you are interested in letting your child participate in this study, please fill in and sign the attached consent form.

Kind regards,

Kieran Skae, BA (Hons)
Phone: (073) 716-0984
Email: g17s4347@campus.ru.ac.za
Prof. Candice Christie

Phone: +27 (0)46 603 8470

Email: c.christie@ru.ac.za

Rhodes University Research Ethics Committee contact details:

Dr Janet Hayward

Phone: 046 603 8232

APPENDIX J: INFORMED CONSENT – PARENT OF PARTICIPANT

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73 African Street, Grahamstown, 6139 • Tel: 046 603 8471 • e-mail: g17s4347@campus.ru.ac.za

- I,__________________________________(full name) hereby agree that my child can participate in this study as described in the information leaflet. The following has been made clear to me:
- The goals and methods of the study.
- That ethical approval of the study has been obtained from the Rhodes University research ethics committee.
- That all results will be treated with the strictest confidentiality.
- That there will be no consequences should participants choose to withdraw from the study.

By signing this form, I agree to provide any information related to injuries my child may have sustained during the 16 weeks of this research analysis. Furthermore, I agree to let them input their daily Heart Rate Variability measurement via the dedicated app, as well as their actual activity Training Volume and the weekly Injury Surveillance via the dedicated questionnaires.

I understand that there are no monetary rewards for participation, and my child is not obliged to participate and can withdraw from the research study at any time.

Signature: ________________________ **Witness**:_________________________

Date:____/__________/2023

PLEASE PROVIDE THE INFORMATION BELOW. All information will be treated with the strictest confidentiality.

NAME OF PARTICIPANT________________________________

DATE OF BIRTH ____________________ AGE _________ GENDER _______________

How long have you been a member of CrossFit? ______________

How would you classify your current commitment to CrossFit training on the scale below,
where 1 = Gentle and 7 = Intense? (Circle applicable number).

GENTLE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**INTENSE**

How regularly do you do CrossFit Training? (Tick applicable box).

DAILY	**4 to 6 times per week**	**2 to 3 times per week**	**2 times per week**	**Less than 2 times per week**

Thank you for completing the above. Please fold it and insert in the box provided.

APPENDIX K: ASSENT SCRIPT – PARTICIPANT UNDER 18

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73 African Street, Grahamstown, 6139 • Tel: 046 603 8471 • e-mail: g17s4347@campus.ru.ac.za

Dear potential participant

My name is Kieran Skae. I am currently enrolled for a Master's degree in Human Kinetics and Ergonomics at Rhodes University. I am researching whether there is an association between training volume, heart rate variability and injury among non-elite CrossFit athletes in South Africa. I am a member of the CrossFit gym and an instructor (coach) at the CrossFit facility in Makhanda. I would be most grateful if you would be willing to participate in this study.

Why is this study critical?

This study will be one of the first studies in South Africa to investigate risk factors associated with injury among non-elite CrossFit athletes. If an association between exercise volume, heart rate variability (HRV) and injury is confirmed, CrossFit coaches might be able to identify athletes at risk of sustaining injuries and address the possible preventable causes, thereby minimising athletes' injury risk. The outcomes of this study may be used to make recommendations to CrossFit coaches with regard to exercise prescription and monitoring of athletes' HRV and training volume. The methods used for data collection in this study are simple, user-friendly and cost-effective. If associations are established, athletes would also be able to track and monitor their own training volume and HRV using the same methods. The results of this study will also be helpful should a follow-up survey be undertaken on a longitudinal basis, especially at other CrossFit facilities in different regions in South Africa. Your results may then be used to enable comparisons and other measures.

What would you be expected to do?

Data will be collected for 16 weeks (January 2023 – April 2023). Standard daily training programmes, the "workout of the day" (WOD), and any additional training you do will be observed. You will be asked to complete a series of questions and procedures during these 16 weeks relating to training volume, heart rate variability, and injuries you may have sustained during the week. HRV and training volume data will be collected daily, while the injury surveillance questionnaire will be completed weekly. Data for training volume and injuries will be collected using an electronic online questionnaire constructed on google forms, and HRV will be collected using the available smartphone application called "HRV4Training". None of the procedures are invasive and will not inflict any pain or discomfort. Your participation is entirely voluntary, and you may withdraw at any time. You will not suffer any consequences and do not have to provide a reason for not wanting to participate.

What are the benefits and risks to the members/participants?

Injury prevention recommendations can be developed based on the results of this study. These recommendations can then be given to the affiliate owners of the CrossFit gym. If you consent to share your information, a report of your analysis results could be provided to the affiliate owners. This will enable them to provide better coaching according to your needs to improve your training performance

The risk factors of this study are deemed to be very low. The researcher is only observing and recording what you would normally be doing. In fact, it is essential to the success of the researcher's study that you do not deviate from what you would have done if you were not a participant in this study. In addition, no social group, institution or community members are being investigated other than CrossFit members who are voluntarily participating in the study. The participants are generally realistic about what they can and cannot do. However, there is a risk that you may encounter a physical injury simply due to you not warming up properly, or over-exerting yourself in the process of your training performance being measured and analysed in the lead-up to the competition. In this regard, you are strongly encouraged to maintain your regimen as if you were not participating in the study.

How will feedback be provided to participants/parents of participants?

Upon request, participants/parents of participants will receive feedback in the form of an email that contains the research results and practical recommendations. The researcher also intends to publish the research results in the form of a Master's Research report as well as a presentation at the end-of-year departmental seminar. However, confidentiality and anonymity of records will be maintained and participants' names and identities will not be revealed to anyone who has not been involved in the conducting of the research.

Will information be handled as confidential?

The names of participants will only be written on the consent form and not on the questionnaires. Consent forms will be kept separately from the questionnaires. All information will be confidential and only be used for this research study. All members/participants will be given a study number and kept in possession of the researcher only.

Hard copies of the data collection tools and the electronic versions and spreadsheets will be held on the researcher and supervisor's computer, which will be password protected and saved in a cloud.

Ethical clearance to conduct this study has been obtained from the Rhodes Human Research Ethics Committee (Ethical clearance number: 2022-5925-7235).

What if I do not want to do this?

Even if your parents have agreed to your participation you may refuse to take part in this study. It is completely up to you and no one else.

For more information, or if you have any queries, please don't hesitate to contact us. Contact details are provided below.

If you are interested in participating in this study, please fill in and sign.

BY SIGNING THIS DOCUMENT I ACKNOWLEDGE THE FOLLOWING:

1. I understand what this research study is about and I am willing to take part in it.

2. The researcher has answered all the questions that I might have asked.

3. My participation is voluntary and I can pull out of the study at any time.

Name and signature _________________________

Date ____________________

Kind regards,

Kieran Skae, BA (Hons)

Phone: (073) 716-0984

Email: g17s4347@campus.ru.ac.za

Prof. Candice Christie

Phone: +27 (0)46 603 8470

Email: c.christie@ru.ac.za

Rhodes University Research Ethics Committee contact details:

Dr Janet Hayward

Phone: 046 603 8232

APPENDIX L: INSTRUCTIONS MANUAL FOR DATA COLLECTION

Title: Risk Factors Associated with Injury among Non-elite CrossFit Athletes in the Eastern Cape, South Africa		
Duration: 16 weeks, from Monday 23rd of January to 14th of May 2023		
Researcher name: Kieran Skae	**Email:** kieranskae16@gmail.com	**Phone:** 0737160985

Before going through the instructions, a couple of things need to be done.
➢ Provide the researcher with your **email address** and then **sign the register**. This is important so the researcher can register you on the HRV4Training system. If you are **not** at the meeting, please email or WhatsApp the researcher your email. This has to be done by **1:00 pm**, Saturday, 21st of January 2023.
➢ Get your **study number** from the researcher. Once you have it, write it on your instruction manual as a reminder. You will need this for the training volume and injury surveillance questionnaire every time you fill them out. ➢ If you are **not** at the meeting, please email or WhatsApp the researcher so he can give you your study number. This has to be done by **1:00 pm**, Saturday, 21st of January 2023.
➢ Get your **code number** from the researcher. You will need this for downloading the HRV4Training app. If you are **not** at the meeting, please email or WhatsApp the researcher so he can give you your code number. You must also specify your **phone type** (iPhone or Android), so the researcher can give you the correct code. This has to be done by **1:00 pm**, Saturday, 21st of January 2023.

● **What is the researcher analysing?**
1. Heart rate variability
2. Acute:Chronic exercise volume ratios and overall training volume
3. Injury surveillance
➢ These three components will be analysed throughout the sixteen weeks of evaluation.
● **How is the researcher going to analyse these components?**
▪ Let's break it up into sections: ➢ Section 1 – Heart rate variability (HRV) (pg. 2-3) ➢ Section 2 – Training volume (pg. 3) ➢ Section 3 – Injury surveillance (pg. 5)

● **Section 1 – Heart rate variability**
➢ Heart rate variability (HRV) will be measured using the available smartphone application called "HRV4training" (https://www.hrv4training.com/).

▪ **How does it work?**
➢ The application utilises photoplethysmography (PPG) to measure HRV. The method detects changes in blood volume during a cardiac cycle by illuminating the skin and measuring changes in light absorption. HRV4training uses your smartphone to extract PPG from your fingertip, which is placed on the phone's camera. This is then used to determine markers of the autonomous nervous system activity.

▪ **How do you get access to the app?**
➢ You must download the app on Apple Store or Play Store, whichever your phone is assigned to. The app is not free to download. However, you will not have to pay. The researcher will support the payment. ➢ You will be given a **code** from the researcher, which you must type in. This code will automatically support the payment for you.
▪ **How do you put in the code?**
❖ iPhone user: ➢ To use the code, open the App Store app on the "featured" page, and scroll to the bottom, where you'll find a "redeem button". Tap the button and enter the code. **You don't need to search for the app. The code is already associated with it and will download it automatically.** ❖ Android user: ➢ To use the code, open the Play Store app, tap Menu, Payments & Subscriptions, Redeem (or Promo), and enter the code. **You don't need to search for the app. The code is already associated with it and will download it automatically.**

▪ **So, what will you do once you have the app?**
➢ Step 1: Follow all the steps and procedures the app requires upon download.
➢ Step 2: Perform a practice HRV measurement. The app will assist you.
➢ Step 3: Once you are in the app, go to settings under the **configure & export** section. Scroll down until you come to the **data settings** section. Click on **Data sharing settings…HRV4Training Coach**. Click accept coach request to share your data with the researcher. This will give the researcher access to monitor your HRV daily.
➢ Step 4: Now that you have access to the app and your data is shareable with the researcher, every morning, upon waking, you will have to open the HRV4training app and perform a one-minute HRV measurement in a relaxed supine (lying down) position, breathing normally. This will involve placing your fingertip on your phone camera so the app can measure your score. After your HRV measurement, you must also answer a set of questions. The questions relate to your sleep, training, physical condition, mental energy, muscle soreness, fatigue, if you are injured, if you travelled, alcohol intake, and if you are sick.

▪	**Important points to understand in this section:**
➢	PLEASE MAKE SURE YOU ARE CONSISTENT. Daily reminders will be sent out to make sure that you are compliant.
➢	DO NOT WALK AROUND TOO MUCH BEFORE TAKING YOUR HRV READING. You can go to the bathroom, but give yourself 2 minutes to relax again before taking the reading.

●	**Section 2 – Training volume**
➢	Training volume will be captured using a Google form accessible via WhatsApp.

▪	**What is training volume, and what is being measured in this study?**
➢	Training volume takes frequency, duration, and intensity into account. Two variables will be measured: Session rating of perceived exertion (sRPE) and session duration (minutes). Additionally, further examination will be done in an Excel spreadsheet which will be used to calculate the acute:chronic exercise volume ratios and overall training volume of each participant throughout the analysis. Acute exercise volume (EV) refers to one week (7 days) of training volume, and chronic EV refers to a rolling training volume average of 3 weeks (21 days).

▪	**What are you supposed to do?**
➢	20-30 minutes after your training sessions/competitions, you must complete the training volume questionnaire posted on the WhatsApp group "Kieran Masters Study". If you only train/compete once that day, you will only have to complete the questionnaire once. The more sessions/competition events you have that day, the more you have to complete the questionnaire.

▪	**Important points to understand in this section:**
➢	PLEASE MAKE SURE YOU ARE CONSISTENT. Daily reminders will be sent out to make sure that you are compliant.
➢	Make sure you complete the questionnaire 20/30 MINUTES AFTER a training session/competition event.
➢	The questionnaire incorporates guided instructions making it easy to understand. Follow the steps.

●	**Section 3 – Injury surveillance**
➢	Injury surveillance will be captured using a Google form accessible via WhatsApp. The questionnaire is based on the Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire.[62,83,84] and modified for this study.
●	**What is an injury defined as in this study?**
➢	An injury is defined as "any new musculoskeletal pain, feeling or injury that results from a CrossFit® workout and leads to one or more of the following: 1. Total removal from

	CrossFit® training and other outside routine physical activities for >1 week 2. Modification of normal training activities in duration, intensity, or mode for >2 weeks 3. Any physical complaint severe enough to warrant a visit to a health professional".

●	**What are you supposed to do?**
➢	Every Sunday, once a week, regardless of injury status, you must complete the injury surveillance questionnaire posted on the WhatsApp group "Kieran Masters Study".

▪	**Important points to understand in this section:**
➢	PLEASE MAKE SURE YOU ARE CONSISTENT. Daily reminders will be sent out to make sure that you are compliant.
➢	Make sure you complete the questionnaire EVERY SUNDAY regardless of your injury status.
➢	The questionnaire incorporates guided instructions making it easy to understand. Follow the steps.

APPENDIX M: ECSS RIMINI CONFERENCE 2025 APPROVAL

See you at ECSS Rimini 2025!

Dear Candice,

Congratulations!

We are delighted to inform you that your abstract has been accepted for the 30th Annual Congress of the European College of Sport Science, taking place from 1 to 4 July 2025 in Rimini!

Following an incredible number of abstract submissions this year, the Scientific Board, Scientific Committee and Executive Board faced a challenging task in shaping an outstanding Congress scientific programme based on the Reviewing Panel's abstract reviews.