



TUS Midlands
Midwest

Performance Attenuation and Recovery in Gaelic Games

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Declaration

I hereby declare that this thesis is entirely the result of my own investigation, and that due acknowledgement, credit and/or reference has been provided wherever necessary throughout the main text. This thesis, or any part thereof, has not been submitted towards any other academic award in any other university or tertiary institution. Finally, all research procedures conducted and reported within this thesis have received the approval of the institutional ethics committee.

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Glossary of terms

Accelerations = an increase in speed for at least 0.5 second with maximum acceleration in the period at least $0.5 \text{ m}\cdot\text{s}^{-2}$

Burnout = physical and/or emotional exhaustion, sport devaluation and reduced athletic accomplishment associated with sport participation.

Decelerations = a decrease in speed for at least 0.5 second with maximum deceleration in the period at least $0.5 \text{ m}\cdot\text{s}^{-2}$

High intensity bursts = the total number of times whereby a minimum of 3 high intensity activities occurred in a time period.

Impacts = maximum accelerometer magnitude values above 2G in a 0.1 second period.

Load = a culmination of stressors accrued during training session(s) and/or match(s). This may relate to the external workload performed and/or the internal responses to a given workload.

Neuromuscular fatigue = exercise induced diminution in the capacity of the neuromuscular systems to generate force and/or velocity under load, which is transiently reversible with rest.

Performance attenuation = an umbrella description of the multifactorial contributors (such as neuromuscular fatigue, muscle damage and perceptual disturbances) that may decrease an athlete's capacity to perform.

Post-exercise recovery = a multifaceted psychophysiological restorative process following exercise relative to time.

Sprint distance = the distance covered at a speed above $5.5 \text{ m}\cdot\text{s}^{-1}$ maintained for at least 1 second.

Sprints = the number of runs recorded above $5.5 \text{ m}\cdot\text{s}^{-1}$ which are maintained for at least 1-second

Total distance = total distance covered by player in the match.

List of Abbreviations

$\Sigma 7$	Sum of 7
°/s	Degrees per second
1RM	One repetition maximum
ACSM	American College of Sports Medicine
ADP	Adenosine diphosphate
AFL	Australian football league
AIT	Athlone Institute of Technology
ATP	Adenosine triphosphate
B	unstandardized regression coefficient
beats·m ⁻¹	Beats per minute
BF	Body fat
Ca ²⁺	Calcium ion
CK	Creatine kinase
cm	Centimetre
CMJ	Countermovement jump
CNS	Central nervous system
CO ₂	Carbon dioxide
DJ	Drop jump
DOMS	Delayed onset muscle soreness
E1RM	Predicted one repetition maximum
E-C	Excitation-contraction coupling
EIMD	Exercise induced muscle damage
EMG	Electromyography
ES	Effect Size
FFM	Fat free mass
GAA	Gaelic athletic association
GPS	Global positioning systems

H ⁺	Hydrogen Ion
HR	Heart rate
Hr	Hour
HRR	Heart rate recovery
HRV	Heart rate variability
Hz	Hertz
IMTP	Isometric mid-thigh pull
Kg	Kilogram
Km	Kilometre
km·h ⁻¹	Kilometre per hour
KPI	Key performance indicator
LGFA	Ladies Gaelic Football Association
LT	Lactate threshold
m	Metre
m·s ⁻²	Metres per second (acceleration or deceleration)
m·s ⁻¹	Metres per second
min	Minute
ml·kg ⁻¹ ·min ⁻¹	Millilitres per kilogram per minute
mmol·L ⁻¹	Millimole per litre
mmol·kg	Millimole per kilogram
MVC	Maximal voluntary contraction
<i>n</i>	Number
Na ⁺ /K ⁺	Sodium-potassium pump
Nm	Newton Metre
NRL	National Rugby League
O ₂	Oxygen
PCr	Phosphocreatine
P _i	Phosphate
PQ	Perceptual questionnaire

RE	Running economy
RFD	Rate of force development
RM	Repetition maximum
RPE	Rate of perceived exertion
s	Seconds
SD	Standard deviation
SE _B	Standard error of the coefficient
SJ	Squat jump
SR	Sarcoplasmic reticulum
SSC	Stretch shortening cycle
TUS	Technological University of the Shannon
VJ	Vertical jump
$\dot{V}O_{2max}$	Maximal oxygen consumption
YoYoIR	YoYo intermittent recovery test
YoYoIR1	YoYo intermittent recovery test level 1
YoYoIR2	YoYo intermittent recovery test level 2
B	Standardised coefficient
μL	Microliter

Project Abstract

Background: Gaelic games match-play involves players undertaking frequent and irregular anaerobic efforts interspersed with low-intensity aerobic activity, while being regularly exposed to physical contact during contests for possession. Performance of such actions in a physically demanding environment results in performance attenuation and the development of fatigue and muscle damage. Success in Gaelic games necessitates consistent high-level performances, with athletes and coaches seeking any advantage in preparation for competition. Developing players components of fitness and optimising recovery strategy use may help increase competitive in-game workloads, reduce performance attenuation and alleviate post-match fatigue and muscle damage.

Aims: This project aims to examine the performance attenuation experienced by Gaelic players, the influence of physical conditioning on these responses and the subsequent timeline and strategies of recovery utilised following match-play.

Study 1 investigated performance attenuation and the timeline of post-match recovery during and following a senior club-level Gaelic football match. Creatine kinase, drop jump height, contact time, reactive strength index, countermovement jump height and a perceptual questionnaire were assessed during and up to 48 hrs post-match. Results suggest large decrements in performance and substantial multifaceted fatigue are induced by a competitive senior club-level Gaelic football match.

Study 2 & 3 examined the relationship between selected components of fitness and in-game workload measures, performance attenuation and post-match recovery. Player's anthropometrics, running speed, strength, power, and aerobic capacity were assessed over two separate days, one week before a competitive match. GPS units were used to examine in-game workload measures. Results suggest that well-developed running speed, body composition and lower-body power are positively associated with competition workloads. Furthermore, measures of performance attenuation and post-match fatigue were reduced in players with well-developed aerobic capacity and lower-body strength.

Study 4 & 5 investigated Gaelic athletes' implementation and perceptions of post-exercise recovery strategies. A survey consisting of a combination of Likert scale, open-ended response and checkbox questions was administered to adult Gaelic games players of different sports, playing standard and biological sex. Sleep, hydration, strategic nutritional intake, stretching and active cool down were perceived to be the most effective strategies. In addition, an active cool down, application of cold, sleep routine, nutritional strategy and massage were the most prevalently used recovery practices by Gaelic games players. Overall, while recovery strategies with well documented efficacy are most regularly used and are rated as the most important, a distinct and possibly problematic discrepancy was identified between the implementation and perceived importance of many regenerative practices and their scientifically demonstrated efficacy

Chapter 1 – Introduction

Gaelic games are sports native to Ireland, with 1618 clubs nationally affiliated and a further 398 clubs internationally (Crampsie, 2016). Players participate and compete in the sports of Gaelic football, hurling, camogie, Gaelic handball and rounders. Taken together, the Gaelic games governing bodies of the Gaelic Athletic Association (GAA), Camogie Association and the Ladies Gaelic football Association (LGFA) form the largest amateur sporting body in the world (Orejan, 2006). Gaelic Football, a field-based invasion team sport, is the most popular sport within the Gaelic games codes and is contested on a grassed pitch with two teams of 15 players. A team is made up of a goalkeeper, 6 defenders (3 full-backs and 3 half backs), 2 midfield players and 6 attackers (3 half forwards and 3 full forwards) with 5 substitutions permitted per game. A match is 60 minutes long at club level and 70 minutes at elite male inter-county level, while ladies club and inter-county level games are both 60 minutes in duration. Matches are officiated by a referee who covers the pitch area, two side-line officials and 2 umpires at each goal (4 in total). Broadly speaking, Gaelic football generally shares similar skill, technical and movement patterns to other field based invasion sports such as soccer (Withers, 1982) and Australian rules football (Coutts et al., 2010). Specific ball movements in Gaelic football include the instep kick, punt kick, tackle, fist pass, ball pick up and the solo run (Reilly and Doran, 2001). The ball used is similar in size to a soccer ball but is slightly heavier and may be passed to another player by hand or foot, or carried using a solo technique which involves kicking the ball from foot to hand during locomotion. A team may score a point by kicking or hand passing the ball over the bar and a goal, which is worth three points, is scored when the ball passes between the posts and under the crossbar. The goal consists of two upright posts which are 6.5 meters apart from each other and connected by a crossbar 2.5 meters in height (Mangan et al., 2017a). Players may compete simultaneously with club, school/college and intercounty

teams at different age grades, with clubs based in local parishes and communities forming the basis of Gaelic games.

Gaelic football match-play necessitates considerable technical and tactical proficiency alongside the physical capacity to cope with intense conditional demands and physical contact (Mangan et al., 2020). The game is characterized predominantly by low and moderate intensity activity interlinked with short bursts of explosive neuromuscular-based actions (Ryan et al., 2018). During the competitive season, Gaelic football players regularly undergo extensive training and match schedules, often playing with more than one team and/or sometimes more than one sport (Kelly et al., 2018b). These summative demands are likely to impose significant metabolic, biomechanical and perceptual stressors which possibly persist over an extended period (Silva et al., 2018, Hagstrom and Shorter, 2018). Notwithstanding the longitudinal demands of the sport, players are likely to face significant acute fatigue and an accompanying attenuation of performance during and following regular team training and match-play (Hader et al., 2019, Hagstrom and Shorter, 2018, McLellan et al., 2011). The progressive quarterly decline in competitive running indices recorded during Gaelic football match-play reinforce this point, and may serve as a surrogate indicator of neuromuscular fatigue endured by players (Malone et al., 2017c). Indeed, Gaelic football is thought to provoke significant central and peripheral fatigue, which is likely to subsequently impose both contractile and neural dysfunction, among other neuromuscular impairments (Amann, 2011, Cormack et al., 2008). Data from similar field-based invasion team sports (i.e., soccer, rugby league and Australian rules) reported significant declines in physical performance, muscle damage and perceptions of muscular soreness/tiredness using a variety of biochemical, endocrine, perceptual and neuromuscular monitoring variables (Twist et al., 2012, Hunkin et al., 2014, Ascensão et al., 2008). A multifactorial monitoring approach using markers such as these may present similar utility

in profiling the timeline of recovery following Gaelic games match-play as has previously been used in rugby union (Ramírez-López et al., 2020), rugby league (McLellan et al., 2011), soccer (Brownstein et al., 2017) and Australian rules (Norris et al., 2019). Indeed, such knowledge is vital to inform tactical player rotation, injury prevention and training load management periodisation strategies (Kelly and Coutts, 2007, McLean et al., 2010a, Moreira et al., 2015) specific to Gaelic games players.

Of note, physical conditioning attributes are likely to influence performance attenuation and external workloads during competitive match-play (Shovlin et al., 2018) when considering the associations reported in similar team sports (Benjamin et al., 2020, Aquino et al., 2020). Developing physical capacity levels to enable the performance of a greater volume, density and intensity of external work than the opposition is a key component of successful competition (Gabbett and Seibold, 2013a). In team sports similar to Gaelic football, superior aerobic conditioning and other associated measures of endurance capacity have been positively related to the performance of high intensity activity, distances covered, and ball involvements during competitive games (Swaby et al., 2016, Rampinini et al., 2007, Dujic et al., 2016, Helgerud et al., 2001). Similarly, body composition is reported to exert an important influence on player's external work capacity as excess fat tissue can add to the physiological strain players experience during match-play (Meir et al., 2001). Additionally, when considering the strenuous power/speed tasks player's undertake during match-play with rapid changes of pace, sprints and contests for possession it may be likely that players neuromuscular qualities represent a key prerequisite to the performance of many important actions during competition (McGahan et al., 2018a, Malone et al., 2017c, Bangsbo, 1994, Reilly et al., 2015). Finally, the current dependence on empirical evidence from other sports presents sub-optimal data for Gaelic games

practitioners in planning and designing training programmes with the goal of effectively and efficiently increasing players competitive in-game workloads.

The post-match performance attenuation and muscle damage response appears to be modulated by physiological attributes in similar team sports (Norris et al., 2019, Owen et al., 2015, Johnston et al., 2015a). Considering the significant physical and metabolic demands of Gaelic football and the previously documented interplay between components of fitness, performance attenuation and muscle damage in other team sports, it may be logical to assume that physical conditioning protects against post-match disruptions (Hunkin et al., 2014, Johnston et al., 2015b). More specifically, advanced aerobic conditioning has been reported to ameliorate the metabolic disruption during the high intensity running of soccer match-play (da Silva et al., 2010). In addition, well-developed lower-body strength and power have been reported to attenuate muscle damage and neuromuscular disturbances following competitive rugby league play (Johnston et al., 2015b, Owen et al., 2015). Taken together, these works may guide the assumption that a wide range of physical conditioning attributes may influence fatigue and muscle damage responses during and following team sport match-play. Nonetheless, this effect has yet to be demonstrated in Gaelic football, where many unique contextual factors associated with the sport (e.g., amateur status, pitch dimensions and sport-specific technical constraints) may yield different associations with physical conditioning attributes when compared with other team sports.

Although periods of intense training/competition eliciting a significant neuromuscular fatigue stimulus are necessary to modulate physiological adaptations and improve performance (Boyas and Guével, 2011), excessive long-term fatigue and muscle damage resulting in overlapping disturbances between training and competition is likely to result in underperformance, increased susceptibility to injury or induce symptoms

associated with overtraining (O'Keeffe et al., 2020, Kellmann, 2010). While evidence has yet to be presented in Gaelic games, athletes in many team sport codes frequently use various passive and active recovery modalities in an attempt to alleviate fatigue, inflammation and muscle damage (Crowther et al., 2017). Strategies such as napping, fluid replacement, massage and cold exposure are well-perceived and regularly used in team sport settings as a means to enhance recovery following exercise (Pooley et al., 2020, Heaton et al., 2017, Sánchez-Ureña et al., 2015). However, given Gaelic games amateur status and the games unique training and competitive demands, specific research may be required to directly examine recovery strategies in these populations to yield appropriately applicable data.

In summation, information detailing Gaelic games players responses to match-play and the influence of factors likely to modulate these responses, such as physical conditioning and various indices of workload are not currently available. Similarly, the subsequent timeline of recovery and practices undertaken during this period (such as diet, massage, sleep etc.) remains uncertain. Therefore, contextually relevant and practically applied research on Gaelic games players is required in order to inform the practitioners who strive to design tailored strategies targeting performance increments, wellbeing management and the mitigation of neuromuscular fatigue, muscle damage and injury. Specifically, it is essential to establish the magnitude and duration of performance attenuation and muscle damage experienced following match-play and the subsequent timeline and strategies of recovery so as to provide objective data for coaches to prepare for subsequent competition and/or training. Furthermore, gaining an understanding of the influence of various physiological attributes on performance attenuation and recovery would also provide valuable insight for coaches who seek to maximise players sport-specific work capacity, minimise neuromuscular fatigue and muscle damage, and profile

the physiological characteristics which best facilitate performance and recovery. Finally, knowledge surrounding recovery strategy use is also required to gain a comprehensive understanding of the kinetics of performance attenuation and recovery within Gaelic games. This is a complex and multifactorial topic that is currently largely unexplored. Therefore, the present thesis sought to investigate performance attenuation and recovery within Gaelic games and explore key variables that may moderate responses such as physical conditioning markers, in-game workloads and recovery strategies.

PhD Project Aim

This PhD project aims to examine the performance attenuation incurred by Gaelic Games players, assess the influence of physiological attributes on these responses and establish the subsequent timeline and strategies of recovery employed following training or match-play. This thesis comprises a pilot study and 5 individual studies (Figure 1. 1).

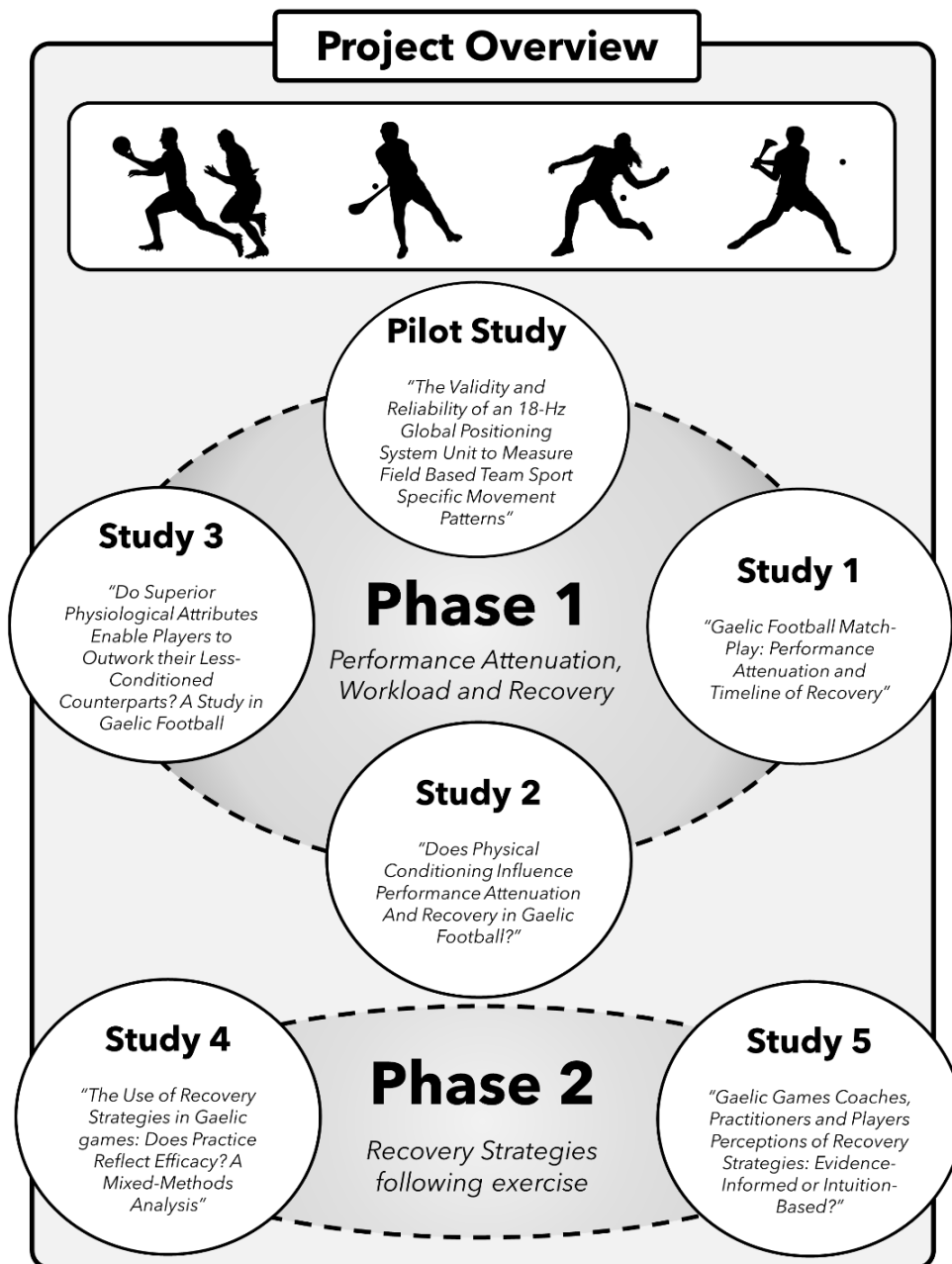


Figure 1. 1. Thesis overview.

Phase 1 – Performance Attenuation, Workload and Recovery

Pilot Study – Aim and Objectives

Aim

To investigate the validity and reliability of an 18 Hz GPS unit to measure team sport specific movements.

Objectives

- To determine the unit's validity in measuring a range of velocities over linear and non-linear courses.
- To investigate the unit's validity in monitoring total distance specific to team sport match-play.
- To examine inter-unit, intra-unit and time of day reliability.

Study 1 – Aim and Objectives

Aim

To evaluate the changes in markers of fatigue and performance attenuation during and following competitive Gaelic football match-play.

Objectives

- To examine Gaelic football players perceptual, neuromuscular and biochemical responses during and following match-play.
- To investigate players in-game workload indices during competitive match-play.
- To assess the influence of in-game workload indices on players psychophysiological responses.
- To determine the magnitude of performance attenuation and subsequent time course of recovery following Gaelic football match-play.

Study 2 – Aim and Objectives

Aim

To investigate the influence of components of fitness on in-game workload in Gaelic football.

Objectives

- To detail Gaelic football players anthropometric characteristics, muscular strength and power, running speed, blood lactate concentrations, running economy and maximal aerobic capacity characteristics.
- To examine possible relationships between these physiological attributes and players external markers of competitive in-game workload.

Study 3 – Aims and Objectives

Aim

To examine the influence of components of fitness on markers of performance attenuation and the subsequent timeline of recovery in Gaelic football.

Objectives

- To investigate the influence of players components of fitness on the magnitude and of perceptual, biochemical and neuromuscular markers expressed during competitive match-play.
- To examine the influence of players components of fitness on the magnitude and duration of psychophysiological disruptions during the post-match timeline of recovery.

Phase 2 – Recovery strategies following exercise

Study 4 – Aims and Objectives

Aim

To determine Gaelic games players use of post-exercise recovery strategies.

Objectives

- To adapt a recovery strategies questionnaire for use in Gaelic games and establish the validity and consistency of the questionnaire.
- To investigate participants training time, training frequency, off-season length and possible additional multi-sport and team activity during the year.
- To examine the use of recovery strategies among Gaelic games players.
- To investigate how and when players implement specific recovery strategies following exercise.
- To investigate if and/or why players change the use of recovery strategies during the competitive season.
- To identify possible differences in the use of recovery strategies between sport, biological sex and playing standard.

Study 5 – Aims and Objectives

Aim

To examine and compare Gaelic games players and practitioners' perceptions of post-exercise recovery practices.

Objectives

- To adapt a recovery strategies questionnaire for use in Gaelic games players and practitioners and establish the validity, internal-consistency and test-retest reliability of the questionnaire.
- To investigate players and practitioners' perceptions of the importance of various recovery strategy use.
- To identify possible differences in perceptions between players and practitioners.
- To establish possible differences in players sport, biological sex and playing standard.
- To identify possible differences in practitioners sport, biological sex and playing standard.

Dissemination of Work During Candidature

Peer-Reviewed Articles

- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T., 2022. Does Physical Conditioning Influence Performance Attenuation and Recovery in Gaelic Football? *International Journal of Sports Physiology and Performance*, (aop), p. 1-9.
- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T., 2020. Gaelic football match-play: performance attenuation and timeline of recovery. *Sports*, 8(12), p. 166.

Submitted Manuscripts

- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T. Do Superior Physiological Attributes Enable Players to Outwork their Less-Conditioned Counterparts? A Study in Gaelic Football. *Journal of Strength and Conditioning Research*. Submitted: 8th March 2022.

Oral Conference Presentations

- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T. Does Physical Conditioning Influence Performance Attenuation and Recovery in Gaelic Football? Exercise and Sport Science Australia Conference: 6th December 2021.
- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T. Does Physical Conditioning Influence in-game workload, Performance Attenuation and Recovery in Gaelic Football? Postgraduate Research Connect Seminar Series. School of Sport and Exercise Science at University of Lincoln: 4th August 2020.

- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T., 2019. Gaelic football match-play: performance attenuation and timeline of recovery. All Ireland Postgraduate Conference in Sport Science, Physical Activity and Physical Education, Athlone Institute of Technology, Athlone, Ireland: 10th May 2019.
- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T., 2018. The Validity and Reliability of an 18-Hz Global Positioning System Unit to Measure Field Based Team Sport Specific Movement Patterns. Athlone Institute of Technology Department of Sport and Health Sciences Research Seminar, Athlone, Ireland: 1st May 2018.

Poster Presentations

- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T. Do Superior Physiological Attributes Enable Players to Outwork their Less-Conditioned Counterparts? A Study in Gaelic Football. SHE Postgraduate Research Symposium: 9th June 2022.
- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T. The influence of Components of Fitness on In-Game Workloads, Performance Attenuation and Recovery in Gaelic Football. Athlone Institute of Technology Research Presentation and Network Day, Athlone, Ireland: 2nd May 2019.
- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T. The Validity and Reliability of an 18-Hz Global Positioning System Unit to Measure Field Based Team Sport Specific Movement Patterns. Athlone Institute of Technology Research Presentation Seminar, Athlone, Ireland: 20th April 2018.

Additional Media Dissemination

- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T. The Use and Perceptions of Recovery Strategies in Gaelic games. Podcast presentation: All You Need to Know About Recovery with Lorcan Daly PhD(c): The importance of strength and aerobic fitness. The Followers Podcast Episode 54: 10th August 2021. Link: https://open.spotify.com/episode/6NWgt7jQpWVZnbfJ56ba9e?si=3OnMKo9QRbm7KOTTwzQ2_g&context=spotify%3Ashow%3A5t8tT9KZsUgxUhb9cvhn1Q&dl_branch=1&nd=1
- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T. Performance Attenuation and Recovery in Gaelic Games. Podcast presentation: Analysing Recovery Protocols in GAA. The Experiment Podcast Episode 26: 21st March 2021. Link: <https://open.spotify.com/episode/7avfkyPHnWP6YJ9zj5pQx8>.
- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T. Performance Attenuation and Recovery in Gaelic Games. Oral Presentation Delivered to the Irish Strength and Conditioning Group. 4th May 2021.
- **Daly, L.S.,** Catháin, C.Ó. and Kelly, D.T. Performance Attenuation and Recovery in Gaelic Games. Ladies Gaelic Football Association Research Pod. The Experiment Podcast Episode 26: 12th January 2021. Link: <https://consent.youtube.com/m?continue=https://www.youtube.com/watch%3Fv%3DkdaKwW3rmdI%26cbrd%3D1&gl=IE&m=0&pc=yt&uxe=eomn&hl=en&src=1>.

Thesis Navigation

The current project was completed in two main phases, comprising a pilot study and five primary experimental studies and is organised into 9 individual chapters. Chapter 1, the current chapter, shares an introduction to the thesis, providing an overview of the project and highlighting the aims and objectives of our planned research. Chapter 2 encompasses a review of literature which firstly details the demands of Gaelic football, fatigue and recovery in team sports, biomechanical/physiological mechanisms underpinning physical performance, muscle damage and fatigue, components of fitness in a team sport setting and the post-match recovery cycles of similar team sports. The second section of the literature review provides an overview of commonly used post-exercise recovery strategies in individual and team sport athletes, highlighting their effectiveness through the lens of applied experimental works and their uses and perceived importance in a range of different sporting populations.

Following the literature review, Chapter 3 is a pilot study outlining the validity and reliability of an 18-hz global positioning system unit. This study was conducted to establish the validity and reliability of a selected GPS unit to measure field-based team sport specific movement patterns prior to their use in recording players in-game workloads during the primary work of this thesis (i.e., Study 1, 2 and 3). Chapter 4 outlines our first primary experimental study which investigated performance attenuation and the timeline of recovery during and following Gaelic football match-play and was published in *Sports* on 17/12/20. Chapter 5 explores the influence of physical conditioning status on external match loads which is under review in the *Journal of Strength and Conditioning Research*. Following this work, Chapter 6 examined associations between components of fitness and

markers of performance attenuation and recovery in Gaelic football. This work is published ahead of print in the *International Journal of Sports Physiology and Performance*.

While the previous chapters outline Gaelic football players responses to match-play, the timeline of recovery and the influence of physical conditioning on these responses, other key moderators in this process remain unexplored. Indeed, players actions during the post-exercise recovery window, such as the implementation of recovery strategies, may significantly alter players regenerative responses. Additionally, study 1 of this thesis demonstrated that Gaelic football athletes display possible signs of ongoing/residual muscle damage and fatigue. We therefore sought to conduct a preliminary analysis into Gaelic games players use of post-exercise recovery strategies. This study explored the use of recovery strategies following exercise in Gaelic games, which can be seen in chapter 7. Next, chapter 8 sought to build on these preliminary findings by investigating and comparing Gaelic games players and practitioners' perceptions of post-exercise recovery strategies. Finally, chapter 9 of this dissertation contains the limitations of the project, directions for future work and final conclusions.

Chapter 2 - Literature Review

**Section 1 – Physical conditioning, post-match fatigue
and in-game workload during Gaelic football**

Introduction to the Literature Review

The aim of the current review is to critically investigate the literature relevant to performance attenuation and recovery from exercise and explore the mechanisms that may underpin these responses in Gaelic games players. Identifying the extent to which Gaelic games players performance attenuates during match play, the duration of recovery and the strategies utilized to recover is an essential step in the development and design of appropriate training and recovery programs. Section 1 of the literature review details the physical demands of Gaelic football match-play, psychophysiological factors underpinning performance attenuation, an examination of physical conditioning within Gaelic football and the interplay between these factors. The subsequent section reviews the use, efficacy and player/practitioner perceptions of recovery modalities following exercise.

Characteristics of Gaelic Football

Gaelic football can be described as a field-based invasion team sport, where players perform frequent movements necessitating a high level of skill and athleticism. The irregular and chaotic nature of Gaelic football match-play is characterised by multidirectional and intermittent short duration high intensity actions (e.g., sprints, changes of pace, contests for possession) interspaced with light activity (e.g., walking, standing, light jogging) (Beasley, 2015, Malone et al., 2021, Ryan et al., 2018, McGahan et al., 2018a). Senior male collegiate players typically perform 95.7 ± 25.7 bouts of high intensity running, with an average active interval of 5.7 ± 1.6 s and an active recovery time between bouts lasting 36.7 ± 14.1 s (spend an average of $14.4 \pm 4.7\%$ of a game performing high intensity actions) (O'Donoghue and King, 2005). Elite level players cover an average total distance of ≈ 8.5 km per game, with approximately 20% of this distance covered at speeds over $17 \text{ km}\cdot\text{h}^{-1}$ and 5.5% of the distance covered at sprinting speeds exceeding $22 \text{ km}\cdot\text{h}^{-1}$

(Malone et al., 2017d, Malone et al., 2016b). Short duration high intensity movements such as these are often crucial to the outcome of a game, and may represent key actions such as running to space during scoring opportunities, defensively tracking the movements of opposition players and successfully contesting for possession (Granero-Gil et al., 2020, Augusto et al., 2021, Mangan et al., 2020). In terms of relative output ($\text{m}\cdot\text{min}^{-1}$) Gaelic football players are reported to cover $116 \text{ m}\cdot\text{min}^{-1}$ (Collins et al., 2013), which is similar to that observed in soccer players ($118 \text{ m}\cdot\text{min}^{-1}$) (Arrones et al., 2014), lower than Australian rules football players ($127 \text{ m}\cdot\text{min}^{-1}$) (Coutts et al., 2010) and higher than rugby union backs ($89 \text{ m}\cdot\text{min}^{-1}$) (Austin and Kelly, 2013). Although amateur, elite level players may train five days per week, while often playing with more than one team and/or more than one sport during the competitive season (Kelly et al., 2018b). Well-developed physiological attributes are a major prerequisite for high performance in Gaelic football (Malone et al., 2016a, Cullen et al., 2013, Reilly and Keane, 2001) and players must be able to execute a number of technical and tactical proficiencies in an evolving high-speed environment with frequent physical contact.

Differences in movement profiles in Gaelic footballer players based on position played are evident (ranging 6,183 - 11,104 m between different playing positions) (Collins et al., 2013), which is comparable to rugby league (Evans et al., 2015, Waldron et al., 2011), soccer (Bloomfield et al., 2007) and Australian rules (Brewer et al., 2010, Veale and Pearce, 2009). Specifically, the midfield positions generally cover the greatest distances while the full forward and full back lines tend to perform the lowest running demands (Malone et al., 2017c, Mangan et al., 2017a, Ryan et al., 2018). The central positions are suggested to perform greater running demands owing to the associated tactical roles that necessitate frequent and rapid transitions from attack to defence whilst covering large areas of the pitch (Mooney et al., 2021, McGahan et al., 2018a). In-game workloads are also reported to

significantly vary across a season, with the largest match-play external loads recorded towards the end of the competitive phase (Mangan et al., 2018b). Within-match analysis has demonstrated that players external loads, in particular high intensity outputs, progressively decline over the course of a match (Mooney et al., 2021, Malone et al., 2017c). Here, high-speed running distance ($\geq 17 \text{ km}\cdot\text{h}^{-1}$) has been exhibited to decline 14% for under 20 elite players (Mooney et al., 2021) and 11% for elite players (Malone et al., 2017c) when comparing the first to fourth quarter of play.

Bioenergetics

A continuous supply, delivery and breakdown of adenosine triphosphate (ATP) is necessary to release energy and support the various cellular processes which underpin muscular contraction(s) (Westerblad et al., 2010, Febbraio and Dancsey, 1999, Bogdanis et al., 1996a). The energy systems which replenish ATP in skeletal muscle are categorised as anaerobic (Phosphagen, and Glycolytic) or aerobic (mitochondrial respiration). These systems differ in the substrates used, the rate and capacity of ATP regeneration and the metabolic by-products associated with each process (Baker et al., 2010). While it is well established that each respective metabolic process is more proficient to provide ATP during certain modes of exercise or events and less proficient during others, the literature suggests some degree of energy derived from each metabolic system is provided during all exercise or event forms (Baker et al., 2010, Kindermann et al., 1979, Beneke et al., 2002). Indeed, rather than one metabolic system exclusively providing energy during a given activity, each system sequentially and adaptively contributes to the imposed energy demands in a concurrent manner (Baker et al., 2010).

The key functions of the bioenergetic systems include the production of muscular contractile force via actin-myosin cross-bridge cycling, upkeep of sarcolemmal excitability levels and the reuptake of Ca^{2+} back into the sarcoplasmic reticulum. These responses are fundamental to athletic performance, and the speed and/or magnitude of these processes must be adapted to reflect the specific sporting demands presently faced by an athlete (Hargreaves and Spriet, 2020, Bogdanis et al., 1996a, Hargreaves, 1994). In order to meet the elevated ATP requirements when performing exercise (which can increase more than 100-fold during intense activity when compared with rest) (Egan and Zierath, 2013, Hargreaves and Spriet, 2020), a variety of metabolic pathways, both aerobic and anaerobic,

activate to supply ATP to skeletal muscle (Westerblad et al., 2010, Febbraio and Dancy, 1999, Booth et al., 2015). The contribution of a given pathway to the supply of ATP to the muscles is predominantly dependent upon the intensity, duration and density of the exercise undertaken and additional factors such as availability of substrates, fatigue status, biological sex and cardiovascular fitness levels (Hargreaves and Spriet, 2020, Febbraio and Dancy, 1999, Bogdanis et al., 1996a).

Anaerobic Energy Provision

Gaelic football players perform frequent high intensity actions throughout a match eliciting significant demands on their anaerobic energy systems and substrate reserves (McGahan et al., 2018a, Malone et al., 2017c, Bangsbo, 1994). The majority of ATP used to power these intermittent bouts of intense activity are derived from the breakdown of (i) glycogen and (ii) phosphocreatine (PCr) (Hargreaves and Spriet, 2020, Egan and Zierath, 2013). High intensity intermittent exercise has been demonstrated to substantially deplete these substrates (Parolin et al., 1999), with relatively larger reductions reported in fast twitch muscle fibres when compared with slow twitch (Green et al., 2006). More specifically, undertaking numerous high intensity actions has been shown to reduce PCr levels to below 30% of resting values if insufficient recovery is afforded between bouts (Bangsbo et al., 2006, Dawson et al., 1997). During team sport training or match-play, it is suggested that the substrate stores depleted during the high intensity intermittent activities are resynthesized during periods of lower intensity movements interspersed between bouts (Bangsbo, 1994, Dawson et al., 1997). Nonetheless, these high intensity actions are often undertaken with incomplete recovery afforded between bouts, owing to the unpredictable physical demands of Gaelic football (McGahan et al., 2018b, Malone et al., 2017d). As a consequence of this incomplete recovery, glycolytic energy sources become increasingly important to deliver the required ATP during the successive performance of high intensity actions, as PCr stores begin to diminish (Spencer et al., 2005).

Reinforcing the assertion of the high anaerobic demands incurred during team sport activity, a four-fold increase in muscle lactate was reported following soccer match-play (approximately $15 \text{ mmol}\cdot\text{kg dry weight}^{-1}$) when compared with resting baseline values (Krustrup et al., 2006). In Australian rules football, blood lactate values following the second quarter were elevated by 5.7% (ES = 6.9) above baseline in comparison to first

quarter values, with progressive increases following each successive quarter (Veale and Pearce, 2009). While no such lactate measurements have been reported during Gaelic football match play, similar results could be anticipated due to comparable intermittent demands of both soccer and Australian Rules football (McGahan et al., 2018a, Buchheit et al., 2010, Young et al., 2012). Overall, high levels of ATP utilisation via anaerobic pathways are likely to be a key component of energy metabolism during Gaelic football match-play (Hargreaves, 1994, Spencer et al., 2005, Dawson et al., 1997). As a consequence of this energy metabolism, metabolic acidosis (Bogdanis et al., 1996a) is a factor that may impair further bouts of rigorous activity (Spencer et al., 2005). A governing mediator in the replenishment of ATP stores between bouts of high intensity activity is suggested to be the capacity of the oxidative metabolic pathway to produce energy (Kowalchuk et al., 1988, Parolin et al., 1999, Rodríguez-Fernández et al., 2017). Indeed, continuous aerobic production of ATP during low intensity actions and/or rest periods between strenuous activity is central to the synthesis of PCr during intermittent activity (Harris et al., 1976, Karatzaferi et al., 2001, Dawson et al., 1997) and is subsequently a pertinent physiological component of successful team sport (Rodríguez-Fernández et al., 2017, Buchheit, 2012, da Silva et al., 2010).

Aerobic Energy Provision

Gaelic football is an intermittent field based sport wherein players aerobic system is highly burdened during training sessions and matches (McIntyre and Hall, 2005, Florida-James and Reilly, 1995). During team sport activity, fat and carbohydrate are oxidatively metabolised to produce most of the skeletal muscles contractile ATP requirements (Vigh-Larsen et al., 2020, Williams and Rollo, 2015, Hargreaves, 1994), particularly during periods of low or moderate intensity activity (Pellegrin et al., 2020, Egan and Zierath, 2013). However, carbohydrate is the predominant fuel used during most activity of this nature (Williams and Rollo, 2015), whereas fat oxidation is likely to play a supporting role during the recovery periods interspersed between these high intensity bouts (Bartlett et al., 2015). Here, fuel may be mobilised from the adipose tissue, liver and skeletal muscle (Figure 2. 1) and include blood glucose, muscle glycogen, and fatty acids derived from intramuscular and adipose tissue stores triglycerides (Hargreaves and Spriet, 2020).

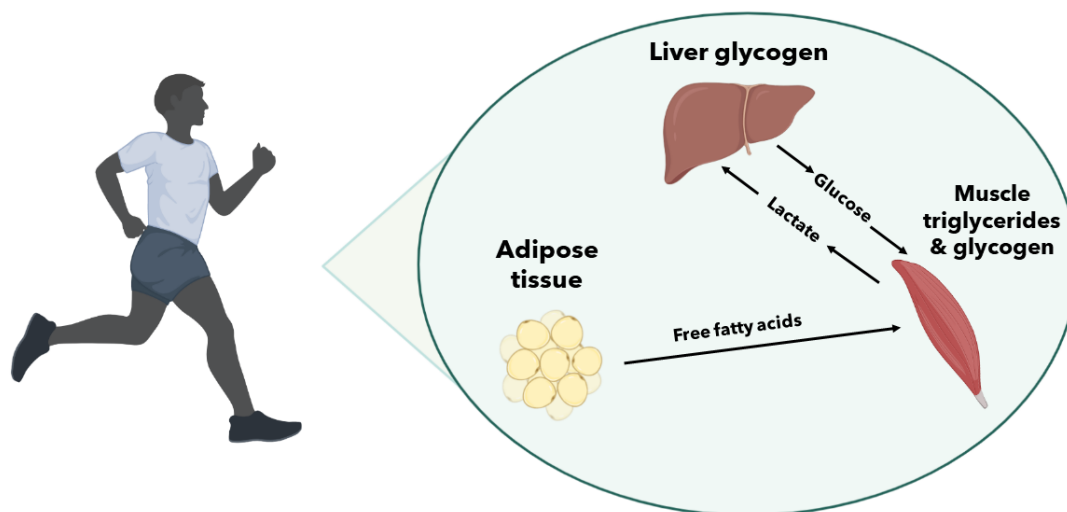



Figure 2. 1. Extra- and intra-muscular sources of fuel. Adapted from the work of Hargreaves and Spriet (2020) with permission.

An efficient cardiovascular system ensures the adequate and continual supply of O₂ to the contracting muscles, and the transportation of metabolic by-products (Pi and ADP) of ATP utilization in the cytoplasm back into the mitochondria for the resynthesis of ATP (Kushmerick, 1995, Blei et al., 1993). Mitochondrial respiration is the process by which ATP is resynthesized in the mitochondria, and requires the presence of suitable levels of fuel (carbohydrates, fat and/or amino acids) and O₂ (Baker et al., 2010). While it is well established that aerobic metabolism supports energy production for muscular contractions during lower intensity actions (i.e., > ≈ 80% VO_{2max}) (Romijn et al., 1993), it is also suggested that the depletion of ATP used via anaerobic pathways is in part compensated by aerobic metabolism (Parolin et al., 1999, Spriet et al., 1989). Importantly, oxygen uptake is likely to display a series of spikes throughout a match due to increased demands when undertaking unpredictable and numerous short duration high intensity bursts of activity (McGawley and Bishop, 2015, Mangan et al., 2020). In support of this premise, work from Haseler et al. (1999) demonstrated improved PCr recovery while breathing a hyperoxic gas and slowed recovery while breathing a hypoxic gas when compared with breathing normoxia. These results and others (Balsom et al., 1994a, Haseler et al., 2007, Balsom et al., 1994b) imply tissue oxygenation plays a key role in PCr recovery, and highlights a clear link between aerobic capacity and the regenerative power of the anaerobic metabolic pathways during intermittent exercise (Haseler et al., 1999).

Notwithstanding the depletion of ATP, an accumulation of lactate, H⁺ ions, Mg²⁺, Pi, ADP (referred to as metabolic acidosis) is also associated with increased anaerobic muscle metabolism during the performance of high intensity intermittent activity (Fitts, 1994, Metzger and Fitts, 1987) and similarly influenced by aerobic metabolic factors (McGawley and Bishop, 2015, Spencer et al., 2005, Bishop et al., 2004). Of note, an accumulation of these metabolites is suggested to interfere with subsequent muscular

contractility and lower the capacity to generate force (Westerblad et al., 1991). Importantly, athletes with superior aerobic capacity are demonstrated to present with an improved tolerance to metabolic acidosis, via an increase in buffering capacity and improved circulation, which combine to efficiently cope with and/or remove the metabolic by-products associated with intense intermittent exercise (Bishop et al., 2004, McGinley and Bishop, 2016)

Evidence indirectly in support of the existence of these physiological effects and interactions are well documented in the applied context of invasion-based team sport (Tomlin and Wenger, 2001, Meckel et al., 2009, da Silva et al., 2010). For instance, soccer players with a well-developed $\dot{V}O_{2max}$ displayed superior peak speed, anaerobic threshold, 20-m multiple stage shuttle runs and heart rate recovery compared with players of a lower aerobic conditioning standard (Rodríguez-Fernández et al., 2017). Additionally, distances covered during matches at various velocities are key variables to success in team sport (Bangsbo et al., 2006) and have been strongly correlated to aerobic fitness in team sports such as soccer and the rugby codes (Swaby et al., 2016, Dujic et al., 2016, Johnston et al., 2015b). In Gaelic football specifically, elite level players are reported to have higher aerobic capacities than sub elite players, with this trait identified as a key factor in competitive Gaelic football performance (Keane et al., 1997, Reilly and Keane, 2001, Cullen et al., 2017). Taken together, these works highlight a clear link between the capacity to oxidatively generate ATP and the repeated performance of total and high intensity workloads (i.e., actions associated with both anaerobic and aerobic metabolic processes) (Dawson et al., 1997, Buchheit, 2012, Bogdanis et al., 1996a). Insufficient regeneration of PCr during this process is suggested to underpin the progressively deteriorated performance observed when repeated high intensity bouts are interspersed with short rest periods (Figure 2. 2) (Ulupinar et al., 2021).

 **Study protocol**
10 x 40 m Sprints with 30 s rest

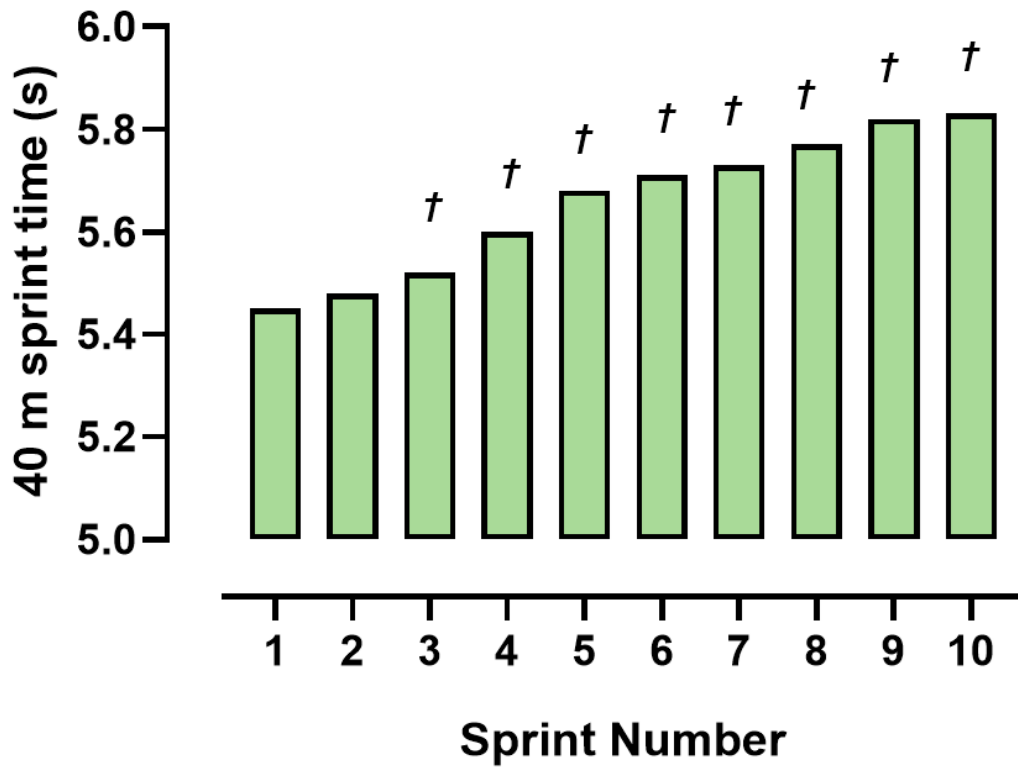


Figure 2. 2. Running speed times measured during a 10 x 40 m repeated sprint protocol with 30 seconds passive rest between sprints. † Indicates a significant difference from the first sprint ($p < 0.05$) adapted from the work of Ulupinar et al. (2021) with permission.

Neuromuscular Fatigue and Performance Attenuation

Neuromuscular fatigue is a complex phenomenon, and as a consequence, conjecture regarding its definition is evident within the literature (Twomey et al., 2017, Dalakas et al., 1998, Jones, 1996, Enoka and Stuart, 1992, Westerblad et al., 1991) which may ultimately impact its determination and characterization (Place and Millet, 2020). Indeed, the composite underlying mechanisms associated with neuromuscular fatigue have been the focus of a large volume of research, and the numerous definitions and mechanisms outlined may in part relate to many between-study differences in (i) the measures used to quantify neuromuscular fatigue and (ii) the timing of their implementation (Cairns et al., 2005, Place and Millet, 2020, Koral et al., 2020, Dalakas et al., 1998). For the purposes of the work presented within this thesis, neuromuscular fatigue will be considered as an exercise induced decline in the capacity of the neuromuscular systems to generate force and/or velocity under load, which is transiently reversible with rest (Häkkinen, 1993, Burnley et al., 2012, Taylor and Gandevia, 2008). Furthermore, performance attenuation will also be used throughout this document as an umbrella term to describe the multifactorial contributors (such as neuromuscular fatigue, muscle damage and perceptual disturbances) that may decrease an athlete's capacity to perform. Indeed, it is important to bear in mind that neuromuscular fatigue, performance attenuation, readiness to perform and other similar concepts cannot be directly quantified or determined and may only be approximated through the evaluation of various markers associated with these constructs (Jason et al., 2010, Vernon et al., 2020, Turner et al., 2016, Cairns et al., 2005).

Mechanisms of Fatigue

Athletes across a range of sports must balance fatigue and muscle damage induced from training and matches with recovery, aiming for an optimal stimulus to generate positive adaptations (Kellmann et al., 2018). Frequently reported causes of neuromuscular fatigue include but are not limited to; the accumulation of various metabolites, depletion of energy systems, a functional decline of the muscle fibres contractile mechanism and impaired nervous system control (Costill et al., 1973, Boyas and Guével, 2011, Westerblad et al., 1991). Neuromuscular fatigue is described to be separate from muscular damage or weakness (Fitts, 1994) and from muscular exhaustion, which is outlined as an inability to maintain exercise at a certain force or intensity (Vøllestad, 1997). Mechanisms underpinning the nature of fatigue are multifaceted, and they can vary depending on many different factors involving the athlete, environment and the type of exercise being completed (Metzger and Fitts, 1987, Coker et al., 2020, Dalakas et al., 1998). These factors include the intensity and duration of the exercise (Baker et al., 1993, Lepers et al., 2002, Hermansen, 1981), the type of muscle contraction (Newham et al., 1983, Molinari et al., 2006), the period of rest between contractions and sets (Jambassi Filho et al., 2020, Mirzaei et al., 2008, Bigland-Ritchie et al., 1986, Richmond and Godard, 2004), and the characteristics of the given muscle or group of muscles (Häkkinen and Komi, 1986, Pincivero et al., 2000, Bilodeau, 2006).

Notably, interference with neuromuscular transmission or a contraction coupling impairment may lessen the membrane excitability of the muscles motor-unit system, thereby inducing fatigue (Jones, 1996). Excitation contraction coupling is the action by which the release of calcium is triggered by the sarcoplasmic reticulum, causing the onset of muscular contraction to be initiated by sarcomere shortening (Rios and Brum, 1987). This excitation contraction coupling impairment may be related to a failure in action

potential propagation, a disruption in the regulation of calcium ions (Ca^{2+}) in contraction or an interference in the coupling mechanism with the release of Ca^{2+} (Jones, 1996). In a previous review on the cellular mechanisms of fatigue, Fitts (1994) articulates that an inactivation of presynaptic nerves while in a fatigued state can behave like a protection mechanism for the muscle during exercise. Knowledge of these different kinds of fatigue, which are likely to be experienced as a result of undertaking a given exercise modality, is key to understanding the nature of the recovery required and degree of fatigue likely to be experienced (Wadden et al., 2012). A chain of physiological events leading from the brain to skeletal muscle, are involved in the sequence of the contraction of a given muscle (Jones et al., 2004) and neuromuscular fatigue can therefore occur at any number of sites along this chain of events (Taylor and Gandevia, 2008, Enoka and Stuart, 1992, Fitts, 1994). In regard to this sequence of events in muscular contraction (Figure 2. 3), central fatigue is described to occur at any stage prior to the site of the neuromuscular junction while peripheral fatigue occurs along the chain either at or beyond the site of the neuromuscular junction (Taylor and Gandevia, 2008).

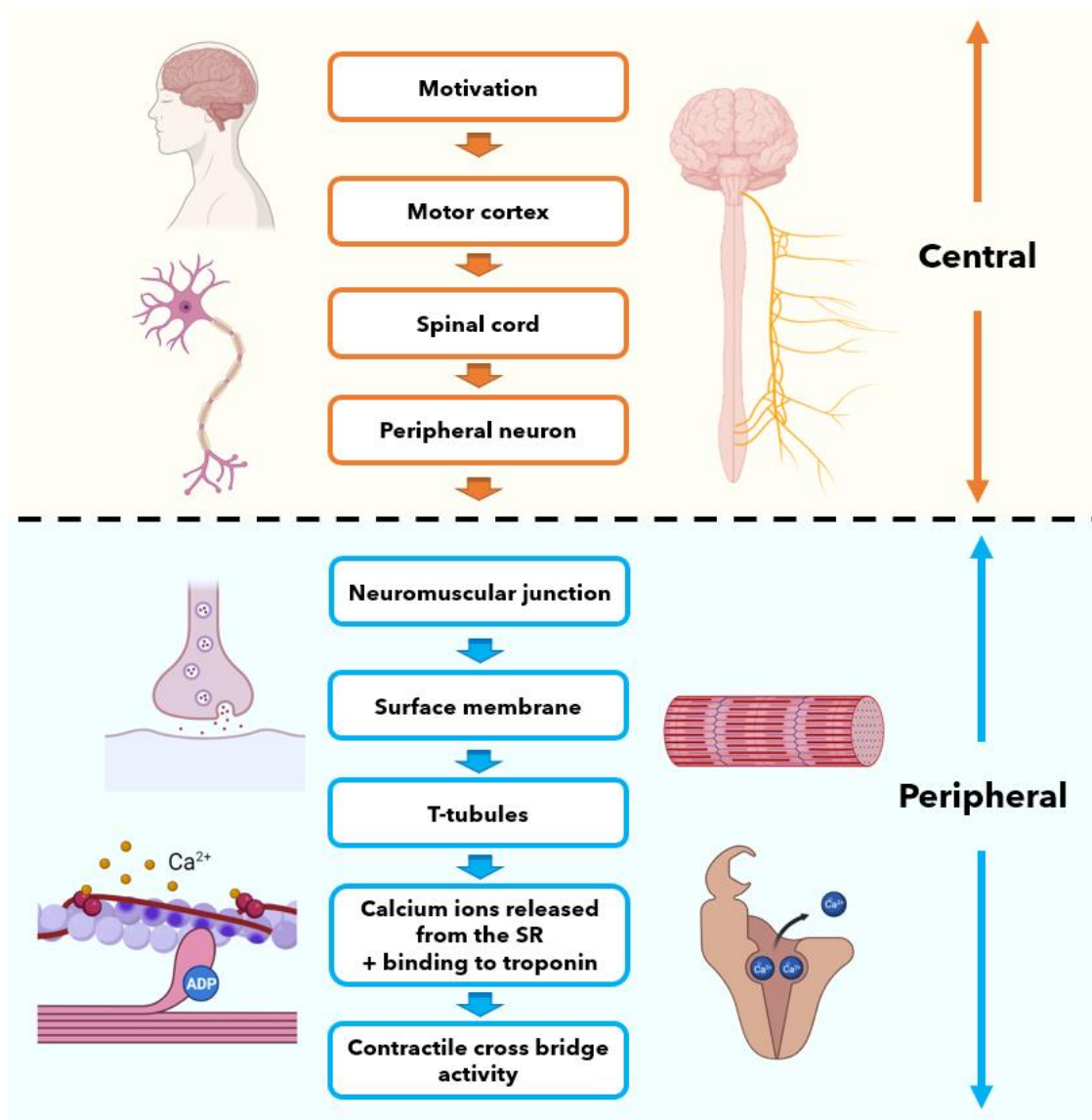


Figure 2. 3. The chain of command which leads from initial motivation to the production of force at the cross-bridges, showing the sites where potentially failure due to fatigue may occur. Based upon the work of Fitts (1994), Enoka and Stuart (1992) and Taylor and Gandevia (2008).

A combination to some degree of both peripheral and central factors is likely to induce neuromuscular fatigue in most forms of exercise (Burnley et al., 2012). The degree at which central or peripheral fatigue influences the response is however predominantly task dependant (Enoka and Stuart, 1992). Following the development of central fatigue, a reduction in the speed of motor unit firing rates in both submaximal and maximal

contractions has been observed (Rubinstein and Kamen, 2005, Carpentier et al., 2001). The mechanisms which underpin peripheral fatigue are generally better understood when compared with central fatigue (Taylor and Gandevia, 2008). Moreover, it is difficult to isolate and measure certain aspects of fatigue on their own without a combination of influences from both peripheral and central aspects of fatigue (Bigland-Ritchie et al., 1986, Bigland-Ritchie et al., 1978, Amann, 2011).

An additional factor to provoke transient attenuations in performance throughout the course of a Gaelic football match may be mental fatigue. Similar to soccer match play, Gaelic football has a constantly dynamic and irregular nature, necessitating continuous concentration, awareness and rapid decision making in high pressure conditions (Smith et al., 2016). Furthermore, players must perform frequent technically demanding skills using the hands and feet, with high levels of coordination needed alongside a rapid decision-making processing (Gréhaigne et al., 2001, Pagnano-Richardson and Henninger, 2008). It is likely that this mental fatigue is strongly interrelated to other symptoms of metabolic and physiological stress. In elite rugby league players the distance travelled, ball involvements and skill ratings were much improved in the first ten minutes of the game when compared to the last ten minutes of a competitive game (Kempton et al., 2013). A trend of progressive skill and workload deterioration is observed where players cover less total and sprint distance, while performing inferior tackling technique during the second half of a rugby match (McLellan et al., 2011, Gabbett, 2008). Additionally, soccer players are reported to cover less total distance and perform less successful passes in the second half of a competitive game (Barros et al., 2007, Burgess et al., 2006). Furthermore, soccer players showed a $25.5 \pm 4.0\%$ decrement in shot accuracy when in a fatigued state, while passes during the last 15 minutes were $7.8 \pm 4.3\%$ slower when in comparison to the initial 15 minute period of a game simulation (Russell et al., 2011).

As previously mentioned, fatigue during Gaelic football match play and other team sports is a complex phenomenon with a number of contributory aspects (Twist et al., 2012, McLellan et al., 2011). Many studies have identified that players ability to perform high intensity actions near the end of a game is decreased due to the accrual of fatigue during Gaelic football competition (Collins et al., 2013, Malone et al., 2016b, McGahan et al., 2018b, O'Donoghue and King, 2005) and a number of other field-based team sports (Granatelli et al., 2014, Gray and Jenkins, 2010, Macutkiewicz and Sunderland, 2011, Rampinini et al., 2011). Total covered distance, sprinting and high intensity running performances are all typically diminished during the second half of a game (O'Donoghue and King, 2005, Malone et al., 2016b, Fuller et al., 2016). Stores of creatine phosphate have been reported as being almost entirely depleted in an athlete's individual muscle fibres while in a state of fatigue following intensive exercise, not dissimilar in nature to the demands undertaken during Gaelic football match-play (Sahlin et al., 1997, Karatzaferi et al., 2001, Florida-James and Reilly, 1995). Another potential contributory mechanism behind the reported reduction of high intensity actions may be glycogen depletion (Spencer et al., 2005, Routledge et al., 2018). It has previously been reported that having elevated glycogen levels prior to a match or exercise can enhance long duration intermittent activity performance, while competing in a glycogen depleted state results in an impaired work rate (Balsom et al., 1999a, Sherman et al., 1981, Hargreaves, 1994, Bangsbo, 1994). Nonetheless, these declines in external load may be mitigated with adequate pre-match nutrition (Williams and Rollo, 2015, Kingsley et al., 2014, Goedecke et al., 2013). Certainly, low levels of glycogen (and subsequently reduced ATP levels) are likely to have a negative affect on important phases of excitation-contraction coupling, such as calcium handling, cross-bridge cycling and action potential propagation, which may accentuate the neuromuscular fatigue response (Mohr et al., 2022). Another confounding factor in

performance attenuation may be dehydration (Edwards et al., 2007). Indeed, significant markers of dehydration were observed following a competitive rugby league match (Jones et al., 2015), while similar findings were reported in soccer (Kingsley et al., 2014) and Australian rules post-match (Veale and Pearce, 2009). However, it remains unclear whether such performance impairments are primarily attributed to (1) fluid loss and dehydration, (2) influenced by thermal strain or (3) psychological factors in the perception of effort while the players were in a dehydrated state (Edwards et al., 2007).

Another possible explanation for fatigue accumulation following stages of intensive exercise in Gaelic football may be linked to electrical disturbances in the cell of the muscles and the associated potassium accrual inside the interstitium of the skeletal muscles (Lindinger and Sjøgaard, 1991, McKenna, 1992). The idea of these disturbances influencing muscle force production and performance is supported by the fact that muscle interstitial potassium concentration levels elevate beyond $11 \text{ mmol} \cdot \text{l}^{-1}$ (Mohr et al., 2004) during exhaustive exercise, which is a high enough level to depolarize the muscle membrane potential. This phenomenon is described to have a strong influence on the reduction of neuromuscular performance (Juel, 1986). It should be noted however that these studies do not fully illustrate the nature of fatigue development in Gaelic football, as they are often very transient in nature and quite difficult to measure in an applied setting.

The Stretch Shortening Cycle and Fatigue

Various forms of locomotion (such as running, jumping or sprinting) and other actions are described as stretch shortening cycle (SSC) movements, whereby a pre-activated muscle is eccentrically stretched prior to being rapidly followed by a concentric shortening movement, resulting in a significant force augmentation (Komi, 2000, Comyns et al., 2011). Fatigue induced from stretch shortening cycle actions is described to be different to other isolated concentric or isometric only forms of exercise in that SSC movements combine mechanical, neural and metabolic elements underpinning its fatigue response (Komi, 2000, Nicol et al., 2006). While a multitude of research papers have investigated fatigue from isolated forms of concentric, isometric or eccentric exercises (Komi and Tesch, 1979, Tesch et al., 1990, Linnamo et al., 2000) much fewer have investigated fatigue induced from SSC actions (McLellan, 2010, Nicol and Komi, 2010b). SSC fatigue has been shown to have an immediate decline post exercise, followed by a transient recovery before a further decrement 24-hr to 48-hr post-exercise (Horita et al., 1996, Avela et al., 1999, Komi, 2000). This immediate decline in performance is predominantly attributed to metabolic factors, while the decrement observed in the 24-hr to 72-hrs days post exercise window is related to delayed inflammatory processes associated with muscle tissue damage (Avela et al., 1999, Kuitunen et al., 2002). Exercise induced muscle damage (EIMD) is often observed alongside a marked decline of muscular force generating capacity and perceived muscular soreness in the day(s) following exercise, with the duration and/or magnitude of disturbances reliant upon the degree of the muscle damage induced (Paulsen et al., 2012). This process is particularly evident following exercise with a significant eccentric muscle action component, which can initiate mechanical muscle damage to more severe degrees compared with other modes of exercise (Brown et al., 1997). While the exact mechanisms of this phenomenon are largely

unknown, EIMD causes the disruption of subcellular structures and prompts an inflammatory response, oxidative stress and an accumulation of macrophages and neutrophils into the damaged tissue (Fatouros and Jamurtas, 2016). These metabolic disturbances within the muscle are thought to cause a discharge of cellular components in a series of events, while an initial adenosine triphosphate (ATP) depletion can result in extracellular calcium ions leaking out into the intracellular space via Ca^{2+} -ATPase and Na^+/K^+ -ATPase pump malfunction. Activity of intracellular proteolytic enzymes can increase cell permeability while promoting the degradation of muscle proteins, allowing some of the cells contents to leak out into blood circulation (Knochel, 1993, Brancaccio et al., 2007). During this period of inflammation, delayed onset muscle soreness (DOMS) develops and muscular strength deteriorates at a rate which is dictated by the exercise stimulus and a number of other influential factors (Peake et al., 2005a, Croisier et al., 2003).

Horita et al. (2003) investigated the effect of an exhaustive SSC exercise bout involving an average of 30 repeated jumps on a sled apparatus and demonstrated that fatigue was characterised by an initially large increase in lactate, followed by a sizable spike in serum CK levels 2 days post exercise. Here, the neuromuscular performance was described to be heavily impacted by the delayed inflammatory and muscle damage responses following the protocol (Horita et al., 2003). Similar results were reported by Cadore et al. (2013), whereby the effects of different volumes of plyometric jumps (100-300 total jumps) on metabolic, neuromuscular and hormonal responses demonstrated significant increases in testosterone, cortisol and lactate immediately following the plyometric exercises. Further, this resulted in neuromuscular performance decline immediately post and 24-hrs post exercise (Cadore et al., 2013). While these studies may not employ protocols closely resembling the match demands of Gaelic football, they do however provide insight into the nature of SSC fatigue commonplace in field based sports

and a rough timeline of recovery following such exercise (Cadore et al., 2013, Horita et al., 2003). Similarly, a repeated sprint protocol of 15 x 30 m sprints with 60 s rest between rounds resulted in significant DOMS, CK and limb girth measurements elevations up to 72-hrs post exercise, while maximum isometric force was significantly reduced 48 hours post-exercise (Howatson and Milak, 2009). This analysis suggests the sprinting protocol had a similar effect in the post exercise recovery window to the aforementioned jump protocols, with elevated markers of muscle damage following these SSC movements similar to the demands of field sport (Horita et al., 2003, Howatson and Milak, 2009, Chaouachi et al., 2010). Following a 10-km run, which is comparable to the total distance reported during a Gaelic football match, (Malone et al., 2016b, Malone et al., 2017c), significant neuromuscular disturbances, as measured by isokinetic knee flexion and extension strength and 50 repetition endurance and CMJ, were reported 24 hours following the run (Gómez et al., 2002).

Considering Gaelic footballers perform similar demands to the aforementioned studies, it would be logical to assume there would be persistent decrements in jump performance 48 hours post-match, reflective of the delayed post-exercise inflammatory processes (Gómez et al., 2002, Howatson and Milak, 2009, Malone et al., 2017c). Understanding the impact and recovery timelines governing these processes of metabolic fatigue, neuromuscular performance decrements and muscle damage following Gaelic football competition is vital in optimally planning subsequent training sessions.

Monitoring Player Demands - Global Positioning System (GPS)

The demands of Gaelic Football are commonly assessed and reported using Global Positioning System (GPS) units to measure a variety of demands including locomotion patterns, impacts and heart rate variables (Ryan et al., 2018, Allister et al., 2018, McGahan et al., 2018a, Malone et al., 2017c). An array of articles have been published in recent years related to the demands of Gaelic football using GPS technology (Mangan et al., 2020, Ryan et al., 2018, Malone et al., 2021, Malone et al., 2019, Shovlin et al., 2018, Malone et al., 2017c, McGahan et al., 2018a). These studies have improved understanding of the differences between playing standards and positions, while providing a clearer comprehension of the actions and movement patterns players undertake during competitive match-play (Malone et al., 2016b, Mangan et al., 2018b, Reilly et al., 2015). Indeed, practitioners may use this sport- and position-specific data to guide the structure of training sessions, deliver a surrogate measure of conditioning status and physical performance, and provide a benchmark with which to infer a player's readiness to train and/or compete (Macutkiewicz and Sunderland, 2011, Wisbey et al., 2010, Hennessy and Jeffreys, 2018, Murray et al., 2017b).

Overview of GPS application in Sport

Satellite navigation came into use during the Gulf War and was funded by the U.S. Department of Defence (Clarke, 1992). This system uses a network of over 27 satellites and allows the triangulation of receiver to be calculated trigonometrically (i.e., the Doppler shift method), thereby determining a geographical three dimensional location (Gray, 2013, Bulusu et al., 2000). The Doppler shift method subsequently allows calculation of movement speed of the reviewer by quantifying the satellite signal frequency degree of change from movement and relative speed between GPS receiver and the satellites (Townshend et al., 2008). In more recent years technological developments in creating

portable and smaller GPS units have allowed an explosion of widespread application related to monitoring human activity in sport and exercise (Cummins et al., 2013). GPS use is now common in elite level team sports such as rugby league (McLellan et al., 2011), soccer (Gaudino et al., 2013), Australian football (Coutts et al., 2010), hockey (Macutkiewicz and Sunderland, 2011) and cricket (Petersen et al., 2009b). By measuring players activity with a GPS unit, external load and player performance can be objectively quantified to provide large amounts of data for coaches and sports scientists; potentially allowing the development of optimal training, recovery or injury prevention strategies (MacLeod et al., 2009). Ever increasing prevalence of GPS use in sport and the development of newer brands and GPS units has resulted in more studies examining their validity and reliability (Chambers et al., 2015, Cummins et al., 2013). Nonetheless, questions remain regarding the validity and reliability of these measurements and whether they are suitable monitoring tools for their widespread application in team sports (Gimenez et al., 2020, Hoppe et al., 2018).

Validity and Reliability

The frequency of satellite signals received by the GPS device is called the sampling rate, which is measured in Hertz (Hz). This appears to be a major factor in GPS validity and reliability, with a lower sampling rate limiting accuracy, most notably over non-linear and/or high-speed movements (Duffield et al., 2010b, Cummins et al., 2013, Varley et al., 2012, Portas et al., 2007). Advances in sampling rate from preliminary devices using 1-Hz to more modern devices using 10-Hz and 15-Hz are reported to increase the accuracy of movements (Edgecomb and Norton, 2006, Portas et al., 2010) wherein the higher sampling rates of newer units appears to considerably improve the accuracy and reliability of devices at recording high intensity movements in particular (Rampinini et al., 2015, Townshend et al., 2008, Varley et al., 2012). Accurately recording high speed movement patterns is

paramount in the applicability of these devices for use in elite team sports, which involve frequent high intensity accelerations, decelerations, sprints and complex agility movements (Bangsbo et al., 2006, Cunniffe et al., 2009, Mohr et al., 2003). While sampling rate in GPS systems is a key factor in validity and reliability, different algorithms and microchip technology between brands also have a large influence. Notable, two devices from different companies both sampling at 5-Hz and reported estimates of sprinting distances to range as much as 29.9% between the two units (Petersen et al., 2009b). With such potential variability between devices of even the same sampling rate, it is very important that newer units emerging on the market are continually assessed for reliability and validity (Weaving, 2016, Crang et al., 2021).

Additional work reported the highest distance errors over a linear course in GPS units were while running at $6 \text{ m}\cdot\text{s}^{-1}$ (5.6%) and lowest while walking $>3 \text{ m}\cdot\text{s}^{-1}$ (0.7%) (Portas et al., 2007). Indeed, a number of GPS units appear to be valid for measuring linear distances over speeds less than $3 \text{ m}\cdot\text{s}^{-1}$ (Edgecomb and Norton, 2006, Portas et al., 2007, Schutz and Herren, 2000, Townshend et al., 2008) whilst the validity of GPS units tends to decrease with an increase in velocity, change of pace or movement over a non-linear path (Gimenez et al., 2020, Hoppe et al., 2018, Malone et al., 2017a, Rampinini et al., 2015, Rawstorn et al., 2014). Despite this, many athletes undergoing activities specific to team sport move at speeds well over $3 \text{ m}\cdot\text{s}^{-1}$ over non-linear paths, suggesting that further validation is necessary for the devices applicability to field based sport (Gray et al., 2010).

Overall, 5-Hz units are reported to be valid in the assessment of a number of movement patterns, with much greater reported precision than preliminary 1-Hz models (Petersen et al., 2009b, Portas et al., 2010, Johnston et al., 2012). It has been reported that 10-Hz models show much greater accuracy at recording distances over sprinting and high speed running paces compared to units of a lower sampling frequency (Castellano et al.,

2011, Rampinini et al., 2015). Generally, the research available on these units suggests the 10-Hz models are superior, especially over short duration and high intensity running movements (Cummins et al., 2013). Previous work assessed the validity of the 10-Hz STATSport 'Viper' unit using a camera to laterally record the runs, and a frame by frame video analysis was conducted to determine instantaneous velocity (Beato et al., 2016). The results indicated that the GPS unit was inaccurate at determining speed because it showed high imprecision when determining the shuttle distance (Beato et al., 2016). While Johnston et al. (2014) suggested that the 10-Hz units were more accurate at reading distance measurements than the 15-Hz units used in the study, it should be noted that this study interpolated a 5-Hz device to a 15-Hz unit rather than using a true 15-Hz device. Inter-unit variability has previously been examined by having one participant wear a number of units, with errors of roughly 12% found between units at high speed movements (Buchheit et al., 2014).

In summary, newer GPS models are being widely used in high level teams across a range of international sports (Gimenez et al., 2020, Malone et al., 2017a), including Gaelic football (Malone et al., 2021, Mooney et al., 2021, Gamble et al., 2019). Production of devices combined with gyroscopes, accelerometers and heart rate monitors also need to be validated. Many more measures are available to be recorded by the devices such as tackle count, player impacts, accelerations and metabolic load calculations. A lack of algorithm information made publicly available due to patent issues means there is some mystery in how some performance indicators are being determined. With this in mind, more validation studies are warranted to determine the accuracy of these newer devices. Accurately gauging the external workload demands and specific movement patterns of match-play in Gaelic football is essential in developing training and recovery protocols which are sport specific, allowing athletes to optimally adapt to stimuli and improve performance (Ryan et al., 2018,

Allister et al., 2018). Nevertheless, GPS units have been commonly used in recent years to quantify movements during Gaelic football matches as a more accurate and convenient method of data collection compared to previous methods (Reilly et al., 2015, Malone et al., 2016b, Allister et al., 2018, McGahan et al., 2018a, McGahan et al., 2018b, Mangan et al., 2018b, Malone et al., 2017d).

Performance Attenuation Monitoring Tools

Global Positioning Systems (GPS) Units

As previously mentioned, the locomotive performances of Gaelic football players are often recorded during competitive games using GPS, and common metrics reported in the literature include but are not limited to total distance, high speed running distance, sprinting distance, number of sprints and number of accelerations (Malone et al., 2017d, Mangan et al., 2018b, McGahan et al., 2018a). However, it is important to consider that GPS collected metrics may present certain issues with accuracy and additional confusion can arise in the literature with inconsistencies reported between different velocity zones (e.g. sprinting reported as $>5.5 \text{ m}\cdot\text{s}^{-1}$ and $>7 \text{ m}\cdot\text{s}^{-1}$) along with metrics such as the number of impacts, accelerations and decelerations (Johnston et al., 2015b, McLellan and Lovell, 2013, Austin and Kelly, 2014). As such, data needs to be interpreted and/or utilised with these limitations and considerations acknowledged. Expanding on the utility of GPS to quantify in-game demands, temporal reductions in these workload markers during competition may be used as proxy measures to infer performance attenuation (Crang et al., 2021, Simperingham et al., 2016, Coutts and Duffield, 2010).

A key variable in the assessment of neuromuscular fatigue is changes in sprint and high-speed running performances relative to time (Buchheit, 2012, da Silva et al., 2010). The capacity to perform sprints can extensively deteriorate during activities involving frequent intermittent high intensity actions are performed in field based team sports (Twist and Highton, 2013). While sprinting performance is often assessed using photoelectric timing gates or similar equipment, GPS may quantify changes in players capacity to perform sprints in training or competition through metrics such as sprint frequency, peak speed or sprint distance covered (Wisbey et al., 2010, Macutkiewicz and Sunderland,

2011). While GPS units have been demonstrated to be less accurate over short distances at high speeds, newer units are seemingly improving the accuracy in which these high octane movements are recorded (Castellano et al., 2011). Despite these limitations, GPS units may still be a suitable monitoring tool in the indirect measurement of neuromuscular fatigue through changes in sprint performance over the course of a game, training session or competitive season (Twist and Highton, 2013). For example, the performances over both short distance sprints was observed to progressively decline during match-play, and this observation may serve as a surrogate indicator of neuromuscular fatigue during handball competition (Ronglan et al., 2006). This phenomenon has also been commonly reported in team sports such as soccer (Hader et al., 2019, Silva et al., 2018), rugby league (Johnston et al., 2015a, Kempton et al., 2013) and Gaelic football (Mooney et al., 2021, Mangan et al., 2020, Malone et al., 2017c).

Intriguingly, players from the most successful teams (top 5 finishers) in the Serie A Italian league covered larger total distances and total high intensity distances compared to the least successful teams (bottom 5 finishers) (Rampinini et al., 2009). When comparing 1st to 2nd half statistics to investigate the effects of fatigue, there was a small 1.8% reduction in total distance completed in the second half, with a larger 6.4% significant reduction in ‘very high intensity running’ during the second half of match-play (Rampinini et al., 2009, Drust et al., 1998). A number of additional studies relating to the competition demands of soccer have provided similar evidence suggesting player’s capacity to perform high intensity running is diminished in the second half, and especially towards the end of games, in both sub-elite and elite level players (Krustrup et al., 2006, Mohr et al., 2003, Reilly and Thomas, 1979).

GPS units in combination with video and heart rate analysis are regularly used to quantify metrics associated with the development of fatigue and performance attenuation

within team sport (Buchheit et al., 2011). Rugby sevens players have been reported to cover 11.2% less distance in the second when compared with the first half (Granatelli et al., 2014). Velocity decrements have been reported ranging from 1.5% at 0 - 2 m·s⁻¹ up to 10.0% at 5 - 6 m·s⁻¹. Additionally, measurements of accelerations had even larger decrements, with moderate accelerations in m·min⁻¹ (velocity change between 2 to 4 m·s⁻² and - 4 to -2 m·s⁻²) reduced by 14% and high accelerations in m·min⁻¹ (velocity change >4 m·s⁻² and < - 4 m·s⁻²) reduced by 16% in the second half compared to the first (Higham et al., 2012). Similar findings have also been reported in soccer, where high-intensity running was found to decline by 35 - 45% in the final 15 minutes when compared to the first 15 minutes (Mohr et al., 2003) and in Australian rules, where an 11% drop in exertion index has been observed (a culmination of weighted instantaneous speed, weighted accrued speed over 10 seconds, and weighted accrued speed over 60 seconds) (Wisbey et al., 2010). Furthermore, elite level soccer players work rate as measured by high intensity running, was found to decline by 35-45% in the final 15 minutes when compared to the first 15 minutes. Perhaps noteworthy for coaches was that players brought on as substitutes covered 25% greater high intensity running distance during the final quarter of the match, highlighting the differences in running performances between fresh players brought off the bench and players in a more fatigued state (Mohr et al., 2003).

While these changes may be interpreted as signs of performance attenuation, it is unclear if these changes are influenced by tactical, contextual or a multitude of different factors that could influence players movements (Augusto et al., 2021, Malone et al., 2017c, Granero-Gil et al., 2020). As such, GPS measurements in combination with other psychophysiological monitoring tools may provide a greater insight into the performance attention response during and following Gaelic football match-play.

Countermovement Jump and Drop Jump

A number of studies have investigated neuromuscular performance using jump exercises (McLellan et al., 2011, Twist et al., 2012, Cormack et al., 2008) as it is important when monitoring athletes neuromuscular status that the tests closely represent the demands and actions of the sport (McLellan, 2010). The countermovement jump (CMJ) is one of the most commonly used tests to monitor neuromuscular status in both team and individual sports (Malone et al., 2015, Kale et al., 2009, Misjuk and Viru, 2007, Ronglan et al., 2006, Twist et al., 2012, McLean et al., 2010a, Thorpe et al., 2015) and is particularly useful because it is relatively non-fatiguing, fast to complete and utilises the SSC of the lower-body musculature, allowing an accurate depiction of an athletes neuromuscular status (Claudino et al., 2017b).

The use of the CMJ and DJ to monitor performance attenuation or super compensation in training is commonly reported to be valid and reliable in the detection of performance changes (Balsalobre-Fernández et al., 2014, Sanchez-Medina and González-Badillo, 2011, Williams et al., 2011, Gathercole et al., 2015a). Conversely, some studies have reported less objective sensitivity (Gathercole et al., 2015b, Malone et al., 2015) with a number of variables such as age, training experience and extent of performance change affecting its accuracy (Claudino et al., 2017b). Using the average of a number of jumps, testing at a consistent time of day and including more variables than jump height alone, is suggested to considerably increase the sensitivity of the test to neuromuscular changes (Claudino et al., 2017b, Gathercole et al., 2015b, Pallarés et al., 2014). Differences between morning and evening test results may be related to athletes core temperature and variations in muscular strength and power capacity emanating from circadian rhythm influences (Pallarés et al., 2014). In further support of the use of CMJ to monitor neuromuscular fatigue, CMJ jump height was reported to be the most sensitive tracking variable to detect

fatigue across the testing period when compared with a 20 m sprint and isokinetic knee extension (Ronglan et al., 2006, McLellan et al., 2010). Similarly, previous work identified that all DJ variables monitored (including jump height, contact time and reactive strength) were sensitive to detect fatigue 72 hours following a repeated sprint fatigue protocol, while the sprint test and squat jump test did not detect any disturbance (Gathercole et al., 2015a).

Perceptual Monitoring Tools

Questionnaires have been reported to be sensitive and reliable to detect changes in training or competition stressors (Kellmann, 2010, Budgett, 1998, Budgett, 1990). Perceptive measurement of training preparedness and fatigue has also been strongly related to different neuromuscular, metabolic and cardiorespiratory monitoring variables (Kuipers et al., 1985, Borg, 1982, Borg, 1998, Scherr et al., 2013). Indeed, perceptual assessments have been commonly used to monitor fatigue and recovery status in different field-based team sports such as rugby league (Johnston et al., 2015b, McLellan et al., 2011, Twist and Highton, 2013), rugby union (West et al., 2014), soccer (Nédélec et al., 2012, Reilly, 1997, Deely et al., 2022) and Australian rules football (Gallo et al., 2016).

Perceptual assessments of muscle soreness, fatigue and overall wellbeing have also been demonstrated to be highly sensitive in detecting changes in muscle damage (Oliver et al., 2015b). Moreover, perceptual measures have been reported to persistently identify fatigue symptoms, even when biochemical measures and neuromuscular performance have returned to baseline pre-exercise levels (Twist et al., 2012). Perceptual monitoring has been described as having a greater capacity to reveal the early warning signs of fatigue or overtraining symptoms more readily than the various immunological, biochemical or physiological markers (Kenttä and Hassmén, 1998). Moreover, psychological or perceptual fatigue is known to impact concentration, sense of effort and motivation in different sport and exercise environments (Wright et al., 2007, Davis and Bailey, 1997). Employing

perceptual measurement of mood, fatigue, wellbeing and muscle soreness is reported to be an effective tool in the long and short term monitoring of athletes (Urhausen and Kindermann, 2002, Budgett, 1998). Assessment methods or validated questionnaires such as the 'Daily Analysis of Life Demands for Athletes questionnaire' (Hooper and Mackinnon, 1995), the 'Profile of Mood States Questionnaire' (POMS) (Grove and Prapavessis, 1992), the 'Total Quality Recovery Scale' (Corrigan et al., 1999), the 'Recovery-Stress Questionnaire for athletes' (Davis et al., 2007) or the design of a questionnaire using validated recommendations and instructions (Hooper and Mackinnon, 1995, McLean et al., 2010a) have been utilised in recent years.

McLean et al. (2010a) designed a five point scale Likert assessment sheet to monitor fatigue and recovery in rugby league players through validated recommendations from previous work (Hooper and Mackinnon, 1995). While it is advantageous to have such questionnaires brief to save time and allow convenience in having athletes frequently complete these evaluations, it is important to note that there may be some inaccuracy in the answers due to certain lack of detail (Twist et al., 2012). However, they do offer a valid tool to regularly monitor key measures of fatigue and recovery (McLean et al., 2010a) and this particular questionnaire has demonstrated a high level of reliability (coefficient of variance: 4.2%) (McNamara et al., 2013).

In summation, monitoring psychological indices is key in order to attain a holistic overview of an athletes responses to fatigue and the progress of recovery following training or competition (Budgett, 1990, Kellmann, 2010). This non-intrusive method of monitoring allows assessment of the complex psychophysiological stressors that are impactful in the fatigue and the recovery process (Budgett, 1998).

Muscle Damage and Biochemical Assessments

Muscle damage following many different exercise modalities has been examined extensively in the literature (Clarkson et al., 1992, Proske and Morgan, 2001, Magal et al., 2010, Clarkson et al., 2006, Evans and Cannon, 1991, Byrne et al., 2004, Tee et al., 2007, Crane et al., 2012). A large volume of eccentric and SSC movements occur during field-based invasion team sports such as Gaelic Football, which is likely to trigger significant muscle damage (Reilly and Doran, 2001, Hrysomallis et al., 2001, Da Silva et al., 2020). The preliminary mechanical disruptions following eccentric muscle actions lead to a cascade of events (Figure 2. 4) that trigger the secondary, often more severe, damage response (Hody et al., 2019). Indeed, the initial muscle damage response resulting from such movements is attributable to a mechanical disturbance of the muscle fibres, while the ensuing long-term reaction is linked to changes in the muscles excitation-contraction coupling alongside different inflammatory processes not yet comprehensively understood (Tee et al., 2007, Clarkson et al., 1992, Paulsen et al., 2012, Hody et al., 2019).

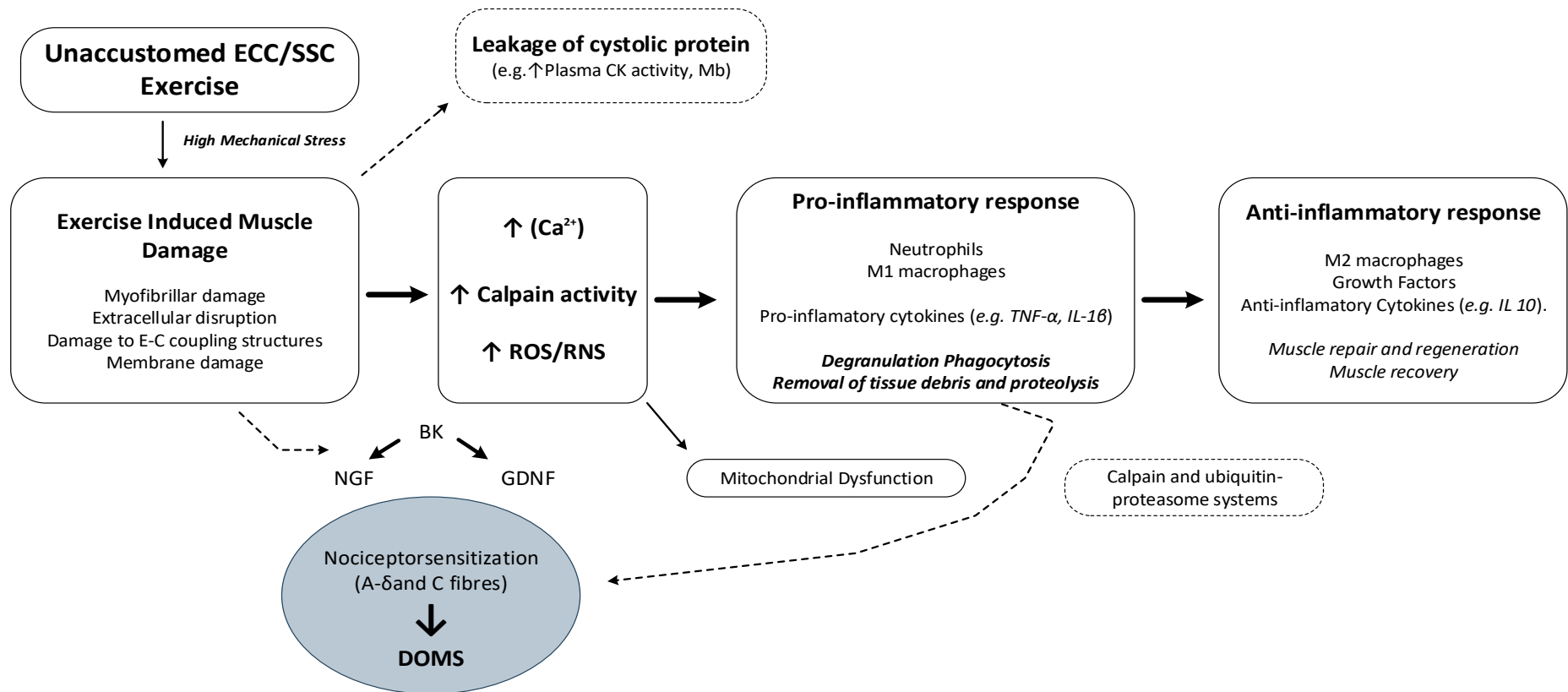


Figure 2. 4. Summary of primary features, effects and potential risks and benefits of eccentric exercise adapted from Hody et al. (2019) with permission.

Direct measurement of muscular damage following exercise involves examination of cellular and subcellular structure disturbances, which are most frequently recorded in the Z-line (Clarkson et al., 1992). However, these measurement procedures are generally invasive, and require specialised equipment and expertise (Ahn, 2020). On the other hand, indirect markers of exercise induced muscle damage include a prolonged reduction in force production as detected in both voluntary and electrically stimulated contractions (especially when the muscle is stimulated at low frequencies), muscular soreness, an increase in markers of inflammation both in the blood and muscle and an elevated presence of muscle proteins leaked into the bloodstream (Clarkson et al., 1992, Proske and Morgan, 2001, Paulsen et al., 2012). Sports practitioners and researchers regularly take samples to quantify a variety of biochemical markers that are associated with muscle damage (Russell et al., 2016, Russell et al., 2015, Peake et al., 2005b). One of the markers most commonly assessed is creatine kinase (CK), a muscle enzyme that can be detected in the blood (Peake et al., 2005b). It is important to note that the level of any protein present in the blood plasma represents a balance of what is being released from the damaged muscle tissues and what is being cleared out from the bloodstream (Fridén and Lieber, 2001). Overall, many potential factors contribute to the muscle damage response and its indicators, and some of these are illustrated in (Figure 2. 5) below in the work adapted from Allen et al. (2016) and Hyldahl et al. (2017) and Proske and Morgan (2001).

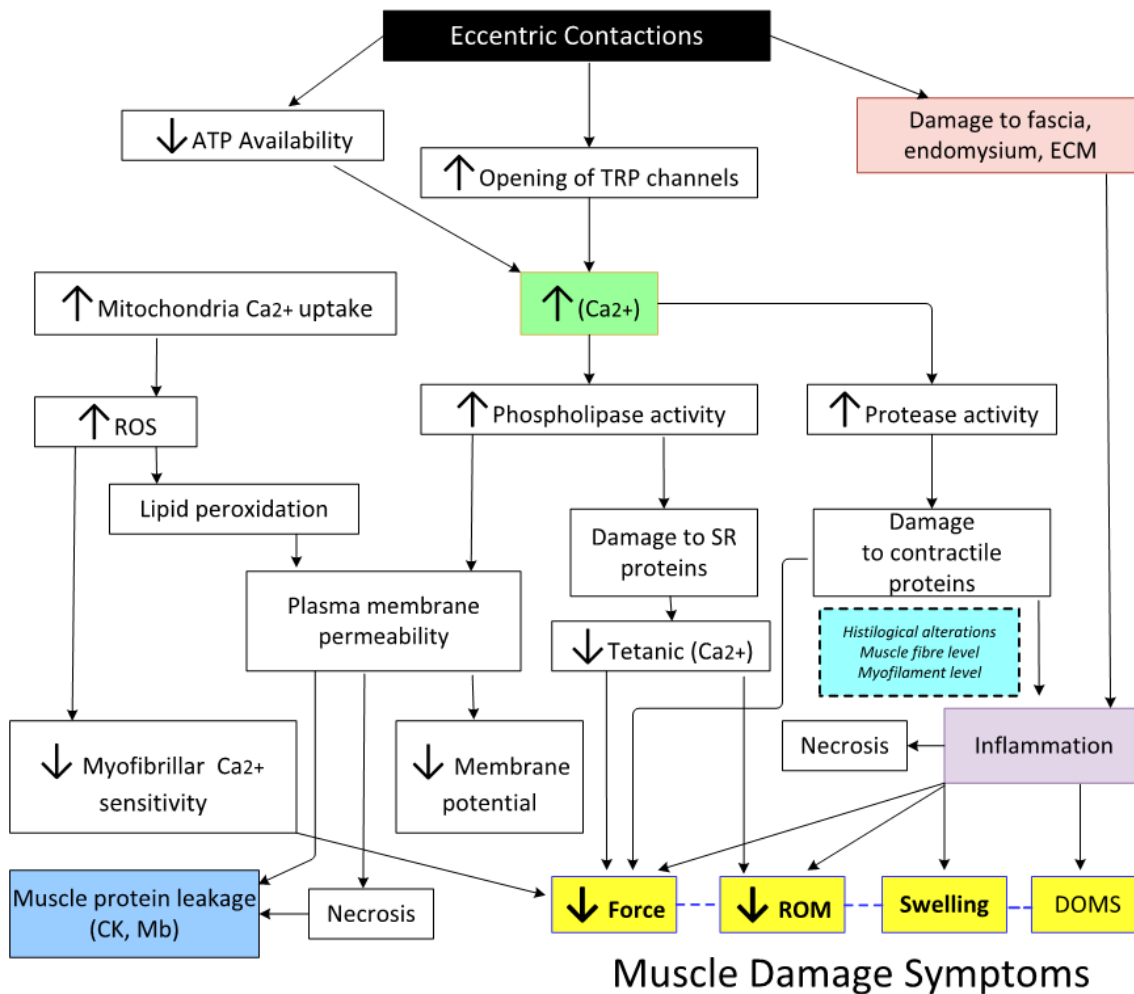


Figure 2. 5. Overview of eccentric exercise effects from the work of Allen et al. (2016) and Hyldahl et al. (2017) with minor input and permission from Proske and Morgan (2001).

Within skeletal muscle tissue, CK is found inside the inter-membrane space of mitochondria and the sarcolemma of muscle cells (Wallimann et al., 1992). Skeletal muscle CK is responsible for buffering cellular ATP and ADP concentrations by catalysing the reversible exchange of high-energy phosphate bonds between phosphocreatine and ADP produced during contraction (Zong et al., 2002). The quantification of this enzyme can serve as a marker of global muscle tissue status, and can vary substantially depending on the influence of many different possible physiological or pathological conditions

(Brancaccio et al., 2007). While CK is almost exclusively found in muscle cells, detection in the blood is often used as an indirect index for exercise induced physiological stress and damage to muscle tissue (Baird et al., 2012). However, there is some uncertainty in the exact process by which CK levels rise in systemic circulation (Lee and Clarkson, 2003, Manfredi et al., 1991). Nevertheless, exercise of a sufficient intensity and/or volume to damage the structure of skeletal muscle tissue cells at the Z-disk (i.e., the region in the sarcomere into which the thin filaments are inserted) and sarcolemma (i.e., muscle cell membrane) (Hornemann et al., 2000) results in a CK efflux which is suggested to subsequently leak into the interstitial fluid, before being processed by the lymphatic system and sent into circulation (Noakes, 1987, Nosaka and Kuramata, 1991, Bijsterbosch et al., 1985). Owing to the lymphatic systems reliance on external movement and/or forces for transportation (Swartz, 2001) circulation can be quite slow, which may partially explain the delay in the observed rise of post-exercise CK (Mena et al., 1996, Nosaka and Clarkson, 1995).

Following a marathon, CK was observed to be significantly elevated just 1 hour post-race, with a peak documented 24-hrs later (Apple et al., 1984). Additionally, eccentric exercise localised to one muscle group has been shown to cause a further delay in the peak spike of CK, collectively implying a number of confounding factors should be considered when monitoring the enzymes behaviour in the bloodstream (Nosaka and Clarkson, 1995, Clarkson et al., 1992, Mair et al., 1995, Fridén and Lieber, 2001, Manfredi et al., 1991). In team sport athletes, levels of plasma CK have been shown to increase following rugby league (Aben et al., 2020, Twist et al., 2012, Webb, 2011), rugby union (Lindsay et al., 2015b, Cunniffe et al., 2009), soccer (Brownstein et al., 2017, Nedelec et al., 2014, Krstrup et al., 2006) and hockey (McMahon et al., 2021, Krueger et al., 2020) competitive match-play. Furthermore, there is often a delay reported in the rise of plasma CK levels

following team sport competition, with a peak levels generally expressed 24-hrs to 48-hrs post-exercise (Jones et al., 2014, Russell et al., 2016, Ascensão et al., 2008, Howatson and Milak, 2009, Proske and Morgan, 2001, Byrne et al., 2004, McLean et al., 2010a, McLellan et al., 2011).

Notably, the magnitude and/or duration of CK increase has been demonstrated to relate to the actions performed during competitive match-play (Hagstrom and Shorter, 2018). For example, CK efflux has previously been associated with tackle count and impacts in rugby union (Takarada, 2003, Smart et al., 2008), high intensity running indices in soccer (Russell et al., 2016), running performance in hockey (McMahon et al., 2021) and coaches perceptions of performance in Australian rules football (Hunkin et al., 2014). In general, actions involving strenuous eccentric muscle actions, such as landing from jumps, decelerating or contact in tackles, often coincides with CK efflux, with peak values presenting 24-hrs post-match (Jones et al., 2014, Rampinini et al., 2009, Hunkin et al., 2014). Nonetheless, there is considerable scope to characterise the muscle damage response to Gaelic games match-play, owing to the sport's unique pitch size, technical constraints and in-game workload demands (Egan et al., 2021, McGahan et al., 2019, Hagstrom and Shorter, 2018).

In Gaelic football competition and training, players typically perform frequent eccentric contractions in an array of SSC movements such as decelerating, sprinting, contesting for possession or side-stepping (Mangan et al., 2020). Although it could be expected that players would induce significant fatigue, performance attenuation, muscular damage and experience delayed onset muscle damage (DOMS) based off research from similar team sports, it is difficult to surmise the magnitude or duration of these disruptions without sport-specific data (Strojnik and Komi, 2000, Cormack et al., 2008, Twist and Highton, 2013). While eccentric actions undertaken in field based team sports are

associated with an increase in plasma CK following exercise, the physical contact and collisions and unique running and technical demands endured by Gaelic football players may also be an important factor in elevated CK levels (Smart et al., 2008).

Research investigating the effects of exercise on muscle damage during various eccentric based movements have found that there is protective effect from undertaking repeated sessions of eccentric based exercise, whereby the muscles rapidly adapt between sessions resulting in less muscle damage following similar subsequent sessions (McHugh, 2003, McHugh et al., 1999, Chen et al., 2007, Nosaka et al., 2001, Howatson and Milak, 2009, Howatson et al., 2007, Paschalis et al., 2008, Willoughby et al., 2003). This process is called the repeated bout effect (McHugh et al., 1999) and has been reported to have a protective dampening effect on direct and indirect measures of muscle damage (Nosaka and Clarkson, 1995, Howatson et al., 2007). This protective mechanism is even observed without full recovery from the previous session of muscle damaging exercise (McHugh, 2003), and is suggested to be a very important mechanism in the adaptation and recovery of field sport competition and training (McLellan, 2010). Neural adaptations, remodelling of the extracellular matrix and alterations to contractile mechanical properties are proposed to underpin the phenomenon (Hyldahl et al., 2017), and these may present detectable protective benefits for as long as 6 months (Nosaka and Aoki, 2011, Nosaka et al., 2001).

A number of studies have investigated the magnitude and duration of post-match psychophysiological disturbances and their recovery timeline in sports including rugby league (McLellan et al., 2011, Twist and Highton, 2013, Johnston et al., 2015b, Twist et al., 2012, Duffield et al., 2012), soccer (Rampinini et al., 2011, Krstrup et al., 2010, Ascensão et al., 2008), handball (Ronglan et al., 2006), rugby union (Mashiko et al., 2004, West et al., 2014, Jones et al., 2014) and Australian Rules football (Cormack et al., 2008). Because of the lengthy season and frequent games played by senior and adolescent Gaelic

football players, it is very likely that players will have to compete under conditions of incomplete recovery following previous training sessions or games (Kelly et al., 2018b). This premise may add importance to the protective rebound effect associated with eccentric exercise, and may subsequently be of particular interest to Gaelic football coaching and strength and conditioning staff. Furthermore, research profiling the performance attenuation and recovery response to Gaelic football match play is therefore required for practitioners who seek to design evidence-informed training programmes that take into account the disturbances caused by match-play. Research investigating rugby league post-match responses has recorded CK levels to increase 50.3%, 211.6% and 96% immediately post-match, 24-hrs post-match and 48-hrs post-match respectively (McLellan et al., 2011). Furthermore, significant positive relationships between high intensity distance covered, total number of sprints and high speed running distance with elevations in CK 24 hrs post-match in soccer were also demonstrated (Russell et al., 2016, Thorpe and Sunderland, 2012). Similarly, pre-match CK levels were negatively associated with in-game workload performances and coaches ranking of performance in Australian rules football, (Hunkin et al., 2014) adding support for the conceptual link between CK and performance attenuation.

Taken together, these results indicate a strong relationship between work completed during a game and rises in serum CK levels, and that elevated levels of pre-game CK are likely to stem from residual muscle damage incurred during previous training sessions or games (Hunkin et al., 2014, Strojnik and Komi, 2000, Strojnik and Komi, 1998). The collective findings discussed highlight a number of the many possible mechanisms which underpin reductions in a player's capacity to undertake work, and the need to adopt a multifactorial monitoring approach in the characterisation of performance attenuation and recovery.

Performance Attenuation and Risk of Injury

While the development of neuromuscular fatigue and/or muscle damage may heavily impair a player's performance and tactical capabilities during competition; it may also increase susceptibility to injury (Smith et al., 2016, Wright et al., 2007, Gabbett, 2008, Higham et al., 2012, Granatelli et al., 2014). Gaelic football players typically have a long duration season, with frequent training and competitive matches throughout. A report by Kelly et al. (2018b) detailed that 68% of players aged 18-21 played with four or more teams during a season. Additionally, 40% of Gaelic football players reported having no off-season rest period at all due to congested fixture and training schedules. The significant workloads undertaken during the competitive season by Gaelic football players could possibly generate a significantly elevated risk of injury (Milewski et al., 2014). In support of this concept, a 6 month prospective study demonstrated the relatively high injury rates during Gaelic football matches, and the indirect influence of neuromuscular fatigue on injury risk (Wilson et al., 2007). Here, injury rate was found to progress from quarter to quarter in matches, with 17.2% of injuries in the first quarter, 22.4% in the second quarter, 27.6% in the third quarter and the highest injury rate of 29.3% sustained during the fourth quarter (Wilson et al., 2007). Arduous demands placed on players over a season with potential muscle damage, culminating fatigue and burnout perhaps may account for the high incidence of injuries reported during the latter stages of Gaelic football seasons and in the final stages of games (Gabbett, 2004, Wilson et al., 2007, Murphy et al., 2012, Waldén et al., 2005). Newell et al. (2006) demonstrated similar evidence regarding the potential influence of fatigue on injury risk in Gaelic football play, reporting 47% of all injuries occurring during final quarter match-play. This phenomenon is even more pronounced in Gaelic football training, where 55% of training injuries were reported to be sustained in the final quarter of the session. The association between the time and injury rate during training

or matches was strong, suggesting fatigue as a key element in Gaelic football injury risk (Newell et al., 2006). The higher prevalence of injuries sustained during last quarter play in Gaelic football (or towards the end of a training session) may be related to both neuromuscular fatigue development and reductions in player's reaction time. As was demonstrated in both team (Skala and Zemková, 2022) and individual sport athletes (Pavelka et al., 2020). Indeed, the performance of high intensity actions towards the concluding stages of a game whilst under conditions of neuromuscular fatigue are linked to a heightened risk of injury (Hrysomallis, 2013) due to diminished coordination and impairments in the muscles contractile mechanisms (Newell et al., 2006).

Injuries sustained during Gaelic football play across all levels are often soft tissue injuries, with the lower limb the most frequent injury site (Cromwell et al., 2000). Hamstring injuries are commonly reported to be the most frequent injury sustained in Gaelic football (Roe et al., 2018a, Newell et al., 2006, O'Connor et al., 2016b, Roe et al., 2018b, Miley et al., 2017). The underlying aetiology of hamstring injury in Gaelic football is not clear, however many potential factors are suggested to increase players hamstring injury risk. These factors include inadequate warm-up, muscle imbalance between the hamstrings and quadriceps, reduced lower-body flexibility, muscle damage and poor neuromuscular force generation capacity, coordination and control (Bahr and Holme, 2003, Gabbe et al., 2005, Howell et al., 1993, Ryan et al., 2014). In soccer, Small et al. (2010) investigated the effects of fatigue induced from multidirectional exercise on hamstring injury risk. Here, the functional hamstring to quadriceps ratio significantly decreased at half time ($116.6 \pm 21.2\%$ to $107.1 \pm 17.6\%$;) and from the second half to the finish of fatigue protocol ($107.1 \pm 17.6\%$ to $98.8 \pm 20.3\%$) where eccentric peak torque also reduced in a progressive manner following each half of the fatigue protocol (1st Half: 272.0 ± 43.2 Nm; 2nd Half: 240.4 ± 43.3 Nm; End of Protocol: 226.3 ± 45.7 Nm). Such a continual

decline in the functional strength ratio and peak eccentric hamstring torque resulting from the progressive development of fatigue would likely increase hamstring injury predisposition during the latter stages of a match (Small et al., 2010). Rahnama et al. (2002) has also observed progressive reductions in lower-body muscle strength and a variety of deteriorative functional characteristics through fatigue associated with increased injury risk and performance mitigation, further suggesting the presence of increasing hamstring injury risk in parallel to the accumulation of fatigue (Rahnama et al., 2002). Evidence demonstrating elevated rates of injury during the last fifteen minutes of match-play supports this premise (Rahnama et al., 2002). Additional work in soccer also reported half of all hamstring injuries occurring during the last fifteen minutes of matches (Hawkins et al., 2001). The trend of elevated injury rates in the latter stages of games is also commonplace in other team sports such as rugby union (Fuller et al., 2016, Cross et al., 2016), rugby league (Booth et al., 2017, Gabbett, 2003) and Australian rules football (Grimmer and Williams, 2003, Verrall et al., 2005). While the majority of research indicates fatigue to be a key influential factor in the risk of injury during field-based invasion sports, many other factors also have an impact on a wide range of soft tissue injury.

Despite 53.7% of training injuries occurring in the later stages of rugby union training sessions, it was also identified that 61.5% of game induced injuries occurred during the first half in the semi-professional players (Gabbett, 2003), which contrasts with other findings (Fuller et al., 2016, Grimmer and Williams, 2003, Gabbett, 2003, Gabbett, 2000). A confounding factor of this standout finding was that injury risk may have been elevated during the rapid intensity increase following pre-season training (Gabbett, 2003). Here, the semi-professional players investigated had elevated physical conditioning parameters when compared then their sub-elite counterparts, perhaps reducing the risk of injury in the second half of play (Gabbett, 2003, Gabbett, 2002). In contrast, a greater body of research

demonstrates most injuries occur towards the end of a match in rugby league (Gabbett, 2000, Hawkins et al., 2001), Australian Rules (Keogh, 1999, Reilly et al., 2015), rugby sevens (Fuller et al., 2016) and Gaelic football specifically (Murphy et al., 2012, Newell et al., 2006)

In Gaelic football, club and youth players often have a congested season with little breaks or downtime (Kelly et al., 2018b). This may lead to player burnout, symptoms of overtraining and potentially increased injury risk as a result of persistent fatigue accumulation from such training and competition schedules (O'Connor et al., 2017, Wilson et al., 2007, Koutedakis and Sharp, 1998, Hrysomallis, 2013). Injuries to adolescent and adult Gaelic football players were more frequently sustained in the second half of games and particularly in the last quarter, which is primarily attributable to fatigue development (Watson and Sharpe, 1996, Murphy et al., 2012, Hawkins et al., 2001). Additionally, the effect of fatigue and muscle damage is accentuated by the unique workload demands and physical contact during Gaelic football match play. Therefore, it could be postulated that a greater understanding of the performance attenuation within a game may provide valuable insight into the possible mechanisms which underpin injury and help inform injury prevention strategies.

Physical Characteristics

Gaelic football is a physically demanding sport, wherein an array of well-developed physical conditioning attributes are essential components of successful match-play (Florida-James and Reilly, 1995, Reilly and Doran, 2001, Cullen et al., 2013, Malone et al., 2021, Mooney et al., 2021). As is the case in other team sports such as soccer or Australian rules football where skills play a decisive role, physical conditioning characteristics should not be the sole predictor of competitive success (Bunc and Psotta, 2001). However, it should be noted that well-developed physiological, metabolic and performance attributes are necessary conditions for successful progression to and play at higher levels of Gaelic football competition (Shovlin et al., 2018, Keane et al., 1997). Notwithstanding the role of physical conditioning on performance outcomes, some key physiological markers have also been reported to modulate post-exercise fatigue and muscle damage responses in similar team sports (Johnston et al., 2015b, Johnston et al., 2015a, Owen et al., 2015).

Body Composition

Body fat has been described as an important marker of performance through its influence on Gaelic football players capacity to run, jump and change direction (Doran et al., 2014). Indeed, players with excessive adipose tissue are likely to be put under increased mechanical and physiological strain in order to support the amplified inertial challenges of bearing a larger body mass against the forces of gravity during the course of a 70-minute match (Meir et al., 2001). As such, increased body fat is likely to impair muscular performance, endurance capacity and slow and/or reduce movement during match-play (Esco et al., 2018, Bangsbo et al., 2006).

In soccer, levels of body adiposity were negatively associated with sprint time, suggesting a leaner body composition enabled the achievement of faster maximal running velocities (Ostojic, 2003). Moreover, body fat percentage has also been associated with agility performance (Chaouachi et al., 2009), running endurance (Miller et al., 2011, Crawford et al., 2011) and power output (Alemdaroğlu, 2012, Esco et al., 2018). Indeed, a higher body fat percentage may be associated with decreased on-field physical performances and is likely to result in an accelerated onset of fatigue (Esco et al., 2018). An additional weakened ability to dissipate heat during the intense and long duration physical activity of a Gaelic football match, which may come as a result of excess adipose tissue, would also be significantly disadvantageous (Meir et al., 2001, Morrissey et al., 2021). Practitioners should therefore aim to achieve optimal body composition in players in order to facilitate high in-game workloads and mitigate the potential fatigue effects associated with bearing high body fat levels (Esco et al., 2018).

Aerobic Endurance

Aerobic capacity is defined as the maximum amount of oxygen that is used per unit of time and body mass (Bergh and Ekblom, 1979, Metaxas et al., 2005) and is a critical attribute for successful Gaelic football performance (Florida-James and Reilly, 1995, Malone et al., 2016a). As mentioned previously, competitive Gaelic football match-play is characterised by frequent and short duration high intensity actions performed over a backdrop of light to moderate aerobic activity (Malone et al., 2017d). Subsequently, high levels of aerobic fitness are required to perform the large distances covered at low speeds, while simultaneously facilitating recovery between the numerous intermittent bouts of high intensity activity (e.g., evading opponents, sprinting or jumping/competing for possession) (Collins et al., 2013, Rodríguez-Fernández et al., 2017, Buchheit, 2012). The capability to repeatedly perform these high intensity actions over the course of a 70 minute match is one

of the important physiological constituents in successful Gaelic football match-play (McGahan et al., 2018a, McGahan et al., 2018b) and is principally governed by a players aerobic function (Rodríguez-Fernández et al., 2017, Buchheit, 2012, da Silva et al., 2010). Furthermore, players with a well-developed aerobic capacity may display a greater capacity to perform work throughout the match, while limiting the large activity decrements that are reported during the latter quarters of the game, which may emanate from acute neuromuscular fatigue (McGahan et al., 2018b, Malone et al., 2017c, Mooney et al., 2021).

Indeed, a higher standard of play has been associated with superior levels of aerobic fitness in Gaelic football (Shovlin et al., 2018, Keane et al., 1997) and it has been previously reported that players possess maximal aerobic capacity values comparable to elite level soccer players (Florida-James and Reilly, 1995). Augmented aerobic conditioning is suggested to improve Gaelic football performance through the facilitation of increased workloads during games, with a relationship between higher distances covered as recorded by GPS units and intermittent exercise capacity evident (McIntyre and Hall, 2005, Malone et al., 2016b). In soccer, superior aerobic endurance is also suggested to improve key performance indicators, such as increasing involvements with the ball, distance covered as measured with GPS, sprint frequency during a match and enhancing work intensity measurements (Helgerud et al., 2001, Aquino et al., 2020). The ability to generate power in repeated sprints has been strongly linked to aerobic conditioning in other field based invasion team sports, with an increased dependence on the aerobic energy system in undertaking high intensity movements reported in the latter stages of competition (Bogdanis et al., 1996a, Rodríguez-Fernández et al., 2017, da Silva et al., 2010).

A number of sports involving intermittent bursts of high intensity movements have illustrated strong relationships between aerobic capacity and numerous high intensity workload parameters such as the number of sprints and accelerations performed, and

distances covered at high speeds (Banzer et al., 2009, Franchini et al., 2005, Bangsbo and Michalsik, 2002). This combination of data suggests that an advanced aerobic fitness can potentially improve recovery from intermittent high intensity exercise, through enhanced aerobic contribution, increased PCr restoration and lactate removal (Balsom et al., 1994a). These factors may combine to assist in the recovery of the anaerobic system needed for repeated bouts of intensive actions (Balsom et al., 1994a, Blei et al., 1993, Thomas et al., 2004). Moreover, an enhanced aerobic capacity has been related to improved post-match recovery and a reduction in post-match muscle damage as measured by CK in Australian rules and rugby league players (Hunkin et al., 2014, Johnston et al., 2015b). In rugby league, players with a superior aerobic capacity performed higher relative workload measures during games (total distance covered, sprint frequency, high intensity running distance etc.) while also recovering faster following match play, as measured by vertical jump performance and CK level.

In addition to maximal aerobic capacity, previous results in soccer (Krustrup et al., 2005) have demonstrated that blood lactate responses significantly contribute to the performance of high intensity work (i.e., the number of sprints and accelerations) and distances covered at a range of velocities during competitive match-play. Additional work in female soccer players revealed that lactate responses significantly influence the performance of high-intensity running distances during competitive match-play (Krustrup et al., 2005) and simulated match-play (Sirotic and Coutts, 2007) in elite players. Indeed, velocity recorded at lactate threshold and running economy have also been described as important determinants of a team sport athletes' capacity to perform game specific work (Kelly et al., 2018a, Hoff and Helgerud, 2004, Higham et al., 2013, Higham et al., 2012). For instance, improvements in running economy, maximal aerobic capacity and lactate responses were all exhibited to improve soccer performance by increasing the distance

covered during competitive match-play, enhancing the average intensity of work performed, and increasing the number of ball involvements and sprints during competition (Helgerud et al., 2001).

In summation, it is well-documented that markers of aerobic function play a significant role in team sport performance (Buchheit, 2012, Stone and Kilding, 2009, Dujic et al., 2016, Malone et al., 2016a, Meckel et al., 2009, Wadley and Le Rossignol, 1998, Aquino et al., 2020). However, the specific influence of these markers on Gaelic football match-play and recovery parameters remains to be seen.

Muscular Strength

Muscular strength refers to the amount of force a muscle and/or group of muscles exert against an external resistance over a single maximal effort (Abernethy et al., 1995, Suchomel et al., 2018). The mechanisms proposed to underpin muscular strength are numerous (Aagaard et al., 2001) and include a combination of neural and morphological factors such as musculotendinous stiffness, architecture and cross-sectional area, motor unit recruitment and synchronization, antagonist neuromuscular inhibition and rate coding (Suchomel et al., 2018, Suchomel et al., 2016). In team sport, possessing an ability to rapidly apply high levels of force or torque is suggested to be a key attribute to successful competition (Johnston et al., 2015b, Young et al., 2005, McIntyre and Hall, 2005) and supports the performance of many athletic and sport-specific actions during match-play (Silva et al., 2015).

Concurrently, Gaelic football players are reported to display high levels of muscular strength as a prerequisite to face the intense neuromuscular demands of competitions (McIntyre and Hall, 2005, Mangan et al., 2020, McGahan et al., 2019). Specifically, Gaelic football players must possess sufficient muscular strength to tackle and evade opponents,

perform high intensity agility movements (Thomas et al., 2018) jump in competition for the ball (Reilly and Doran, 2001), and change pace and/or direction (McBurnie et al., 2022, Harper et al., 2019). Information relating to 1RM strength performance in Gaelic football is lacking, however studies have previously investigated isokinetic quadriceps and hamstring strength of elite and sub-elite level players (O'Sullivan et al., 2008, Roe et al., 2018a). In sub-elite collegiate players, hamstring torque at 60 °/s were 136.2 Nm and quadriceps torque at 60 °/s were 196.9 Nm, which were slightly less than readings of elite Australian Rules football players (O'Sullivan et al., 2008, Young et al., 2005). Likewise, recent evidence suggests that elite and sub-elite Gaelic football players generate similar knee flexor torque values to those displayed by elite level rugby union players (Roe et al., 2018a). However, it should be noted that single joint measures of strength may present limited generalisability to field-based measures of athletic performance (Suchomel et al., 2016, Falk et al., 2019, Cronin and Hansen, 2005) and research is required to assess additional measures.

In international level rugby union players, strong relationships between strength, as measured by isometric mid-thigh pull (IMTP) and a number of key performance indicators, such as total possessions, tackle success rate and successful carries over the gain line ($r = 0.53$ to 0.79) were identified (Cunningham et al., 2018). Similarly, semi-professional rugby league players who were selected to play had a 15.2% greater three repetition maximum (3RM) squat when compared with non-starters ($ES = 1.02$) (Gabbett and Seibold, 2013b), while bench press strength was identified to be an accurate predictor of players achievement levels in professional rugby league players (Baker, 2002). Also of note, muscular strength has presented a significant influence on kicking power in soccer (Masuda et al., 2005), a protective effect against injury in soccer (Lehance et al., 2009, Lehnert et al., 2017, Zouita et al., 2016, Croisier et al., 2008), performance rating ('Champion Data' formulated player

performance ranking) and high intensity match running performance in Australian rules football (Stares et al., 2015). Taken together, these results suggest muscular strength is a principal determinant of successful performances in field-based invasion team sports (Comfort et al., 2014, Baker and Nance, 1999, Gabbett and Seibold, 2013b).

In addition to the reported relationships with a number of different match workload and performance metrics (such as accelerations, sprints, successful turnovers etc.), muscular strength has also been associated with reduced disturbances to psychophysiological markers of performance attenuation and post-match recovery (Abbott and Clifford, 2021, Johnston et al., 2015b, Johnston et al., 2015a, Owen et al., 2015). One such study reported that rugby league players who exhibited greater 1RM squat strength completed more work during a game as measured by GPS units, while presenting with less post-match disturbances (i.e., CK efflux) up to 48 hours post-match ($ES = 0.25 - 0.39$) (Johnston et al., 2015b). Notably, the study concluded that players who exhibit superior lower-body strength were able to both perform greater workloads and recover faster than their counterparts following competitive rugby league, despite undertaking larger volumes of work during competition (Johnston et al., 2015b). In soccer, muscular strength has also been identified as a moderating factor in protecting against post-match psychophysiological disturbances (Abbott and Clifford, 2021, Owen et al., 2015).

While collisions in contact sports such as Gaelic football play a role in the development of muscle damage, rapid and frequent SSC movements throughout a game can also heavily contribute to post-match muscle damage (Hunkin et al., 2014, Ascensão et al., 2008). Players who possess greater lower-body muscular strength, in particular eccentric strength, may be better suited to dealing with the high forces associated with SSC movements, allowing them to subsequently recover faster following exposure to match-play demands (Johnston et al., 2015b). Indeed, the relationship between maximal strength

and the capacity to efficiently perform explosive SSC movements such as sprinting, jumping or rapid changes of direction is well documented (Miyaguchi and Demura, 2008, McBurnie et al., 2022). This relationship between maximal strength and SSC efficiency has also been linked to the fatiguing nature of SSC movements, with higher strength levels reported to have a protective effect against post-exercise performance attenuation (Strojnik and Komi, 2000, Nicol and Komi, 2010b, Miyaguchi and Demura, 2008, Wisløff et al., 2004, Helm et al., 2019). Indeed, higher levels of strength are reported to coincide with lower levels of muscle damage and decrements in performance following repetitive SSC exercise, incurred during both non-sport specific intense intermittent exercise (Proske and Morgan, 2001, Clarkson et al., 1992) and team sport match-play specifically (Owen et al., 2015, Abbott and Clifford, 2021, Johnston et al., 2015b). Overall, these findings suggest superior levels of muscular strength appear to facilitate the performance of greater external workloads during match-play. Furthermore, well-developed muscular also appears to protect against fatigue and muscle damage, even despite the larger workloads associated with well-developed strength,

Therefore, it's possible that muscular strength could provide multiple benefits to Gaelic football players; (1) elevation of sport specific work capacity, (2) reduction of injury risk and (3) a resilience against psychophysiological disturbances during and following competition (Johnston et al., 2015b, Nicol et al., 2006, Proske and Morgan, 2001). However, in the absence of sport specific research it is difficult to infer as to the extent or magnitude of these possible interactions.

Muscular Power

Muscular power is described as rate of work being done per unit of time (Kraemer and Looney, 2012), and power is produced during any form of dynamic movement associated with an applied force, regardless of the contraction speed (Sapega and Drillings,

1983, Samozino et al., 2016). In invasion team sports, the capacity to produce large amounts of force rapidly is a key determinant of success, as many key actions undertaken during match-play (such as sprinting, jumping or side stepping) are often only afforded a limited temporal window (≈ 150 ms) with which to apply force (Andersen and Aagaard, 2006, Granero-Gil et al., 2020). Therefore, the transient rate at which contractile forces rise at the onset of the muscles contraction (rate of force development) (Aagaard et al., 2002) is a primary consideration in the success of team sport athletes (Suchomel et al., 2016).

A body of literature exists presenting evidence that the capacity to produce external power is a central factor in team sport performance (Suchomel et al., 2016, Cormier et al., 2020, Stares et al., 2015, Villaseca-Vicuña et al., 2021, Aquino et al., 2020, Cunningham et al., 2018, Kabacinski et al., 2022). Indeed, markers of muscular power are reported to be higher in elite players (Fry and Kraemer, 1991, Baker, 2001, Vukasevic et al., 2021, Keane et al., 2021) and starting players (Sell et al., 2018, Magrini et al., 2018, Jajtner et al., 2013) when compared with sub-elite and non-starting players respectively. Indeed, power as measured by vertical jump performance was found to be a primary variable in the prediction of players ratings, indicating its sport specific importance (Sawyer et al., 2002). Similarly, CMJ is often reported to be a key determinant of success in other sports of similar demands and movement patterns to Gaelic football (Nibali et al., 2013, Chamari et al., 2008), whereby more successful players possess superior CMJ height performances when compared with less successful players. In Gaelic football specifically, vertical jump (13.2%) and broad jump (6.5%) were observed to be significantly higher in elite level players when compared with sub-elite players (Keane et al., 1997), while more recent data in hurling presents a similar trend (Keane et al., 2021).

In team sports with comparable physical demands to Gaelic football, muscular power has been positively associated with a number of key performance indicators such as

ball possessions, successfully turnovers, distances covered at a range of different velocities and the number of sprints and accelerations completed during competitive match-play (Johnston et al., 2015a, Aquino et al., 2020, Cunningham et al., 2018). Therefore, muscular power is likely to discriminate the performance and on-field work capacity of Gaelic football players and may also present a high transfer effect into the performance of technical in-game tasks such as contests for possession, punt distance and running into space (Mangan et al., 2020, McGahan et al., 2018b).

Running Speed

Competitive team sport match-play necessitates the performance of high velocity running and intense changes of pace and direction (Rhodes et al., 2021, Harper et al., 2019). Indeed, capacity to perform these high intensity locomotive demands are often critical factors for team sport success (Rhodes et al., 2021, Keller et al., 2020) and within Gaelic football specifically (Reilly and Doran, 2001, Ryan et al., 2018). Furthermore, an ability to rapidly accelerate and achieve high running velocities enables the performance of elevated in-game workloads (Johnston et al., 2015a, Aquino et al., 2020, Cunningham et al., 2018) and may provide protection against injury (Malone et al., 2019)

It is evident from data in Gaelic football that running performance consists of a variety of movement intensities, wherein low intensity actions are unpredictably interspersed between high-speed running and frequent changes of direction and pace (Malone et al., 2016b). In elite Gaelic football, while only 21.2% of the total distance is covered at high speed ($>17 \text{ km}\cdot\text{h}^{-1}$) and 5.5% of the total distance is covered at a sprinting pace ($\geq 22 \text{ km}\cdot\text{h}^{-1}$), these high intensity movements contribute to crucial points in a game through the direct contribution of winning possession of the ball or scoring (McGahan et al., 2018a, Malone et al., 2016b). Considering the average sprint distance ($\geq 22 \text{ km}\cdot\text{h}^{-1}$) in

Gaelic football is ≈ 10 m, acceleration is considered a key attribute to the performance of these crucial actions during matches (Malone et al., 2016b).

In soccer, elite level youth players are reported to display a 9.7% significantly faster 10 m time when compared with sub-elite players, implying the importance of the acceleration capacity in the sport (Gissis et al., 2006). Similarly, rugby league elite level starting players exhibit higher running velocities over short distances and change of direction speed than non-starters and sub-elite players respectively (Gabbett et al., 2009), while starting Australian rules players were faster than non-starting players (Young et al., 2005). Finally, elite level Gaelic football and hurling players have also displayed significantly faster running speeds when compared with their sub-elite counterparts (Keane et al., 1997, Keane et al., 2021). Taken together, these findings suggest that acceleration and maximal running velocity are particularly important for successful team sport performance (Gissis et al., 2006, Gabbett et al., 2009, Young et al., 2005).

While the above findings provides valuable context and infers the importance of maximal running velocity and acceleration capacity in Gaelic football, it is difficult to deduce how these physiological and performance attributes may influence work capacity, performance attenuation and recovery in Gaelic football. While one could argue that high intensity running capacity is likely to enable superior work capacity and protect against the demands of match-play (Malone et al., 2019), it could be also postulated that the fast twitch muscle fibre typology typically associated with well-developed running speed may result in slower recovery (Lievens et al., 2020, Colliander et al., 1988, Hamada et al., 2003) and actually present a potent injury risk (Lievens et al., 2022). As such, sport-specific research is required in order to provide insight into the potentially complex interplay that may exist between high intensity running and acceleration capacity, in-game workloads, performance attenuation and post-match recovery kinetics.

Section 2 – Post-exercise Recovery Strategies in Gaelic Games

In professional team sports similar in nature to Gaelic games, recovery strategies are seen as imperative for the repeated high-performances necessary for a successful season (Field et al., 2021). While the perceptions and use of various recovery strategies have been investigated in many of these similar team sports such as rugby union or soccer, data has yet to be published in a Gaelic games population. Although Gaelic games players are amateur athletes, they are exposed to very demanding training and match schedules over a season, while many players also report multi-team and multi-sport activity in addition to their regular Gaelic games commitments (O'Connor et al., 2017, Kelly et al., 2018b). Furthermore, players may encounter additional stressors emanating from occupational and/or academic pressures, which may add significant psychophysiological stressors (Mann et al., 2016, Trockel et al., 2000). Owing to these collective demands, players physiological and psychological capacities to recovery are significantly challenged (Davis et al., 2007, Kellmann, 2010). As such, the below review will discuss the effectiveness, perceptions and prevalence of commonly reported recovery strategies in other field-based invasion team sports, highlighting their potential application across Gaelic games codes.

Active Recovery

Post-exercise active recovery or cool-downs are regularly used in field based invasion team sports following training or match-play with the goal of accelerating recovery (Tavares et al., 2017b, Nédélec et al., 2013). The strategy traditionally involves a lower-intensity exercise (often light jogging in a field sport setting) for approximately 10 – 20 min in duration following the cessation of a training session or match (Pooley et al., 2020). The recovery strategy is generally applied at an intensity below 60% of an athletes maximal oxygen consumption, with the primary reported goal of enhancing recovery kinetics by way of accelerating pH return to baseline values and increasing lactate removal via increased blood flow (Nédélec et al., 2013). Specifically, the low intensity exercise may

result in accelerated lactate redistribution over to the liver for reconversion to glycogen or oxidation, while simultaneously increasing muscle and heart lactate uptake and utilisation (Van Hall, 2010). This strategy yields effective performance recovery when implemented between bouts of exercise in quick succession, where the highest magnitude of recovery is demonstrated in contexts when the exercise bouts are a few minutes apart (Bogdanis et al., 1996b). Nonetheless, following intense work blood lactate spikes and returns to baseline levels well before athletes are likely to participate in their next training, potentially negating this suggested benefit in a team sport context (Barnett, 2006). Importantly, when employed in the context of invasive team sport when the next match or training session is generally 24 hours or more away, the effects of active recovery on subsequent performance become less effective or even present no net physiological benefit (Bond et al., 1991, Nédélec et al., 2013, Koizumi et al., 2011, Webb, 2011).

Preliminary work into active recovery from Gisolfi et al. (1966) demonstrated that the use of low intensity jogging following exhaustive treadmill running lowered oxygen debt and increased lactate removal, thereby increasing short-term recovery. Other studies have presented similar findings, highlighting an active recovery protocol as a significantly superior strategy to enhance short-term recovery between exercise bouts 4 to 25 mins apart when compared with passive measures (Bogdanis et al., 1996b, Martin et al., 1998, Monedero and Donne, 2000, Riganas et al., 2015). In rugby league and union, a number of studies have reported no benefit, and others a trivial benefit, to the implementation of an active recovery protocol (Tavares et al., 2017b, Jouglu et al., 2010, Webb, 2011, Gill et al., 2006). A key potential advantage of utilising active recovery in rugby league and union literature is accelerated CK clearance 24 to 36 hours post-exercise (Tavares et al., 2017b). This may be especially evident in rugby codes as compared to soccer, where CK elevations associated with the strenuous and repeated physical contact and tackling are generally

larger in magnitude (Takarada, 2003, Baird et al., 2012, Russell et al., 2015), possibly leaving more opportunity for active recovery to facilitate relatively greater CK removal. In professional rugby league players, Webb (2011) reported that an active recovery protocol provided a small advantage in CK removal, neuromuscular performance recovery and subjective muscle soreness reduction although the recovery benefits were inferior to cold water immersion. Other work has similarly reported active recovery to have a positive effect in lowering CK levels 36 hours and 84 hours following cessation of competitive elite rugby league match-play (Gill et al., 2006). In contrast, studies in similar rugby populations have reported no worthwhile benefit of a post-exercise active recovery protocol on recorded performance or metabolic measures (Suzuki et al., 2004, Lindsay et al., 2015b).

In contrast to rugby, research in soccer suggests active recovery is less effective, with many studies demonstrating no advantage of using active recovery on subsequent physical performance measures in comparison to passive recovery even despite the greater lactate clearance reported (Andersson et al., 2010a, Kinugasa and Kilding, 2009, Andersson et al., 2010b, Pooley et al., 2020). Of note, active recovery protocols have even been suggested to be somewhat detrimental to post-exercise recovery in soccer-specific environments (Nédélec et al., 2012). More specifically, active recovery modalities have been reported to even blunt recovery when assessed by performance outcomes 1 or 2 days subsequent to exercise cessation (Van Hooren and Peake, 2018), with the diminished performance suggested to be due to further addition of fatigue and impaired glycogen resynthesis resulting from the increased activity of the cool down used (Fairchild et al., 2003, Choi et al., 1994, Kuipers et al., 1987).

Overall, active recovery protocols demonstrate little to no benefits in a team sport context (Van Hooren and Peake, 2018, Nédélec et al., 2013). A comprehensive summary of recently published work investigating the effects of active recovery can be seen in Table

2. 1 adapted from Van Hooren and Peake (2018). However, the effects of an active recovery protocol following a match or training session in any code of Gaelic games remains yet to be investigated and future research is warranted.

Table 2. 1. Heatmap summary detailing the effects of an active cool down on various markers associated with recovery. Adapted from the work of Van Hooren and Peake (2018) with permission.

	Significant benefit	No significant effect	Significant harm
Sports performance			
Same day performance		4	
Next day performance		14	
Long-term effects			
Injury prevention	1	6	
Adaptive response	1		
Physiological effects			
Blood lactate clearance	>18	1	1
Muscle tissue lactate	2	1	1
Delayed onset muscle soreness	2	14	
Indirect markers of muscle damage	2	6	
Neuromuscular/contractile function		3	
Stiffness and range of motion		7	
Muscle glycogen resynthesis		3	5
Immune system	2	2	
Cardiovascular/respiratory system	5	2	2
Sweat rate and thermoregulation		6	
Hormone concentrations		4	
Psychological effects			
Mood state and sleep		12	1

Each number represents the number of studies demonstrating a significant benefit (green), no significant difference or an inconclusive effect (blue), or significant harm (red) of an active cool-down on the variable of interest when compared with passive measures.

Stretching

Static and dynamic stretching are commonly used as supplementary components of Gaelic games training/match warm up and cool down protocols (Loughran et al., 2017, O'Connor et al., 2019). During a post-exercise cool down, static stretching is the most frequently prescribed stretching modality used to target enhanced recovery in rugby union (Campher et al., 2017), soccer (Judge et al., 2020), basketball (Judge et al., 2011) and other team sports (Sands et al., 2013, Gremion, 2005). Specifically, this style of stretching involves the placement of the body/limbs in an extended range of motion position while maintaining this position for a period (usually for around 30 s) using agonist muscular tension, partner assistance or gravity to maintain the stretch (Sands et al., 2013). In many invasive team sports stretching constitutes a frequently used regeneration strategy, aimed at enhancing and accelerating post-exercise recovery response profiles (Rey et al., 2018, Verrall et al., 2005, Fletcher and Jones, 2004). For example, over half of French professional soccer teams use stretching as a recovery strategy (Nédélec et al., 2013) while almost 40% of total training time in English premiership clubs was dedicated exclusively to stretching in the early 2000's (Dadebo et al., 2004). Despite the consistent use and considerable time devoted to stretching as a post-training and post-match recovery modality in team sport, scientific evidence promoting stretching as an effective recovery parameter is lacking (Connolly et al., 2003, Pooley et al., 2017, Nédélec et al., 2012, Gremion, 2005). In contrast to the belief of many coaches and athletes, static stretching performed pre- or post-exercise has not been reported to reduce muscle soreness (Spinks, 2013, Herbert et al., 2011) or reduce the risk of enduring acute (Shrier, 1999) or long term degenerative injuries (Baxter et al., 2017). Similarly, evidence supporting the use of stretching as a means to accelerate physical performance recovery following exercise modalities similar in nature to field-based Gaelic games is also lacking (King and Duffield, 2009, Dawson et al., 2005,

Sands et al., 2013). Finally, a large meta-analysis encompassing a dozen studies (including over 2000 participants) from Herbert et al. (2011) assessed the impact of pre- and post-exercise stretching on muscle soreness 24 to 72 hours after exercise and reported no clinically relevant impact of stretching. Considering the aforementioned studies, stretching as a modality to increase performance recovery following exercise may be less effective than is perceived by team sport athletes and coaches (Nédélec et al., 2013), although this is yet to be demonstrated in Gaelic games specifically.

Nutritional Strategies

Athletes face many nutritional challenges during the preparatory and competitive phases of the Gaelic games season. Numerous nutritional factors are reported to have a significant impact on post exercise recovery processes in team sport athletes (Heaton et al., 2017). Nutrition is likely to have a similarly strong influence on players recovery cycles in Gaelic games although research in the area is largely extrapolated from similar invasive team sports such as soccer or rugby league (Beasley, 2015, Ranchordas et al., 2017). In elite and sub-elite Gaelic football and hurling, players have been reported to consume inadequate carbohydrate during match preparation and across the post-match recovery timeline, increasing the potential for impaired recovery kinetics (Ó Catháin et al., 2020, Murphy and O'Reilly, 2020). Moreover, assessments of nutritional knowledge in Gaelic football and hurling populations have demonstrated weak scores, highlighting a potential issue impacting players post-exercise dietary and rehydration strategies and subsequently leading to impeded recovery responses (Renard et al., 2020, McCrink et al., 2021, O'Brien et al., 2021, Renard et al., 2022).

Overall, field based team sport athletes require a foundational diet adequate in carbohydrates, fat, protein, micronutrients and fluid intake to facilitate optimal post-exercise recovery kinetics (Heaton et al., 2017). The intense physical demands of Gaelic

games require a diet rich in carbohydrate to facilitate both high-intensity performance and many processes associated with post-exercise recovery (Williams and Rollo, 2015, Ó Catháin et al., 2020). These include but are not limited to supporting fuel demands, mitigated fatigue, limiting energy deficit and the maintenance of the immune system and competitive performance (Meeusen et al., 2013, Balsom et al., 1999b, Gunnarsson et al., 2013). In contrast to carbohydrates, Gaelic football players (Ó Catháin et al., 2020) and hurlers (Murphy and O'Reilly, 2020) have been suggested to consume adequate dietary protein, although this is yet to be reported in camogie, hurling or handball populations. An important co-founding factor to consider here may be playing standard, wherein inter-county players may have greater access to nutrition resources and/or support staff, and may subsequently present with improved nutrition knowledge, and as a consequence, improved nutritional practices (Ó Catháin et al., 2020, Renard et al., 2020, O'Brien et al., 2021, Mitchell et al., 2021, Renard et al., 2022). Protein is responsible for many significant functions in players recovery processes including muscular repair and remodelling, immune function and numerous other important roles in the body (Heaton et al., 2017). In addition, muscle protein synthesis, a primary factor in the post-exercise muscle repair and remodelling processes, is modulated by many components of an athletes dietary strategies such as the co-ingestion of other nutrients, protein sources/dose and meal timing (Witard et al., 2016, Tipton et al., 2018). With regards to dietary fat, excessive consumption is regularly deemed disadvantageous owing to negative connotations with body composition and sub-optimal energy availability for high-intensity exercise (Burke et al., 2004). Moreover, it should be noted that fat consumption should not be kept below recommendations, as the macronutrient plays numerous important roles in hormone modulation, cell membrane construction, fuelling for low-intensity exercise, immune system function maintenance and enzyme function together with many other key bodily

processes (Venkatraman and Pendergast, 2002, Muoio et al., 1994). A well-balanced diet containing a variety of vegetables and fruits is recommended, with the inclusion of dietary supplements where appropriate, to help support recovery during the season (Heaton et al., 2017, Maughan et al., 2018). Here, adequate consumption of micronutrients and possible supplements such as vitamin b, c and d, omega 3 fatty acids creatine, collagen/vitamin C, and antioxidants can also play a role in modulating post-exercise recovery through numerous mechanisms such as improved immune function, elevated muscle protein synthesis and mediated post-exercise inflammation responses (Venkatraman and Pendergast, 2002, Heaton et al., 2017).

Alongside adequate dietary consumption, fluid replacement is a crucial part of the post-exercise recovery cycle from team sport training or match-play (Maughan and Shirreffs, 2004). Here, the restoration of fluid and electrolytes plays an important role to replace sweat loss (Sawka et al., 2015), while inadequate rehydration can result in significant performance decrements and impairments in recovery status (Sawka et al., 2015). This may be a particularly important consideration during hot conditions in the summer months, wherein the more important competitions are often played (Aragón-Vargas et al., 2009, Kelly et al., 2018b).

In summary, Gaelic games players engaging in effective nutritional strategies are significantly more likely to express improved recovery responses than athletes utilising sub-optimal dietary intake (Ranchordas et al., 2017) where fluid replacement, carbohydrate and protein are regularly identified as important modulators of a team sport athletes' recovery (Heaton et al., 2017).

Application of Cold

Ice baths, cryotherapy, cold water immersion and other cold modalities are recovery strategies that have gained a lot of traction and popularity in recent years among field based invasion team sport athletes (Pooley et al., 2020). The most common, cold water immersion, is regularly used and prescribed by athletes and Coaches to accelerate recovery during competition and training, while the method of application can vary a lot in both temperature and duration (Ihsan et al., 2021). Notably, many experimental studies and reviews have reported a significantly beneficial effect of cold water immersion on accelerating short-term performance recovery and alleviating markers of muscle damage (Leeder et al., 2012, Higgins et al., 2017, Sánchez-Ureña et al., 2015, Bailey et al., 2007). Cold water immersion has many profound physiological, metabolic and psychological effects and could be considered to elicit a powerful physiological stimulus (Ihsan et al., 2021). These physiological effects include but are not limited to increased metabolic waste product efflux, mitochondrial content, oxygen supply to cells, analgesic effects, reduced acute inflammation from muscle damage and decreased muscle spasm, muscle perfusion and anabolic signalling which are illustrated in (Figure 2. 6) (Ihsan et al., 2021, Tipton et al., 2017, Higgins et al., 2017).

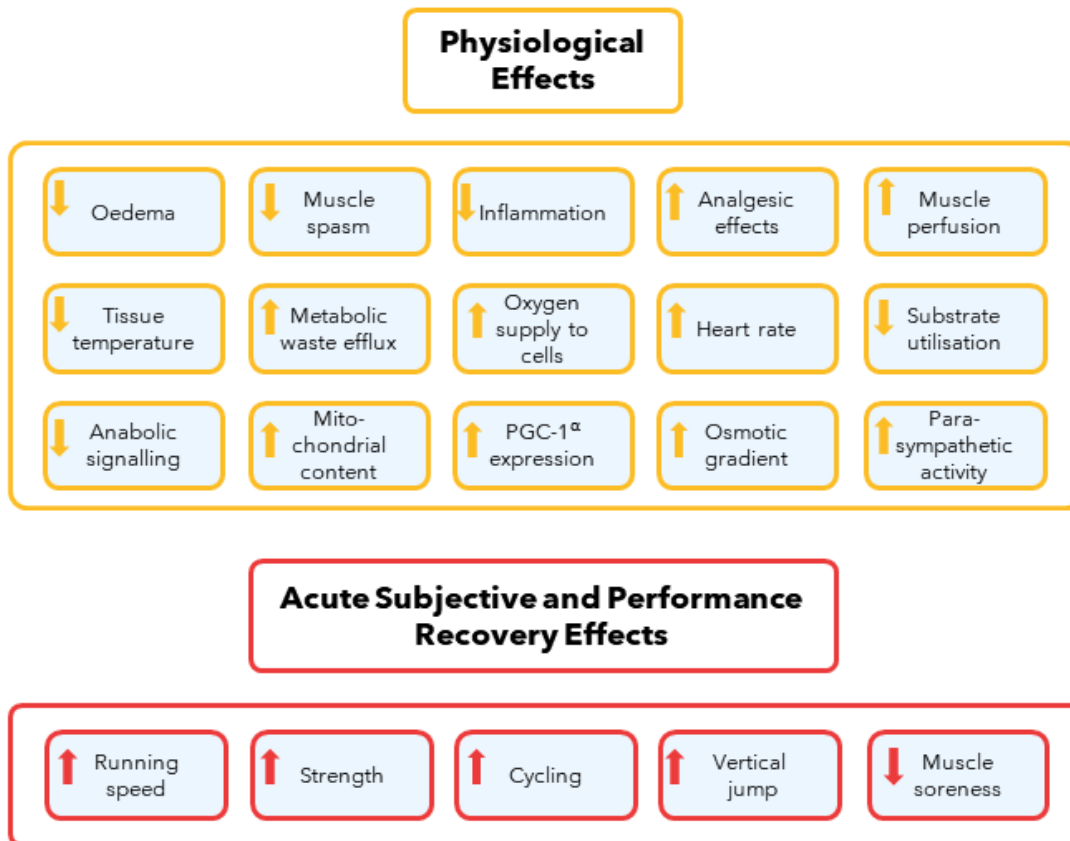


Figure 2. 6. Physiological, subjective and performance outcomes associated with cold water immersion. Adapted from Tipton et al. (2017) with permission.

Perhaps of particular interest to Gaelic games players, cold water immersion has been regularly reported to decrease elevations of myoglobin and CK (Ascensão et al., 2011) and subjective markers of muscle soreness (Higgins et al., 2017, Ihsan et al., 2021) which are important and commonly assessed markers of recovery status. In relation to performance measures associated with the demands of field-based team sport, cold water immersion has been reported to accelerate post-exercise recovery of strength (Vaile et al., 2008), running speed (Ingram et al., 2009) and countermovement jump (King and Duffield, 2009) parameters. Additional work has also demonstrated beneficial effects of cold-water immersion to enhance maximal isometric strength, cycling performance, short distance

running speed and vertical jump performance using a variety of cold-water immersive techniques (Bailey et al., 2007, Pooley et al., 2020, Tavares et al., 2017b). A summary of key subjective, performance and physiological responses associated with cold exposure is illustrated in Figure 2. 7.

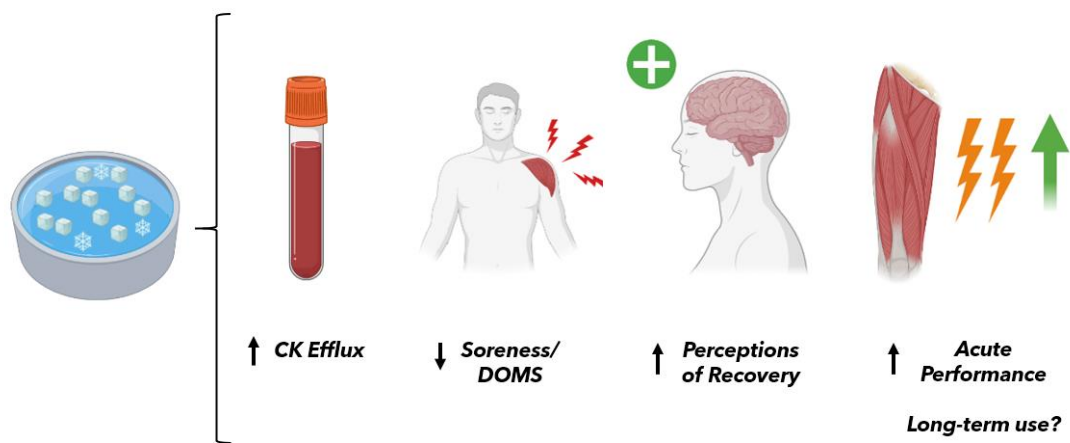


Figure 2. 7. A visual summary of some key effects of cold exposure that may be relevant to Gaelic athletes. Adapted from Tipton et al. (2017) with permission.

While beneficial performance outcomes are generally observed in the short-term using cold water immersion, it should be noted that the repeated dulling of physiological stressors and anabolic signalling resulting from cold exposure may diminish training adaptations over extended periods (Tavares et al., 2017b). This blunting of physiological adaptations to training is particularly evident in muscle size and strength responses to resistance exercise (Ihsan et al., 2021). On the contrary, cold water immersion was not reported to disrupt aerobic adaptations to endurance training (Ihsan et al., 2021), which may possibly be explained in part by previously documented increases in mitochondrial content (Chung et al., 2017). It should be noted however that many of the participants in

the aforementioned studies and reviews had much lower weekly training loads (in many cases participants were completely untrained) than that typically reported for a Gaelic games players (O'Keeffe et al., 2020, Ihsan et al., 2021, Kelly et al., 2018b). Therefore, it may be possible that a higher training stimulus (as is likely to be prevalent in Gaelic games players) may circumvent the inhibited adaptive responses from cold water immersion and may subsequently confer improved responses when compared with the aforementioned work. In addition, a number of the studies that demonstrated blunted anabolic signalling used relatively more extreme cold exposure protocols (for example, 2 bouts of 20 minutes in 5 °C) which differs substantially in duration and temperature to that of methods commonly reported in team sport athletes (Ihsan et al., 2021, Leeder et al., 2012).

While diminished anabolic stimuli is a common justification for the avoidance of cold-water immersion use, it is important to note that Gaelic games are complex sports with many technical, tactical and physical conditioning factors at play. In light of this, the application of cold-water exposure in a controlled environment while avoiding use around strength training may theoretically increase general training preparedness. This may be especially pertinent when considering players have previously displayed signs of ongoing fatigue/muscle damage during the competitive season (Daly et al., 2020). To further limit potential disruptions to players strength or hypertrophy characteristics, cold water may be avoided during preparatory phases of the season entirely while implemented during important competitive phases of the in-season, (i.e., where on pitch performance is more important than attaining muscular size and/or strength). In order to explore these concepts more research is needed in team sports and within Gaelic games specifically.

Figure 2. 8. A visual summary of some key effects of cold exposure that may be relevant to Gaelic athletes. Adapted from Tipton et al. (2017) with permission.

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Application of Heat

When compared to cold water immersion or other forms of cold application, investigation into the effects of heat therapies are less prevalent in the realm of team sport post-exercise recovery (McGorm et al., 2018). While heat exposure following exercise has been demonstrated to hamper recovery (Skorski et al., 2019, Girard et al., 2015), various forms of heat therapy and acclimation have been reported to increase muscular size adaptations (Touchberry et al., 2012, Goto et al., 2011) and markers associated with endurance such as haematocrit and blood plasma volume (Scoon et al., 2007, Stanley et al., 2015, Goto et al., 2007, Sunderland et al., 2007). Indeed, different adaptations linked with heat acclimation may be associated with several physiological benefits that could be highly applicable to the performance of Gaelic games players. These include (1) improved endurance performance (Costa et al., 2014, Sawka et al., 1996, Garrett et al., 2012, Scoon et al., 2007), (2) increased muscle hypertrophy responses to exercise (Selsby et al., 2007) and (3) reduced muscle loss during inactivity (Naito et al., 2000, Selsby et al., 2005). While these factors may indirectly promote recovery outcomes following the longitudinal

application of the modality, the subsequent section will discuss heat therapies through the specific lens of post-exercise recovery responses in an acute setting.

Despite the physiological adaptations associated with heat exposure in team sport athletes, the use of heat exposure as a means to accelerate short term post-exercise recovery in a team sport context is generally lacking. Research in swimmers from Skorski et al. (2019) has reported that heat exposure using sauna bathing has been detrimental to performance recovery. This finding may indicate that heat exposure as a stimulus to promote skeletal muscle and cardiorespiratory adaptations which likely stem from and impose acute fatigue and stress; thereby hampering recovery in the short term. More specifically, the additional load of the heat exposure is likely to significantly stress athletes circulatory and cardiorespiratory systems (Skorski et al., 2019). Importantly, additional research using less strenuous heat exposure duration and intensity has reported to improve participants subjective measures of recovery and CK clearance (Viitasalo et al., 1995), limit losses in post-exercise range of motion (Khamwong et al., 2012) and increase muscle relaxation (Iguchi and Shields, 2011). Furthermore, heat exposure was also reported to relieve pain 24 hours following exercise (Mayer et al., 2006) and reduce post-exercise decrements in jumping power, ground contact time during repeated jumps (Viitasalo et al., 1995) and isometric squat performance (Vaile et al., 2008). Although a lack of research undermines our capacity to pinpoint the exact mechanisms underpinning these effects, a conceptual framework has been proposed (Figure 2. 9) (Kim et al., 2020, McGorm et al., 2018).

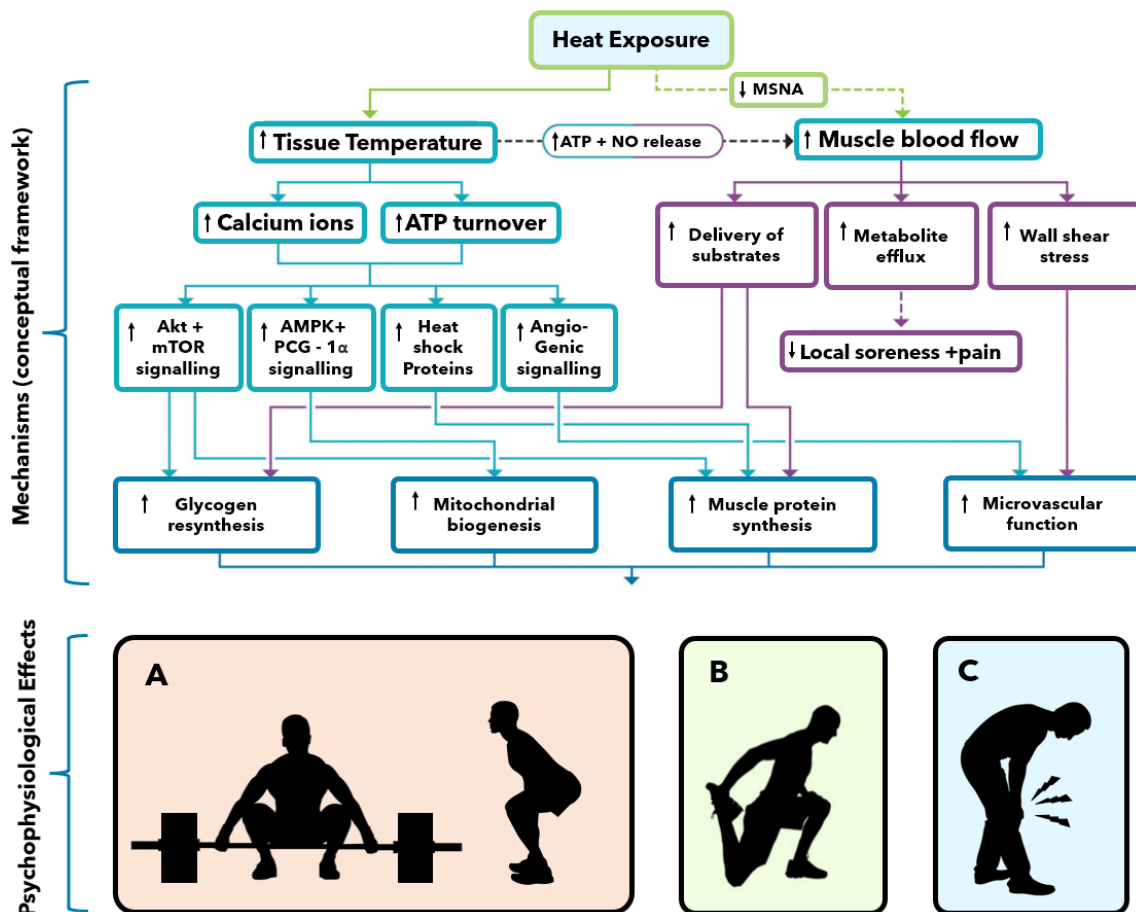


Figure 2. 9. Schematic diagram of most consistently demonstrated benefits of post-exercise heating: (A) Muscular strength and power recovery; (B) range of motion return and (C) a reduction in muscular swelling and soreness and a putative conceptual framework of the mechanisms underpinning their effects. Adapted from the work of McGorm et al. (2018) and Kim et al. (2020). MSNA; muscle sympathetic nerve activity.

It is important to note that many of the studies demonstrating benefits of post-exercise heat exposure were conducted in animals or exercise-naive participants (Kim et al., 2020), and research is therefore warranted in well trained and/or following team sport activity in order to provide team sport/Gaelic games specific context. Nonetheless, there is accumulating evidence to suggest that post-exercise heat exposure may provide a suitable

tool to accelerate the recovery of cardiometabolic and contractile function (Kim et al., 2020, McGorm et al., 2018).

Contrast Temperature Therapy

Contrast water therapy involves alternating cold and warm water immersion with the goal of enhancing recovery responses (Cochrane, 2004). The primary mechanism of contrast water therapy is suggested to be alternating peripheral vasodilation and vasoconstriction, subsequently resulting in a ‘pumping’ effect which may increase blood flow and accelerate the clearance of metabolic waste products (Gregson et al., 2011, Higgins et al., 2017). Due to this pumping effect contrast therapy is suggested to mirror the mechanisms of active recovery, without the associated demands of performing additional exercise (Wilcock et al., 2006). To date however, the present authors are not aware of empirical evidence directly highlighting the mechanisms underpinning the vasodilation/vasoconstriction pump suggested to explain the recovery benefits of contrast water therapy. As with any water immersion protocol, the compressive hydrostatic effects on the body are suggested to help direct movement of fluid inward from the peripheries (Tavares et al., 2018). These compressive effects of water immersion are explained to increase cardiac output, metabolic substrate transportation while reducing muscle oedema and extracellular fluid volume by influencing the intracellular and intravascular osmotic gradients (Wilcock et al., 2006). The reductions in oedema resulting from the movements of these fluids may help to alleviate short term losses in neuromuscular function and accelerate contractile tissue repair and reconstruction (Wilcock et al., 2006). Furthermore, temperature has been demonstrated to have a significant impact on the physiological responses to water immersion and is an important factor for practitioners to consider when implementing water immersive recovery strategies (Tavares et al., 2018, Wilcock et al., 2006, Vromans et al., 2019).

Despite a lack of consensual understanding of how contrast therapy works, it has been shown to result in acute reductions of markers of muscle damage (Gill et al., 2006, Webb, 2011), accelerated sprint cycling performance recovery (Crampton et al., 2011) and lower perceptual disturbances with regard to muscle soreness and perceived fatigue (Tavares et al., 2018, Webb, 2011). Notably, the post-exercise enhancements in perceptual markers are generally more common and larger in magnitude than the physiological or performance recovery improvements (Higgins et al., 2017, Bieuzen et al., 2013). In an attempt to explain these findings, contrast water therapy may have a therapeutic and relaxing effect on the body, while the warm water is suggested to help mask pain perception in the brain through its stimulation of various thermoreceptors in accordance with the gate control theory (Moayedi and Davis, 2013, Bieuzen et al., 2013). While a number of studies have illustrated beneficial effects of contrast water therapy on performance and perceptual measures of recovery, others have reported trivial or a non-significant impact on markers (Barnett, 2006, Nédélec et al., 2013, Versey et al., 2013). In conclusion, the recovery benefits of implementing contrast therapy following exercise are generally supported within the literature, although the magnitude of effects are generally small (Hing et al., 2010, Bieuzen et al., 2013, Higgins et al., 2017).

Sleep

Sleep is defined as a state of behaviour encompassing perceptual unresponsiveness, reduced consciousness and disengagement with environmental stimuli (Halson, 2008, Doherty et al., 2019), and a growing body of research exists demonstrating strong relationships between sleep and post-exercise recovery (Samuels, 2008). Unlike other professional team sports, Gaelic games players endure significant physical, metabolic, and psychological stressors during training and match-play in combination with work/study commitments (Daly et al., 2020, Kelly et al., 2018b). Subsequent to these demands, Gaelic

games players must prioritise recovery in order to avoid excessive and cumulative fatigue and muscle damage which may have a negative impact on physical fitness, psychological motivation and competitive performances (Budgett, 1998, Fry et al., 1991). Management of Gaelic games players sleep is critical to the balance of these stress/recovery cycles based on well documented evidence in other sports (Brandt et al., 2017) and similar invasion team sport athletes (Fullagar et al., 2015a, Claudino et al., 2019). Indeed, good sleep hygiene is suggested to be a major requisite for the functional physical and psychological recovery of athletes, with optimal sleep key to high performances (Meeusen et al., 2013, Kellmann, 2010, Kirschen et al., 2020). Despite the significant focus on the impact of sleep in the literature, evidence highlighting the mechanistic underpinnings of sleeps role in athletic recovery are somewhat unclear (Samuels, 2008, Milewski et al., 2014). Factors suggested to determine the restorative influence of sleep include circadian timing, quality and duration of sleep (Fabbri et al., 2021). Importantly, in athletic populations akin to Gaelic games competitors who's sport entails strenuous physical and cognitive demands requiring tactical/technical proficiency and well-developed physical conditioning, sleep duration requirements may increase in comparison to less trained individuals (Kirschen et al., 2020, Watson et al., 2021).

Several review papers have been recently published highlighting the negative impacts of circadian disruptions and variation in athletes physical/psychological status and performance (Kirschen et al., 2020, Thun et al., 2015, Halson, 2014, Chennaoui et al., 2015, Fabbri et al., 2021). In general, the ramifications of sleep deprivation on athletes psychological, physiological and performance markers are well documented and demonstrate that disturbed sleep provokes significant disturbances in perceptual and performance outcomes (Fullagar et al., 2015a, Lastella et al., 2014). In general, sleep deprivation is demonstrated to impose more harm on aerobic or cognitive based tasks when

compared to anaerobic tasks such as maximal isometric strength or vertical jump performance (Kirschen et al., 2020). Specifically, sleep deprivation has been illustrated to impair tennis serve performance (Reyner and Horne, 2013), muscular strength, power and endurance (Pilcher and Huffcutt, 1996, Reilly and Piercy, 1994, Skein et al., 2013), glycogen storage and running performance (Mejri et al., 2016) and numerous measurements of perceived exertion during exercise and mood status (Bolin, 2019, Lastella et al., 2014, Brandt et al., 2017). Furthermore, sleep deprivation was reported to impact metabolic and cardiovascular responses following high-intensity exercise by increasing oxygen intake and ventilation; possibly indicating greater physiological strain during the post-exercise recovery period (McMurray and Brown, 1984).

In contrast, sleep extension is reported to provide numerous advantages for competitive team sport performance (Kirschen et al., 2020). In rugby players, greater sleep was reported to increase total voluntary training workload ($ES = 2.33$) (Cook et al., 2012) and improve passing accuracy from both dominant and non-dominant sides (Cook et al., 2011). Similar trends were reported in martial art competitors, wherein improved sleep was associated with significantly greater muscular strength (Latiri and Dogui, 2016, Souissi et al., 2013), Wingate performance (Souissi et al., 2013) and Yo-Yo intermittent recovery test performance (Mejri et al., 2016). Finally, sleep extension was reported to significantly improve technical skills (Mah et al., 2011), countermovement jump and running endurance (Fullagar et al., 2016) and shuttle run performance (Boukhris et al., 2020) in team sport athletes.

Interestingly, naps have been commonly used by team sport athletes in an attempt to mitigate the negative effects of sleep deprivation (Fullagar et al., 2015a). Research has demonstrated that the use of napping to top up sleep levels can improve reactions, alertness, sprint performance jump velocity and coaches perceptions of performance (O'Donnell et

al., 2018, Waterhouse et al., 2007). Based on the evidence presented in the current review, there is scope to further explore the sleep practices of team sport athletes, in particular Gaelic games players, and how these parameters are perceived to influence the physical performance and post-exercise recovery kinetics of these athletes

Compression Garments

Compression garments are a popular recovery modality, and have become widely adopted in individual and team sport athletes (Weakley et al., 2021, Duffield et al., 2008). They are described to be items of clothing which impose mechanical tension to the body (Weakley et al., 2021, Franke et al., 2021) with many possible mechanisms associated with this mechanical pressure suggested to potentially elicit ergogenic and/or recovery benefits (Weakley et al., 2021, Franke et al., 2021, Tyurin et al., 2019). The effects are possibly underpinned by psychophysiological and biomechanical outcomes, such as increased arterial blood flow, reduced muscle oscillation and reductions in perceived muscular soreness following exercise (Hill et al., 2014, Duffield et al., 2010a, Davies et al., 2009). In a recent systematic review, Weakley et al. (2021) reported that the most commonly researched forms of compression garments are reported to be full leg (> 80 studies) and below the knee (> 60 studies), followed by full body (< 20 studies), thigh (< 20 studies), upper body (< 10 studies), arm (< 5 studies) and knee compression (< 5 studies).

The physiological mechanisms underpinning the effects of compression garments on recovery outcomes has received much speculation (Kraemer et al., 1996, Brown et al., 2017). Possible mechanisms (Figure 2. 10) supporting their potential benefits include reduced blood lactate accumulation (Rimaud et al., 2010, Berry and McMurray, 1987), an assistance of venous return and peripheral circulation (Ibegbuna et al., 2003, Venckūnas et al., 2014), increased efflux of markers associated with muscle damage (Hill et al., 2014, Tyurin et al., 2019, Marqués-Jiménez et al., 2016), reduced muscle vibration and oscillation

(Deng et al., 2021, Ehrström et al., 2018, Kraemer et al., 1998) and influenced cellular and haemodynamic function (Sarin et al., 1992).

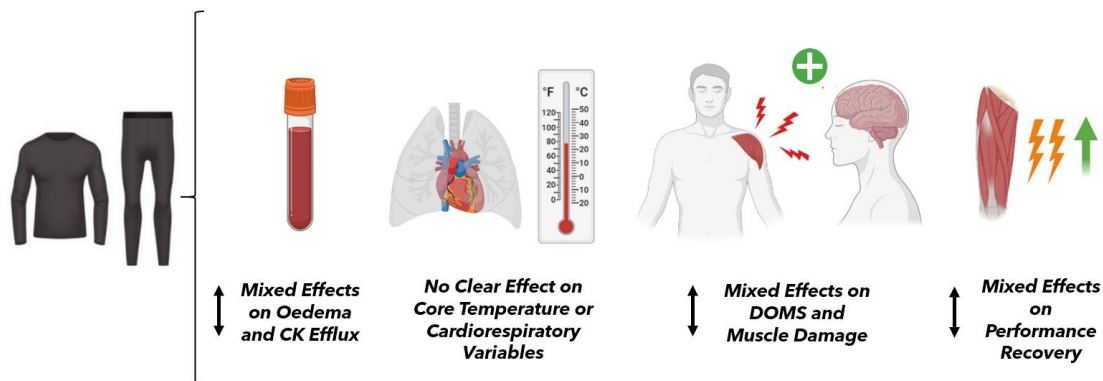


Figure 2. 10. Effects of compression garments on recovery outcomes adapted from Brown et al. (2017) and Weakley et al. (2021).

Notably, compression-mediated effects may have some premise with regards to promoting recovery of muscular power and to a greater extent muscular strength, in the day(s) following strenuous eccentric exercise (Brown et al., 2017, Hill et al., 2014). This response may stem from compression garments ameliorative influence on DOMS, post-exercise oedema accumulation and muscle damage (Kraemer et al., 2001, Jakeman et al., 2010b). This accumulation of cellular fluid may increase the osmotic pressure of muscle cells (Sarin et al., 1992) and have a snowballing effect on muscle damage responses, whereby the increased osmotic pressure may result in cellular lysis and subsequently further muscle damage (Földi et al., 1985, Sarin et al., 1992, Hill et al., 2014). Compression garments may mediate this responses, whereby the external pressure may attenuate the release of oedema and cellular debris and increase venous return (Tyurin et al., 2019, Marqués-Jiménez et al., 2016). Importantly, improved CK clearance has been demonstrated

in some studies (Duffield et al., 2008, Kraemer et al., 2001) but not in others (Duffield et al., 2010a, King and Duffield, 2009, Jakeman et al., 2010b, Jakeman et al., 2010a) suggesting mixed or weak effects.

Taking into account all of the available evidence, it is possible to suggest that compression garments may add a small recovery benefit from resistance or strenuous SSC activity, although most findings are mixed (i.e. trivial benefit or inconclusive) (Marqués-Jiménez et al., 2016). Additionally, the effects of compression on recovery from endurance and/or metabolically taxing exercise such as interval running or repeated sprint work (as opposed to strenuous resistance/eccentric modes of exercise) currently present more limited benefits (Ali et al., 2007, Argus et al., 2013, Driller and Halson, 2013). Nevertheless, there may be some small benefit to the use of compression garments following strenuous resistance exercise, and future research would be worthwhile to examine Gaelic games players practitioners and practitioners use and beliefs of the modality.

Massage

Massage involves the mechanical manipulation of the bodies tissues using rhythmical stroking or pressure (Cafarelli and Flint, 1992), and is a recovery strategy commonly used in Gaelic games players (O'Sullivan and Keane, 2009). In a large review paper, Weerapong et al. (2005) detail that there are many techniques of massage that have been reported to be used in athletic populations; while Swedish or classic western styles of massage are the most commonly implemented forms. The effects of massage may encompass numerous physiological, psychological, biomechanical and neuromuscular mechanisms, some of which are detailed in Figure 2. 11. Here, benefits of massage during post-exercise recovery may include increased muscle compliance, changes in Hoffmann reflex and parasympathetic activity, improved mood state and reductions in subjective muscle soreness (Gasibat and Suwehli, 2017). Despite a long list of suggested benefits of

massage on various markers of recovery, clinically relevant data providing robust evidence as to the mechanisms of these effects are generally limited (Weerapong et al., 2005).

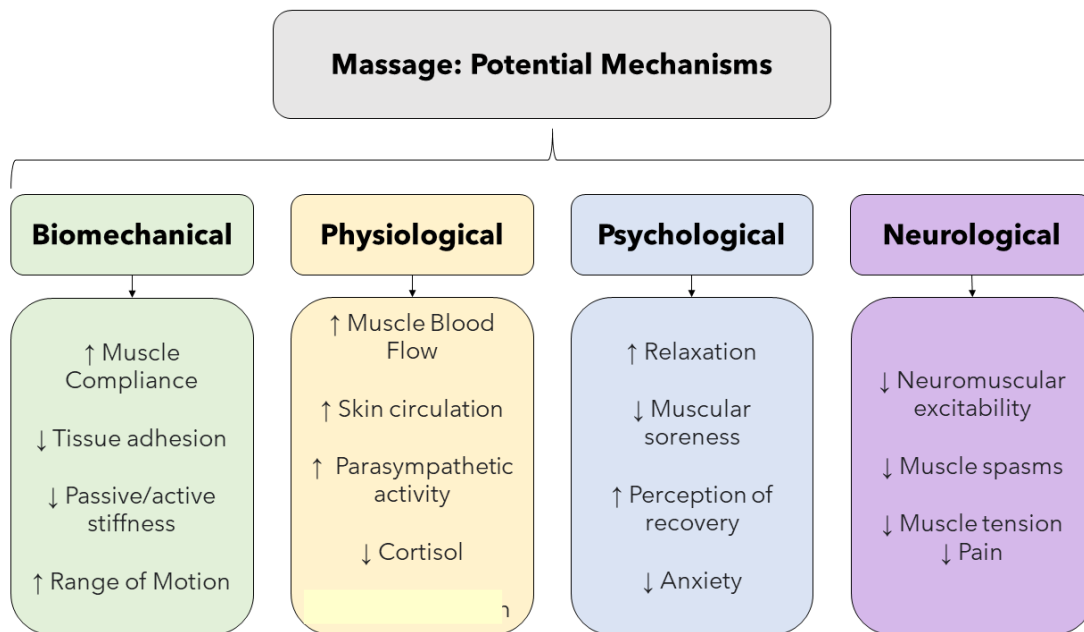


Figure 2. 11. Mechanisms and effects of massage as adapted from Weerapong et al. (2005) with permission.

Reinforcing the contention that massage presents trivial recovery effects; the modality has reported limited benefits for strength recovery (Tiidus and Shoemaker, 1995), blood flow and blood lactate removal (Wiltshire et al., 2010, Tiidus and Shoemaker, 1995), and hydrogen ion removal (Wiltshire et al., 2010). In contrast however, the literature investigating the psychological impact of massage generally display stronger beneficial effects (Nédélec et al., 2013). Here, improved mood state (Weinberg et al., 1988, Micklewright et al., 2005), reduced subjective muscle soreness markers (Guo et al., 2017, Davis et al., 2020) and perceived recovery (Kerautret et al., 2020, Andreossi et al., 2021) have been demonstrated following massage interventions. Notwithstanding the reported improvements in psychological markers of recovery following a massage intervention, a

meta-analytical review investigating the effects of massage on recovery of athletic performance reported only a negligible benefits ($g = 0.19$) (Poppendieck et al., 2016). Similar results were reported in another systematic review from Davis et al. (2020) where no evidence of improved endurance, strength, power or running speed recovery was demonstrated in the reviewed literature.

Recovery Intervention Considerations

Complete post-exercise recovery is described as a return to bodily homeostasis, wherein biological and psychological factors fully regenerate (Hauswirth and Mujika, 2013, Lewis et al., 2018, Jentjens and Jeukendrup, 2003). In the absence of adequate regeneration following exercise, neuromuscular fatigue, muscle damage and/or inflammation incurred during the performance of this exercise may not be fully compensated (Kellmann et al., 2018, Dellal et al., 2015, Johnston et al., 2015a) and as a consequence, the capacity to perform during subsequent training or match play may become limited (Hunkin et al., 2014, Julian et al., 2021, Skala and Zemková, 2022, Cooper et al., 2020). In circumstances where these recovery reserves become challenged, the implementation of effective, timely and contextually appropriate recovery strategies may be recommended (Calleja-González et al., 2021b, Huyghe et al., 2020, Dupuy et al., 2018, Kellmann et al., 2018).

Firstly, the primary recovery strategies (i.e., adequate sleep, hydration and nutrition) and fatigue management (i.e., the incorporation of rest days and appropriate training load) strategies are recognised as the most important factors to effectively and consistently implement year round to maintain an appropriate stress-recovery equilibrium (Huyghe et al., 2020, Kellmann et al., 2018). In addition to the appropriate use of the primary recovery measures, the use of hydrotherapy (i.e., cold water immersion, contrast water immersion or warm water immersion), massage and compression garments may

provide a small benefits to reduce perceptual fatigue, and possibly some markers of neuromuscular and/or biochemical fatigue (Huyghe et al., 2020, Calleja-González et al., 2016). Nonetheless, while the short term benefits of some secondary recovery strategies have been identified (Kellmann et al., 2018), athletes and practitioners should consider that the performance and adaptation effects associated with their long-term implementation are largely under researched (Ihsan et al., 2021, Pooley et al., 2020, Argus et al., 2013, Dupuy et al., 2018).

Perceptions and Uses of Recovery Strategies

The prevalence of use and perceived effectiveness of a variety of recovery strategies within different populations of athletes has previously been investigated (Venter et al., 2010, Venter, 2014, Nédélec et al., 2013, Crowther et al., 2017). Overall, athletes perceive sleep, nutritional practices and an active cool down as highly effective strategies to promote post-exercise recovery (Shell et al., 2020, Murray et al., 2017a, Murray et al., 2018, Venter, 2014). The perceptions and uses of recovery modalities are reported to be influenced by sex, playing standard and sport (Crowther et al., 2017, Venter et al., 2010, Venter, 2014). Athletes and practitioners regularly use/prescribe a range of strategies which include massage, stretching, post-exercise cool down, cold water immersion napping, and perceive these as effective in accelerating recovery beyond passive outcomes (Tavares et al., 2017b, Nédélec et al., 2013, Shell et al., 2020, Venter, 2014). Overall, research surveying coaches and athletes uses and perceived effectiveness of different recovery modalities (Table 2. 2) have generally demonstrated a discord between reported effectiveness in the literature and use/perceived importance (Nédélec et al., 2013, Kinugasa and Kilding, 2009, Tavares et al., 2017b, Barnett, 2006).

Table 2. 2. Summary of key research examining recovery strategy use and perceptions.

Author (s)	Validation and/or Reliability	Survey / Study Characteristics	Population	Sample (n)
Hing et al., (2010)	Not mentioned.	Questionnaire developed to survey elite NZ sports teams on their use of contrast therapy.	Elite NZ Sports teams (basketball, soccer, volleyball etc. 13 total sports.	39
Venter et al., (2010)	Pilot study with team sport athletes.	Recovery modalities currently used by elite South African sports persons. Focused on types and frequency of recovery strategies used by players from four different sport codes.	Hockey, netball, rugby and soccer.	890
Nedelec et al., (2013)	No mention in paper.	Recovery strategies used by professional French soccer teams.	Professional soccer teams.	32
Venter, (2012)	Pilot study with team sport athletes.	Examining how elite team athletes perceive the importance of various recovery modalities. Differences between men and women, players from various team sports etc.	hockey, netball, rugby and soccer (n = 890) -different analysis to 2010 study.	890
Taveres et al., (2017)	No mentioned pilot. Simple questionnaire format.	Questionnaire designed to determine the usage and the perception of 15 different recovery modalities. A 5-point Likert scale was used to examine the perceived importance of recovery and effectiveness of each recovery modality	Fifty-eight rugby union athletes -amateur (n = 26) and elite (n = 32).	58
Van Dyke and Lambert., (2009)	Sample of health professionals completed the questionnaire.	Determine strategies used to accelerate recovery of elite rugby players after training and matches, as used by medical support staff of rugby teams in South Africa.	Rugby coaching and training practitioners.	58
Duyn and Evers., (2019)	Colleagues access and readability. Reviewed by experts of content validity.	To assess collegiate women's soccer and volleyball athletes' use of recovery strategies and perceptions of the effectiveness.	Volleyball (n = 39) and soccer total.	90
Kraft et al., (2020)	Not a survey but comparisons of players recovery.	Compared coach and athlete perceptions of effort and recovery and evaluated the efficacy of perceptually based training load monitoring.	Volleyball, soccer, basketball and coaches.	60
Simjanovic (2009)	No mention of validity or reliability processes.	Semi-structured interviewing of high-performance coaches from 7 different sports. Practicality and accessibility deemed most important factors.	High-performance coaches from different sports.	14

Employing methods such as these to profile players and practitioners' perceptions and opinions of recovery modalities could deliver valuable insight into their possible understanding and beliefs, and help make an inference into possible compliance rates surrounding various recovery practices, which are likely to impact psychophysiological responses from possible prior experience or via placebo or nocebo effects (Hurst et al., 2020, Higgins et al., 2011, Juliff et al., 2014). Similarly, profiling the use of recovery strategies in Gaelic games is also necessary to establish the practices currently being implemented and if these align with evidence-based recommendations. Importantly, Gaelic games amateur status may also limit players access to training facilities, strength and conditioning coaches, nutritional expertise, athletic rehabilitation staff and recovery modalities which are often more readily available in professional organisations (Renard et al., 2020, Ó Catháin et al., 2020, Renard et al., 2022, Murphy and O'Reilly, 2020). Finally, it would also be pertinent to establish possible differences between playing standard, biological sex and sport as has been demonstrated in other team sports (Venter, 2014, Tavares et al., 2017a).

Section Link

The previous chapter (literature review) examined the aetiology of neuromuscular fatigue and muscle damage, bioenergetics, in-game workloads and their interplay with physiological attributes. As identified in this body of work, there is much uncertainty surrounding Gaelic games players psychophysiological responses to competition and the modulating factors that govern these responses. In particular, an examination of the influence of physical conditioning status responses, and players possible selection and implementation of recovery strategies following exercise would provide valuable insight for practitioners.

Indeed, understanding these responses and interactions in Gaelic games players specifically is incumbent for the development of informed recommendations that take into account unique sporting demands and amateur context. As such, the ensuing studies of this thesis aim to build on the body of work presented in the literature review and narrow the research gap identified for Gaelic games players. Specifically, methods to assess players psychophysiological responses to match-play, physical conditioning attributes and in-game workloads will be employed. With regard to the latter, various technological resources available to monitor players competitive internal and external loads were considered for this task. Following an assessment of the practices adopted within the literature and the applied sport science industry, it was recognised that GPS units may be a sufficient tool to deliver the necessary data. Having selected a new and widely used GPS unit for this purpose, it was identified that the device in question required analysis in relation to its reliability and validity to quantify team sport specific movements. Therefore, prior to undertaking the primary studies of this thesis, the ensuing chapter 3 aims to assess the precision and accuracy of the aforementioned GPS unit.

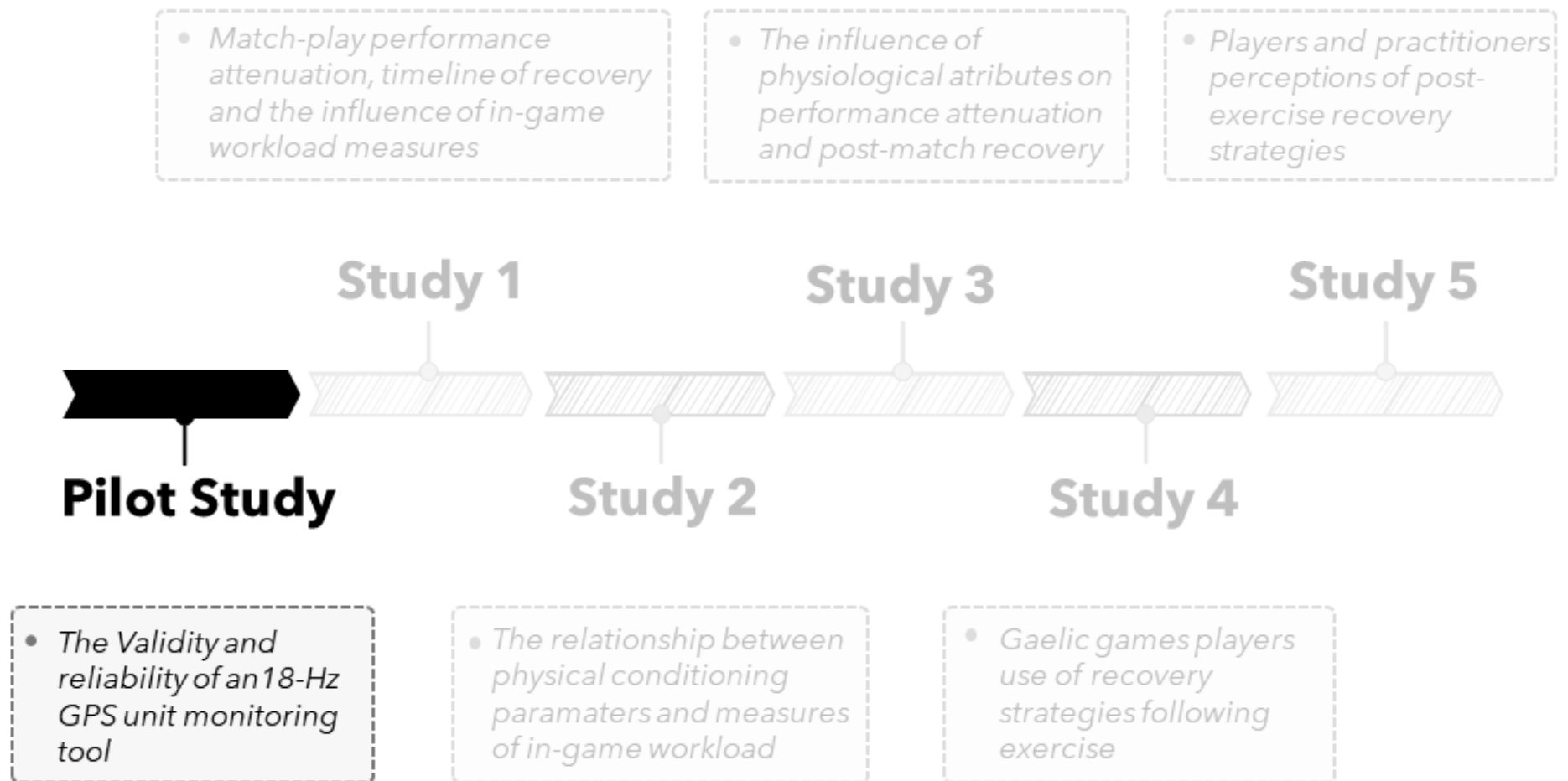


Figure 2. 12. Thesis timeline infographic highlighting the pilot study.

Chapter 3 - Pilot Study

The Validity and Reliability of an 18-Hz Global Positioning
System Unit to Measure Field Based Team Sport Specific
Movement Patterns.

Abstract

Purpose: Global positioning system (GPS) devices are often used to monitor the physical loads of team sport athletes during training and competition, and the data generated has been used to inform training periodisation, mitigate injury risk and improve subsequent performance. Given the importance of these potential applications, it is paramount that the validity and reliability of the devices used to assess and quantify these loads are investigated. Thus, the aim of this study was to determine if an 18-Hz GPS unit (Apex, STATSports, Newry, Northern Ireland) accurately and reliably quantifies velocity and distance over linear and non-linear courses at varying velocities.

Methods: A total of 438 trials were completed to assess reliability (intra-unit, inter-unit and time-of-day) and construct validity. Here, velocity trials in linear ($n = 270$), non-linear ($n = 100$), jump ($n = 60$) and distance trials ($n = 8$) were completed over 10 testing days. Linear and non-linear velocity trials were completed over 10 m and 40 m, while jump trials were completed over 10 m. Mean velocity was recorded using a GPS unit and criterion photoelectric timing gates. The distance trials were completed over 8000 m around an outdoor athletic track using 3 devices at 9 a.m. and 9 p.m. of the same day (over 4 separate days) to assess unit reliability and the influence of time of day.

Results: The units were accurate at measuring the 8000 m distance with a mean bias ranging from -0.80% to -1.10%. Time of day had no significant impact on the validity and reliability of the devices ($p > 0.05$). Velocity measurements demonstrated errors across all velocities for both linear and non-linear trials that increased from -2.5% and -4.2% at the lowest velocities to -16.7% and -14.0% at the highest velocities ($p < 0.05$).

Conclusions: Increases in velocities were paralleled with progressively larger recorded errors, wherein change of pace may be a key factor in the GPS unit's accuracy. Understanding the limitations of these devices may allow practitioners and researchers to effectively select the appropriate tool for a specified monitoring purpose and enable informed interpretations of collected data.

Introduction

The popularity of Global Positioning System (GPS) tracking devices has proliferated in the sporting world, with particularly widespread use in field-based invasion team sports (Egan et al., 2021, Aquino et al., 2020, Gabbett, 2013). This recently popularised adoption of GPS units has enabled the objective quantification of players external and internal (via proxy heart rate monitors) loads, thereby providing a large amount of data otherwise tedious to collect (Cummins et al., 2013). Consequently, this method of data collection has been widely used to detect physical loads in many team sports (Aughey and Falloon, 2010, Gabbett et al., 2012, Wisbey et al., 2010), in turn providing a monitoring tool that may indirectly infer fatigue development, inform availability to train/compete and provide a proxy measure of conditioning status/physical performance (Macutkiewicz and Sunderland, 2011, Wisbey et al., 2010, Hennessy and Jeffreys, 2018, Murray et al., 2017b). For example, appropriately utilising the measurement of specified competition/training loads (i.e., specific to the athlete's sport, playing standard and position etc.) could be invaluable for conceptualising and informing the design of tailored and periodised training programmes (Russell et al., 2021, Hennessy and Jeffreys, 2018). As highlighted by Gray and colleagues (Gray et al., 2018), a reduced homeostatic disturbance (and a concomitantly lower metabolic cost) associated with a given training/match-play stimulus is a fundamental aspect of the physiological adaptation response in team sports (Phillips et al., 1996, Billaut et al., 2012, Kelly et al., 2021). Thus, accurately monitoring these loads is consequently a central component in the optimisation of this evolving adaptive process (Hennessy and Jeffreys, 2018). Indeed, GPS collected data may (1) contribute to the inclusion/exclusion of athletes from competition and training, (2) inform practitioners as to the position-specific acute and longitudinal internal and external loads athletes are subject to during training/competition and (3) monitor individual athletes'

capacity to perform physical work (Hausler et al., 2016, Chambers et al., 2015). Therefore, it is critical that the validity and reliability of these devices be empirically examined so that practitioners may be informed of the possibility and/or magnitude of errors when making decisions derived from GPS collected data (Di Salvo et al., 2007, McLellan et al., 2011). As it is not viable to have a unifying consensus on the construct validity and reliability of GPS units as a whole, each model across commercial companies should be independently examined (Akenhead et al., 2014).

Within previous work examining the validity and reliability of a STATSport device (10-Hz Viper unit), measurements of velocity and distance over a shuttle run with a 180 degree change of direction were compared with a criterion kinematic analysis (VICON system, Yarnton, UK) (Beato et al., 2016). The results suggested that the 10-Hz Viper unit displayed errors when detecting velocity due to imprecision when determining the shuttle distance. Furthermore, the GPS underestimated velocity over a 5 m distance by 9% and over a 20 m distance by 3% (Beato et al., 2016). While the sampling rate appears to elicit a large influence on the accuracy of a GPS device, different firmware is also likely to affect the recorded data. Of note, the latest STATSports 18-Hz ‘Apex’ unit has an additionally higher gyroscope and accelerometer sampling rate when compared with the 10-Hz Viper unit, which is likely to influence the devices’ validity and reliability. These units have demonstrated small errors (≈ 1 to 2%) when compared with the criterion distances during two circuits and 20 m trials, and presented small levels of bias (2.0 to 2.4%) during peak velocity trials (Beato et al., 2018).

While these findings provide valuable insight, the assessment of higher velocities, changes of direction at higher velocities ($> 2.5 \text{ m}\cdot\text{s}^{-2}$) and other movements such as jumps (Cummins et al., 2013) would also provide beneficial sport-specific context for practitioners (Taylor et al., 2017, Harper et al., 2019). Indeed, a thorough examination of a

given technologies capacity to record a spectrum of sport-specific data accurately and precisely is vital in ensuring that practitioners and researchers are leveraging a robust, reliable and valid monitoring tool (Simperingham et al., 2016, Gray et al., 2018). Consequently, this study aimed to assess the accuracy of an 18-Hz GPS unit and establish construct validity whilst determining distance and velocity over linear and non-linear courses at different velocities, distances, changes of direction, accelerations and decelerations. Furthermore, this study also sought to assess inter-unit, intra-unit and time-of-day reliability of the unit.

Methods

Participants

Three participants took part in this study; a national level sprinter (age: 24 years; stature: 177.0 cm; body mass: 72.4 kg) and two developmental level team sport athletes (Gaelic football and soccer player; age 22 ± 1 years; stature 184.3 ± 9.5 ; body mass: 77.4 ± 3.5 kg). Physiological characteristics of the national level sprinter (body fat: 7.8%; CMJ: 52.7 cm; maximum aerobic capacity [$\dot{V}O_{2\max}$]: 61.3 ml/min/kg) and two developmental level team sport athletes (body fat: $11.6 \pm 2.9\%$; Countermovement jump [CMJ] height: 36.2 ± 1.6 cm; $\dot{V}O_{2\max}$: 48.6 ± 3.5 ml/min/kg) were assessed using methods described previously (Berryman et al., 2010). A national level sprinter was specifically selected in addition to the team sport athletes in order to attain a velocity and rate of acceleration at the higher end or possibly beyond the locomotion values that may be expected during team sport activity (Townshend et al., 2008), thereby enabling a more comprehensive validity and reliability evaluation. Written informed consent was obtained by each participant, and the study was approved by the Technological University of the Shannon research ethical research committee (code 20180501).

Experimental Approach to the Problem

Three participants took part in 438 trials to establish the reliability (intra-unit, inter-unit and time-of-day) and construct validity of a commercially available STATSports Apex GPS unit. The tests consisted of 270 linear, 100 non-linear and 60 jump velocity trials and 8 distance trials. The velocity and distance trials were completed on the courses outlined in Figure 3. 1. These methods were completed in accordance with prior work (Hoppe et al., 2018, Petersen et al., 2009a) and were all specifically selected to reflect different in-game scenarios (Taylor et al., 2017, Vigne et al., 2010, Waldron et al., 2011).

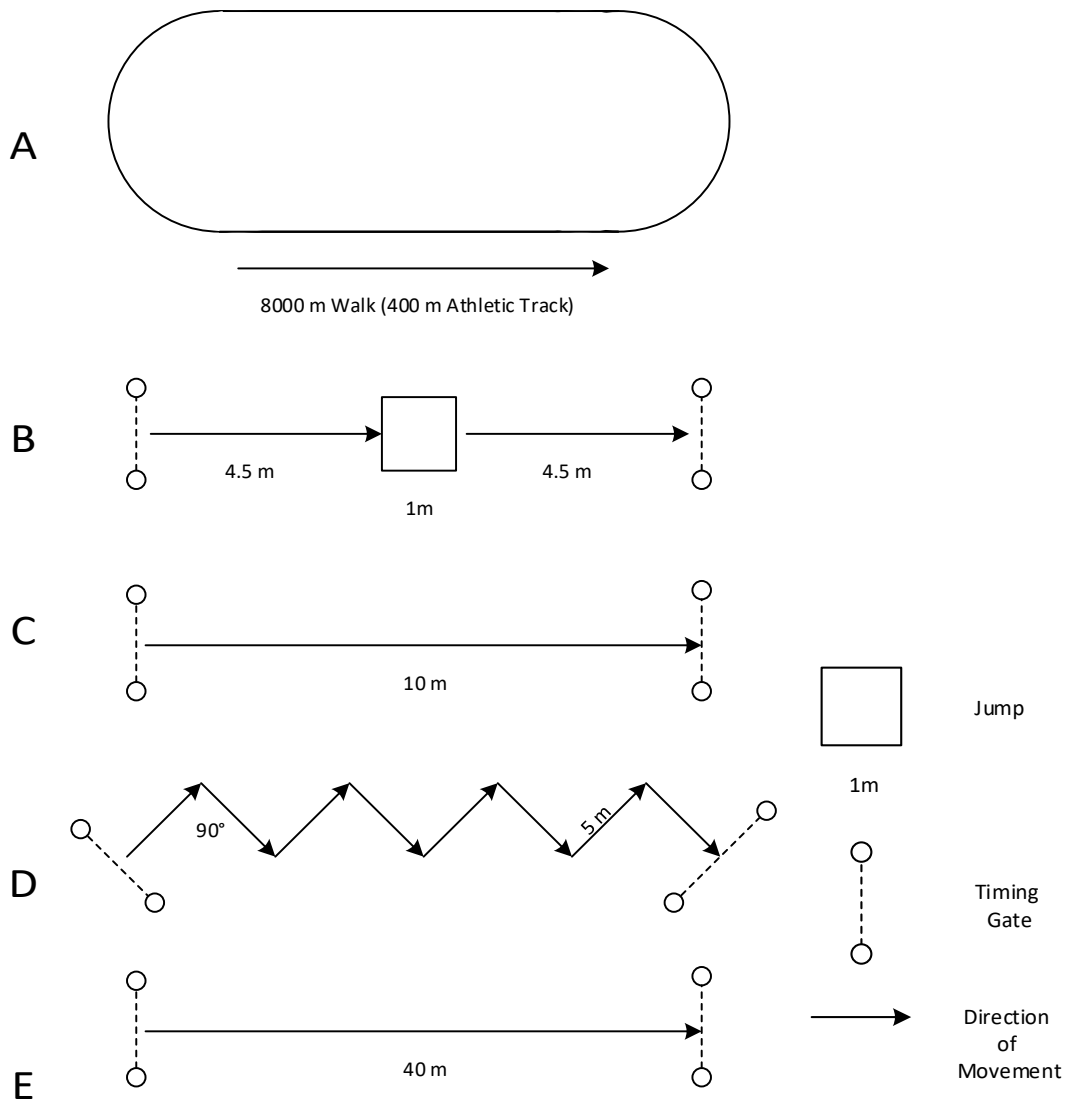


Figure 3. 1. Diagram of (A) 8000 m distance course, (B) 10 m jump course, (C) 10 m course, (D) 40 m COD course and (E) 40 m straight course.

Experimental Procedures

All four experiments were undertaken on an internationally certified outdoor athletic track free from any obstructive vegetation or tall buildings that could potentially disrupt satellite signal. There was either light cloud cover or clear skies during all testing days and all tests were completed during dry conditions. The courses were marked out with tape and measured using a calibrated measuring tape (100 m open reel tape, Silverline, Yeovil, UK) and a goniometer (Prestige Medical, Blackburn, UK). Timing gates (Brower Timing Systems, Utah, USA) were set up at the start and finish, with cones 5 m past the last gates as a target for participants to avoid early deceleration. A STATSports vest of the appropriate size was worn by participants for all velocity protocols. Here, the GPS unit was placed in a pouch located on the upper back between the scapulae. Participants adopted a two-point stance at the start of all trials, with tape marking exact foot positions, wherein the front foot was 50 cm from the start of the course. The GPS units were turned on outside 15 minutes before any trials were undertaken to allow sufficient time to achieve GPS lock (Malone et al., 2017a). During this time, a self-paced 15 minute warm up was undertaken by the participants on all testing days. This involved approximately 10 minutes of low intensity jogging and 5 minutes dynamic stretching of the lower-body.

All velocity trials were undertaken between 11 a.m. and 1 p.m. of each testing day. The 210 linear velocity trials were completed during testing days 1 to 4 and the 100 non-linear trials were undertaken during testing days 5 and 6. The 8 distance trials were completed at 9 a.m. and 9 p.m. of days 7 to 9 and the 60 jump trials were completed on day 10. Participant 1 and 2 (developmental level team sport athletes) completed all 100 non-linear trials and 200 trials of the linear course. Participant 2 completed the 60 linear trials, 60 jump trials and the eight distance trials, while participant 3 (national level sprinter)

completed 10 linear velocity trials. The same GPS unit was used for all velocity trials to eliminate potential inter-unit variability in the validity assessments. To examine inter-unit variability, 3 units of the same make and model (Apex, STATSports, Northern Ireland) were used to measure distance at 2 distinct times (9 a.m. and 9 p.m.) of the same day on 4 separate days.

Distance validation, inter-unit and intra-unit reliability

Three 18-Hz devices of same make and model (Apex unit, STATSports, Newry, Northern Ireland) were attached to the handle of a trundle wheel (MW40M Counter Measuring Wheel, Stanley, Sheffield, UK) and walked around the first lane of the track for 20 laps (totalling 8000 m). This distance was selected as it represents an approximate total distance covered by players during competitive invasive team sport match-play such as Gaelic football (Malone et al., 2016b), soccer (Barros et al., 2007) and rugby union (Cunniffe et al., 2009). The devices were attached 10 cm apart from each other, as a minimum distance of 7 cm is needed between devices to eliminate electronic radiation noise interference (Hoppe et al., 2018, Malone et al., 2017a). Throughout the test, the wheel never lost contact with the ground or moved backwards, as the distance travelled would have been subsequently altered on the trundle wheel measure if this occurred. Additionally, any leaning movements of the handle were avoided during the trials, as these had the potential to add logged distance because the devices were attached along the handle of the trundle wheel (Tessaro, 2017).

Linear velocity

The participant started from a stationary position and then proceeded through the 40 m course at the required average velocity range (Jennings et al., 2010). A trial order of jogging ($3.2 - 4.5 \text{ m}\cdot\text{s}^{-1}$), running ($4.5 - 6 \text{ m}\cdot\text{s}^{-1}$), walking ($1.5 - 1.8 \text{ m}\cdot\text{s}^{-1}$) and high-speed running (HSR) ($6.2 - 7 \text{ m}\cdot\text{s}^{-1}$) were undertaken. Participant 3 (national level sprinter) completed all 10 trials only at the highest velocity zone (sprinting; $7.1 - 8.2 \text{ m}\cdot\text{s}^{-1}$). After each trial, the participant decelerated, walked slowly for a self-selected recovery period and returned to the start position of the course. Here, the participant waited without movement for exactly 30 seconds before beginning the next trial, as measured by a stopwatch (Traceable 1045, Control Company, USA). The 30 seconds of no movement between each trial, and the consistent trial order of jogging, running, walking and sprinting was used throughout all testing to minimise fatigue and make distinguishing between trials easier in the forthcoming data analysis. Verbal encouragement was given to all participants across the trials. Velocity zones were based on the participants self-selected paces of walking ($1.5 - 1.8 \text{ m}\cdot\text{s}^{-1}$), jogging ($3.2 - 4.5 \text{ m}\cdot\text{s}^{-1}$), running ($4.5 - 6 \text{ m}\cdot\text{s}^{-1}$), HSR ($6.2 - 7 \text{ m}\cdot\text{s}^{-1}$) and sprinting ($7.1 - 8.2 \text{ m}\cdot\text{s}^{-1}$).

Non-Linear velocity

The change of direction course was 40 m in total distance and is illustrated in Figure 3. 1 (A). The same starting positions and between trial procedures as the linear course were employed in this course. The course had 7 changes of direction of 90° , with 5 m straights between each turn, using methods previously described by Jennings and colleagues (Jennings et al., 2010). At each turn, poles were erected in the midpoint of each cone to ensure each trial followed the same course, and the participant could not lean over the cones whilst turning. The same start position, trial order and stationary time was used as the linear velocity protocols. Velocity zones were based on the participants self-selected

paces of low intensity ($1 - 1.5 \text{ m}\cdot\text{s}^{-1}$), medium intensity ($1.8 - 2.2 \text{ m}\cdot\text{s}^{-1}$) and high intensity ($2.4 - 3.1 \text{ m}\cdot\text{s}^{-1}$).

Linear velocity with a jump

The jump course can be seen in Figure 3. 1 (B). This procedure was completed using the same start position and trial sequence as the linear and non-linear courses. During the jump trials, a 1 m horizontal jump was set at the 4.5 m to 5.5 m midpoint for the participant to jump over whilst simultaneously achieving maximal vertical height. This jump zone was marked out with tape on the track. For each trial the participant went through the course at a self-selected jogging pace ($2.3 - 3 \text{ m}\cdot\text{s}^{-1}$) and jumped across the 1 m gap. The participant was instructed to jump vertically as high as possible whilst clearing the 1 m gap. To serve as a control, the participant completed the same number of 10 m trials within the same velocity range without performing the jump.

Statistical Analysis

Upon completion of each respective experiment, the data was uploaded to the STATSports Apex analysis platform before being transferred to Microsoft excel. Data from the GPS was truncated using the timing gate result for each trial, with the average velocity of the GPS and timing gate results then calculated and compared. With regards to the distance measurement, the total distance recorded by the GPS was compared with the trundle wheel reading. Descriptive statistics were calculated for all variables and then reported as the mean \pm SD. Bland-Altman plots were employed to determine the bias and 95% limits of agreement (LOA) of all velocity and distance trials. Using the Statistical Package for Social Sciences (Statistics for Windows, SPSS, Version 22.0, Chicago, IL, USA) paired-samples t-tests were used to compare differences between the distance measurements recorded at 9 a.m. and 9 p.m. of the same day. Independent samples t-tests were used to compare timing gate measurements to GPS recorded velocity measurements.

Hopkins validity and reliability spreadsheets (Hopkins, 2017) were employed to determine the standard error of estimates (SEE), slope, intercept, 95% confidence intervals (CI) and intraclass correlations. These methods were employed in accordance with previous work also assessing the validity and reliability of a GPS unit (Akenhead et al., 2014). For all statistical tests, an alpha p level of $p < 0.05$ was set as the level of significance.

Results

Distance Validation and Between-Unit Variation

The bias \pm 95% LOA between the trundle wheel and GPS recorded distance results can be seen in Table 3. 1, while the individual points are illustrated in a Bland Altman plot (Figure 3. 2). Percentage mean bias \pm 95% LOA were recorded for device 1 ($-0.80 \pm 0.40\%$), device 2 ($-1.10 \pm 0.60\%$) and device 3 ($-0.90 \pm 0.50\%$).

Table 3. 1. GPS measured distance vs. criterion distance.

<i>Intra-unit reliability 8000 m walk</i>	Percentage Mean Bias (95% LOA)	Samples (<i>n</i>)
Device 1	-0.8 (-1.3 to -0.4)	8
Device 2	-1.1 (-1.6 to -0.6)	8
Device 3	-0.9 (-1.4 to -0.4)	8
<i>Time of day influence 8000 m walk</i>		
9 a.m.	-1.0 (-1.4 to -0.6)	12
9 p.m.	-0.9 (-1.3 to -0.6)	12

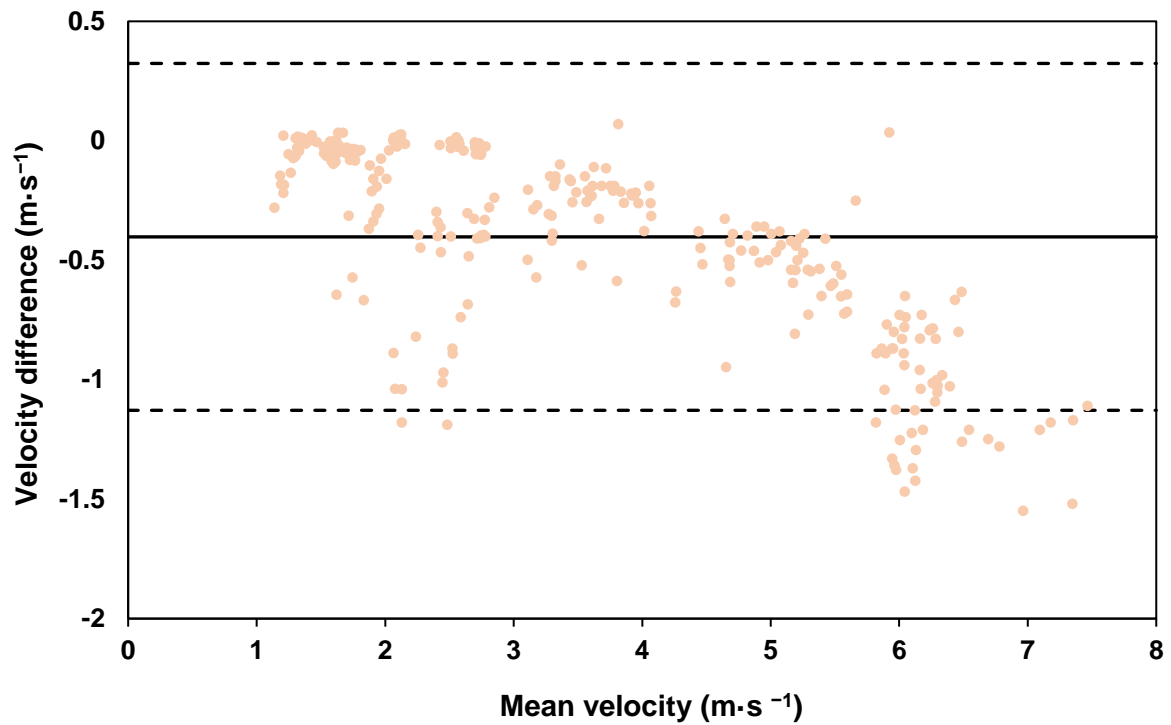


Figure 3. 2. Bland-Altman plot for mean velocity recorded at each 40 m velocity Trial. Solid black line indicates Bias and broken lines indicate the Upper and Lower Limits of agreement.

The time-of-day differences, between 9 a.m. and 9 p.m. (Figure 3. 3), were non-significant ($t = -0.483$, $p = 0.639$) and the mean bias \pm 95% LOA were similarly accurate at 9 a.m. ($-1.00 \pm 0.40\%$) and 9 p.m. ($-0.90 \pm 0.50\%$).

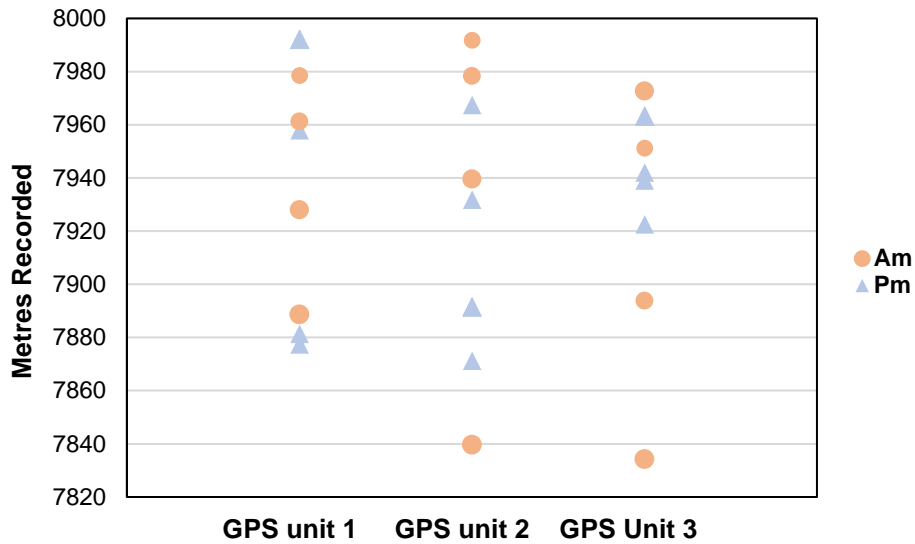


Figure 3. 3. Data assessing the validity of an 8000 m distance. The walk trials were completed at 9 a.m. and 9 p.m. of the same day for 4-days wherein 3 GPS units recorded data at each timepoint.

Linear, Non-linear and Linear velocity with a Jump

The validity and reliability results are shown in Table 3. 2. All velocity measures over the linear course were significantly different ($t = 6.696$ to 27.342 ; $p < 0.05$) to the criterion timing gate measures (Figure 3. 4). For the non-linear protocol, low intensity movement was not significantly different ($t = 1.900$; $p = 0.06$) while medium and high intensity movements were significantly different ($t = 4.306$ to 7.322 ; $p < 0.05$) to the criterion timing gate measures (Figure 3. 5).

Table 3. 2. GPS measured mean velocity vs. criterion timing gates

Movement	Slope \pm 95% CI	Intercept \pm 95% CI	SEE (95% CI)	Mean Bias \pm 95% LOA	% Mean Bias \pm LOA	Intraclass correlation (95% CI)	Effect Size	Trials (<i>n</i>)
<i>Linear</i>								
Walking	0.82 \pm 0.18	0.35 \pm 0.29	0.06 (0.05 - 0.09)	-0.04 \pm 0.05	-2.48 \pm 2.95	0.89 (0.80 - 0.94)	0.57	50
Jogging	0.83 \pm 0.14	0.84 \pm 0.48	0.15 (0.12 - 0.18)	-0.25 \pm 0.24	-6.64 \pm 6.43	0.93 (0.88 - 0.96)	0.71	50
10 m Jog	0.85 \pm 0.01	0.95 \pm 0.02	0.09 (0.07 - 0.11)	-0.46 \pm 0.03	-12.43 \pm 0.10	0.97 (0.95 - 0.98)	1.64	60
10 m Jog with jump	0.28 \pm 0.29	2.05 \pm 0.63	0.12 (0.10 - 0.15)	-0.36 \pm 0.29	-13.23 \pm 10.80	0.42 (0.03 - 0.66)	2.96	60
Running	0.91 \pm 0.11	0.95 \pm 0.52	0.15 (0.12 - 0.19)	-0.51 \pm 0.30	-9.51 \pm 5.62	0.96 (0.93 - 0.98)	1.28	50
HSR	0.15 \pm 0.15	5.76 \pm 0.85	0.17 (0.14 - 0.22)	-1.04 \pm 0.63	-15.77 \pm 9.45	0.38 (-0.09 - 0.65)	3.99	50
Sprinting	0.90 \pm 0.32	1.89 \pm 2.03	0.15 (0.10 - 0.29)	-1.27 \pm 0.29	-16.69 \pm 3.74	0.96 (0.83 - 0.99)	3.94	10
<i>Non-Linear</i>								
Low Intensity	0.40 \pm 0.13	0.83 \pm 0.17	0.04 (0.03 - 0.06)	-0.06 \pm 0.17	-4.17 \pm 12.83	0.78 (0.49 - 0.90)	0.57	25
Medium Intensity	0.14 \pm 0.11	1.78 \pm 0.21	0.06 (0.05 - 0.09)	-0.18 \pm 0.41	-8.82 \pm 20.09	0.42 (- 0.32 - 0.74)	1.09	25
High Intensity	0.40 \pm 0.13	0.83 \pm 0.17	0.18 (0.15 - 0.23)	-0.38 \pm 0.72	-14.0 \pm 26.27	0.16 (- 0.48 - 0.53)	1.44	50

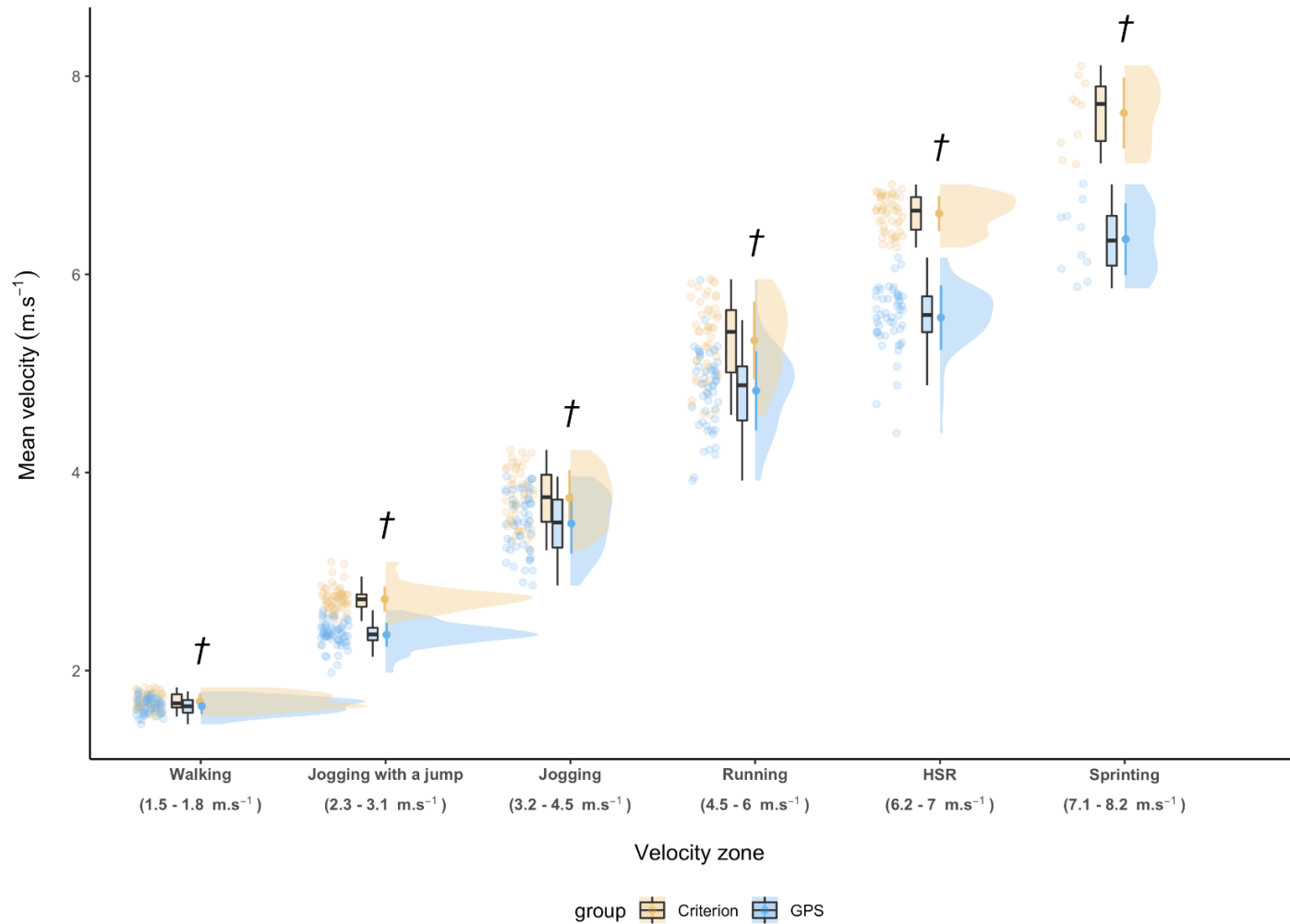


Figure 3. 4. Raincloud plot of the linear timing gate and GPS recorded velocity. Points represent raw data; box plots represent the median and interquartile range (upper quartile=75th percentile; lower quartile=25th percentile). The whisker ends represent the maximum and minimum data values. The cloud represents probability density and point and error bars at their base represent the mean \pm SD. † indicates significant difference.

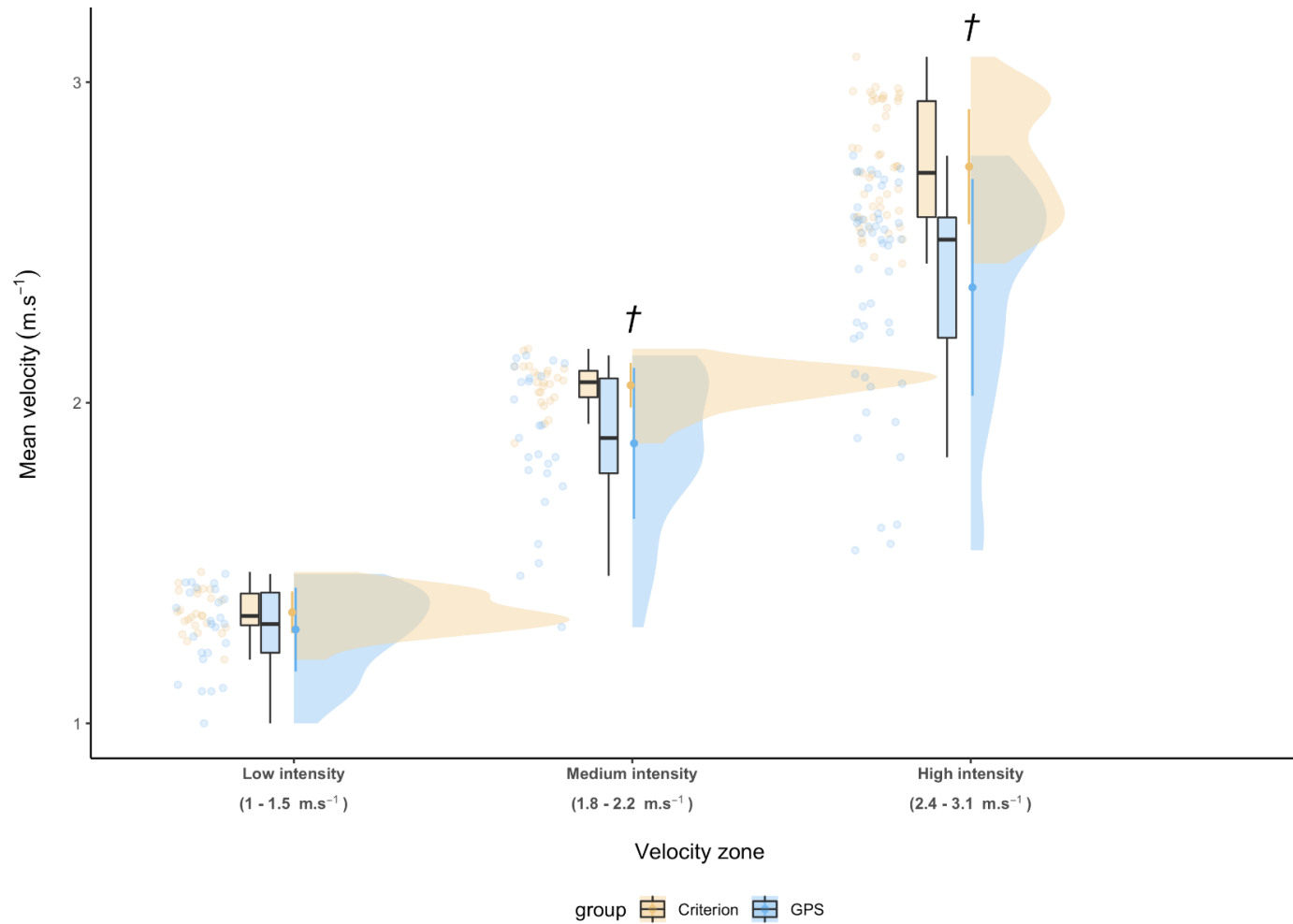


Figure 3. 5. Raincloud plot of the non-linear timing gate and GPS recorded velocity. Points represent raw data; box plots represent the median and interquartile range (upper quartile=75th percentile; lower quartile=25th percentile). Whisker ends represent the maximum and minimum data values. The cloud represents probability density and point and error bars at their base represent the mean \pm SD. † indicates significant difference

Discussion

This pilot study aimed to establish the validity and reliability of an 18-Hz GPS unit (Apex, STATSports, Newry, Northern Ireland). The current results suggest the STATSports Apex units are highly valid at measuring total distance (bias: -0.8% to -1.1%) also presenting high inter-unit, intra-unit and time-of-day reliability (Figure 3. 3). However, the degree of GPS validity was lower when evaluating velocity, whereby errors were demonstrated to increase in tandem with an increase in velocity. Specifically, bias was low during linear walking and non-linear low intensity velocities (-2.5% and -4.2% respectively) and increased when assessing the highest velocity linear and non-linear movements (-16.7% and -14.0% respectively; Figure 3. 4 and Figure 3. 5).

The present findings are in line with prior research demonstrating that GPS recorded errors are lowest whilst walking ($< 3 \text{ m}\cdot\text{s}^{-1}$; 0.7%) and highest whilst running ($> 6 \text{ m}\cdot\text{s}^{-1}$; 5.6%) (Portas et al., 2007). The STATSports Apex units assessed in the current study recorded team sport specific movements with similar or greater accuracy (SEE: 5.0% to 17.5%) than earlier devices and/or units of a lower sampling frequency (SEE: 9.0% to 30.9%) (Jennings et al., 2010). Importantly, the current study identified that the 18-Hz units analysed were more accurate at measuring high velocities over short to moderate distances (-16.3% bias at 7.1 to $8.2 \text{ m}\cdot\text{s}^{-1}$) when compared with previously investigated units (e.g., SPI-Pro 5-Hz units - 17.8% bias at $>5.5 \text{ m}\cdot\text{s}^{-1}$) (Rampinini et al., 2015). This finding complements prior work, whereby another 18-Hz device was reported to have increased validity and reliability when compared with a 10-Hz unit (Hoppe et al., 2018). However, the current analysis highlights significant differences between the GPS recorded mean velocities and the criterion timing gate values. More specifically, all comparisons were significantly different except for the low intensity change of direction trials (Figure 3. 4

and Figure 3.5). which is similar to prior assessments of various GPS units (MinimaxX v2 5-Hz and MinimaxX v4 10-Hz) and contrasts with others (MinimaxX S4 10-Hz and SPI-Pro X 15-Hz, GP Sports, Queensland, Australia). (Vickery et al., 2014, Johnston et al., 2014) Ultimately, past (Hoppe et al., 2018) and current results imply that caution should be taken when making specific decisions based off GPS recorded data during movements of a high intensity ($> 6 \text{ m}\cdot\text{s}^{-1}$) and/or non-linear movements.

When compared with another 18-Hz device (EXELIO srl, version M03, GPEXE PRO, Udine, Italy), the current device presented similar accuracy at a walking pace (-2.5 vs -2.2% Bias) and lower accuracy at a sprinting pace (-16.7% vs -6.7% bias) (Hoppe et al., 2018). The disparity in results recorded at high velocities may be related to the differences in research methods, wherein the prior work utilised a continuous circuit with timing gate splits and the current study began trials from a standing start (Hoppe et al., 2018). Here, it is possible the acceleration from a standing start during each trial in the present study may be a factor in the higher errors reported when comparing the results to previous work where continuous circuits were employed. Indeed, earlier research reported that acceleration movements recorded on a 10-Hz unit when compared with a laser gun demonstrated to have -2.9% Bias, while constant velocity only displayed a 0.6% Bias (Varley et al., 2012). An additional study identified that the largest errors are recorded at the start of a split (coefficient of variation [CV] 13.1%) and smallest at the end of a split (CV of 0.9%) implying the change of pace at the start of the trial resulted in the largest error. Overall, the current results and others (Barr et al., 2017, Varley et al., 2012) collectively suggest changes of pace have a much more detrimental impact on GPS accuracy when compared with constant velocity.

Of note, work from Beato and colleagues (Beato et al., 2018) using a continuous circuit to examine the same Apex device as the present study, exhibited substantially lower

errors than those reported in the current analysis (ES = 0.03 to 0.42 vs. ES = 0.57 to 3.99). This difference likely stems from the more significant acceleration values that exist in the current studies methods (i.e., accelerations from $0 \text{ m}\cdot\text{s}^{-1}$ to well over $1.5 - 8.2 \text{ m}\cdot\text{s}^{-1}$ in the velocity trials). Moreover, the jogging trials ($\approx 2.8 \text{ m}\cdot\text{s}^{-1}$) over the shorter 10 m distance presented almost double the errors when compared with a similar or higher velocity ($\approx 3.8 \text{ m}\cdot\text{s}^{-1}$) recorded over the longer 40 m trials (-6.6 vs. -12.4% bias) in the current analysis. These results further imply that the initial acceleration phase of the movements, which is likely to be a much larger component of the shorter 10 m trials, may decrease the accuracy of the unit's measurement. Overall, our results are in agreement with prior findings (Scott et al., 2016, Rawstorn et al., 2014) and reiterate that intense changes of pace are a major contributor to GPS recorded inaccuracies, and that the devices are generally a lot more accurate when monitoring velocities at a relatively consistent pace (Scott et al., 2016, Beato et al., 2018, Rawstorn et al., 2014). Importantly, as maximal and/or constant velocity is seldom achieved during team sport match-play (especially during pivotal moments of a game) (Vigne et al., 2010, Lindsay et al., 2015a) it could be argued that a devices accuracy at recording acceleration over short distance ($>20 \text{ m}$) is more important in quantifying in-game demands (Simperingham et al., 2016) and GPS units may display limitations in this context (Varley et al., 2012, Bourdon et al., 2017).

Jumping is also a common movement in many field-based team sports (Taylor et al., 2017) and the current study identified only a small increase in bias associated with a jump movement when compared with a linear movement without a jump controlled for velocity (-13.2% vs. -12.4%). Notably, greater errors over a 10 m jog with a jump were observed when compared with previous data applying the same methodology to a different 18-Hz device ($-0.2 \pm 0.6\%$). Similar to the other velocity protocols in the current study, it is important to note that each jump trial was initiated from a static position, rather than

assessed during a section of a continuous circuit as was completed by Hoppe and colleagues (Hoppe et al., 2018), and therefore making a direct and practically meaningful comparison is difficult on account of the aforementioned acceleration differences (Varley et al., 2012).

There are some limitations which need to be considered when interpreting the results of this study. Firstly, while the photoelectric cells used as the criterion measure have been reported as valid (SEM: 0.1 seconds) and reliable (coefficient of variation: 0.1%) (Haugen et al., 2012), these small errors should nonetheless be considered when extrapolating results. Secondly, the present study investigated average velocity, which incorporated a mixture of accelerations, decelerations and a range of velocities during each trial. Thus, methods utilising a radar gun to examine velocity (Beato et al., 2018), and the specific recording of high intensity accelerations, decelerations, and high velocity changes of direction should be adopted in future. This type of analysis could possibly highlight measurement discrepancies that may exist between the acceleration phase (from a static start or following a change of direction), continuous velocity phases and the deceleration phase. Additionally, while poles were erected at each turn to make sure the participant didn't travel over the cones, it should be noted that the path covered could have deviated from the intended course, as the participant may have had to decelerate after making each turn (and thus extend the distance covered) before moving on to the next turn (Figure 3. 1 [D]). It is important GPS units are assessed in their capacity to sensitively detect high intensity movements specific to the sport they are being used in, as these movements tend to be pivotal movements occurring during team sport match-play (Rhodes et al., 2021, Harper et al., 2019, Granero-Gil et al., 2020). The authors recommend future research to consider investigating the influence of physical contact, sharp decelerations (Varley et al., 2012) or agility movements (e.g., shuffle steps, crossover cutting, spins and side steps) that closely replicate actions within team sport activities (Dos' Santos et al., 2022). Finally, in

order to comprehensively determine construct validity, a devices capacity to record a full spectrum of velocities, sport specific movements and the intense increases/decreases in pace is necessary (Akenhead et al., 2014, Scott et al., 2016).

Conclusion

This study provides an appraisal of the validity and reliability of the now widely used STATSports Apex GPS unit. In summation, the increased 18-Hz sampling rate, firmware updates and other possible differences have brought about improved validity in the STATSports Apex unit when compared with other previous commercially available devices evaluated on similar courses (Jennings et al., 2010). While the devices appear reliable and valid at low velocities, errors become apparent when higher velocities and/or changes of direction are monitored. Indeed, intense changes of pace appear to present a key factor in the reduction of velocity measurement accuracy. While the STATSports Apex units utilised in the present study present a high level of reliability (inter-unit, intra-unit and time-of-day), it is nonetheless recommended that athletes use the same device in competition and training to eliminate any possible inter-unit variances in recorded data. Overall, our results suggest practitioners should show restraint when making specific decisions based on data recorded at velocities $> 6 \text{ m}\cdot\text{s}^{-1}$ or during high intensity changes of pace and direction. Despite the validity issues identified at high velocities, the devices exhibit greater potential to detect an array of team sport sport-specific movements and subsequently quantify the multifactorial physical loads players perform during training sessions and matches. The units also display high levels of reliability and validity when measuring distance, suggesting their applicability and utility to assess these markers consistently. Indeed, the use of these devices may be appropriate in providing practitioners and researchers with another tool in the toolbox with which to infer sport-specific work capacity, performance attenuation, positional-specific demands and subsequently periodise training loads. In conclusion, knowledge of the devices measurement performance and limitations as highlighted in the current work may inform and empower practitioners and researchers who seek to select the most appropriate tool(s) for a given monitoring purpose.

Section Link

The previous chapter demonstrated the level of validity and reliability of a widely used GPS monitoring tool (STATSports Apex 18-Hz unit). Indeed, practitioners and researchers may use this information to understand the devices applicability and limitations, and consequently make informed interpretations and decisions based off its data.

As highlighted within the literature review of chapter 2, there is an apparent need to profile the performance attenuation and recovery kinetics of Gaelic games players to enable practitioners to be informed as to players within- and post-match responses and the subsequent timeline of recovery. Among many other factors, this information is critical for training programme design, appropriate load management and injury prevention strategies (Kelly and Coutts, 2007, Thorpe et al., 2015, Brownstein et al., 2017). It is important to consider that performance attenuation and recovery status are constructs that cannot be directly measured and may only be estimated and approximated through the assessment of various surrogate indicators. Nonetheless, profiling players responses to competition and the subsequent recovery kinetics is a pertinent and necessary endeavour to help inform practitioners who seek to plan training in the day(s) following match play. Understanding what specific demands result in the largest post-match decrements may allow practitioners to prepare players for upcoming performance accordingly. Similar team sports commonly implement biochemical (Russell et al., 2015, McLellan et al., 2010, Hunkin et al., 2014), neuromuscular (Oliver et al., 2015a, Hagstrom and Shorter, 2018, Johnston et al., 2015b) and perceptual (Oliver et al., 2015a, Hogarth et al., 2015, Twist et al., 2012) markers to establish players responses to training and competition and the subsequent time course of recovery to pre-exercise levels. Therefore, the purpose of the following chapter was to investigate these responses in Gaelic football using a multifactorial monitoring approach.

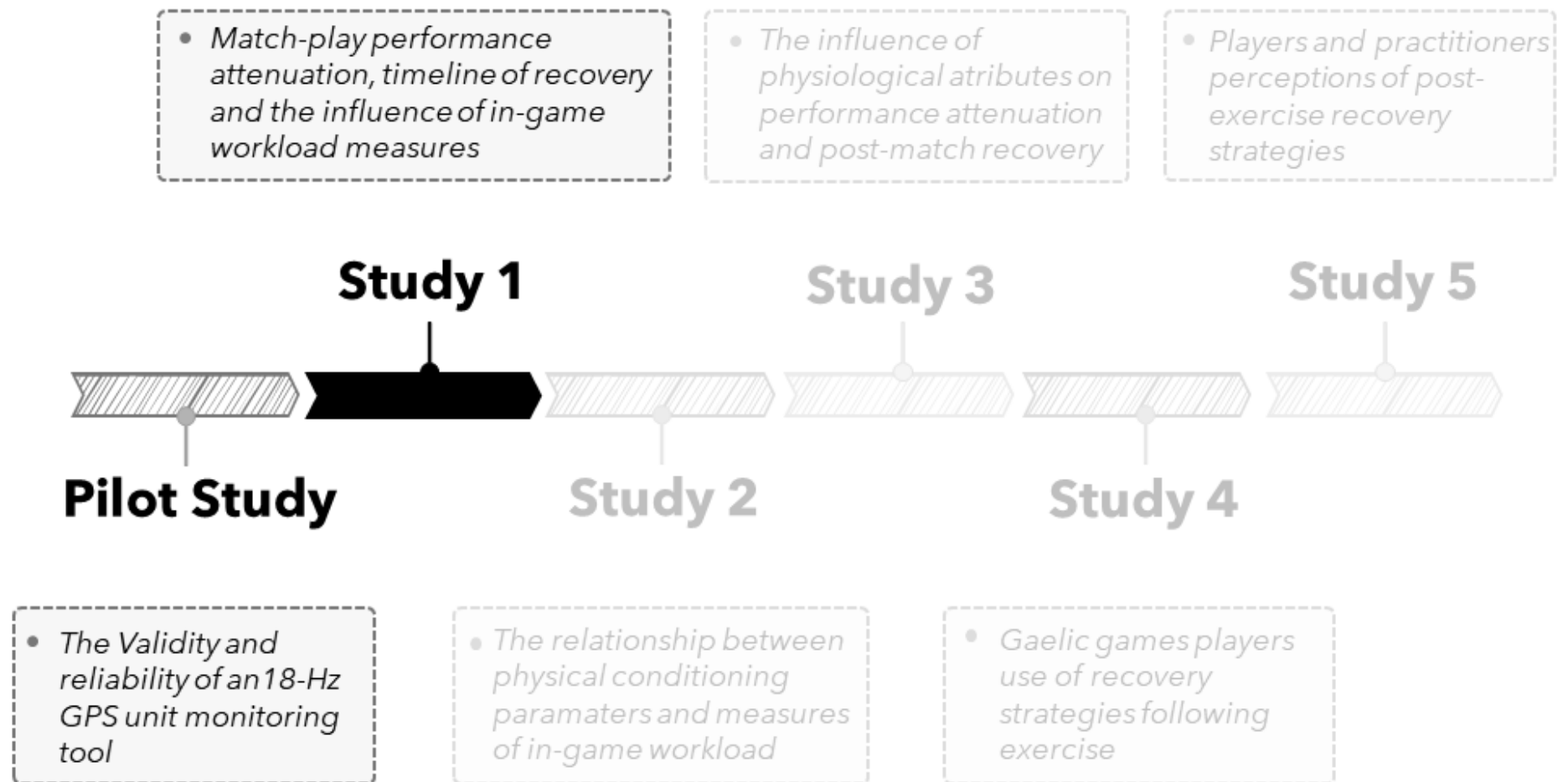


Figure 3. 6. Thesis timeline infographic highlighting study 1.

Chapter 4 – Study 1

Gaelic Football Match-Play: Performance Attenuation and Timeline of Recovery

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Abstract - Study 1

Purpose: This study investigated acute changes in markers of fatigue and performance attenuation during and following a competitive senior club-level Gaelic football match.

Methods: Forty-one players were tested immediately pre-match, at half-time, full-time, 24 h post-match and 48 h post-match. Creatine kinase, drop jump height and contact-time, reactive strength index, countermovement jump height and perceptual responses were assessed at the aforementioned time-points. 18 Hz global positioning system devices were used to record players in-game workload measures.

Results: Compared to pre-match, perceptual responses (-27.6%) and countermovement jump height (-3.9%) were significantly reduced at full-time ($p < 0.05$). Drop jump height (-8.8%), perceptual responses (-27.6%), reactive strength index (-15.6%) and countermovement jump height (-8.6%) were significantly lower 24 h post-match ($p < 0.05$). Pre-match creatine kinase significantly increased (+16.2% to +159.9%) when compared to all other time-points ($p < 0.05$). Total distance, total accelerations, total sprints, sprint distance and average heart rate were all correlated to changes in perceptual responses ($r = 0.34$ to 0.56 , $p < 0.05$). Additionally, maximum speed achieved ($r = 0.34$) and sprint distance ($r = 0.31$) were significantly related to countermovement jump changes ($p < 0.05$), while impacts ($r = 0.36$) were correlated to creatine kinase increases ($p < 0.05$).

Conclusions: These results demonstrate that Gaelic football match-play elicits substantial neuromuscular, biochemical and perceptual disturbances. Understanding players psychophysiological responses to competitive match-play and the subsequent time course of recovery will inform coaches and practitioners who seek to effectively plan ensuing training sessions and prepare for upcoming matches.

Introduction

Gaelic football is a field-based team sport native to Ireland which is contested on a grass pitch with two teams of 15 players (Reilly and Doran, 2001). It is an intermittent invasion field sport, whereby intensive anaerobic efforts occur in a cyclical nature behind a background of light aerobic activity (Reilly and Doran, 2001). The game is fast paced, with frequent turnovers of possession, necessitating players to have well developed components of fitness and technical skills (Ryan et al., 2018, Reilly and Doran, 2001). During competitive matches, players typically cover large total distances (5 km to 11 km) with variation in workloads and physical demands depending on the playing level, player position, tactics and many other factors (Malone et al., 2017c, Mangan et al., 2020). Elite-level players are reported to cover 1563 ± 605 m of high-speed running distance (≥ 4.7 m·s⁻¹), 524 ± 190 m of very high speed running distance (≥ 6.1 m·s⁻¹) and perform 166 ± 41 m of accelerations (Ryan et al., 2018).

During Gaelic football match-play, workloads following intensive periods of play are temporarily impeded due to performance attenuation, while work rates progressively decline over the course of a game (Mangan et al., 2020). In elite-level Gaelic football, a significant progressive reduction in total and high speed running distance (≥ 5.5 m·s⁻¹) is reported across the final three quarters when compared with the first quarter (Malone et al., 2017c). While such research is beneficial in quantifying the workloads which players undertake during a game, there is a lack of information surrounding players' responses during the post-match recovery timeline and their relationships with the in-game workloads.

The demands that team sport players are exposed to during match-play likely invokes considerable immediate and prolonged decrements in contractile function (peripheral fatigue) and the capacity of the central nervous system to activate muscles (central fatigue)

(Amann, 2011, Cormack et al., 2008). Fatigue following Gaelic football match-play may be attributed to a combination of metabolite accumulation, impaired nervous system control, energy system depletion and a functional decline of the muscle fibres, contractile mechanisms similar to other team sports (Krustrup et al., 2006, Ascensão et al., 2008, Twist et al., 2012, Doeven et al., 2018). Research from team sports with comparable on-field demands to Gaelic football suggests players are likely to endure substantial perturbations in neuromuscular function, muscle damage and increased perceptions of tiredness and muscle soreness (Cormack et al., 2008, Nicol and Komi, 2010a, Da Silva et al., 2020). Previous work evaluating post-match fatigue and muscle damage across a range of team sports has used a variety of methods, including neuromuscular, biochemical, endocrine and perceptual markers, to assess players' responses (Twist et al., 2012, Hunkin et al., 2014, Ascensão et al., 2008).

When evaluating responses to match-play, neuromuscular markers, such as countermovement jump (CMJ) and drop jump (DJ), are particularly useful because they are relatively non-fatiguing, fast to complete and utilize the stretch shortening cycle (SSC) of the lower-body musculature, allowing an accurate depiction of an athletes' neuromuscular condition (Claudino et al., 2017a). A combination of neuromuscular and biochemical markers is reported to be highly reflective of subcellular and cellular muscular disturbances following intense eccentric actions and physical contact during games and may provide valuable indications of the degree of muscle damage following Gaelic football match-play (Silva et al., 2018, Baird et al., 2012). Previous discrepancies observed between objective neuromuscular and biochemical markers and subjective perceptual responses (PR) have provided rationale for the inclusion of a perceptual questionnaire to extensively illustrate the early warning signs of fatigue, overtraining and post-match recovery kinetics (Kenttä and Hassmén, 1998, Twist et al., 2012). Furthermore, in-game workload measures, such as

high speed running distance and sprint frequency, have also been reported to be highly sensitive monitoring tools when characterizing post-match neuromuscular and biochemical disturbances (Jones et al., 2014, Hader et al., 2019). Subsequently, in order to accurately evaluate the impact of Gaelic football match-play, a multifactorial testing approach may be required to comprehensively assess players' responses and post-match recovery profiles (Doeven et al., 2018).

Reliance on data from other sports is currently necessary for the determination of training load, recovery practices and performance profiling of Gaelic football players, providing sub-optimal guidance to coaches and players within the sport (Silva et al., 2018, Johnston et al., 2015a, Da Silva et al., 2020, Kelly et al., 2018a). Different team sports are reported to have unique post-match recovery kinetics due to large variations in competitive demands (Doeven et al., 2018). Additionally, the amateur status of Gaelic football provides environmental factors, such as work and study, which are important to consider during post-match recovery (Kelly et al., 2018b). Consequently, effectively preparing for subsequent training or competition necessitates the monitoring of Gaelic football players during the post-match recovery timeline. Such knowledge is vital for injury prevention and nutritional strategies, tactical player rotation and the optimal management and periodization of training loads (Kelly and Coutts, 2007, Doeven et al., 2018, Ó Catháin et al., 2020, Renard et al., 2020). Therefore, this research aims to investigate the changes in markers of fatigue and performance attenuation during and following competitive Gaelic football match-play. A secondary aim of this study is to examine the relationship between in-game workload measures and changes in the markers of fatigue and performance attenuation.

Methodology

Study Design

A familiarization session was used to explain the testing procedures to the participants 1 week before testing. Participants' neuromuscular, perceptual and biochemical markers were tested pre-match, at half-time, full-time, 24 h post-match and 48 h post-match (Figure 4. 1). The participants' in-game workloads were recorded during a competitive match. Pre-match testing was assessed after the participants had completed their regular team warm up. Participants were asked to refrain from any form of alcohol consumption or strenuous activity in the 24 h prior to and during the match-day and post-match testing days. Additionally, participants were instructed to arrive hydrated and well rested, and to avoid caffeine three hours before the testing sessions.

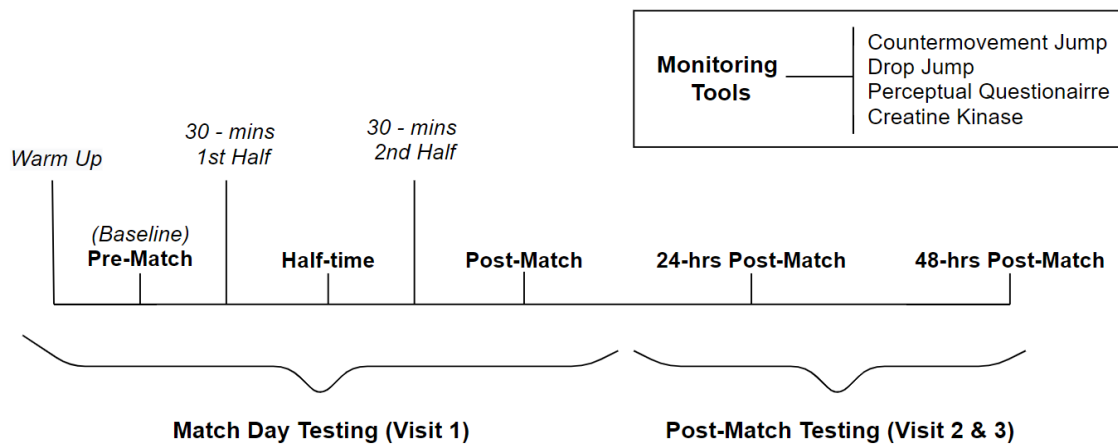


Figure 4. 1. Experimental study design.

Participants

Forty-one physically active and healthy male participants (mean \pm SD, age: 23.3 \pm 4.2 years; height: 178.3 \pm 7.91 cm; body mass: 80.64 \pm 9.47 kg, sum of 7 skinfolds: 81.3 \pm 28.0, percentage body fat: 14.3 \pm 5.2) between 18–32 years of age currently playing senior

club-level Gaelic football volunteered to participate in the study. Each participant had a minimum of 2 years of resistance training experience and 3 years of experience playing adult-level Gaelic football. Participants in the present study were recruited from a convenience-based sample from 5 clubs in the local region playing Gaelic football at senior level. Throughout the competitive season, participants trained an average of 3 days each week, with a mixture of gym and field-based training sessions, and were involved in Gaelic football matches predominantly at weekends. Participants were omitted from the study if they had suffered any lower-body musculoskeletal injury in the past 2 months or failed to pass a Physical Activity Readiness Questionnaire (PAR-Q) assessment. Informed consent was acquired from all participants in accordance with the Athlone Institute of Technology (AIT) guidelines. The AIT Research Ethics Committee granted ethical approval for this research (code 20180501).

Anthropometrics and Body Composition

Body mass and height were measured to the nearest 0.1 kg and 0.1 cm, respectively, using a portable stadiometer and scales (Seca 707 Balance Scales, GmbH, Hamburg, Germany) (Figure 4. 2). Skinfold thickness was measured at 7 anatomical sites (abdomen, midaxillary, biceps, chest, thigh, triceps, and subscapular) using handheld Harpenden Skinfold callipers (Baty International Ltd., Sussex, UK). While the investigator was not accredited with the International Society for the Advancement of Kinanthropometry (ISAK), pilot testing was used to verify the accuracy of the anthropometrical measurements performed (Hume and Marfell-Jones, 2008, Norton and Olds, 1996). When intra-rater reliability was assessed for skinfolds, the technical error of measurement of 4 repeated trials was lower than 5%, which is in line with recommendations [26]. Triple measurements for skinfolds were obtained to the nearest 0.2 mm on the right side of the body using the ISAK protocols (Norton and Olds, 1996). If the difference was greater than 2 mm for any

measurement, a fourth measurement was taken. To calculate participants' body fat, the equation of Withers et al. (1987) was used ($\% \text{ body fat} = 495 / (1.0988 - 0.0004 \times [\text{sum of 7 skinfolds}]) - 450$). This equation has been commonly used in the case of team sport athletes (Silva et al., 2009) and has been reported to have the lowest bias and highest relationship and agreement with dual-energy absorptiometry (DEXA) referenced values when compared with a number of other equations (Withers et al., 1987, Reilly et al., 2009).

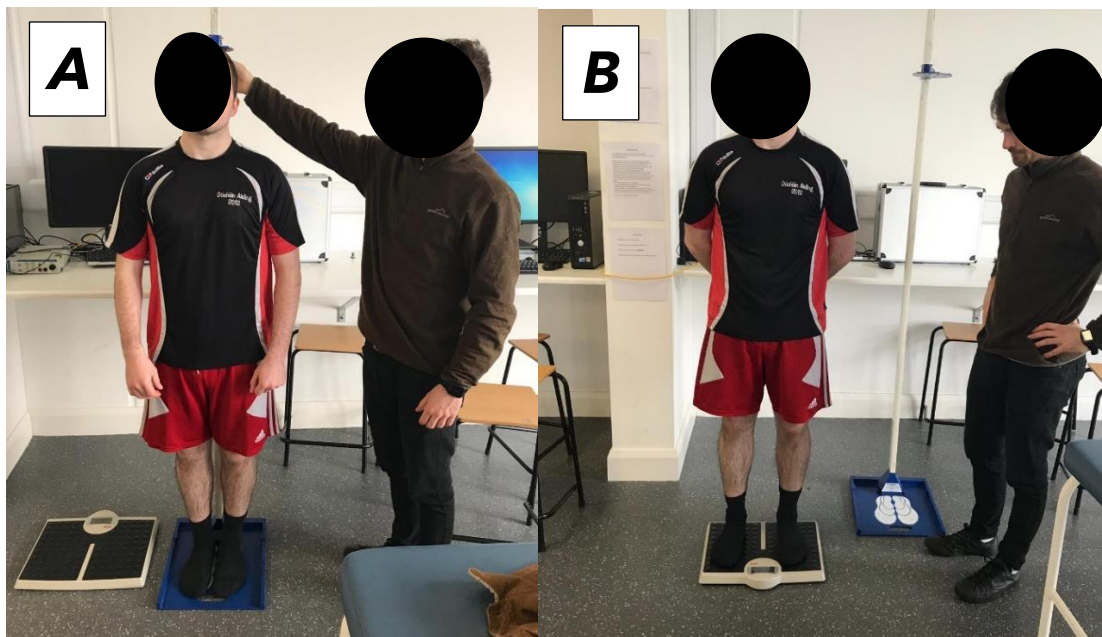


Figure 4. 2 (A) Height and (B) Body Mass Measurement using Scales and Stadiometer.

Sampling of Plasma Creatine Kinase

Concentrations of participants' CK were obtained from capillary blood, collected via a finger-prick (32 μL) on the middle or index finger (Zhang et al., 2011b) and analysed by means of a colorimetric assay process (Reflotron Plus reader, Roche Diagnostics, Mannheim, Germany) (Figure 4. 3). Pre-match, half-time and full-time samples were taken at the club grounds, while the 24 h and 48 h post-match samples were taken in the sport science laboratory at AIT. All samples were analysed immediately upon collection. Calibration, testing and storage of strips were undertaken according to the manufacturers' specifications (Horder et al., 1991).



Figure 4. 3 (A) Sample Collection and (B) Analysis Procedure during CK Assessment.

Perceptual Responses (PR)

A 5-question Likert scale questionnaire was chosen to assess the participants' perceptual status (McLean et al., 2010b, Gallo et al., 2016, Oliver et al., 2015a). The questionnaire involved a graded Likert system of answers, with 5 questions on fatigue, sleep quality, general muscle soreness, mood and levels of stress (Figure 4. 4). The readings were rated 1–5. Overall perceptual wellbeing was determined through the addition of the five scores. All of the participants completed the questionnaire in private behind a folding screen, either at the club grounds or in the sport science laboratory at AIT, so as to avoid external influence from coaches and/or other players (Twist et al., 2012).

	5	4	3	2	1	Score
Fatigue	Very fresh	Fresh	Normal	More tired than usual	Always tired	
Sleep Quality	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia	
General Muscle Soreness	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore	
Stress Levels	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed	
Mood	Very positive mood	A generally good mood	Less interested in others &/ or activities than usual	Snappiness at team-mates, family and co-workers	Highly annoyed/ irritable/ down	
					Score	

Figure 4. 4. Likert perceptual questionnaire adapted from McLean et al. (2010b).

Countermovement Jump (CMJ) and Drop Jump (DJ)

The CMJ and DJ were performed using the Optojump (Optojump, Microgate, Bolzano, Italy) photoelectric optical measurement device (Figure 4. 5). The subjects stood between the Optojump bars on a standardised surface, hands placed on their hips, and jumped vertically to a maximum height (Young et al., 1995b). A 30 cm high plastic step was used throughout all DJ testing. Participants stood on this step with their hands placed on their hips and stepped off with their dominant foot first (both feet landing on the floor simultaneously) before immediately jumping vertically as high as possible. Participants were instructed to minimise ground contact time. Three CMJ and three DJ trials were performed, with 1 min of rest between attempted jumps. The reactive strength indexes

(RSI) of the players were calculated by dividing the height jumped (m) in the DJ by the ground contact time (s) (Young et al., 1995b). For all CMJ and DJ measures, the average of three attempts was used in all match-day and post-match testing, as this has been reported to be more sensitive to players' recovery status (Claudino et al., 2017a).



Figure 4. 5. Countermovement Jump on standardised surface.

Global Positioning System (GPS) Monitoring

Participants' in-game workloads were recorded using 18 Hz GPS units (Apex, STATSports, Newry, UK). A heart rate (HR) telemetry system (Polar Vantage NV Polar, Port Washington, NY, USA) was placed around the chest to collect HR data simultaneously. The participants were fitted with an appropriately sized custom vest that held in place the GPS receiver. Approximately 15 min before the game's throw in, the GPS unit was powered on and then inserted into a padded slot towards the top of the rear section of the vest, sitting between the scapulae in the upper thoracic spinal region. The HR telemetry strap was placed through the custom-made slits in the front of the vest at the level of the chest. The GPS unit was switched off immediately following completion of the game.

Exact times and durations of throw ins, stoppages, additional time or any tactical substitutions or sending offs were recorded manually by the researcher. Players were only included in the study if they completed ≥ 60 min of match-play (Malone et al., 2017c).

Statistical Analysis

Descriptive statistics using mean and standard deviation (\pm SD) were calculated for all anthropometrics (age, body mass, height and sum of 7 skinfolds) and in-game workload measures (max speed ($\text{m}\cdot\text{s}^{-1}$), distance (m), accelerations, sprints ($\geq 5.5 \text{ m}\cdot\text{s}^{-1}$), total impacts ($>2 \text{ g}$ in 0.1 s), explosive distance (m), average HR ($\text{beats}\cdot\text{m}^{-1}$). The assumption of normality was assessed using the Shapiro–Wilk test. All data passed the assumption of normality, according to the Shapiro–Wilk test ($p > 0.05$). Multiple repeated measure ANOVAs with Bonferroni post-hoc analysis was used to compare biochemical, perceptual and neuromuscular measures (CK, PR, DJ, RSI, CT and CMJ) across each of the time-points (pre-match, half-time, full-time, 24 h post-match and 48 h post-match). Pearson product–moment correlation coefficient analysis was used to assess the strength of the linear relationships between changes in markers of fatigue and performance attenuation and in-game workloads. Multiple repeated measure ANOVAs were used to guide the selection of two time-points with the largest number of significant disturbances to markers of performance attenuation and fatigue (CK, PR, DJ, RSI and CMJ) for Pearson product–moment correlation coefficient analysis. The Holm–Bonferroni correction was employed for multiple correlations at each time-point to reduce the risk of type I errors (Abdi, 2010). All data were analyzed using Statistical Package for Social Sciences (SPSS Version 26, SPSS Inc. Chicago, IL, USA). Statistical significance was set at an alpha level of $p < 0.05$.

Results

In-Game Workload Measures

Table 4.1 outlines the workload metrics of the players during the first half, second half and the full game.

Table 4. 1.Global Positioning System (GPS) metric classification using the STATSports software analysis platform.

Workload Metric	1st Half	2nd Half	Full Game
Max Speed ($\text{m}\cdot\text{s}^{-1}$)	8.2 ± 0.7	7.9 ± 0.5	8.1 ± 0.6
Total Distance (m)	3834.7 ± 654.0	3300.1 ± 714.2	7134.7 ± 1194.9
Total Accelerations ($\geq 0.5 \text{ m}\cdot\text{s}^{-2}$) (<i>n</i>)	20.7 ± 6.7	15.4 ± 5.5	37.2 ± 11.4
Total Sprints (<i>n</i>) ($\geq 5.5 \text{ m}\cdot\text{s}^{-1}$)	17.8 ± 8.3	12.8 ± 5.9	30.5 ± 11.9
Total Impacts ($\geq 2\text{g}$ in a 0.1s) (<i>n</i>)	85.4 ± 81.3	47.6 ± 36.2	133.5 ± 122.4
Total Sprint Distance ($\geq 5.5 \text{ m}\cdot\text{s}^{-1}$) (m)	426.4 ± 137.7	315.5 ± 119.7	742.0 ± 229.9
Average Heart Rate ($\text{beats}\cdot\text{m}^{-1}$)	165.7 ± 9.2	170.2 ± 7.8	167.9 ± 8.3

(Data presented as mean \pm SD, 1st = First half of game, 2nd = second half of game).

Changes in Measurements of Fatigue and Performance Attenuation

Drop Jump Height (DJ), Contact Time (CT) and Reactive Strength Index (RSI)

Figure 4. 6 (A) outlines the drop jump height results over the five assessed time-points (pre-match, half-time, full-time, 24 h and 48 h post-match). Post hoc analysis indicated that there was a significant decrease between pre-match and 24 h post-match (-8.8% , $p < 0.001$), half-time and full-time (-5.1% , $p = 0.03$), half-time and 24 h post-match (-9.9% , $p < 0.001$) and half-time and 48 h post-match (-5.2% , $p = 0.005$). A significant increase was also found between 24 h post-match and 48 h post-match ($+5.7\%$, $p < 0.001$). No significant differences were observed when comparing DJ CT at any of the five time-points ($p > 0.05$). Figure 4. 6 (C) illustrates the RSI data collected over the five assessed time-points (pre-match, half-time, full-time, 24 h post-match and 48 h post-match). Post hoc analysis

indicates that there was a significant decrease between pre-match and 24 h post-match (-15.6% , $p = 0.014$) and half-time and 24 h post-match (-14.1% , $p = 0.010$).

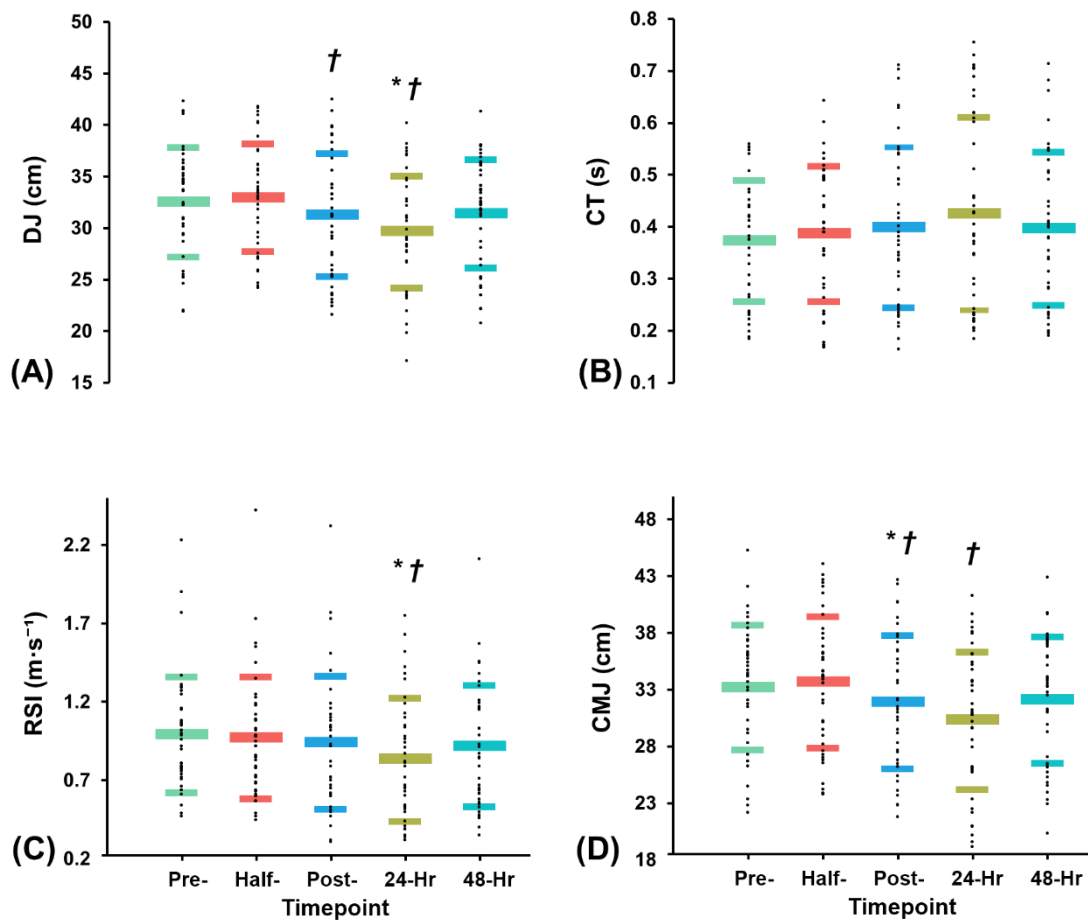


Figure 4. 6. Values at pre-match, half-time, full-time, 24 h post-match and 48 h post-match for (A) drop jump height (cm), (B) drop jump contact time (s), (C) reactive strength index and (D) countermovement jump height (cm). Data are presented as mean \pm SD from left to right: pre-match, half-time, full-time, 24 h post-match and 48 h post-match) (* $p < 0.05$ vs. pre match; † $p < 0.05$ vs. half-time).

Countermovement Jump (CMJ)

Figure 4. 6 (D) illustrates the CMJ height results collected over the five time-points (pre-match, half-time, full-time, 24 h post-match and 48 h post-match). Post hoc analysis indicates that there was a significant decrease between pre-match and full-time (-3.9% , $p = 0.039$), pre-match and 24 h post-match (-8.6% , $p < 0.001$). Additionally, significant decreases were found between half-time and full-time (-5.2% , $p < 0.001$), half-time and 24 h post-match (-9.9% , $p < 0.001$), half-time and 48 h post-match (-4.6% , $p = 0.040$) and 24 h post-match and 48 h post-match ($+5.8\%$, $p < 0.001$).

Creatine Kinase

Figure 4. 7 (A) illustrates the CK results over the five time-points (pre-match, half-time, full-time, 24 h and 48 h post-match). Post hoc analysis results indicate that there was a significant increase between pre-match and half-time ($+16.2\%$, $p < 0.001$), pre-match and full-time ($+43.8\%$, $p < 0.001$), pre-match and 24 h post-match ($+159.9\%$, $p < 0.001$) and pre-match and 48 h post-match ($+70.1\%$, $p < 0.001$). A significant increase was also found between half-time and full-time ($+23.7\%$, $p < 0.001$), half-time and 24 h post-match ($+123.5\%$, $p < 0.001$) and half-time and 48 h post-match ($+46.3\%$, $p < 0.001$). Additionally, a significant increase was found between full-time and 24 h post-match ($+80.7\%$, $p < 0.001$) and a significant decrease between 24 h post-match and 48 h post-match (-18.3% , $p < 0.001$).

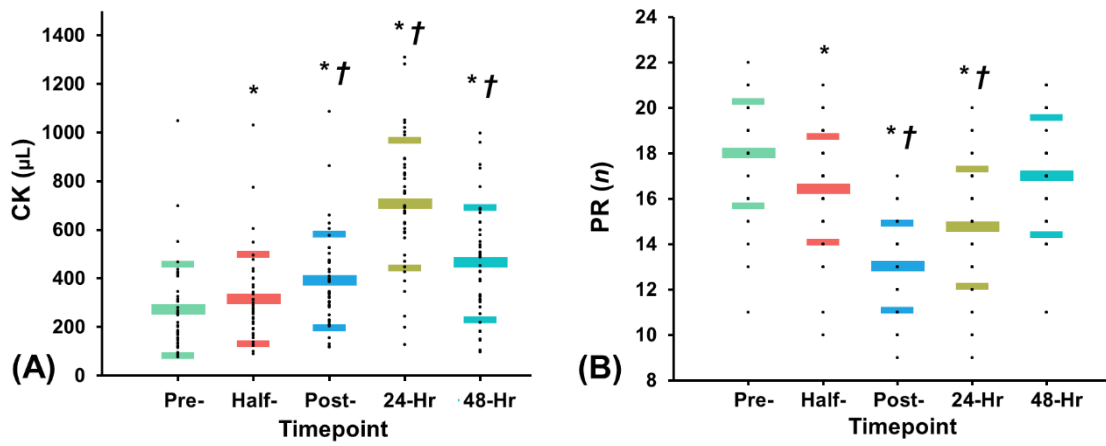


Figure 4. 7. Values pre-match, half-time, full-time, 24 h post-match and 48 h post-match for (A) creatine kinase and (B) perceptual responses (Data are presented as mean \pm SD from left to right: pre-match, half-time, full-time, 24 h post-match and 48 h post-match)

(* $p < 0.05$ vs. pre match; † $p < 0.05$ vs. half-time).

Perceptual Questionnaire

Figure 4. 7 (B) illustrates the perceptual score results over the five assessed time-points (pre-match, half-time, full-time, 24 h and 48 h post-match). Post hoc analysis indicates that there was a statistically significant decrease between pre-match and half-time (-8.7% , $p < 0.001$), pre-match and full-time (-27.6% , $p < 0.001$) and pre-match and 24 h post-match (-18.0% , $p < 0.001$). A significant decrease was also found between half-time and full-time (-20.8% , $p < 0.001$) and half-time and 24 h post-match (-10.5% , $p < 0.001$). Additionally, a significant increase was also found between full-time and 24 h post-match ($+9.6\%$, $p < 0.001$), full-time and 48 h post-match ($+22.1\%$, $p < 0.001$) and 24 h post-match and 48 h post-match ($+12.5\%$, $p < 0.001$).

Correlations between Markers of Performance Attenuation and In-Game Workload

Changes in PR from pre-match to full-time were correlated to total distance ($r = 0.48$, $p = 0.014$), total accelerations ($r = 0.34$, $p = 0.029$), total sprints ($r = 0.37$, $p = 0.018$) and sprint distance ($r = 0.56$, $p < 0.001$). PR change from pre-match to 24 h post-match was correlated with total sprints ($r = 0.37$, $p = 0.017$) and average HR ($r = 0.36$, $p = 0.022$). CMJ change from pre-match to full-time correlated with max speed ($r = 0.34$, $p = 0.032$), while sprint distance correlated with CMJ change from pre-match to 24 h post-match ($r = 0.31$, $p = 0.049$). Finally, CK change from pre-match to 24 h post-match was significantly correlated with number of impacts ($r = 0.31$, $p = 0.048$).

Discussion

The aim of the current study was to examine changes in markers of fatigue and performance attenuation during and following a competitive senior club-level Gaelic football match. A secondary aim was to investigate the relationships between in-game workload measures and these changes in markers of fatigue and performance attenuation. To the authors knowledge, this is the first study to document changes in markers of fatigue and performance attenuation in Gaelic football match-play.

Our results suggest match-play causes significant increases in CK across all time-points in comparison to pre-match baseline values. The largest increases were recorded at 24 h (159.9%) and 48 h (70.1%) post-match compared to pre-match values, which is in agreement with previous studies examining changes in CK following soccer (Silva et al., 2018), Australian rules football (Young et al., 2012) and rugby league (Johnston et al., 2015b, Johnston et al., 2015a) match-play. An elevated presence of plasma muscle proteins in the form of CK at these time-points is associated with muscle damage, a prolonged suppression in force production, muscular soreness and increased markers of inflammation in both the muscle itself and leaked into the bloodstream (Evans and Cannon, 1991, Baird et al., 2012). The relative increases in CK observed in the present analysis are 25.7% to 43.1% higher 24 h post-match and 24.3% to 54.9% higher 48 h post-match in comparison with professional rugby league, soccer and Australian rules football (Russell et al., 2015, McLellan et al., 2010, Cormack et al., 2008). Our work suggests the number of impacts recorded (133.5 ± 122.4) during Gaelic football match-play correlates with increases in CK 24 h post-match ($r = 0.34$). A similar link between physical contact and elevations in CK during the post-match recovery timeline has been previously reported (Smart et al., 2008, Takarada, 2003, Gill et al., 2006). Physical contact in Gaelic football involves frequent shoulder charges and tackling when contesting for possession (Reilly and Doran, 2001).

Damage to muscle tissue from the blunt force trauma of physical contact and eccentric actions during high speed running is suggested to increase cell permeation of muscle enzymes into the bloodstream and may explain the rises in post-match CK (Baird et al., 2012). The amateur status of Gaelic football may be indicative of less developed components of fitness when compared with the professional athletes described in the above research, thus partly explaining the relatively larger increases observed in CK (Johnston et al., 2015b, Hunkin et al., 2014, Johnston et al., 2015a, Strudwick and Doran, 2002). The present cohort covered on average $118 \text{ m}\cdot\text{min}^{-1}$ (table 1) is similar to previous work on this population ($119 \text{ m}\cdot\text{min}^{-1}$) (Mangan et al., 2020), but lower than elite-level soccer players ($126 \text{ m}\cdot\text{min}^{-1}$) (Carling et al., 2012) or Australian rules football players ($127 \text{ m}\cdot\text{min}^{-1}$) (Coutts et al., 2010), who undertake larger relative workloads. Interestingly, players' pre-competition CK levels were 7.1% higher than pre-match levels for professional rugby league players, 7.8% higher than Australian rules players and 18.8% higher than soccer players (Young et al., 2012, McLellan et al., 2010, Varley et al., 2017). This may be due to residual fatigue and muscle damage from previous training or competition, especially considering this study was conducted during the competitive season where Gaelic football players must balance busy training and match schedules alongside working life, as amateur athletes (Oliver et al., 2015a, Kelly et al., 2018b). Elevated CK levels prior to competition have been linked with an increased risk of injury (Baird et al., 2012, Nicol and Komi, 2010a) and attenuated match performance (Hunkin et al., 2014). In the present data, elevated CK prior to match-play may provide evidence of residual fatigue and suggest that players may not be sufficiently recovered prior to matches during the competitive season.

Neuromuscular decrements recorded following Gaelic football match-play are similar to those reported during the recovery timeline of other team sports (Johnston et al., 2015b, Hagstrom and Shorter, 2018, Cormack et al., 2008, Rampinini et al., 2011). CMJ was

observed to decline at full-time (-3.9%) and 24 h post-match (-8.6%), while reductions in RSI (-15.6%) and DJ height (-8.8%) became evident 24 h post-match compared to pre-match, suggesting players neuromuscular capacity is at its lowest the day after a match. While there was a significant deterioration in DJ height and RSI performance 24 h post-match, there was no significant change in CT. This may suggest that neuromuscular fatigue and muscle damage 24 h post-match reduces players rate of force development during the DJ, without having a significant impact on ground reaction time. These findings echo previous reports highlighting a delayed peak in neuromuscular decrements relating to muscle damage and inflammatory responses following strenuous SSC activity (Nicol and Komi, 2010a, Silva et al., 2018), which may explain the larger neuromuscular disturbances reported 24 h post-match (Evans and Cannon, 1991, Nicol and Komi, 2010a). Similar impairments in neuromuscular function have been shown to negatively affect players capacity to undertake high intensity running, total distance, ball disposals and coaches ratings of performance in Australian rules (Hunkin et al., 2014), while compromising the performance of technical skills and high intensity running in soccer (Rampinini et al., 2009, Krstrup et al., 2006). This information may be helpful to coaches planning training sessions in the days following a Gaelic football match, where players' capacity to perform high intensity running or technical skills would likely be diminished.

In the current analysis significant differences in perceptual status were observed between pre-match and full-time (-27.6%), 24 h post-match (-18%) and 48 h post-match (+12.5%). Perception of fatigue, muscular soreness and overall wellbeing have been previously documented to be sensitive to changes in players neuromuscular status, similar to markers of muscle damage and neuromuscular parameters (Oliver et al., 2015a, Twist et al., 2012, McLean et al., 2010a). Surprisingly, the lowest PR score was recorded at full-time, while all other markers of performance attenuation presented with the largest

decrement 24 h post-match. The reported differences in peak disturbance between these objective and subjective indicators of performance attenuation corresponds to previous research on team sport athletes (Twist et al., 2012, Oliver et al., 2015a). Discrepancies between neuromuscular, biochemical and PR markers during the recovery timeline have been suggested to provide rationale for the inclusion of a PR questionnaire to comprehensively monitor players physical and psychological preparedness to train or compete (McLean et al., 2010b, Kenttä and Hassmén, 1998). In this analysis, PR displayed the greatest decrement at FT with a recovery to baseline at 48 h, suggesting players may have reduced perceptions of fatigue and muscular soreness in the presence of ongoing biochemical and neuromuscular disturbances. Therefore, it may be important to not exclusively rely on PR when evaluating players recovery profiles (Twist et al., 2012, McLean et al., 2010a). The divergence between PR and the other markers of performance attenuation highlights the multifactorial nature of fatigue and muscle damage evoked by Gaelic football match-play and implies that numerous monitoring tools may be necessary to optimally determine players readiness to compete or train.

In the present study, disturbances to PR, CK and CMJ following match-play positively correlated with total distance, total accelerations, total sprints, max speed, sprint distance and average HR ($r = 0.34$ to 0.56). While the reported correlations may be weak, these findings are in agreement with previous research suggesting an association between in-game workloads and post-match fatigue (Jones et al., 2014, Young et al., 2012), with high speed running distance ($\geq 5.5 \text{ m}\cdot\text{s}^{-1}$) has been reported to be an especially sensitive monitoring variable ($r = 0.44$ to 0.67) (Hader et al., 2019, Jones et al., 2014). The correlations between high intensity running indices and post-match disturbances in the current analysis may be explained by the large mechanical loads and rapid transitions from eccentric to concentric actions involved in sprinting and accelerations, which have

previously been associated with greater muscle damage (Young et al., 2012, Jones et al., 2014). In addition, the intense eccentric actions during the landing phase of sprinting movements have been hypothesised to be a key contributor to the elevation of CK throughout the post-match recovery timeline (Johnston et al., 2015b, Silva et al., 2018, Hader et al., 2019). Such associations between in-game workloads and post-match fatigue have also been correlated to players' characteristics of fitness in team sport, which could be a factor in the present analysis (Cunningham et al., 2018, Dujic et al., 2016) and may warrant future research. Specifically, players with higher levels of conditioning are reported to undertake greater competitive workloads, while presenting with improved post-match recovery responses than their less conditioned counterparts (Johnston et al., 2015b, Dujic et al., 2016). Overall, these findings suggest that high intensity running indices during match-play may provide a useful indicator to subsequent perceptual, biochemical and neuromuscular disturbances. This may be particularly useful in scenarios where teams do not have access to CK or neuromuscular assessments but can instead use measurements of in-game workload to characterise post-match responses.

In summary, the results from this study suggest there are large decrements in performance and substantial multidimensional fatigue experienced by players following Gaelic football match-play. Specifically, DJ, CMJ, RSI and CK presented with the greatest disturbances 24 h post-match, while PR were lowest at FT. The recovery of neuromuscular and perceptual measures was observed 48 h post-match in the presence of continued biochemical disturbance. Consequently, players' capacity to perform intense exercise is likely to be impaired during the 48 h post-match recovery timeline. Additionally, total accelerations, max speed, total distance, total sprints, average HR and sprint distance may be used as tracking variables to characterise changes in PR, CK and CMJ following match-play. The faster trend for PR recovery may suggest coaches need an additional objective

parameter to accurately determine players' recovery profile. Considering the variation in responses observed across the utilised markers, coaches may require more than one monitoring tool to effectively establish players' preparedness for subsequent training or competition. Understanding players' responses to match-play may allow for a more tailored manipulation of training and recovery modalities to improve their ensuing competitive performances.

A number of limitations exist in the present study which should be considered. Firstly, a maximum of five players could be assessed per game, meaning there was variation in match conditions, opposition, match outcome and other tactical influences which may have influenced results (Johnston et al., 2015a, Augusto et al., 2021, Aquino et al., 2020). Additionally, the final post-match testing was undertaken 48 h post-match, with all parameters not yet recovering to pre-match values. A 72 hour window may have been enough to witness a return to pre-match baseline; however, most players had a subsequent training session before this time-point. The current study was also limited by its sample size and the fact that the players were only monitored around one competitive match during mid-season. Monitoring a larger sample of players at different stages of a season may yield a better description of players' responses to match-play. In addition, while players were asked to refrain from exercise during the 48 h post-match timeline, we could not ensure players followed these recommendations. Other external factors such as physical conditioning, nutrition, work stress and recovery strategies were not controlled and may have influenced our findings (Ó Catháin et al., 2020).

Conclusion

Competitive Gaelic football match-play elicited significant disturbances to players' neuromuscular and perceptual markers up to 24 h post-match, while full recovery of these variables occurred 48 h post-match despite a prolonged elevation in the biochemical marker CK. Performance of high intensity running and acceleration indices coincide with greater decrements to neuromuscular and perceptual status following match-play, suggesting that monitoring selected high intensity running variables during competitive games may help contribute to customized training load management during the 48 h post-match window. Further research is necessary to ascertain the influence of players' components of fitness and performance characteristics on in-game workload and post-match recovery kinetics. Understanding how players respond to match-play and the subsequent time course of recovery will allow coaches to effectively plan ensuing training sessions and prepare for upcoming competitive matches. When making decisions regarding players' recovery status, coaches should consider the context of long-term and short-term recovery. For example, in situations where important matches are a few days apart, neuromuscular performance may have recovered to pre-match values in the presence of biochemical disturbances. This may be sufficient in the short-term, provided full recovery is possible after these matches. However, if a high density of matches exists for an extended period without an upcoming phase of rest, a reduction of training load and implementation of recovery strategies may be necessary to avoid cumulative fatigue. This may be especially important in scenarios where coaches do not have access to biochemical assessments, and insufficient recovery may not be detected by perceptual or neuromuscular markers.

Section Link

Chapter 4 detailed player's responses to match play, the key actions during competition that contributed to post-match disturbances and the subsequent time course of recovery. Significant disturbances to player's psychophysiological markers were observed, and these were reported to significantly coincide with eccentric muscle actions (i.e., high intensity running and changes of pace). Therefore, monitoring these in-game workload variables potentially provides an avenue for practitioners with which to characterise in-game performance attenuation and post-match recovery. In light of these findings, it may also be pertinent to further investigate the many possible factors that influence players in-game workload indices, such as quality of opposition played (Barrett et al., 2018) (Johnston et al., 2015b), match location and outcome (Augusto et al., 2021, Granero-Gil et al., 2020) and physical conditioning (Aquino et al., 2020, Pedersen et al., 2021, Buchheit, 2012) which have been identified in other sports. Regarding the latter, it's reasonable to speculate that physiological attributes in particular dictate players capacity to cope with the physical tasks and demands of match-play, subsequently mitigating performance attenuation (Johnston et al., 2015a) and increasing sport-specific work capacity (Aquino et al., 2020). Nonetheless, the specific interactions of different physical conditioning markers with in-game workloads remains unknown in any cohort of Gaelic games players, where the many unique contextual factors (i.e., amateur status, technical and pitch constraints and physical demands) may moderate these interactions. As it is difficult to infer how various components of fitness may influence players workload indices, practitioners who seek to develop specific physiological attributes with the goal of mitigating performance attenuation and enhance game specific work capacity are at a disadvantage. To overcome these limitations, the subsequent chapter set out to explore the influence that key components of fitness impose on players in-game workload measures.

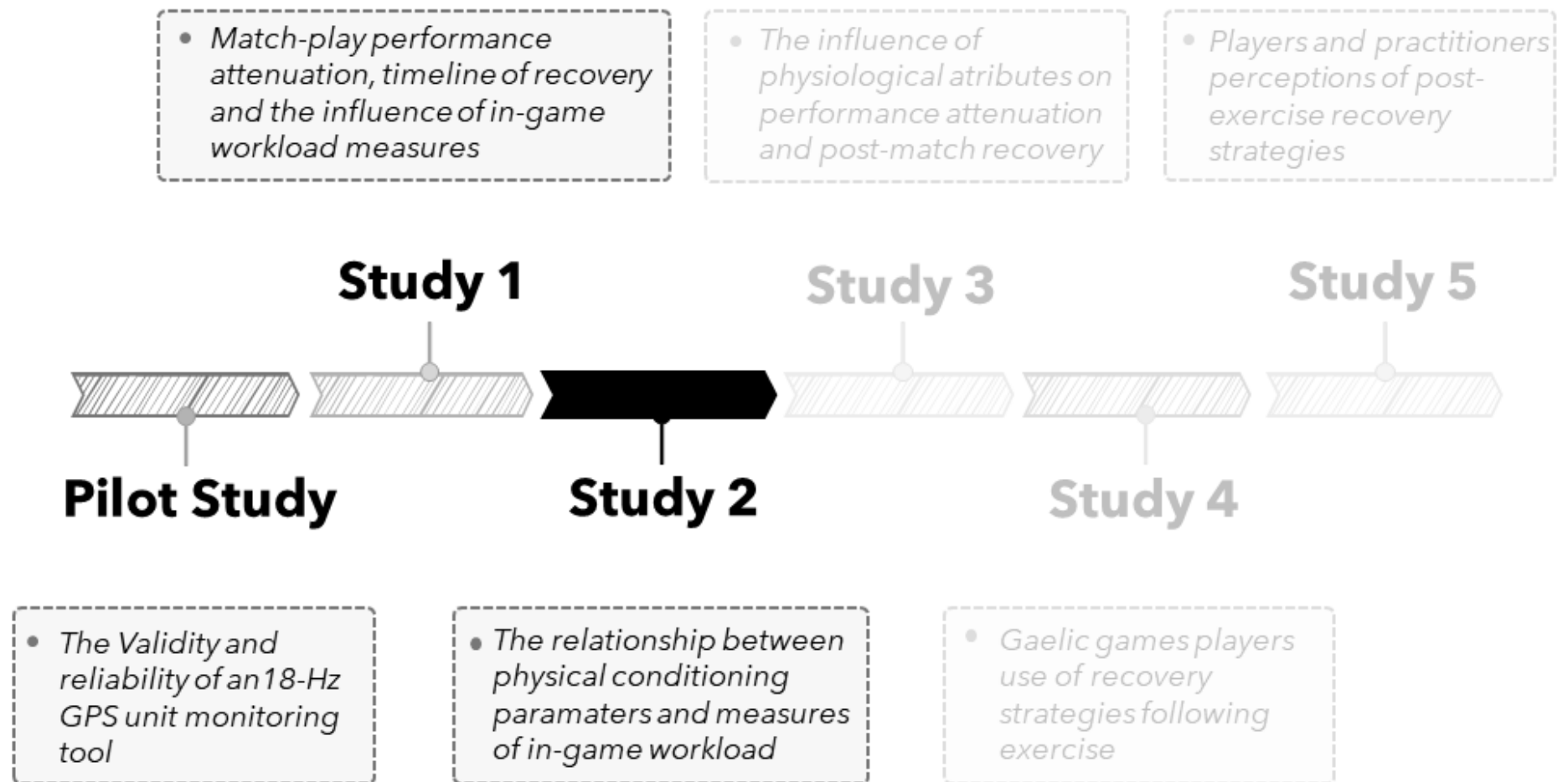


Figure 4. 8. Thesis timeline infographic highlighting study 2.

Chapter 5 – Study 2

Do Superior Physiological Attributes Enable Players to Outwork their Less-Conditioned Counterparts? A Study in Gaelic Football

Submitted to *The Journal of Strength and Conditioning Research* on 09/03/22.

Abstract

Purpose: This study investigated the influence of Gaelic football players physical conditioning and body composition on in-game workload measures during competitive match-play.

Methods: Fifty-two male Gaelic football players (mean \pm SD; age: 22.9 ± 3.8 years; stature: 179.2 ± 7.5 cm) underwent measurements of anthropometric characteristics, running speed, muscular strength and power, blood lactate responses, running economy and aerobic capacity during two separate testing visits. One week following baseline testing, 18-Hz Global Positioning System units were used to record players in-game workloads during competitive match-play.

Results: Players body fat percentage, drop jump height and velocity at $4 \text{ mmol}\cdot\text{L}^{-1}$ significantly influenced the number of sprints completed (Adjusted R^2 26.8% to 39.5%; $p < 0.05$) while 20 m running speed, velocity at $2 \text{ mmol}\cdot\text{L}^{-1}$ and drop jump height significantly influenced the number of accelerations completed (Adjusted R^2 17.2% to 22.0%; $p < 0.05$) during match-play. Additionally, aerobic capacity and body fat percentage significantly influenced total distance covered (Adjusted R^2 14.4% to 22.4%; $p < 0.05$) while body fat percentage, drop jump height and 20 m running speed significantly influenced sprint distance covered (Adjusted R^2 17.8% to 22.0%; $p < 0.05$). Players were also divided into higher-standard and lower-standard groups using a median split of these physiological attributes. Here, players in the higher-standard groups completed significantly more sprints and accelerations and covered significantly larger total and sprint distances (+10.4% to +36.8%; $ES = 0.67$ to 0.88 ; $p < 0.05$) when compared to the lower-standard groups.

Conclusion: This study demonstrates that superior levels of physical conditioning contribute to larger in-game workloads during competitive Gaelic football match-play.

Introduction

Gaelic football is a field-based team sport predominantly characterised by low to moderate intensity activity interspersed with critical bouts of high-intensity actions, which can often influence a games result (Malone et al., 2017d, Mangan et al., 2020). To support these demands, well-developed aerobic capacity, blood lactate responses and efficient running economy may be necessary to generate and maintain the considerable workloads (≈ 100 to $130 \text{ m} \cdot \text{min}^{-1}$) recorded during match-play (Malone et al., 2017d, Mangan et al., 2020). On the other hand, neuromuscular-related performance characteristics such as short distance running speed, power and relative strength likely underpin the performance of numerous high-speed running and power-based tasks (Malone et al., 2016b). Notwithstanding the significant tactical organization and technical skill proficiency necessary for a team sport such as Gaelic football, possessing the physical capacity to undertake a greater volume and intensity of work than the opposition is suggested to be a key requisite to successful match-play (Gabbett and Seibold, 2013a).

While components of fitness are anecdotally thought to influence players in-game workloads during competitive Gaelic football match-play (Kelly et al., 2021), empirical data exploring these interactions are limited. In contrast, a body of research exists assessing relationships between physical conditioning, playing standard, coaches' perceptions of performance and in-game workload measures in team sports similar to Gaelic football (Cunningham et al., 2018, Rhodes et al., 2021, Hunkin et al., 2014). For instance, evidence suggests that players with superior levels of aerobic-based performance attributes undertake more sprints and accelerations, cover larger total and high-speed distances and participate in more ball involvements than their less aerobically proficient counterparts in rugby union (Cunningham et al., 2018) and soccer (Dujic et al., 2016, Aquino et al., 2020).

Although this data does not currently exist within Gaelic football, the ability to frequently express high levels of power, speed and changes of pace/direction during match-play necessitates the rapid regeneration of anaerobic substrates (da Silva et al., 2010) which is a process heavily reliant on aerobic metabolism (Bogdanis et al., 1996a, Stone and Kilding, 2009). In Gaelic football, elite-level players are reported to exhibit significantly higher estimated $\dot{V}O_{2\max}$ values than sub elite players, possibly reflecting the importance of aerobic fitness in high-level performance (Keane et al., 1997). While it may be likely that well-developed aerobic capabilities are necessary to cope with the physiological stressors of Gaelic football match-play, (Malone et al., 2017d) this is yet to be investigated directly.

Similar to markers of aerobic function, body composition has also been identified as an important indicator of Gaelic football performance through its impact on players capacity to run, jump and change direction/pace (Meir et al., 2001, Kelly et al., 2021, Reeves and Collins, 2003). In soccer for example, players body fat levels have been negatively associated with high-speed running performance (Meir et al., 2001). Despite the implications of these reports, an absence of applied data in Gaelic football makes it difficult to accurately surmise the extent with which body composition and other relevant components of fitness influence the unpredictable and multivariate in-game workload demands players face during competition (Malone et al., 2017d).

Given the strenuous mechanical loads players are subject to during Gaelic football match-play, such as frequent accelerations/decelerations, sharp changes of direction and landing from jumps; it is reasonable to assume that strength, power and running speed facilitate players capacity for work (Silva et al., 2015, Owen et al., 2015, Johnston et al., 2015a). In team sports comparable to Gaelic football, lower-body strength (relative to body mass), power and running speed have been positively associated with acceleration and sprint frequency, distances covered at varying speeds and a number of key performance

indicators such as effective turnovers and ball possessions during match-play (Johnston et al., 2015a, Aquino et al., 2020, Cunningham et al., 2018). Supporting the relevance of these markers in a team sport performance-specific setting, research in soccer reported that the number of high-intensity accelerations ($>3 \text{ m}\cdot\text{s}^{-2}$) and decelerations ($<-3 \text{ m}\cdot\text{s}^{-2}$) recorded during elite match-play presented a significant dose-response relationship with match outcome; whereby outputs were highest during wins and lowest during draws or losses (Rhodes et al., 2021).

Successfully undertaking these tasks in a fast-paced contact environment necessitates the rapid application of high force levels accompanied by the repeated performance of quick and powerful muscular contractions (Johnston et al., 2015b). Thus, corresponding relationships between neuromuscular performance characteristics and workloads may exist in Gaelic football, wherein players undertake large volumes of stretch shortening cycle based movements comprising high eccentric loads (Daly et al., 2020, Rhodes et al., 2021). Indeed, when comparing playing standards in Gaelic football inter-county level players reportedly display significantly greater vertical and broad jump scores than their club level counterparts, possibly highlighting a key role of lower-body power in successful competitive performances (Keane et al., 1997).

In summary, the above studies have detailed how various components of fitness positively impact in-game workload measures, playing standard and match outcome in team sports similar to Gaelic football (Johnston et al., 2015b, Cunningham et al., 2018, Aquino et al., 2020). Nevertheless, this research has yet to be replicated in Gaelic football, where many considerations unique to the sport may limit the applicability of training or match-based decisions derived from data collected in other team sport codes. Consequential to this lack of research, pivotal assumptions as to the importance of different components of fitness in relation to game-specific work capacity are rooted in data from other sporting

populations. As such, in order to provide objective data for coaches to design effective training programmes with the goal of increasing competitive workloads, it may be necessary to address these interactions in an ecologically valid context (Daly et al., 2020). Therefore, this study aims to investigate the influence of players components of fitness on in-game workload measures in Gaelic football.

Methods

Experimental Approach to the Problem

The present study sought to investigate the influence of different components of fitness on the in-game workloads of Gaelic football players. Previous research in similar team sports (Johnston et al., 2015b, Cunningham et al., 2018, Aquino et al., 2020) and the physiological demands of Gaelic football match-play (Mangan et al., 2020, Daly et al., 2020) guided the selection of physical conditioning measures to be assessed during baseline testing (Figure 5. 1). The testing procedures were explained to the participants during a familiarization session. During the first visit, participants anthropometric characteristics (body mass, height and body fat percentage (body fat [%])) one repetition maximum (1RM) relative squat strength, blood lactate concentrations (BLa) (lactate threshold, running velocity at 2 and 4 mmol·L⁻¹), RE and maximal aerobic capacity ($\dot{V}O_{2max}$) were assessed. Participants' countermovement jump height (CMJ), drop jump height (DJ), contact time (CT), reactive strength index (RSI), 5 m and 20 m running speed (running speed [5 m] and [20 m]) and 1RM relative hip thrust strength were measured during the second visit to our lab. Both testing sessions were completed at the same time of day. Participants were instructed to arrive hydrated and well rested. One week after the baseline testing, participants' in-game workload measures were recorded during a competitive match using global positioning system (GPS) units. To facilitate a high level of ecological validity, a maximum of four players were tested per game during a number of competitive matches and these players were recruited from 5 different senior club level teams.

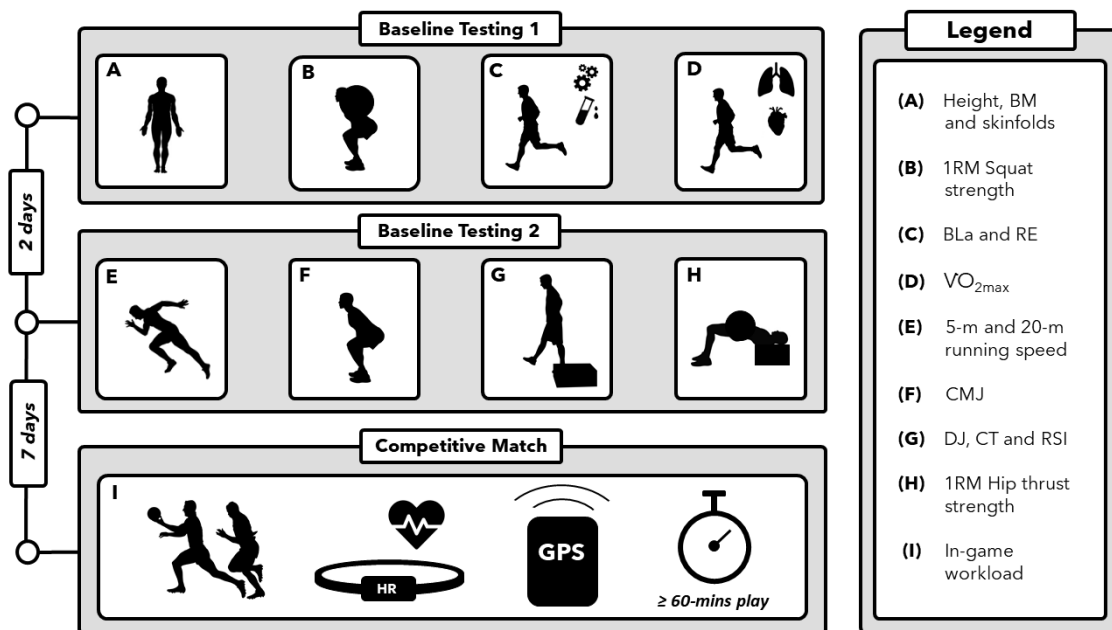


Figure 5. 1. Schematic overview of study methodology.

Participants

Fifty-two male Gaelic football players (mean \pm SD; age: 22.9 ± 3.8 years; stature: 179.2 ± 7.6 cm; sum of seven skinfolds: 83.2 ± 26.1) currently representing a senior club level Gaelic football team volunteered to participate in this study. Participants had a minimum of 3-years playing experience at adult-level Gaelic football. Participants were omitted from this study if they failed to pass a physical activity readiness questionnaire (PAR-Q) or had endured a lower-body injury in the previous 8-weeks. Informed consent was obtained from each participant and ethical approval was granted for this research by the Technological University of the Shannon Research Ethics Committee (code 20180501).

Procedures

Anthropometric Characteristics. Body mass and height were measured to the nearest 0.1 cm and 0.1 kg respectively, using a portable scales and stadiometer (Seca 707 Scales, Hamburg, Germany). Participants skinfold thickness was measured at seven anatomical sites (midaxillary, biceps, chest, abdomen, thigh, subscapular and triceps) using a skinfold callipers (Baty International Ltd, Burgess Hill, UK) as described in previous methods (Daly et al., 2020, Malone et al., 2016b). Here, three measurements for each skinfold on the right side of the body were obtained to the nearest 0.2 mm using the International Society for the Advancement of Kinanthropometry (ISAK) protocols (Daly et al., 2020). To calculate participants' body fat (%), the equation of Withers et al. (1987) ($\% \text{ BF} = 495 / (1.0988 - 0.0004 \times [\text{sum of seven skinfolds}]) - 450$) was used. This equation has previously demonstrated the lowest bias and highest agreement ($r = 0.88$) with criterion dual energy absorptiometry (DEXA) measurements when compared to a number of commonly used equations (Reilly et al., 2009).

Markers of Physiological and Metabolic Endurance. Participants $\dot{V}O_{2\text{max}}$ and RE were measured using a Moxus metabolic cart (AEI Technologies, Pittsburgh, PA, USA) on a motorized treadmill (Quasar, HP Cosmos, Nußdorf, Germany) using an incremental incline ramp protocol. Subsequent to a 3-minute warm-up at $8\text{km}\cdot\text{h}^{-1}$ on a 1% gradient, the speed of the treadmill incrementally increased by $1\text{ km}\cdot\text{h}^{-1}$ every 3-minutes until the participant's blood lactate concentrations reached $4\text{ mmol}\cdot\text{L}^{-1}$ or higher. Next, a constant speed of $10\text{ km}\cdot\text{h}^{-1}$ was set on a 4% gradient, increasing the gradient by 1% each minute until volitional exhaustion. Participant's heart rate was measured using a watch and chest strap (Polar Vantage, Polar Electro, Kempele, Finland) at the end of each stage. Expired CO_2 , ventilatory volume and rate of perceived exertion were continuously monitored

throughout the test. RE and $\dot{V}O_{2\max}$ were reported in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ using the average of the final two 30 s values (Kelly et al., 2018a).

Running Speed. Participants running speed was recorded over 5 m and 20 m using photoelectric cells (Brower Timing Systems, Draper, UT, USA). These photoelectric cells have been reported as valid (standard error of measurement = 0.1 s) and reliable (coefficient of variation = 0.1%) (Haugen et al., 2012). The participants were instructed to start by placing forward their dominant foot on a mark 50 cm behind the starting line. Timing gates were placed at the starting line, 5 m line and the 20 m line. Participants completed three runs, with the best time recorded as their result.

Lower-body Strength and Power. Participants one repetition maximum (1RM) hip thrust and squat values were assessed using the incremental protocol described previously by Baechle and Earle (2008). Participants one repetition maximum was recorded as the greatest resistance (kg) lifted successfully through a full range of motion with good form as assessed by the lead investigator. Participants relative strength measures were calculated by dividing 1RM values (kg) by their body mass (kg). Participants CMJ and DJ were evaluated using a photoelectric optical device (Optojump, Microgate, Bolzano, Italy). This measurement system has previously displayed low random errors (± 2.8 cm) and coefficients of variation (2.7%) (Glatthorn et al., 2011). Participants performed the CMJ whilst standing on a standardised surface between two photoelectric measurement bars with hands placed on their hips. Next, a countermovement action was undertaken by the participants using self-selected ankle, knee and hip flexion angles before jumping vertically as high as possible. When performing the DJ, participants began the jump standing on a 30 cm high step with their hands placed on their hips before stepping off and immediately jumping vertically as high as possible when contacting the ground. Here, participants were

instructed to jump to a maximal height while simultaneously minimising ground contact time.

GPS Monitoring. Participants' in-game workloads were recorded using 18 Hz GPS units (Apex, STATSports, Newry, UK). This model of GPS unit has previously demonstrated good accuracy whilst recording movements during team sport specific activity (Bias < 5.0%) (Beato et al., 2018). The participants were fitted with an appropriately sized custom vest to hold the GPS receiver. Each GPS unit was powered on 15-minutes before throw in and inserted into a slot towards the top of the fitted vest sitting in the upper back between the scapulae. A heart rate (HR) telemetry system (Polar Vantage, Polar Electro, Kempele, Finland) was placed around the chest to collect HR data. The data was then extracted from the GPS devices and downloaded using the STATSports analysis platform.

Statistical Analysis

Descriptive statistics using means and standard deviations (\pm SD) were calculated for all anthropometric characteristics, components of fitness and in-game workload measures. All data were normally distributed. Standard multiple regression analysis was performed to examine possible relationships between components of fitness and in-game workload measures. A median split divided players into higher-standard (HS) and lower-standard (LS) groups for each component of fitness significantly contributing to the multiple regression analysis. The selected measures were body fat (%), $\dot{V}O_{2\max}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), velocity at 2 $\text{mmol}\cdot\text{L}^{-1}$, velocity at 4 $\text{mmol}\cdot\text{L}^{-1}$, running speed (20 m) and DJ. Independent samples t tests and Cohen's effect size (ES) statistic were used to examine differences between HS and LS groups (Cohen, 2013). Effect sizes of >0.20, 0.20–0.60, 0.61–1.19, and >1.20 were considered trivial, small, moderate, and large respectively (Hopkins et al., 2009). All data were analysed using Statistical Package for Social Sciences

(SPSS Version 27, SPSS Inc, Chicago, IL, USA). Statistical significance was accepted at an alpha level of $p < 0.05$.

Results

Results of the multiple regression analysis are summarised in Table 5. 1 and the plots of actual versus predicted residuals are depicted in Figure 5. 2 and Figure 5. 3.

Table 5. 1. Multiple regression analysis summary.

Model predictors	Dependant variable	Adj. R ² (%)	<i>p</i> value
Body fat (%), DJ and velocity at 4 mmol·L ⁻¹	Total sprints (<i>n</i>) (≥ 5.5 m·s ⁻¹) (1 st half)	27.5	<0.001
	Total sprints (<i>n</i>) (≥ 5.5 m·s ⁻¹) (2 nd half)	26.8	<0.001
	Total sprints (<i>n</i>) (≥ 5.5 m·s ⁻¹) (Match)	39.8	<0.001
Relative squat strength and DJ	Total accelerations (<i>n</i>) (≥ 5.5 m·s·s ⁻¹) (1 st half)	17.2	0.007
	Total accelerations (<i>n</i>) (≥ 5.5 m·s·s ⁻¹) (2 nd half)	22.0	0.002
	Total accelerations (<i>n</i>) (≥ 5.5 m·s·s ⁻¹) (Match)	21.2	0.002
$\dot{V}O_{2\max}$ and body fat (%)	Total distance covered (m) (1 st half)	14.4	0.009
	Total distance covered (m) (2 nd half)	21.3	0.001
	Total distance covered (m) (Match)	22.4	0.001
Running speed (20 m), velocity at 2 mmol·L ⁻¹ and DJ	Total sprint distance (m) (≥ 5.5 m·s ⁻¹) (1 st half)	17.8	0.006
	Sprint distance (m) (≥ 5.5 m·s ⁻¹) (2 nd half)	21.2	0.002
	Total sprint distance (m) (≥ 5.5 m·s ⁻¹) (Match)	27.0	<0.001

Abbreviations; Adj: Adjusted, DJ: drop jump, $\dot{V}O_{2\max}$: maximal aerobic capacity,

1st half: first half of a match, 2nd half: second half of match; Match: full match.

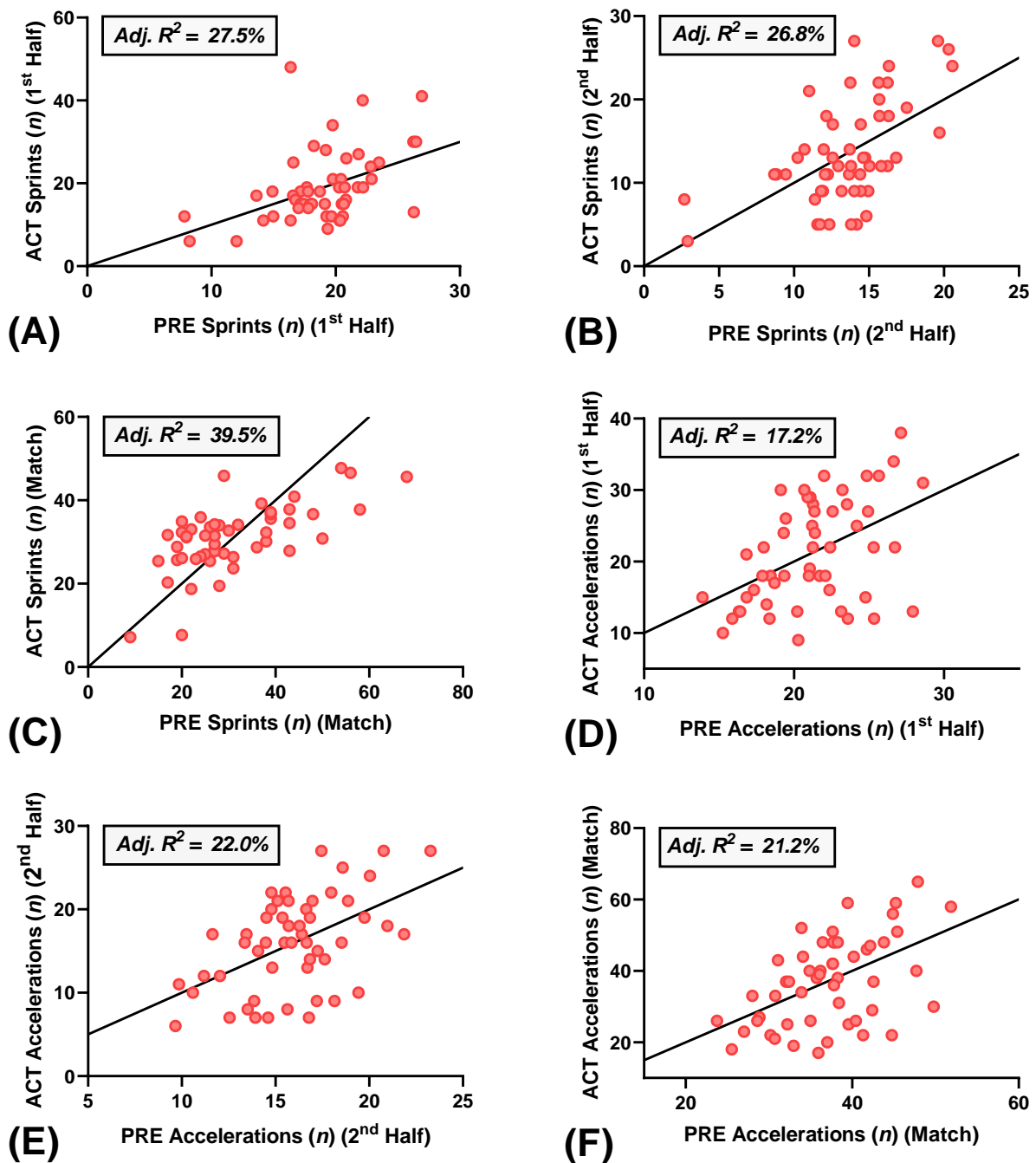


Figure 5. 2. Plot of actual (ACT) vs. predicted (PRE) values for the number of (A) 1st half sprints, (B) 2nd half sprints, (C) full match sprints, (D) 1st half accelerations, (E) 2nd half accelerations and (F) full match accelerations completed during match-play. Dependant variables for the number of sprints ($\geq 5.5 \text{ m}\cdot\text{s}^{-1}$): body fat (%), drop jump and velocity at $4 \text{ mmol}\cdot\text{L}^{-1}$. Dependant variables for the number of accelerations ($\geq 5.5 \text{ m}\cdot\text{s}\cdot\text{s}^{-1}$): running speed (20 m), velocity at $2 \text{ mmol}\cdot\text{L}^{-1}$ and DJ).

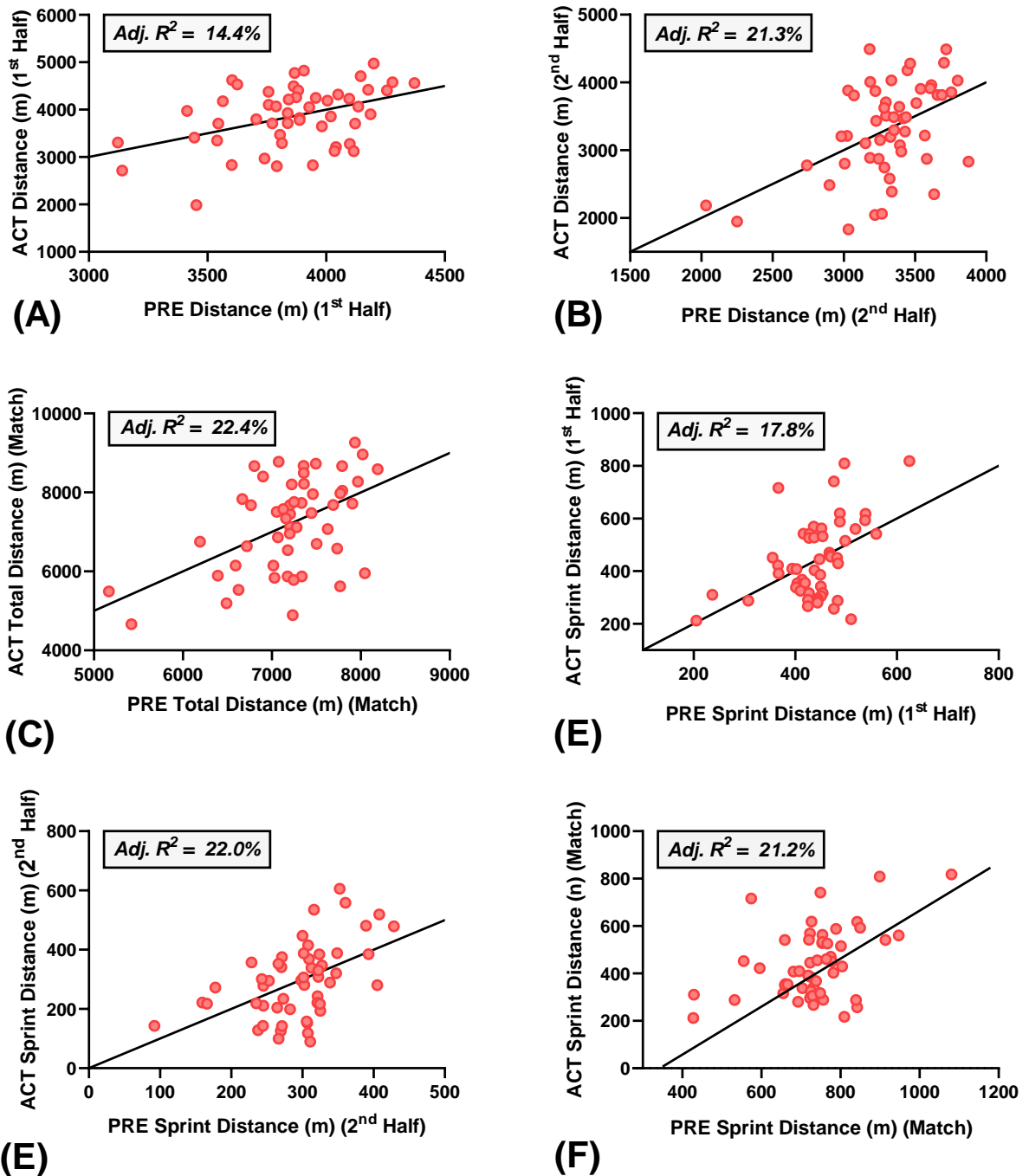


Figure 5. 3. Plot of actual (ACT) vs. predicted (PRE) values for (A) 1st half distance, (B) 2nd half distance, (C) full match distance, (D) 1st half sprint distance, (E) 2nd half sprint distance and (F) full match sprint distance covered during match-play. Total distance (m)

dependant variables: $\dot{V}O_{2max}$ and body fat (%). Sprint distance ($\geq 5.5 \text{ m} \cdot \text{s}^{-1}$) (m)

dependent variables: body fat (%), drop jump and 20 m running speed.

Table 2 shows the HS and LS descriptive variables for each component of fitness.

Table 5. 2. Descriptive results for each higher-standard and lower-standard group.

Component of Fitness	Higher standard	Lower standard
Body fat (%)	11.5 ± 2.0	17.5 ± 4.1
$\dot{V}O_{2max}$ (ml·kg ⁻¹ ·min ⁻¹)	57.4 ± 4.2	45.3 ± 3.8
Velocity at 2 mmol·L ⁻¹ (km·h ⁻¹)	11.2 ± 0.8	8.2 ± 0.4
Velocity at 4 mmol·L ⁻¹ (km·h ⁻¹)	14.4 ± 0.7	12.5 ± 0.8
Running speed (20 m) (s)	3.04 ± 0.04	3.18 ± 0.05
DJ (cm)	37.6 ± 2.5	29.7 ± 3.6

Abbreviations; DJ: drop jump, $\dot{V}O_{2max}$: maximal aerobic capacity.

The differences between HS and LS groups based off each component of fitness are shown in Figure 5. 4 and Figure 5. 5. When players were dichotomized into HS and LS velocity at 2 mmol·L⁻¹ groups, the HS group performed significantly more 1st half accelerations (ES = 0.76; $p = 0.008$), 2nd half accelerations (ES = 0.64; $p = 0.027$) and total accelerations (ES = 0.76; $p = 0.009$) than the LS group. Additionally, the HS velocity at 2 mmol·L⁻¹ group covered significantly larger 1st half sprint distances (ES = 0.62; $p = 0.031$) and performed significantly more 1st half sprints (ES = 0.88; $p = 0.003$), 2nd half sprints (ES=0.86; $p=0.003$) and total sprints (ES = 0.95; $p < 0.001$) when compared to the LS group. When players were divided into HS and LS velocity at 4 mmol·L⁻¹ groups the HS group performed significantly more total sprints (ES = 0.68; $p = 0.015$) than the LS group. When players were divided into HS and LS $\dot{V}O_{2max}$ groups the HS group covered significantly greater 1st half distances (ES = 0.56; $p = 0.048$) and total distances (ES = 0.57; $p = 0.045$) when compared to the LS group.

When players were divided into HS and LS body fat (%) groups, the HS group covered significantly greater 2nd half distances (ES = 0.75; $p = 0.038$), total distances (ES = 0.67; $p = 0.20$), 1st half sprint distances (ES = 0.58; $p = 0.042$) and total sprint distances

(ES = 0.59; $p = 0.038$) in comparison to the LS group. Additionally, players in the HS body fat (%) group performed significantly more 2nd half sprints (ES = 0.77; $p = 0.008$) and total sprints (ES = 0.71; $p = 0.014$) when compared to the LS group. Furthermore, when players were split into HS and LS 20 m running speed groups, the HS group performed significantly more accelerations during the 1st half (ES = 0.74; $p = 0.011$), 2nd half (ES = 0.60; $p = 0.035$) and full game (ES = 0.72; $p = 0.013$) when compared to the LS group. Finally, when players were dichotomized into HS and LS DJ groups, players in the HS group performed significantly more 2nd half sprints (ES = 0.57; $p = 0.047$) than the LS group.

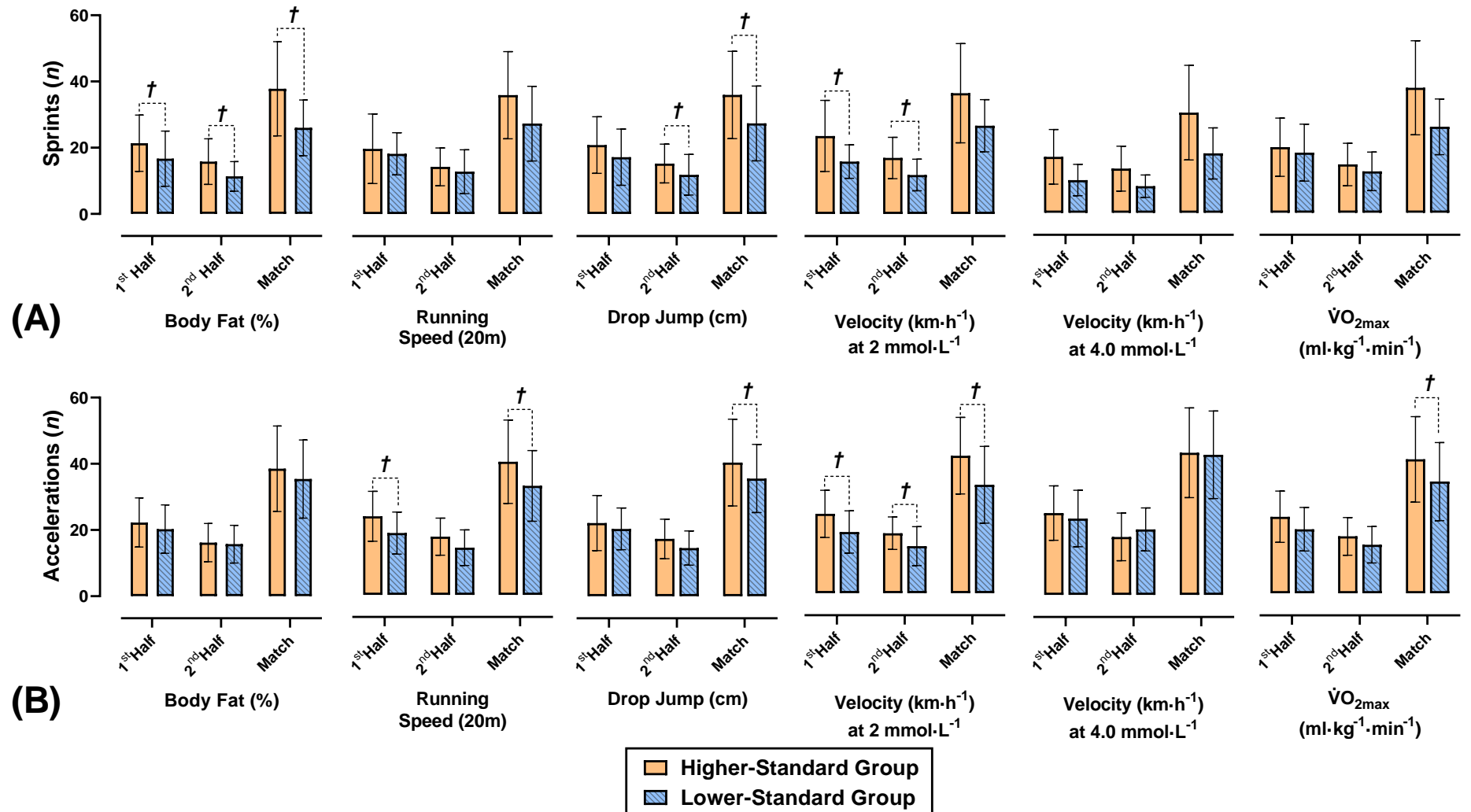


Figure 5. 4. Differences in the number of accelerations (A) and sprints (B) completed during match-play between higher-standard (HS) and lower-standard (LS) component of fitness groups. † Denotes a significant difference between HS and LS groups.

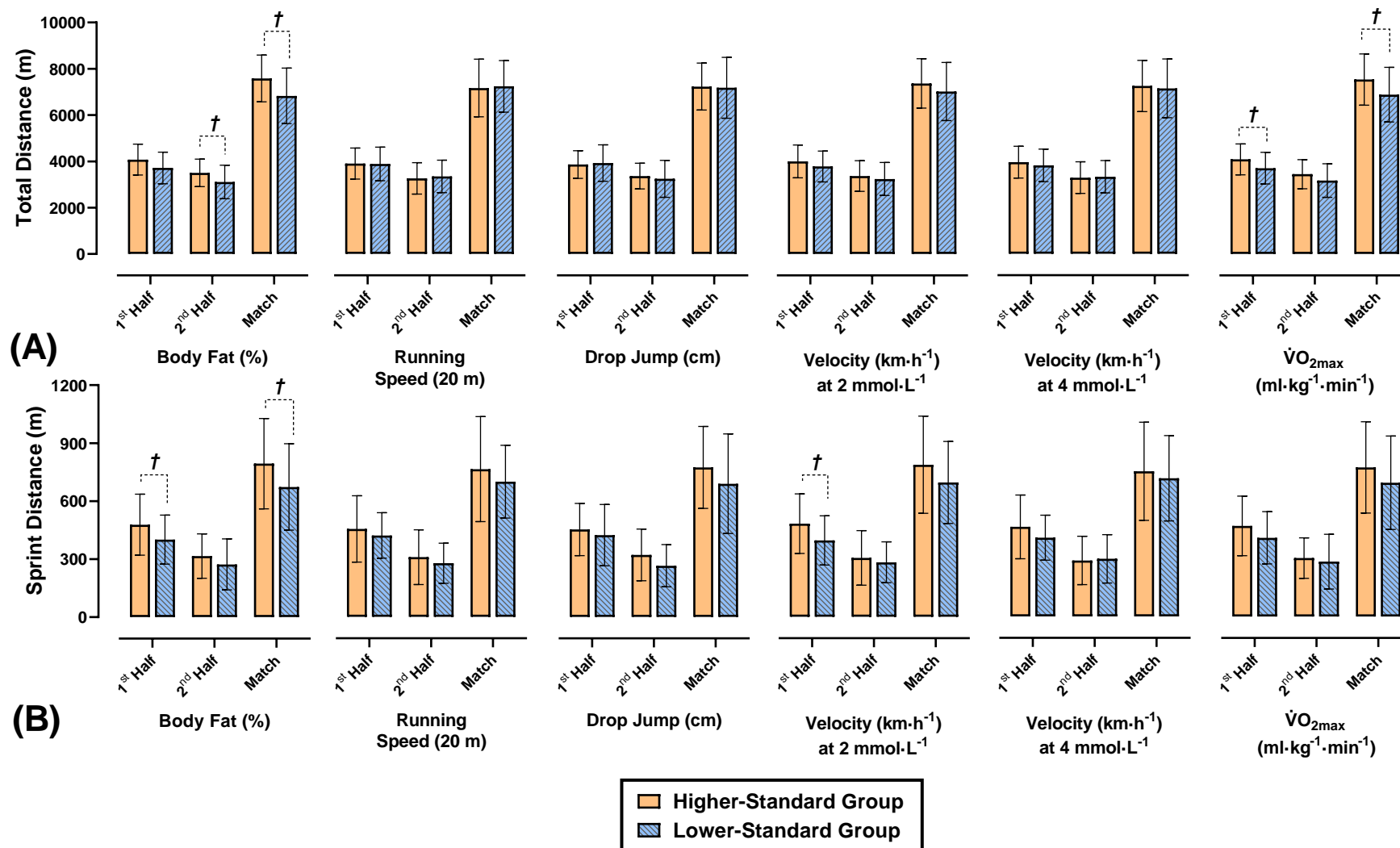


Figure 5. 5. Differences in total distance covered (A) and sprint distance covered (B) during match-play between higher-standard (HS) and lower-standard (LS) component of fitness groups. † Denotes a significant difference between HS and LS groups.

Discussion

The current study aimed to investigate the influence of Gaelic football players body composition and markers of physical conditioning on in-game workload measures. Complimenting research in similar team sports (Dujic et al., 2016, Johnston et al., 2015a, Aquino et al., 2020), our data demonstrates that a wide range of components of fitness have a significant impact on external load measures during competitive match-play.

Similar to previous results in soccer (Krustrup et al., 2005), blood lactate responses were identified as a good indicator of the number of accelerations and sprints completed and the sprint distance covered during competitive match-play in the present analysis (Table 5. 1). Capacity to perform these high-intensity tasks are often crucial for team sport performance; possibly serving as a surrogate measure of successful contests for possession, entering space during scoring opportunities, defensively tracking opposition players movements and coping with fast-paced and potentially evolving tactical requirements (Granero-Gil et al., 2020, Augusto et al., 2021, Mangan et al., 2020). Moreover, when players were divided into HS and LS groups based on running velocity at $2 \text{ mmol}\cdot\text{L}^{-1}$, the HS groups performed significantly more accelerations and sprints during match-play than the LS groups, which corresponds with previous work in ice hockey (Green et al., 2006). Equivalent associations were also reported in female soccer players, where lactate responses were significantly correlated with high-intensity running distances during simulated (Sirotic and Coutts, 2007) and elite competitive match-play (Krustrup et al., 2005).

Other markers of aerobic function displayed comparable trends in the present analysis, whereby well-developed $\dot{V}O_{2\text{max}}$ (in combination with body fat [%]) significantly contributed to regression models associated with total distance covered during match-play.

Furthermore, when players were dichotomised into groups using higher and lower $\dot{V}O_{2\max}$ scores, the HS $\dot{V}O_{2\max}$ group covered significantly greater total distances when compared to their LS group counterparts, which is consistent with work in rugby league using a similar analysis (Johnston et al., 2015a). These collective observations present evidence that aerobic capacity plays a fundamental role in the considerable running demands undertaken during team sport match-play. In line with this concept, aerobic capacity was positively associated with total distance, high speed running distance and high-intensity efforts during rugby league (Johnston et al., 2015b), Australian rules (Young and Pryor, 2007) and soccer (Aquino et al., 2020) match-play respectively. Furthermore, well-developed aerobic conditioning and blood lactate response have been reported to accelerate metabolite clearance, improve phosphocreatine resynthesis and reduce the metabolic and cardiovascular strain associated with recurrent high-intensity running (Kelly et al., 2018a, da Silva et al., 2010) possibly helping to explain the present findings. More specifically, energy for these high-intensity actions are supplied by anaerobic metabolism resulting in lactate formation, hydrogen ion accumulation, pH reduction and the depletion of adenosine triphosphate phosphocreatine stores paralleled with inorganic phosphate increases (Kelly et al., 2018a, Bogdanis et al., 1996a, Stone and Kilding, 2009). In response to these disruptions, oxidative phosphorylation is a necessary process to achieve adequate recovery prior to the next bout of intense work during match-play and this mechanism is enhanced in aerobically fitter athletes (da Silva et al., 2010, Bogdanis et al., 1996a). Overall, many possible adaptations associated with well-developed aerobic function and/or blood lactate responses, such as increased muscle capillarization, mitochondrial volume and density and oxidative enzyme activity could have possibly contributed to the present results (Stone and Kilding, 2009, da Silva et al., 2010, Kelly et al., 2021).

Similar to prior research in soccer (Meir et al., 2001), body fat percentage was negatively associated with the number of sprints and accelerations completed and the total and sprint distance covered. Body composition exerts an important influence on players game-specific work capacity, as excess adipose tissue can increase mechanical and metabolic strain by adding unnecessary resistance against the forces of gravity during movements such as jumping, running or changes of direction (Reeves and Collins, 2003, Meir et al., 2001). In addition to the energy cost of bearing a larger body mass over the course of a match, it is possible that excessive adipose tissue in Gaelic football could impair thermoregulatory function by impeding players capacity to transport and dissipate metabolically generated body heat, thereby potentially disrupting thermal balance (Meir et al., 2001, Morrissey et al., 2021). In support of this notion, it is commonly reported that inter-county level players possess lower-body fat percentages than their club and/or collegiate counterparts in Gaelic football (Keane et al., 1997) and within other team sports (Gabbett et al., 2009, Keane et al., 2021). Considering the potential overlap in training adaptations associated with improving body composition, blood lactate responses and aerobic conditioning, programming strategies to increase these attributes in tandem with the goal of improving players work capacity may possibly be employed with relatively minimal physiological interference (Wilson et al., 2012). That being said, the multifaceted physical demands of Gaelic football match-play imply that other components of fitness such as strength, power and running speed may also moderate players external match-play loads as has been reported previously in other team sports (Johnston et al., 2015a, Aquino et al., 2020, Silva et al., 2015).

Although movement patterns during invasive team sports such as Gaelic football are predominantly low-intensity in nature, explosive stretch shortening cycle actions imposing high mechanical tension regularly occur at pivotal moments of a game (Malone

et al., 2017d, Mangan et al., 2020). As a consequence of such taxing neuromuscular demands, muscular strength and power are commonly acknowledged as important attributes for team sport performance (Owen et al., 2015, Kelly and Collins, 2018, Johnston et al., 2015a). Indeed, measures of maximal force and power generating capacity have been previously related to in-game workload measures such as running speed and the number of sprints/accelerations completed in rugby league (Johnston et al., 2015b). Our data supports these findings, whereby DJ was found to be a significant contributor to the number of sprints and accelerations performed by players. A high DJ score necessitates well-developed neuromuscular characteristics and an ability to rapidly produce a large amount of force (Young et al., 1995a). Furthermore, players with a highly-developed DJ may express a greater capacity to undertake intense eccentric based movements during match-play, possibly due to a number of physiological mechanisms associated with superior jump characteristics (Young et al., 1995a). Therefore, coaches may select the development of players lower-body power as an effective means to increase high intensity running indices and the capacity to perform numerous accelerations during competitive matches. In agreement with prior work (Pedersen et al., 2021), the current analysis reported that players in the HS 20 m running speed group performed significantly more accelerations during match-play than their LS group counterparts. Based on this data, the number of sprints and accelerations recorded during competitive Gaelic football match-play appear to be adjusted depending on players baseline DJ and 20 m running speed values. Consequently, implementing training processes to develop these performance attributes may deliver a high transfer efficacy for Gaelic football specific tasks and subsequently promote players external workloads, and ultimately performance.

Taken together, the findings of this study provide evidence that Gaelic football players competitive running and acceleration profiles are influenced by their physical

conditioning markers. Lower-body power, running speed, body composition, aerobic capacity and blood lactate responses are of particular importance which is complementary to findings in other team sports (Aquino et al., 2020, Krstrup et al., 2005, Green et al., 2006). Furthermore, when players were dichotomised into HS and LS groups based off these conditioning markers, the HS groups almost always performed more external work than the LS groups. In combination with our preliminary research, these findings suggest that players with well-developed components of fitness express comparatively lower fatigue and muscle damage responses, even despite undertaking larger external loads during competition than their less physically conditioned counterparts. This data may improve coaches understanding of the complex interactions between physical conditioning and in-game workload measures, thereby providing relevant guidance for effective training programme design intent on increasing sport-specific work capacity. Despite promising findings as to the role of physical conditioning in the determination of game-based workloads, this data is most relevant to the population studied and limitations may exist applying this research in female players or in other team sport athletes. Additionally, while the present data collection was undertaken across multiple teams and matches to present high ecological validity; it is important to note that differences in opposition, pitch and weather conditions, match outcome and other potential elements arising from the design of this study should be considered when interpreting results. Finally, future research assessing relationships between players physical conditioning attitudes and coaches subjective scoring of match performance would provide beneficial information for a more sport-specific outlook when viewed in conjunction with the current work.

Conclusion

The numerous physical, tactical and technical components that govern successful Gaelic football match-play make effective preparation for the sports demands a complex task. Our results reflect the multifaceted physical and metabolic loads players face during match-play, highlighting a significant influence of body composition, running speed, muscular power and aerobic conditioning on players competitive workload measures. From a programming perspective, concurrent endurance training to develop players markers of aerobic function combined with strength and/or power training to target the neuromuscular system will likely translate into increased external workloads. Importantly, considering the divergence in physiological and metabolic responses to strength and aerobic exercise; it is essential to appropriately periodise training variables to best enable functional compatibility and reduce any potential interference effects in desired physiological adaptations (Wilson et al., 2012). Furthermore, coaches should aim for high transferability from training induced adaptations to meet the specific mechanical, metabolic and technical demands of Gaelic football match-play. This may be best achieved using appropriate training strategies that drive physical conditioning adaptations during the general preparatory phases of the season, while limiting disruptive magnitudes of fatigue and muscle damage during the competitive in-season period.

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Section Link

The results of the prior studies demonstrate that physiological attributes positively influence in-game workloads measures and highlight the need to assess the influence of specific physical conditioning parameters on the performance attenuation and recovery response. Indeed, physical conditioning parameters may similarly adjust players psychophysiological and performance responses during and following match-play as demonstrated in rugby league (Johnston et al., 2015b, Johnston et al., 2015a) and soccer (Owen et al., 2015) player's. While no such work yet exists in Gaelic games, data in any team sport is generally sparse with little to no research investigating the influence of a range of components of fitness (such as running economy, power, body composition and running speed) on performance attenuation and recovery. From a practical perspective, understanding these interactions could provide valuable insight for coaches who seek to tailor player's training programmes with the goal of specifically developing physiological attributes that protect against performance attenuation and subsequent perceptual, neuromuscular and biochemical disturbances following training or match-play. With this in mind, the following chapter sought to build on the previous studies findings. In particular, this work will focus on how a range of physiological and performance attributes moderate various markers of performance attenuation and recovery in Gaelic football players.

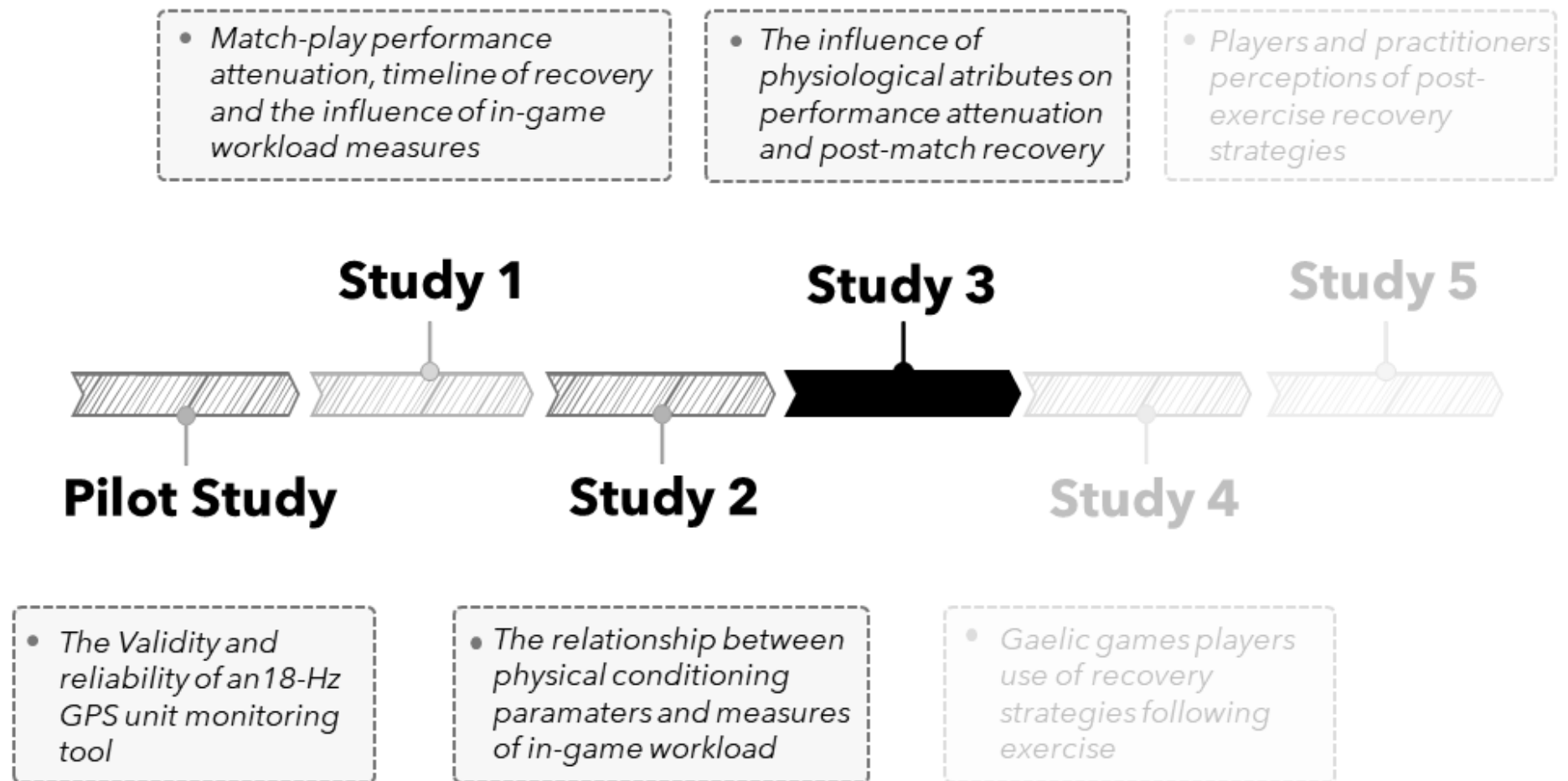


Figure 5. 6. Thesis timeline infographic highlighting study 3

Chapter 6 – Study 3

Does Physical Conditioning Influence Performance Attenuation
and Recovery in Gaelic Football?

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Abstract

Purpose: This study investigated the influence of Gaelic football players components of fitness on measures of performance attenuation and recovery during and following competitive match-play.

Methods: Measurement of player's anthropometric characteristics, short distance running speed, lower-body strength and power, blood lactate concentrations, running economy and aerobic capacity ($\dot{V}O_{2\max}$) were taken over two separate days prior to a competitive match. Creatine kinase, drop jump height, contact time, reactive strength index, countermovement jump height and perceptual responses were tested pre-match, at full-time, 24-h post-match and 48-h post-match.

Results: Multiple components of fitness were associated with reduced performance attenuation and improved recovery responses (Adjusted R^2 9.8% to 27.6%; $p < 0.05$). Players were divided into higher-standard and lower-standard $\dot{V}O_{2\max}$ (Higher-standard: $57.4 \pm 4.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; Lower-standard: $45.3 \pm 3.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) groups. After adjusting for differences at baseline, there were significant differences between $\dot{V}O_{2\max}$ groups in drop jump (5.3% to 5.8%; $\eta_p^2 = 0.078$ to 0.154 ; $p < 0.05$) and countermovement jump height (4.9%; $\eta_p^2 = 0.134$; $p < 0.05$) where the lower-standard group expressed larger decrements. Additionally, players were divided into higher-standard and lower-standard relative squat (Higher-standard: $1.46 \pm 0.11 \text{ 1RM kg/BM}$; Higher-standard: $1.20 \pm 0.08 \text{ 1RM kg/BM}$) groups. Here, there were significant differences between relative squat groups in contact time (15.8% to 25.1%; $\eta_p^2 = 0.156$ to 0.194 ; $p < 0.05$), reactive strength index (21.5% to 25.6%; $\eta_p^2 = 0.127$ to 0.223 ; $p < 0.05$) and perceptual responses (6.3%; $\eta_p^2 = 0.152$; $p < 0.05$) where the lower-standard group expressed larger decrements.

Conclusions: Coaches should prioritize the development of players aerobic capacity and neuromuscular function as a primary method of reducing performance attenuation and enhancing recovery kinetics in Gaelic football.

Introduction

Gaelic football is a physically demanding contact team sport indigenous to Ireland (Reilly and Doran, 2001). The game is characterized by intermittent and short duration high-intensity actions interspersed with light aerobic activity (Reilly and Doran, 2001, Malone et al., 2017d). While the sport requires significant aerobic energy provisions to cover large distances (6 – 11 km), a broad range of components of fitness are essential to undertake frequent high-intensity efforts of sprinting, changes of direction, rapid accelerations/decelerations, tackling and contesting for possession (Malone et al., 2017d). These demands inevitably result in a multifaceted fatigue and muscle damage response, modulated by numerous physiological, psychological and metabolic processes (Silva et al., 2018). Well-developed components of fitness are necessary to cope with the intense physical demands of Gaelic football match-play and training across the competitive season (Reilly and Doran, 2001) as match-play results in immediate and prolonged neuromuscular, perceptual and biochemical disturbances. More specifically, 48-h following match-play is sufficient to restore neuromuscular and perceptual measures but not biochemical measures of players (Daly et al., 2020). Owing to the competitive schedules of Gaelic football players, an adequate post-match recovery time period may not always be afforded between successive training sessions/matches (Kelly et al., 2021).

While well-developed components of fitness have been associated with reduced fatigue and muscle damage in team sports such as soccer and rugby league (Norris et al., 2019, Owen et al., 2015, Johnston et al., 2015a); Gaelic football's distinctive match-play demands, recovery profiles and the sports amateur status may yield different results (Johnston et al., 2015b, Silva et al., 2018, McLean et al., 2010a, Hunkin et al., 2014). The progressive and significant declines in workloads recorded during Gaelic football match-

play elude to the impact of accumulated fatigue and subsequent performance attenuation (Malone et al., 2017d). Gaelic Football players are exposed to considerable demands during match-play and this likely causes significant central and peripheral fatigue, manifesting through metabolite accumulation, reduced muscle contractility potential, impaired nervous system control and depleted glycogen stores (Malone et al., 2017d, Daly et al., 2020). In addition to the acute demands surrounding competitive match-play, Gaelic football players have been reported to regularly participate in congested match and training schedules over extended periods, oftentimes in combination with multi-team and multi-sport commitments during the season (O'Keeffe et al., 2020, Kelly et al., 2018a). Many possible factors may influence Gaelic football players capacity to cope with these acute and longitudinal demands, such as sleep quantity and quality, nutritional status and physical conditioning attributes (Halson, 2014, Owen et al., 2015).

The influence of anthropometric characteristics, neuromuscular function, running economy, blood lactate responses and aerobic capacity on markers of performance attenuation and recovery in Gaelic football is currently unknown. Well-developed aerobic capacity has been associated with reduced biochemical disturbances in Australian rules (Hunkin et al., 2014), while positively influencing the restoration of neuromuscular function in rugby league (Johnston et al., 2015b). Athletes with a greater aerobic capacity are reported to endure lower metabolic disturbances following frequent bouts of high-intensity running when compared to their less conditioned counterparts, consequently limiting fatigue and subsequent performance attenuation (Johnston et al., 2015a, Johnston et al., 2015b). Although more speculative due to a lack of research, other markers of endurance performance, such as lactate threshold and running economy, may yield similar benefits in limiting performance attenuation and accelerating recovery kinetics. Additionally, well-developed lower-body strength is suggested to attenuate neuromuscular

fatigue and muscle damage, and has also been associated with reduced biochemical disturbances (Johnston et al., 2015b, Owen et al., 2015). Due to the physiological and biomechanical similarities in the training induced adaptations between muscular strength, power and short distance running speed, these neuromuscular-related performance measures may also have a mediative effect on neuromuscular and biochemical marker disturbance subsequent to match-play (Owen et al., 2015, Nicol et al., 2006). Detailing the influence of different components of fitness on match-day performance attenuation and the post-match recovery cycle has many important implications for performance profiling and training programme design in Gaelic football. While advanced physical conditioning has been suggested to moderate fatigue and muscle damage in other team sports (Hunkin et al., 2014, Johnston et al., 2015b), the unique demands of Gaelic football may provoke different responses, thus warranting further investigation. Therefore, this study aims to examine the influence of components of fitness on markers of fatigue and muscle damage following Gaelic football match-play.

Methods

Design

A familiarization session was used to explain the testing procedures to the participants prior to data collection. During visit 1, participants height, body mass, skinfolds, maximal squat strength, blood lactate concentrations (BLa), RE and maximal aerobic capacity ($\dot{V}O_{2max}$) were assessed (Figure 6. 1). Visit 2 was used to test participants' drop jump height (DJ), countermovement jump height (CMJ), 5 m and 20 m running speed and maximal hip thrust strength. Participants' peri-match neuromuscular, perceptual and biochemical markers were monitored (pre-match, full-time, 24-h post-match and 48-h post-match) during visits 3, 4 and 5. In order to facilitate a high degree of ecological validity, a maximum of 4 players were tested during one game, with participants recruited from a convenience-based sample of 5 Gaelic football teams currently participating at senior club level. During the match-day data collection, participants pre-match assessments were taken within a 10-minute period immediately prior to each games throw in, while participants full-time assessments were taken within 10-minutes of each games cessation. Lastly, readers should be aware that the match and post-match testing measures employed in this study are similar to those outlined in the methods section of study 1, whilst the baseline testing measures are similar to those outlined in the methods section of study 2.

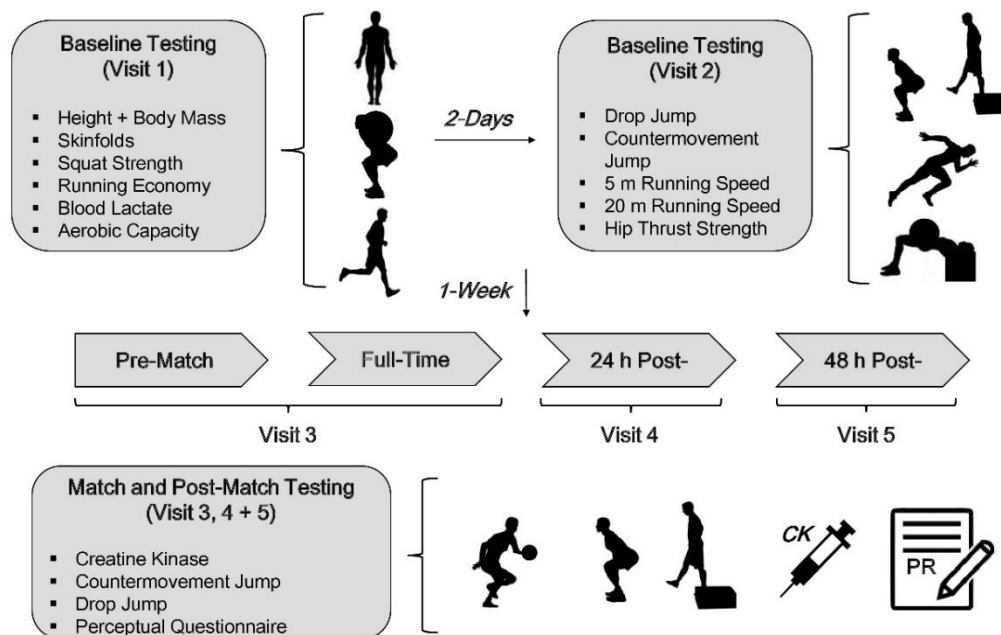


Figure 6. 1. Schematic overview of the study design.

Participants

Fifty-two healthy and physically active male participants (mean \pm SD, age: 22.9 \pm 3.8 years; stature: 179.2 \pm 7.55 cm, sum of seven skinfolds: 83.2 \pm 26.1) between 18 – 32 years of age currently playing Gaelic football at senior club-level volunteered to participate in the study. Each recruited participant had played Gaelic football for a minimum of 3-years at adult-level and had at least 2-years of resistance training experience. Informed consent was acquired from all participants and ethical approval for this research was granted by the Technological University of the Shannon Research Ethics Committee (code 20180501).

Anthropometric Characteristics and Body Composition

Height and body mass were measured to the nearest 0.1 cm and 0.1 kg respectively, using a portable stadiometer and scales (Seca 707 Balance Scales, Germany). Skinfold thickness was measured at 7 anatomical sites (midaxillary, biceps, chest, abdomen, thigh,

subscapular and triceps) using handheld Skinfold callipers (Baty International Ltd., UK) using methods described previously (Daly et al., 2020). To calculate participants' body fat percentage, the equation of Withers et al. (1987) ($\% \text{ BF} = 495 / (1.0988 - 0.0004 \times [\text{sum of 7 skinfolds}]) - 450$) was used.

Running Speed

Running speed was assessed over 5 m and 20 m using photoelectric cells (Brower Timing Systems, USA). Participants were instructed to start by putting forward their dominant foot, which was placed 50 cm back from the starting line. Timing gates were placed at the starting line, 5 m line and the 20 m line.

Running Economy, Blood Lactate Responses and Aerobic Capacity

Participants RE and $\dot{V}O_{2\text{max}}$ were quantified using a Moxus metabolic cart (AEI Technologies, USA) on a motorized treadmill (HP Cosmos, Germany). Participants completed an incremental incline ramp protocol using methods previously outlined (Kelly et al., 2018a). Following a warm-up at $8 \text{ km} \cdot \text{h}^{-1}$ for 3-minutes at a 1% gradient, the speed of the treadmill was increased by $1 \text{ km} \cdot \text{h}^{-1}$ after every 3-minute stage until the participant's BLa reached $4.0 \text{ mmol} \cdot \text{L}^{-1}$ or higher. Next, the treadmill was set to a constant speed of $10 \text{ km} \cdot \text{h}^{-1}$ with a 4% gradient, increasing by 1% every minute until the participant reached volitional exhaustion. Participant's heart rate was measured using a watch and chest strap (Polar Vantage, USA). Expired CO_2 , expired O_2 , ventilatory volume and rate of perceived exertion (RPE) were logged continuously throughout the test. RE and $\dot{V}O_{2\text{max}}$ were reported in $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ (Kelly et al., 2018a).

Lower-body Strength

Participants undertook one repetition maximum (1RM) testing using the same incremental protocol as Baechle and Earle (2008) to assess maximal squat and hip thrust strength values. The 1RM was recorded as the maximum resistance (kg) lifted successfully through the criterion full range of motion (whereby the crease of the hip descended below the top of the knee) with good form as determined by the lead researcher (Baechle and Earle, 2008). Participants relative squat and relative hip thrust strength values were calculated by dividing the 1RM (kg) value by their body mass (kg).

Countermovement Jump and Drop Jump

The DJ and CMJ were performed and recorded using a photoelectric optical measurement device and accompanying software (Optojump, Microgate, Italy). CMJ and DJ testing was completed using the same protocol as methods previously described. (Daly et al., 2020) During the CMJ, participants stood on a standardised surface between two photoelectric measurement bars with hands placed on their hips. Next, participants performed a countermovement action using a self-selected hip, knee and ankle flexion angle before immediately jumping vertically to a maximum height. During the DJ, participants stood on a 30 cm high step with their hands placed on their hips before stepping off using their dominant foot first (both feet landing on the floor simultaneously) and then immediately jumping vertically as high as possible. Participants were instructed not to lift their centre of gravity during the step off phase and to jump to a maximal height while minimising ground contact time. (Daly et al., 2020) The average of 3 jump attempts was used to monitor responses to match-play as this has been reported as a more sensitive indicator of neuromuscular status when compared to the highest of 3 attempts (Claudino et al., 2017a). In contrast, the best of 3 jump attempts was used to determine players

performance characteristics during baseline component of fitness testing (Figure 6. 1: visit 2). Players reactive strength index (RSI) values were calculated by dividing the DJ height jumped in metres by the ground contact time (CT) in seconds (Daly et al., 2020).

Perceptual Responses

A 5-question Likert scale questionnaire was chosen to assess the participants' perceptual responses (PR) (McLean et al., 2010a). This questionnaire was developed by McLean et al. (2010a) using a Likert scale system of responses and designed according to the recommendations of (Hooper and Mackinnon, 1995). The questionnaire involved 5-questions assessing participants sleep quality, fatigue, muscular soreness, stress level and mood with a 1 to 5 graded Likert scale structure (Joshi et al., 2015, McLean et al., 2010a). The questionnaire was administered and assessed as described previously (Daly et al., 2020). This model of Likert scale questionnaire has been reported as valid in measuring perceived muscle soreness (Vickers, 1999) and other perceptual markers associated with fatigue, stress or muscle damage (Ryan et al., 2019).

Creatine Kinase

Concentrations of participants' creatine kinase (CK) were obtained from capillary blood via a finger-prick (32 μ L) (Zhang et al., 2011a) and analysed by means of a colorimetric assay (Reflotron Plus, Roche Diagnostics, Germany). Testing, strip storage and calibration were completed according to the manufacturers' specifications. (Zhang et al., 2011a).

Statistical Analysis

Descriptive statistics using mean and standard deviation (\pm SD) were calculated for all anthropometric and component of fitness measures. Multiple regression analysis was

used to establish associations between components of fitness and measures of performance attenuation and recovery (PR, CK, DJ, RSI, CMJ and CT) at each timepoint. The multiple regression analysis and previous research guided the selection of two components of fitness with the largest influence on measures of performance attenuation and recovery. (Johnston et al., 2015b, Owen et al., 2015) A median split dichotomised higher-standard (HS) and lower-standard (LS) groups for the two selected components of fitness ($\dot{V}O_{2\max}$ [$\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$] and relative squat [kg/BM]). Analysis of covariance (ANCOVA) with Bonferroni post hoc analysis and partial eta squared (η_p^2) were used to examine any differences between groups in measures of performance attenuation and recovery at full-time, 24-h post-match and 48-h post-match using baseline pre-match values as covariates (Vickers, 2001). Changes in measures of performance attenuation and recovery in each group were investigated using repeated measures analysis of variance (ANOVA) and Cohen's effect size (ES) statistic (Cohen, 2013, Vickers, 2001). Effect sizes of >0.20 , $0.20\text{--}0.60$, $0.61\text{--}1.19$, and >1.20 were considered trivial, small, moderate, and large respectively (Hopkins et al., 2009). Statistical analysis was undertaken on raw data while percentage changes from baseline values were plotted in Figure 6. 2 and Figure 6. 3. All data were analysed using Statistical Package for Social Sciences (SPSS Version 27, SPSS Inc., Chicago, IL, USA). Statistical significance was accepted at an alpha level of $p < 0.05$.

Results

The results of the multiple regression analysis are summarised in Table 6. 1. Differences in responses between HS and LS $\dot{V}O_{2\max}$ groups (HS: $57.4 \pm 4.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; LS: $45.3 \pm 3.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) are plotted in Figure 6. 2. After adjusting for differences at pre-match baseline, there were significant differences in DJ between groups at 24-h post-match ($F_{(1,48)}4.155$; $\eta_p^2 = 0.078$; $p = 0.047$) and 48-h post-match ($F_{(1,49)}8.906$; $\eta_p^2 = 0.154$; $p = 0.004$). There were also significant differences in CMJ between groups at 48-h post-match ($F_{(1,49)}7.551$; $\eta_p^2 = 0.134$; $p = 0.004$).

Table 2 displays the HS and LS $\dot{V}O_{2\max}$ groups peri-match neuromuscular, biochemical and perceptual responses at each timepoint. Both the HS and LS groups displayed significant CK elevations at all post-match timepoints when compared to pre-match values ($p < 0.05$). PR were significantly lower in both groups at full-time and 24-h post-match when compared with baseline values ($p < 0.05$). DJ and CMJ were significantly lower at 24-h post-match for both groups compared with pre-match values ($p < 0.05$). At 48-h post-match, CMJ and DJ remained significantly lower at 48-h post-match in the LS group only when compared with pre-match values ($p < 0.05$).

Table 6. 1. Summary of multiple regression analysis.

Model contributors	Dependant variable	Adjusted R² (%)	p value
Relative squat and RE ($\dot{V}O_2$ at 10 km·h ⁻¹)	RSI (full-time)	19.6	0.002
	RSI (24-h post-match)	19.0	0.002
	RSI (48-h post-match)	12.0	0.032
Relative squat and DJ	CT (full-time)	12.9	0.014
	CT (48-h post-match)	11.1	0.021
Relative squat and CMJ	CT (24-h post-match)	25.5	<0.001
DJ, CT and 20 m running speed	PR (full-time)	19.5	0.013
Relative squat and 20 m running speed	PR (24-h post-match)	27.6	0.001
	PR (48-h post-match)	16.3	0.013
$\dot{V}O_{2max}$ and RE ($\dot{V}O_2$ at 10 km·h ⁻¹)	CK (24-h post-match)	14.2	0.002
$\dot{V}O_{2max}$ and RE ($\dot{V}O_2$ at 8 km·h ⁻¹)	CK (48-h post-match)	9.8	0.017

Abbreviations; CK: creatine kinase, CT: contact time, DJ: drop jump, PR: perceptual responses, RE: running economy and RSI: reactive strength index.

Table 2. Differences in markers at each timepoint between higher-standard and lower-standard $\dot{V}O_{2max}$ and relative squat groups.

Marker at each timepoint	HS and LS groups responses							
	HS $\dot{V}O_{2max}$ (n = 26)	ES	LS $\dot{V}O_{2max}$ (n = 26)	ES	HS Relative squat (n = 26)	ES	LS Relative squat (n = 26)	ES
CK (μL)								
Pre-match	318.3 \pm 207.5		223.3 \pm 91.4		270.9 \pm 147.6		270.7 \pm 185.3	
Full-time	406.3 \pm 221.1 **	0.41	330.7 \pm 116.4 **	1.03	388.4 \pm 177.0 **	0.72	383.6 \pm 171.3 ***	0.63
24-h post-match	590.1 \pm 291.9 ***	1.07	655.3 \pm 293.5 ***	1.99	672.6 \pm 283.5 ***	1.78	744.9 \pm 198.2 ***	2.47
48-h post-match	417.5 \pm 229.6 **	0.45	432.9 \pm 212.1 ***	1.28	446.3 \pm 210.6 **	0.96	483.8 \pm 205.2 ***	1.09
CMJ (cm)								
Pre-match	33.8 \pm 5.3		32.8 \pm 5.1		34.9 \pm 4.2		31.7 \pm 5.6	
Full-time	33.1 \pm 5.6	0.13	31.3 \pm 5.4	0.25	33.9 \pm 4.9	0.21	30.0 \pm 5.8	0.30
24-h post-match	32.1 \pm 5.2 **	0.32	29.9 \pm 6.2 **	0.50	32.7 \pm 5.8 *	0.43	28.8 \pm 5.6 **	0.52
48-h post-match	33.6 \pm 4.9	0.04	31.1 \pm 5.3 **	0.32	33.9 \pm 5.0	0.22	30.7 \pm 5.5	0.18
DJ (cm)								
Pre-match	32.8 \pm 5.3		33.2 \pm 5.2		34.2 \pm 5.0		31.8 \pm 5.2	
Full-time	32.6 \pm 5.7	0.04	31.4 \pm 6.1	0.32	33.2 \pm 5.9	0.18	30.6 \pm 6.7	0.20
24-h post-match	31.4 \pm 5.5 **	0.27	30.0 \pm 5.9 **	0.57	32.0 \pm 5.6 **	0.41	29.0 \pm 5.7 **	0.51
48-h post-match	32.9 \pm 5.4	0.02	31.3 \pm 5.3 **	0.37	33.2 \pm 5.5	0.19	30.8 \pm 5.6	0.19
CT (s)								
Pre-match	0.35 \pm 0.11	0.12	0.37 \pm 0.11		0.33 \pm 0.10		0.40 \pm 0.11	
Full-time	0.35 \pm 0.12	0.40	0.41 \pm 0.16	0.29	0.31 \pm 0.10	0.20	0.45 \pm 0.14	0.45
24-h post-match	0.41 \pm 0.18	0.17	0.40 \pm 0.17	0.21	0.31 \pm 0.13	0.17	0.49 \pm 0.17 *	0.63
48-h post-match	0.37 \pm 0.13		0.39 \pm 0.13	0.17	0.32 \pm 0.14	0.08	0.46 \pm 0.11 *	0.55
RSI								
Pre-match	1.05 \pm 0.41	0.00	1.00 \pm 0.31		1.18 \pm 0.40		0.88 \pm 0.24	
Full-time	1.05 \pm 0.40	0.27	0.92 \pm 0.41	0.22	1.26 \pm 0.47	0.18	0.76 \pm 0.34	0.41
24-h post-match	0.94 \pm 0.39	0.10	0.87 \pm 0.39	0.37	1.14 \pm 0.37	0.10	0.66 \pm 0.28	0.84
48-h post-match	1.01 \pm 0.42		0.92 \pm 0.40	0.22	1.18 \pm 0.41	<0.01	0.72 \pm 0.24	0.67
PR (n)								
Pre-match	17.9 \pm 2.5	1.41	18.1 \pm 2.3		18.7 \pm 1.9		17.4 \pm 2.7	
Full-time	12.8 \pm 1.7	0.91	13.3 \pm 2.0	2.40	13.3 \pm 1.5 ***	3.15	12.8 \pm 2.2 ***	1.87
24-h post-match	14.6 \pm 3.1	0.29	14.9 \pm 2.2	1.18	15.8 \pm 2.2 **	1.41	13.5 \pm 2.6 ***	1.47
48-h post-match	17.1 \pm 3.0	0.12	16.9 \pm 2.3	0.52	17.8 \pm 2.1	0.45	16.0 \pm 2.7	0.52

Abbreviations; CK: creatine kinase, CT: contact time, DJ: drop jump, ES: effect size, HS: higher-standard, LS: lower-standard, PR: perceptual responses, RE: running economy, RSI: reactive strength index. Data are presented mean (\pm SD) and ES. denotes a significant difference from pre-match value (* p <0.05; ** p <0.01; *** p <0.001).

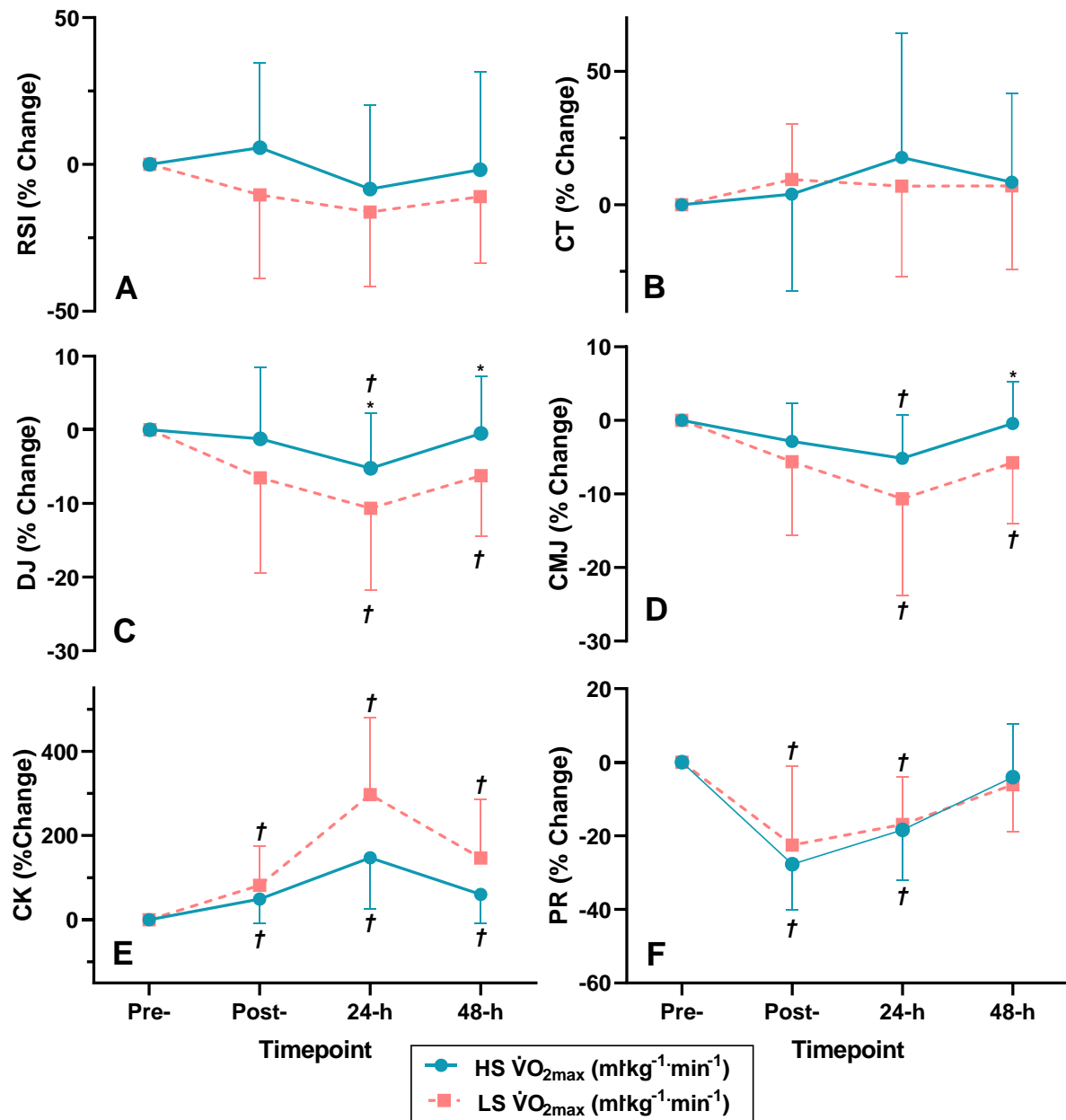


Figure 6. 2. Percentage changes in (A) reactive strength index, (B) contact time, (C) drop jump height, (D) countermovement jump height, (E) creatine kinase and (F) perceptual responses between higher- and lower-standard $\dot{V}O_{2max}$ (ml·kg⁻¹·min⁻¹) groups. (Data presented as mean \pm SD) (* indicates a significant difference between groups adjusted for baseline; † indicates a significant difference compared with baseline).

Players were also divided into HS and LS relative squat (HS: 1.46 ± 0.11 1RM kg/BM; LS: 1.20 ± 0.08 1RM kg/BM) groups. Differences between groups are plotted in Figure 6. 3. After adjusting for differences at baseline, there were significant differences in CT between groups at FT ($F_{(1,49)}11.557$; $\eta_p^2 = 0.191$; $p = 0.001$), at 24-h post-match ($F_{(1,49)}11.796$; $\eta_p^2 = 0.194$; $p = 0.001$) and at 48-h post-match ($F_{(1,49)}9.083$; $\eta_p^2 = 0.156$; $p = 0.004$). Additionally, there were significant differences in RSI between groups at FT ($F_{(1,49)}7.150$; $\eta_p^2 = 0.127$; $p = 0.010$), at 24-h post-match ($F_{(1,49)}14.089$; $\eta_p^2 = 0.223$; $p < 0.001$) and at 48-h post-match ($F_{(1,49)}10.871$; $\eta_p^2=0.182$; $p = 0.002$). There were also significant differences in PR between groups at 24-h post-match ($F_{(1,35)}6.285$; $\eta_p^2 = 0.152$; $p = 0.017$).

Table 2 displays the HS and LS relative squat groups neuromuscular, biochemical and perceptual responses to match-play at each timepoint. Both groups displayed significant increases in CK at all post-match timepoints when compared with pre-match values ($p < 0.05$). Additionally, there were significant decreases in CMJ and DJ in both groups at 24-h post-match when compared with pre-match values ($p < 0.05$). PR were significantly lower in both groups at full-time and 24-h post-match compared to pre-match values ($p < 0.05$). Finally, there were significant CT and RSI disturbances at 24-h and 48-h post-match in the LS group only ($p < 0.05$).

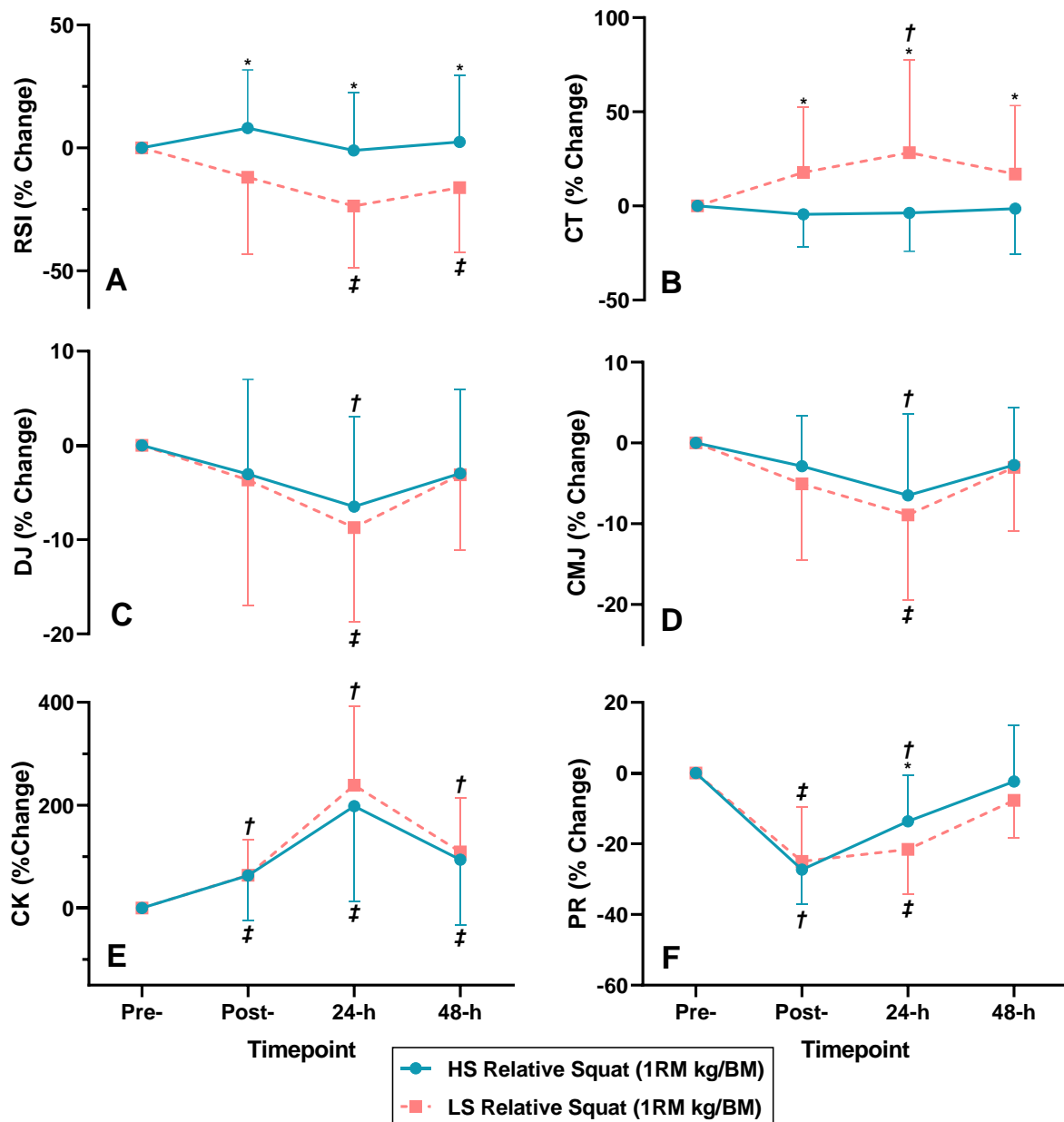


Figure 6. 3. Percentage changes in (A) reactive strength index, (B) contact time, (C) drop jump height, (D) countermovement jump height, (E) creatine kinase and (F) perceptual responses between higher- and lower-standard relative squat (1RM kg/BM) groups. (Data presented as mean \pm SD) (* indicates a significant difference between groups adjusted for baseline; † indicates a significant difference compared with baseline).

Discussion

This study aimed to investigate the influence of Gaelic football players components of fitness on performance attenuation and post-match recovery kinetics. Our results suggest that a number of components of fitness exert a positive influence on markers of performance attenuation and post-match recovery profiles.

In agreement with previous research, (Johnston et al., 2015a, Owen et al., 2015) multiple regression analysis revealed that relative squat strength was positively associated with reduced post-match perceptual, neuromuscular and biochemical disturbances. Similar to previous work, (Johnston et al., 2015b) when players were dichotomised based on relative squat strength, the LS group experienced significantly greater disturbances in CT and RSI. Overall, these findings suggest well-developed lower-body strength may protect against the accumulation of fatigue and manifestation of muscle damage during and following match-play as reported in previous work (Owen et al., 2015, Johnston et al., 2015b). The more pronounced reductions in contractile function, as exhibited by CT and RSI performance in the LS relative squat group, may be attributed in part to muscle damage and corresponding neuromuscular disturbances incurred during match-play (Silva et al., 2018, Owen et al., 2015). Players with higher levels of lower-body strength may be better equipped to deal with large mechanical loads during match-play through a number of possible mechanisms, such as a superior mechanical properties or extracellular matrix function, subsequently presenting with reduced post-match muscle damage and associated contractile disruption (Silva et al., 2018, Owen et al., 2015, Hyldahl et al., 2017). Additionally, the regular training necessary to develop and maintain high strength levels may result in a repeated bout effect providing further defence against muscle damage

stemming from the frequent high force eccentric actions of match-play (Owen et al., 2015, Hyldahl et al., 2017).

Notably, a key finding of this study was that additional neuromuscular-related performance measures such as CMJ, 20 m running speed and DJ were positively associated with reduced neuromuscular and perceptual disturbances during and following match-play. Similar to strength, the neuromuscular function associated with these physiological performance characteristics may offer resilience against muscle damage resulting from the intense eccentric workloads during match-play, (Owen et al., 2015) thus lessening declines in muscular force and power-generating capacity (Nicol et al., 2006, Norris et al., 2019). While short distance running speed, vertical jump and maximal strength performance express different force-velocity characteristics, there is a large overlap in the physiological and biomechanical mechanisms foundational to these components of fitness and thus may provide similar protection against fatigue and muscle damage (Baena-Raya et al., 2020, Nicol et al., 2006).

In the current study, RE displayed a significant inverse association with CK and RSI disturbances following match-play. RE is influenced by a complex combination of many factors involving metabolic, neuromuscular, biomechanical and cardiorespiratory components, while large variances in RE are even reported in athletes of a homogenous $\dot{V}O_{2max}$ (Barnes and Kilding, 2015). Moreover, many training induced adaptations associated with aerobic capacity, such as enhanced cardiorespiratory function, running mechanics, muscle oxidative capacity and optimized motor unit recruitment also influence RE (Kelly et al., 2021) and components such as these may have contributed to the lower RSI and CK disturbances presently reported. Importantly, more research is necessary to establish the mechanisms underpinning the current studies association between well-developed RE and reduced neuromuscular and biochemical disturbances following team

sport match-play. Similarly, $\dot{V}O_{2\max}$ was associated with reduced biochemical, perceptual and neuromuscular decrements which corresponds with previous work in Australian rules football (Hunkin et al., 2014) and rugby league (Johnston et al., 2015a). Furthermore, when comparing HS and LS $\dot{V}O_{2\max}$ groups, the HS group reported a smaller magnitude of CK increase at 24-h post-match and at 48-h post-match (Figure 6. 2). This data is consistent with research reporting a blunted CK elevation in athletes with superior aerobic conditioning (Hunkin et al., 2014). Comparable trends were reported in the present investigation's neuromuscular markers, where the LS group expressed significantly lower DJ and CMJ values 48-h post-match compared to their HS group counterparts. Noteworthy for strength and conditioning coaches, the LS groups DJ and CMJ values remained significantly deteriorated 48-h post-match. This may have implications for the design of in-season training programmes, where players with lower aerobic conditioning may present with impaired readiness to train 48-h post-match. Our findings support the notion that increasing players aerobic capacity may reduce the magnitude and time-course of neuromuscular and biochemical disruptions following match-play.

Given that Gaelic football players have reported possible signs of ongoing fatigue and muscle damage, developing components of fitness as a means to improve responses may be especially pertinent (Daly et al., 2020). Of note, our previous research suggested disturbances to post-match markers of fatigue and muscle damage are significantly associated with internal measures (average heart rate) and external measures (sprint and total distance covered, impacts and the number of sprints/accelerations) during Gaelic football match-play. In combination with these findings, current data provides further insight into the multifactorial contributory factors influencing players fatigue and recovery responses to competitive play (Daly et al., 2020). Collectively, these findings suggest coaches may reinforce the importance of developing components of fitness, in particular

strength and aerobic capacity, as a means to limit degeneration of players biochemical, perceptual and neuromuscular status. In turn, this may promote players preparedness to train in the days following match-play and possibly reduce their risk of fatigue related injury during the competitive season (Owen et al., 2015). Finally, the specific physiological mechanisms underpinning this study's findings were not directly examined and limitations may exist applying the results of this study during different phases of the season or in other team sport populations. Future research assessing players physical conditioning, responses to match-play and recovery strategies during multiple timepoints across the season may provide valuable insight. In line with the present analysis, investigating the influence of components of fitness on competitive in-game workload measures would also be beneficial.

Conclusions

Our data suggests players with well-developed neuromuscular-related performance measures and aerobic capacity are likely to exhibit reduced performance attenuation and accelerated post-match recovery. When players were dichotomised into HS and LS groups based off $\dot{V}O_{2\max}$ and relative squat strength values; players in the HS groups tended to express a reduced magnitude and duration of temporal fatigue and muscle damage when compared to their LS group counterparts. Furthermore, players with lower $\dot{V}O_{2\max}$ and relative squat strength values may present with compromised neuromuscular status 48-h post-match. Advanced physical conditioning may facilitate increased metabolite clearance, reduced neuromuscular fatigue and a higher resilience against muscle damage. These observations may be used to inform fatigue management and recovery strategies, in-season training programme design and long-term athletic development plans within Gaelic football.

Managing the development and maintenance of physical conditioning with sufficient recovery in an amateur sport such as Gaelic football poses unique challenges to coaches and players. This balance is especially sensitive during the in-season phase, where an effective training dose-response cycle necessitates periods of tapered load in preparation for matches while also providing an adequate stimulus to avoid detraining. Our results suggest an increase in players aerobic capacity and neuromuscular function may translate into a smaller magnitude and shorter timeframe of perceptual, biochemical and neuromuscular disturbances during and following match-play. With this in mind, undertaking specific training dedicated to improving $\dot{V}O_{2\max}$ and running economy may improve players in-season responses to match-play. When targeting the development of players neuromuscular function, careful consideration should be given to the manipulation of strength and power training programming so as to elicit a high adaptive stimulus relative to the degree of fatigue and muscle damage accrued. This is especially important during the in-season period, where undue neuromuscular fatigue or muscle damage accumulated during such resistance-based training has the potential to undermine players competitive preparedness. Given the multidimensional physical demands of Gaelic football, combined training processes to increase players lower-body strength, power and aerobic capacity in the context of sport specific periodisation may constitute a well-rounded approach to limit fatigue and muscle damage.

Acknowledgements

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Section Link

Taken together, the findings of the previous chapters provide a profile of Gaelic football players responses to match-play, describe associations between various in-game workload indices and post-match disturbances, detail the timeline of recovery and demonstrate the influence of physical conditioning attributes on these collective factors. Importantly, what players *do* or *don't do* during the post-exercise recovery window can significantly alter the quality and magnitude of muscular healing and psychophysiological regeneration (Calleja-González et al., 2019, Heaton et al., 2017, Argus et al., 2013, Kinugasa and Kilding, 2009) and represent a key piece in the complex puzzle that represents the recovery of team sport athletes. This puzzle may be particularly intricate and multifactorial within Gaelic games, given that players must balance the strenuous demands of sports participation with work and/or study pressures (Kelly et al., 2018b) which have previously been documented to impede athletic recovery outcomes (Main et al., 2010, Stults-Kolehmainen et al., 2016). Consequently, there is a need to assess what post-exercise recovery strategies Gaelic games players implement to inform practitioners and direct future work, and the following chapter set to address this lack of important information. Accordingly, study 4 of this thesis will investigate the use of recovery strategies within Gaelic games.

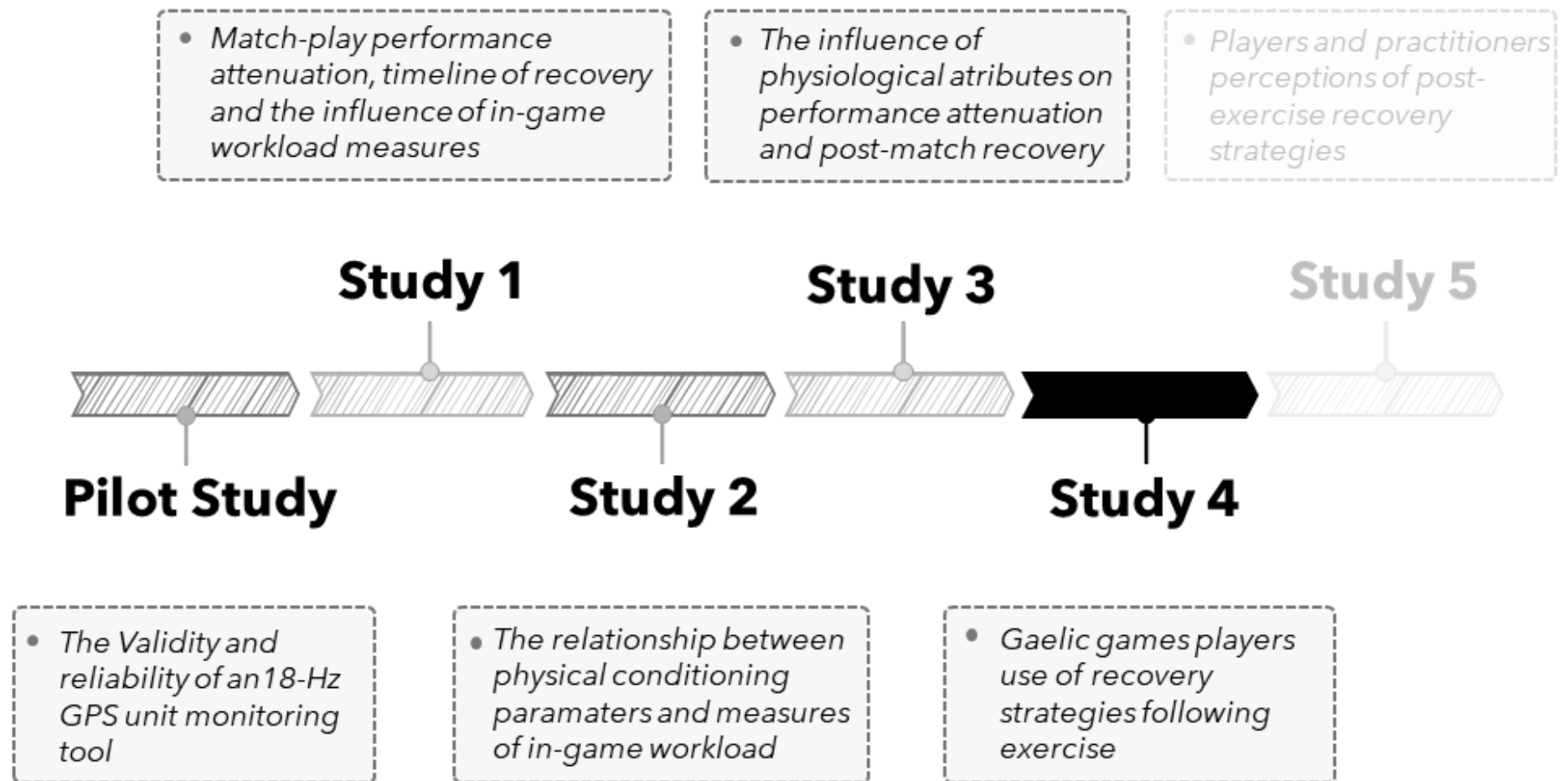


Figure 6. 4. Thesis timeline infographic highlighting study

Chapter 7 – Study 4

Perceptions and Use of Recovery Strategies in Gaelic games: Does
Practice Reflect Efficacy? A Mixed-Methods Analysis

Abstract

Purpose: The use of a wide range of recovery modalities are ubiquitous in professional team sports, despite many having limited practical regenerative efficacy and their implementation based upon intuitive and experiential evidence. The use of regenerative strategies within Gaelic games remains unknown, meaning (i) practitioners who seek to prescribe recovery interventions are ill-informed as to players beliefs or preferences and (ii) it is unclear if contemporary practices align with evidence-informed recommendations. Therefore, the aim of this study is to conduct a preliminary examination into Gaelic games players use of post-exercise recovery strategies.

Methods: A total of 1178 Gaelic games players (age: 24.6 ± 6.6 years) consisting of male ($n = 604$; age: 25.9 ± 7.0 years) and female ($n = 574$; age: 23.1 ± 5.8 years) participants completed a questionnaire investigating recovery practices following exercises. Participants were further dichotomised by playing standard, into club/collegiate ($n = 869$; age: 25.0 ± 6.8 years) and inter-county ($n = 309$; age: 23.2 ± 6.0 years) levels. Participants were also sub-categorised into each of the Gaelic games sporting codes: Gaelic football ($n = 813$; age 24.3 ± 6.5 years), camogie ($n = 176$; age: 22.8 ± 5.8 years), hurling ($n = 166$; age: 26.6 ± 7.5 years) and handball ($n = 23$; age: 23.7 ± 10.1 years). Payer's application of a range of psychological, physiological, social, alternative and complimentary recovery practices were investigated.

Results: Active recovery (90.4%), cold temperature exposure (79.5%), regular sleep routine (79.1%), strategic nutritional intake (72.3%), and massage (68.8%) were the most commonly used strategies to consolidate recovery. Significant differences between sport, playing standard and biological sex were demonstrated in the implementation of various

recovery strategies ($p < 0.05$). Additionally, approximately a third of Gaelic players (30.0%) periodise their use of recovery strategies during the season.

Conclusions: This work provides novel insight into the recovery practices Gaelic games players employ to enhance post-exercise recovery. Overall, a number of discrepancies exist between Gaelic games players uses of various recovery modalities and their relative effectiveness to accelerate post-exercise recovery. These results may be used to develop tailored educational resources which aim to maximise the effectiveness and efficiency of recovery interventions in Gaelic games.

Introduction

Gaelic games are sports indigenous to Ireland which include the field-based invasive team sports of Gaelic football, hurling, camogie, and the court-based sport of Gaelic handball. These sports are played at club/collegiate (club/collegiate) and inter-county (inter-county) levels, with different sub-categories of competition across biological sex and age groups. The field-based invasive Gaelic sports require significant physiological and tactical-technical proficiency to execute numerous sport-specific tasks in a fast-paced and highly unpredictable environment (Young et al., 2019, Daly et al., 2020). These tasks must be completed under conditions of accumulating fatigue, competitive pressure and under the threat of regular physical contact (i.e., fending off defenders or tackling) (Kelly et al., 2021, Young et al., 2021). During match-play, players perform frequent short-distance sprints and changes of pace/direction, which are generally dispersed between intervals of lower intensity running, jogging or walking (Mullane et al., 2018, Mangan et al., 2020). These intensive intermittent demands impose significant metabolic and mechanical loads (Mangan et al., 2020) and provoke acute psychobiological disruption (Daly et al., 2020). In contrast, Gaelic handball players perform a higher density of explosive power movements (such as multi-directional agility, jumps and accelerations/decelerations) in a high-speed reactive environment similar to squash or tennis (O'Connor et al., 2016a, Montpetit, 1990).

Gaelic games players are exposed to demanding training and competitive schedules over a lengthy season, and these amateur athletes (at inter-county levels) are typically expected to pursue near professional levels of commitment (Kelly et al., 2018b). Additionally, underage and inter-county level players report a high prevalence of multi-team and multi-sport activity in addition to their regular team commitments during the

season (O'Connor et al., 2017, Kelly et al., 2018b). Within Gaelic football specifically, players have expressed signs of possible cumulative fatigue and muscle damage during the in-season (Daly et al., 2020), which may provide a proxy indicator of sub-optimal recovery. These chronic demands with limited time afforded for recovery between training sessions and/or matches may exceed Gaelic games players capacity to physically and psychologically recover from their collective training, match-play and life stressors (Kellmann, 2010). Despite the well-documented intensive demands of Gaelic games (Daly et al., 2020, Egan et al., 2021), no empirical evidence is currently available to describe the strategies that these athletes may use to cope with these stressors. Additionally, it also remains to be seen if specific recovery strategies that are utilised by Gaelic players are empirically justified, or if their application is contextually (un)suitable. Therefore, profiling the use of recovery strategies in Gaelic games is necessary to establish what practices (if any) players are implementing to expediate post-exercise recovery, and whether or not these practices are endorsed by the literature (i.e., is research being integrated into practice?).

Importantly, physiological and performance adaptations resulting from training and competition stimuli are heavily dependent upon the quality and duration of recovery with which these stressors are overlaid (Kellmann et al., 2018). Thus, with the intention of optimising physiological adaptations and improving long-term performances, allowing sufficient systemic recovery following periods of accentuated training or match loads is a necessary process to modulate fatigue, resynthesise substrates and heal muscle tissues (Marrier et al., 2017, Gamble, 2006, Aoki et al., 2017). Conversely, extended periods of intensive competition and/or training with limited recovery may lead to excessive levels of physical and psychological fatigue; possibly leading to diminished performance, conditioning and motivation (Budgett, 1998, Fry et al., 1991). Furthermore, mechanical

stimuli imposed from training and competition workloads are not applied (and subsequently recovered from) in a vacuum. Rather, a comprehensive evaluation of an athlete's recovery kinetics necessitates the consideration of many possible sport and non-sport stressors, and the interplay between these combined stimuli and numerous characteristics associated with the individual. These factors include genetics (Mann et al., 2014), physical conditioning status (Daly et al., 2022), acute and chronic training/competition loads (Malone et al., 2017b), recovery strategy use (Pooley et al., 2020) and many other physiological, immunological and psycho-emotional considerations (Kellmann et al., 2018, Meeusen et al., 2013). Overall, these multifaceted and inherently complex interactions can combine to amplify or diminish an athlete's recovery capacity, subsequently influencing their responses to physical training and match loads (Meeusen et al., 2013, Norris D et al., 2019).

Given the routine exposure to longitudinal training and competitive demands Gaelic players face, it's reasonable to assume that they experience inadequate recovery and subsequently endure sub-optimal restorative processes on occasion (Hartmann and Mester, 2000, Kelly et al., 2018b, Whelan, 2011). In similar team sport athletes, an array of recovery practices are regularly used in an attempt to reduce fatigue/inflammation and accelerate muscle tissue healing (Crowther et al., 2017, Minett and Duffield, 2014). Some widely used practices among team sport athletes (such as cold-water immersion [CWI], napping, rehydration and strategic nutritional intake) are reported to alleviate many of the detrimental symptoms associated with fatigue and muscle damage (Pooley et al., 2020, Heaton et al., 2017, Sánchez-Ureña et al., 2015). As no research has yet investigated the use and/or effectiveness of any post-exercise recovery strategies in Gaelic games players (data is also limited in female team sport athletes), (Cowley et al., 2021) the unique physical and technical demands of competition/training (Hulton et al., 2008, Fenton, 1996, Kelly et

al., 2022) may lower the generalisability of findings from other professional team sports. Gaelic games amateur status means players encounter additional work and study pressures which may add further psychophysiological stress and could conceivably influence recovery responses (Mann et al., 2016). Notably, academic and work related stress in other amateur athletes has been associated with compromised training, performance and recovery outcomes (Main et al., 2010, Stults-Kolehmainen et al., 2016), and a higher incidence of injury (Ivarsson et al., 2017, Ivarsson et al., 2014). Furthermore, Gaelic games amateur status may also limit players access to training facilities, strength and conditioning coaches, nutritional expertise, athletic rehabilitation staff and recovery modalities which are often more readily available in professional organisations (Renard et al., 2020, Ó Catháin et al., 2020). Accordingly, this study aims to conduct a preliminary investigation into Gaelic games players use of recovery strategies.

Methods

Participants

A total of 1178 Gaelic games players (age: 24.6 ± 6.6 years) comprising male ($n = 604$; age: 26.2 ± 9.6 years) and female ($n = 574$; age: 23.1 ± 5.6 years) players were recruited for this study. Players participating in inter-county competition during the current season were considered inter-county ($n = 309$; age: 23.2 ± 6.0 years), while players whose highest level of representation during the season was at club or collegiate level were considered club/collegiate ($n = 869$; age: 25.0 ± 6.8 years). Participants were further categorised into the Gaelic games sports of Gaelic football ($n = 813$; age 24.3 ± 6.5 years), camogie ($n = 176$; age: 22.8 ± 5.8 years), hurling ($n = 166$; age: 26.6 ± 7.5 years) and handball ($n = 23$; age: 23.7 ± 10.1 years). Participants under 18-years of age, with less than 6-months experience of competitive training in Gaelic games or not currently active with a team were excluded from analysis. Informed consent was obtained from all participants, and ethical approval was granted for this research by the Technological University of the Shannon Research Ethics Committee (code 20200304).

Questionnaire Development

A questionnaire previously designed for and utilised by team sport athletes (Venter, 2014, Venter et al., 2010) was adapted for use in Gaelic games participants (appendix x). Prior to the design and use of the proposed questionnaire, a number of measures were undertaken to help limit possible error or biases during the forthcoming data collection phase. Specifically, the questionnaire was (1) purposely adapted to maximise clarity, time efficiency and user-friendliness, (2) the questions were tested and reviewed during piloting work to establish face, ecological and content validity and (3) internal consistency was reported during successive analysis to ensure adequate reliability (Bland and Altman,

1997). Piloting work was completed to assess the measures of validity. To fulfil this procedure, six qualified sport scientists, two athletic rehabilitation therapists and two Gaelic games coaches were invited to review, critique, and provide feedback on the proposed questionnaire similar to prior research assessing another questionnaire exploring post-match recovery strategies in soccer (Querido et al., 2021). All of these 10 reviewers (each with ≥ 5 years' experience working with Gaelic games players) agreed to participate and signed informed consent, providing a sufficient sample (Trevelyan and Robinson, 2015, Keeney et al., 2011). The proposed questionnaire was based on research initially designed for use with South African team sport athletes (Venter et al., 2010), and the goal of this piloting work was to establish validity for Gaelic games players. The participating reviewers had 7.7 ± 1.7 years of experience working with Gaelic games players, and all held a bachelor's degree (one participant held a PhD) at the time of appraising the present questionnaire. To establish face, content and ecological validity the questionnaire was circulated to the reviewers in an online format using the SurveyMonkey (San Mateo, CA, USA) platform. The reviewers indicated changes that they felt needed to be made on an accompanying Google forms document (Microsoft Corporation, Redmond, WA, USA) in which they specifically indicated the section(s)/question(s) where they had concerns relating to possible lack of relevance/understanding, or issues relating to spuriousness or question/section sequence. In addition to highlighting their concerns, they were encouraged to indicate their suggested corrections to address these issues on the supplementary Google forms document. Where a disparity in suggested corrections occurred between two or more reviewers, the relevant reviewers were contacted, and an agreement was brokered with regard to the questionnaires updated structure. Following the completion of the reviewers' requests and suggestions (and the subsequent redesign and adaptation of the questionnaire), the final version was prepared.

Questionnaire Overview

After the initial informed consent page, the introductory section of the questionnaire was used to assess the participants demographics and playing standard. The successive sections of the questionnaire explored the use of various recovery strategies. The sections of the questionnaire specifically assessing recovery strategy implementation were sequenced in eleven sections as follows: (i) nutritional intake and rehydration, (ii) sleep, (iii) active cool down, (iv) the application of eternal cold, (v) the application of eternal heat, (vi) the application of contrast temperatures, (vii) massage and (viii) aromatherapy, (viii) music therapy, (ix) complementary and alternative therapies and (xi) relaxation. Questions on each strategy were consistently formatted and involved an initial contingency question (i.e., whether the strategy was implemented or not) which guided the respondent to the appropriate successive section of the questionnaire. If the participant selected ‘yes’ to using a certain recovery strategy, they were directed to subsequent sections that further investigated when they used the strategy (i.e., before/after training/match or on non-training days), the frequency of its implementation (always, sometimes, rarely and never) and how they used the strategy (i.e., the specific method and context of its implementation). Conversely, if the participant selected ‘no’ to using a certain recovery strategy, they were redirected towards a different section detailing another recovery strategy. The questionnaire was distributed to players using the SurveyMonkey (San Mateo, CA, USA) platform.

Statistical Analysis

This research followed a cross-sectional and observational study design. The data was extracted from the online survey platform (SurveyMonkey) on to Statistical Package for Social Sciences (SPSS, Version 27.0, Chicago, IL, USA) for analysis. For descriptive purposes, means with standard deviations were reported for ordinal (Likert Scale)

measurements and frequencies were used to describe categorical data. Chi squared tests were run to identify any differences in frequency variables across the different sports, biological sexes and playing standards. Phi (ϕ) values of 0.1, 0.3 and 0.5 represented small, medium and large effect sizes respectively (Cohen, 1988). When more than 20% of expected counts were less than five, a Fisher's Exact test with Cramer's V (ϕ -c) was utilised. Additionally, ϕ -c was used to determine effect sizes, as all degrees of freedom were more than 1 (Field et al., 2021). Cronbach alpha was calculated to assess the internal consistency of the Likert scale survey responses. The score was interpreted as good in the range of 0.80 to 0.89 and excellent if ≥ 0.90 . Statistical significance was set at an alpha p level of $p < 0.05$.

In order to determine the observed frequency magnitudes of the prevalence of recovery strategy use, the following qualitative terms were assigned: All = 100%; Most = $\geq 75\%$; Majority = 55 to 75%; Approximately half = $\sim 50\%$; Approximately a third = $\sim 30\%$; Minority = $< 30\%$ (Starling and Lambert, 2018). A qualitative thematic analysis approach was used to investigate the open-ended responses following the guidelines of Braun and Clarke (Braun and Clarke, 2014) and similar in approach to that of Crowther and colleagues (Crowther et al., 2017) who previously assessed recovery strategy use in team sport athletes. Briefly, this process involved the following stages: (1) familiarization with the responses, (2) generation of codes, (3) identification of themes, (4) reviewing and assessing each theme, (5) characterisation and naming of each theme and (6) reporting the information. This thematic analysis allowed the identification of key topics and consistent patterns that were evident in various open-ended sections (Braun and Clarke, 2014, Healy et al., 2021). The lead researcher and supervisors of this study independently assessed the open-ended responses, and a consensus was reached on the themes and quotes used in the analysis (Crowther et al., 2017).

Results

The Cronbach alpha result of the current questionnaire was 0.87, demonstrating a high level of internal consistency. Table 7. 1 summarises the participants competition and training practices during the season.

Table 7. 1. Participant's training and competition practices.

	Sample	Biological sex		Playing standard		Sport		
	Total (n = 1178)	Male (n = 604)	Female (n = 574)	Club/collegiate (n = 869)	Inter- county (n = 309)	Gaelic Football (n = 813)	Camogie/ hurling (n = 342)	Gaelic Handball (n = 23)
Training time (n, %)								
Less than 4 h	139 (11.8%)	52 (8.6%)	87 (15.2%)	130 (15.0%)	8 (2.6%)	116 (14.2%)	20 (5.8%)	3 (13.0%)
4 – 5 h	276 (23.4%)	101 (16.7%)	175 (30.5%)	246 (28.3%)	29 (6.4%)	191 (23.5%)	79 (23.1%)	5 (21.2%)
5 – 6 h	240 (20.4%)	130 (21.5%)	110 (19.25)	188 (21.6%)	52 (16.8%)	171 (21.0%)	66 (19.3%)	3 (13.0%)
6 – 7 h	218 (18.5%)	128 (21.2%)	90 (15.7%)	142 (16.3%)	77 (24.9%)	142 (17.5%)	71 (20.8%)	4 (17.4%)
7 – 8 h	168 (14.3%)	104 (17.2%)	64 (11.1%)	96 (11.0%)	71 (22.9%)	116 (14.2%)	49 (14.3%)	3 (13.0%)
More than 8 h	139 (11.8%)	89 (14.7%)	48 (8.4%)	67 (7.7%)	72 (23.3%)	77 (9.5%)	57 (16.7%)	5 (21.2%)
1 or more rest days (n, %)								
Yes	1113 (94.5%)	575 (95.2%)	537 (93.6%)	830 (95.5%)	282 (91.2%)	766 (94.2%)	324 (94.7%)	23 (100.0%)
No	65 (5.5%)	29 (4.8%)	37 (6.4%)	39 (4.5%)	26 (8.4%)	47 (5.8%)	18 (5.3%)	0 (0.0%)
Additional activity (n, %)								
<i>Multi-Sport Activity</i>								
Yes	602 (51.1%)	329 (54.5%)	272 (47.4%)	431 (49.6%)	168 (54.4%)	391 (48.1%)	193 (56.4%)	15 (65.2%)
No	576 (48.9%)	275 (45.2%)	302 (52.6%)	458 (52.7%)	141 (45.6%)	422 (51.2%)	149 (43.6%)	8 (34.8%)
<i>Multi-Team Activity</i>								
Yes	604 (51.3%)	299 (49.5%)	305 (53.1%)	344 (39.6%)	259 (83.8%)	390 (48.0%)	207 (60.5%)	7 (30.4%)
No	574 (48.7%)	305 (50.5)	269 (46.9%)	545 (62.7%)	50 (16.1%)	423 (52.0%)	135 (39.5%)	16 (69.7%)
Off season (n, %)								
No off season	181 (15.4%)	89 (14.7%)	92 (16.0%)	122 (14.0%)	59 (19.0%)	114 (14.0%)	57 (16.7%)	11 (47.8%)
2 weeks or less	191 (16.2%)	100 (16.6%)	92 (16.0%)	111 (12.8%)	79 (25.6%)	122 (15.0%)	60 (17.5%)	8 (34.8%)
2 to 4 weeks	287 (24.4%)	150 (24.8%)	138 (24.0%)	184 (21.2%)	104 (33.7%)	210 (25.8%)	75 (21.9%)	2 (8.7%)
Over 4 weeks	519 (44.1%)	264 (43.7%)	252 (43.9%)	452 (52.0%)	67 (21.7%)	367 (45.1%)	150 (43.9%)	2 (8.7%)

Post-match Recovery Timeline and Physical Conditioning

Gaelic games players most commonly perceive post-match recovery takes 48 hours (42.5%), approximately a third indicate 24 hours (32.7%) and a minority indicate 12 hours or less (11.2%), 72 hours (12.1%) and more than 72 hours (1.5%). Gaelic games players perceived that muscle damage and fatigue as a result of match-play are mostly caused by changes of pace (2.66 ± 1.10), total workload (2.56 ± 1.08), physical contact (2.50 ± 1.14) and high-intensity workload (2.27 ± 1.05) when ranked out of 5. Additionally, components of fitness that were perceived as the most important to promote post-match recovery included running speed (2.91 ± 1.15), power (2.74 ± 0.85), strength (2.32 ± 1.00) and aerobic fitness (1.99 ± 1.17) when ranked out of 5.

Recovery Strategies

Descriptive statistics for the strategic use of various recovery strategies following training and match-play are illustrated in Figure 7. 1. Differences in the prevalence of these strategies between biological sex and playing standard are illustrated in Figure 7. 2, while between-sport differences are illustrated in Figure 7. 3.

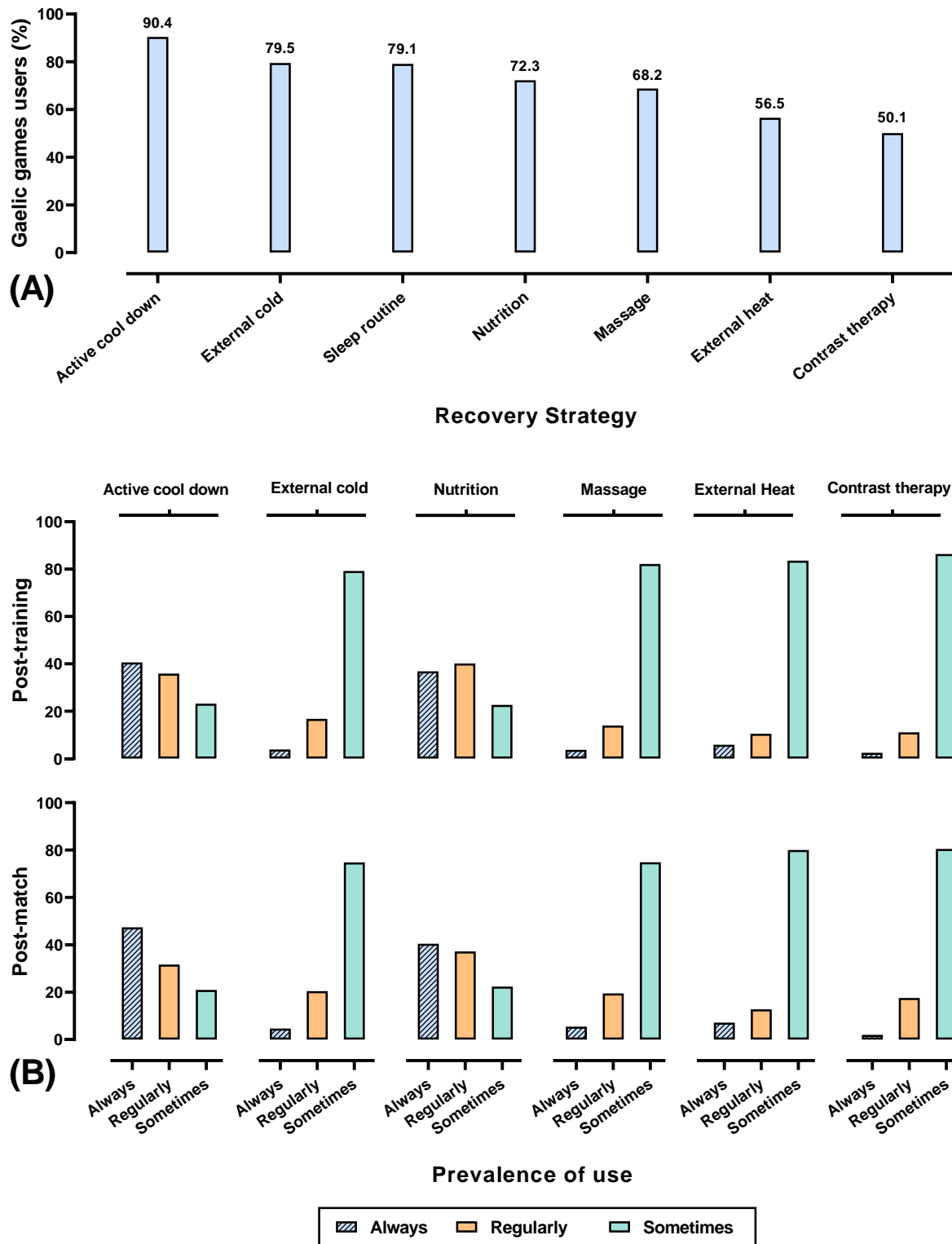


Figure 7. 1. Recovery strategies of Gaelic games players for (A) overall prevalence and (B) post-training and post-match prevalence respectively.

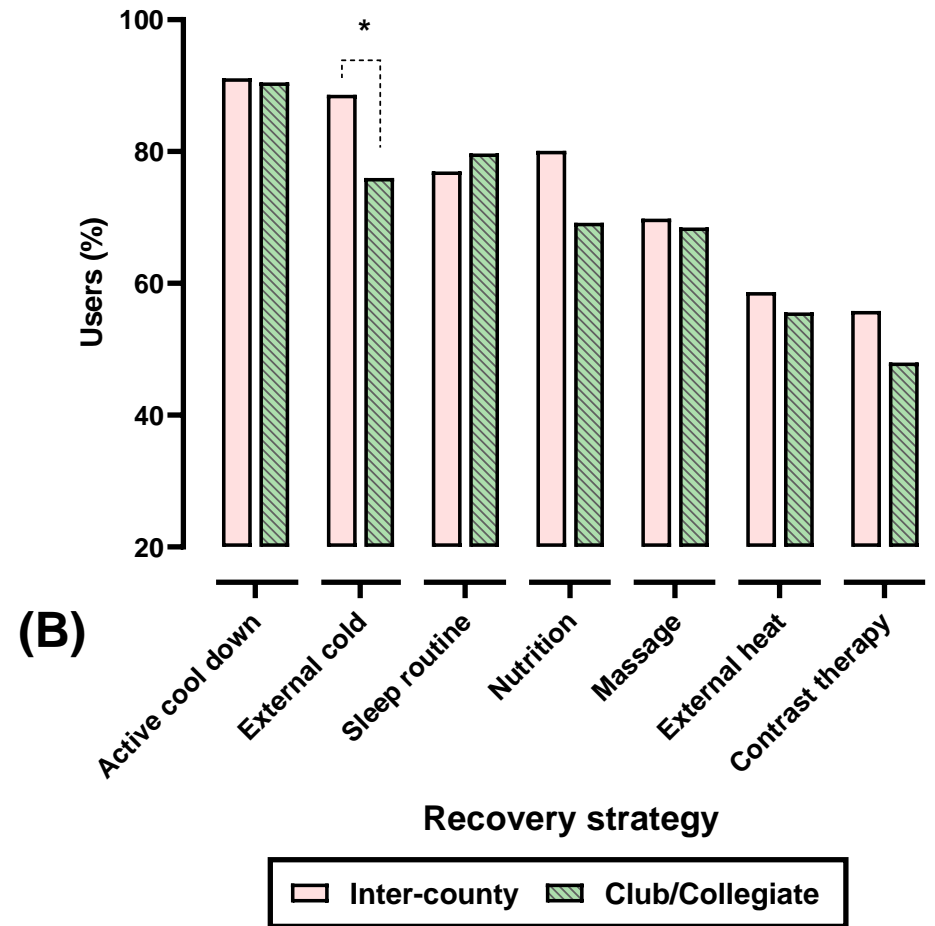
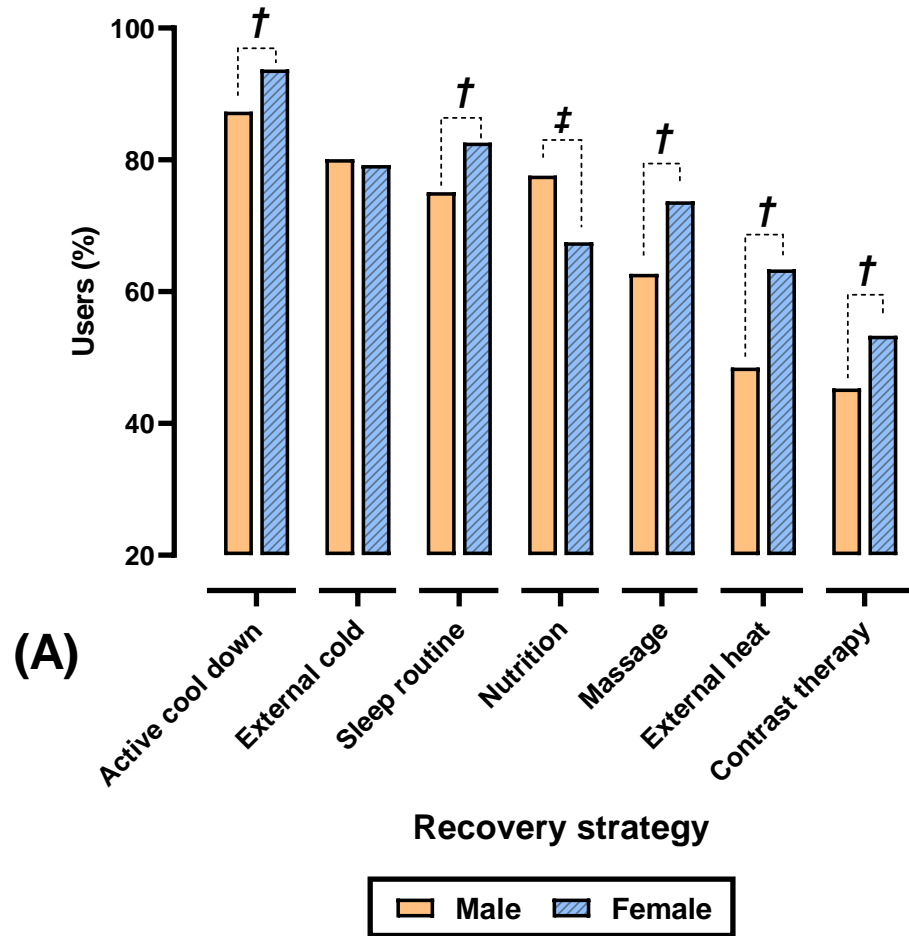


Figure 7. 2. Prevalence of recovery strategies (%) used by (A) male and female players, (B) inter-county and club/collegiate players, † indicates significantly more prevalent use for females; ‡ indicates significantly more prevalent use for males; * indicates significantly more prevalent use for inter-county players ($p < 0.05$).

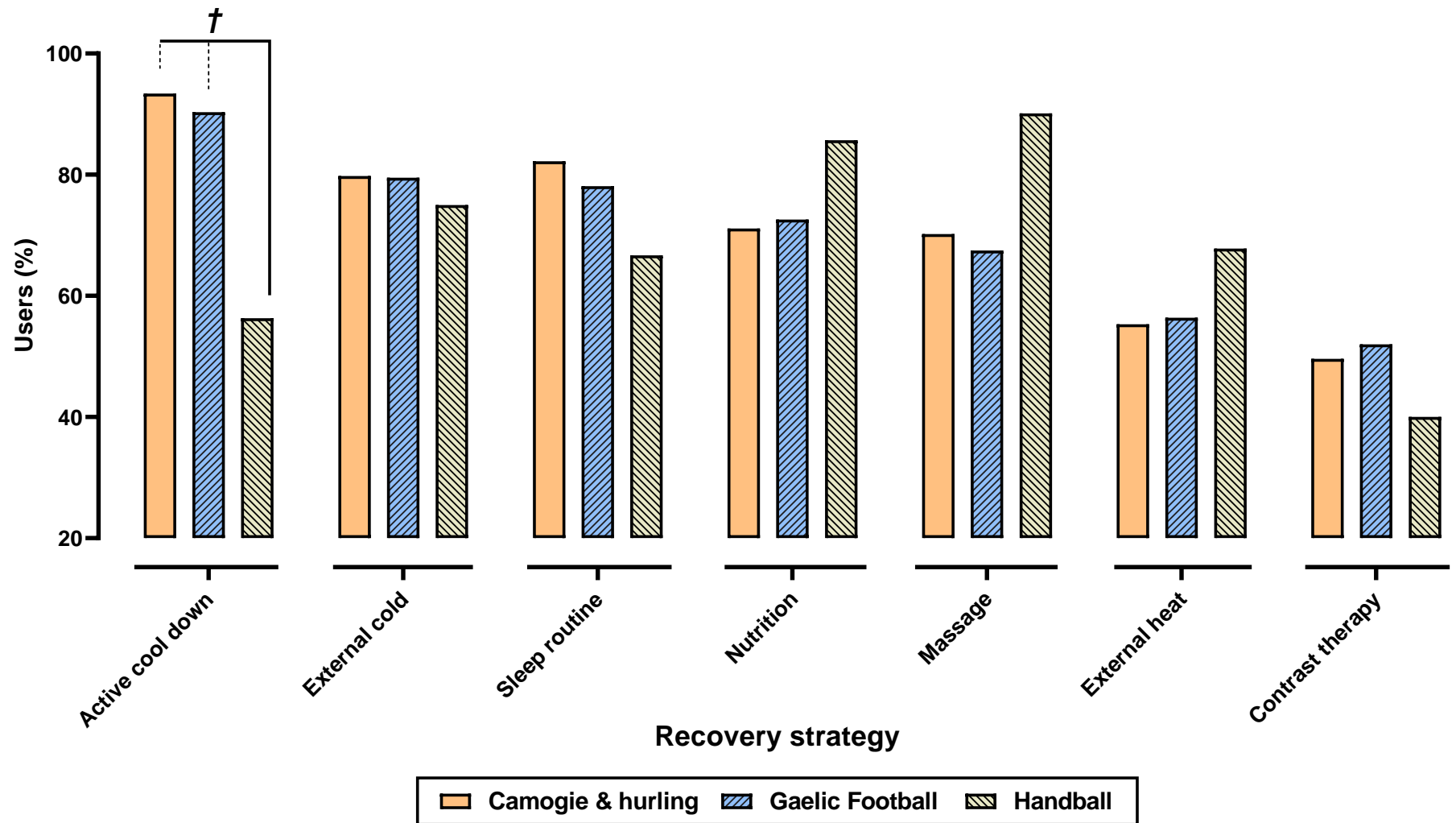


Figure 7. 3. Prevalence of recovery strategies (%) used by Gaelic football, Camogie/hurling and handball players. † Indicates significantly less prevalence of use for handball players ($p < 0.05$).

Notably, 30% of players changed their post-training/match-play strategies depending on the time of season (Table 7. 2). Common open text responses from players suggest there is a much greater emphasis on recovery during the championship phase of the season when compared with the off-season, pre-season or league. Furthermore, the primary response theme ‘focus more on recovery during championship/important phases of season’ and other similar themes are detailed in Table 7. 2.

Table 7. 2. Reasons for changing the use recovery strategies during the season ($n = 163$).

Rank	Identified Theme	Example Response	Responses (n)
1	Increased recovery prioritisation during championship/important phases of competition	“During championship season there is more of an emphasis on recovery” - Participant #88	80
2	Implement water immersion during warm weather	“If its drier and warmer I go for a post-match dip in the lake” - Participant #4	43
3	Increased recovery prioritisation during pre-season	“Pre-season a lot of recovery needed in between training from ice baths, massage from the physio etc.” - Participant #75	15
4	Increased recovery prioritisation during periods of high workload	“It depends on the workload” - Participant #30	14
5	Increased recovery prioritisation following activity on difficult pitch conditions	“Depending on how hard or soft the pitch is, the legs would feel very heavy on a soft pitch after training or a match so I would have to spend more time stretching to help loosen out the muscles again” - Participant #150	7
6	Avoid use of recovery strategies when looking to develop neuromuscular qualities	“I wouldn't use cold water immersion during pre-season because of its effect on adaptation but I would include as part of in-season recovery” - Participant #139	4
7	Use or disuse recovery strategies based on feeling	“It depends on how I'm feeling” - Participant #32	3

Active Cool Down

The active cool down section was completed by 773 players (65.6%) with a very small number of players (1.2 - 2.1%) never using a cool down following a training session or match respectively. The most commonly used activities in players active cool down protocols were post-exercise stretching (78.2%) and light jogging (72.1%). There were significant differences across sports and biological sex for an active cool down ($p < 0.001$), where handball players used an active cool down significantly less than all other sports (56.3% vs. 77.3 to 94.3%; $p < 0.05$) and a significantly larger proportion of female players use an active cool down when compared with males (87.3% vs. 76.0%; $\chi^2[1] = 9.174$; $\phi = -0.1$; $p = 0.003$). Furthermore, a significantly larger proportion of females perform stretching as a post-exercise recovery technique when compared with males (66.4% vs. 76.5%; $\chi^2[1] = 9.609$; $\phi = -0.1$; $p = 0.002$). Players perceived an active cool down as most important to decrease muscle soreness (3.97 ± 1.26), remove waste products from muscles (3.52 ± 1.34) and wind down after exercise (3.17 ± 1.26) when ranked out of 5.

Nutrition and Hydration

The nutrition and hydration section was completed by 571 players (48.4%). A significantly larger proportion of inter-county players and male players employed strategic nutritional intake strategies when compared with club/collegiate players (80.1% vs. 69.2%; $\chi^2[1] = 6.681$; $\phi = -0.1$; $p = 0.012$) and female players (77.6% vs. 67.5%; $\chi^2[1] = 7.332$; $\phi = -0.1$; $p = 0.007$) respectively. A significantly larger proportion of male (62.1% vs. 28.0%; $\chi^2[1] = 90.919$; $\phi = -0.2$; $p < 0.001$) and inter-county (64.7% vs. 55.4%; $\chi^2[1] = 3.928$; $\phi = -0.1$; $p = 0.47$) players consume a combination of protein and carbohydrate following intense exercise. Also, a significantly larger proportion of male players (28.8% vs. 15.8%; $\chi^2[1] = 15.634$; $\phi = -0.1$; $p < 0.001$) use supplements when compared with females. Players

perceived nutrition and hydration strategies as most important to replace fluid loss (4.47 ± 1.03), repair muscle damage (4.33 ± 1.05), replenish energy stores (4.22 ± 1.11) and increase preparedness for subsequent training (4.18 ± 1.09) when ranked out of 5.

Sleep

The sleep section was completed by 559 players (47.5%). Approximately half (47.0%) of players *sometimes* experience problems falling asleep, while 38.6% do not regularly experience problems. Roughly a third (34.1%) of players were affected by noise and 40.5% of players were affected by light in the environment that they slept in. Additionally, 43.6% of players *sometimes* experience problems waking in the morning, while 40.6% do not regularly report issues. Of the players who experience problems falling asleep at night (64.3%), 35.4% perceive late evening training sessions or matches cause issues and 27.5% believe their caffeine consumption impairs their sleep onset. In addition to regular sleep, 42.7% of players reported *sometimes* taking a nap, 7.9% *always* take a nap and approximately half (48.2%) do not take naps during the day. A significantly larger proportion of female players have a regular sleep routine than males (82.6% vs. 75.1%; $\chi^2[1]=4.723$; $\phi=-0.1$; $p=0.037$). Gaelic players perceived sleep as most important for repair and growth of the body (4.54 ± 0.90), emotional well-being (4.36 ± 0.97), counteracting lack of sleep related depression (4.05 ± 1.16) and the maintenance of normal bodily rhythms (4.04 ± 1.08) when ranked out of 5.

Application of cold

The application of cold section was completed by 555 players (47.1%). Of the players who apply external cold (79.5%), commonly reported methods of cold application were CWI (79.9%) ice packs/bags (73.8%) and cold showers (53.2%). The open-ended responses also highlighted that many players engage in sea, lake or river swimming ($n =$

43; Table 7. 2) as a method of applying cold. Furthermore, a significantly larger proportion of inter-county players apply cold temperatures when compared to club/collegiate players (73.1% vs. 86.7%; $\chi^2[1]=10.561$; $\phi=-0.1$; $p=0.001$). The application of cold was perceived by players as beneficial to reduce swelling (4.23 ± 1.05), inflammation (4.21 ± 1.02) and muscle soreness (4.12 ± 1.26) when ranked out of 5.

Application of Heat

The application of heat section was completed by 421 players (37.7%). Players who apply external heat use methods such as a hot shower (59.4%), hot water bottle (39.2%), hot bath (35.4%), sauna (22.8%) or heated pool (18.8%). A significantly larger proportion of female players apply external heat when compared to male players (63.4% vs. 48.5%; $\chi^2[1] = 9.555$; $\phi = -0.2$; $p=0.002$). Players who apply heat perceive the modalities benefits to aid relaxation (4.04 ± 1.23), reduce muscle soreness (3.97 ± 1.23) and provide a feel good effect (3.80 ± 1.30) when ranked out of 5.

Application of Contrast Temperature

The contrast temperature therapy section was completed by 335 players (28.4%). Of the players who use contrast temperature therapies, alternating hot and cold showers is the most commonly used method of application (56.2% of respondents). Replies in the open-ended sections indicate players apply contrast therapy using other methods such as 'sauna and cold shower' ($n = 7$), and 'heat pack and ice pack' ($n = 9$). Gaelic players perceive contrast therapies as important for reducing muscle soreness (3.81 ± 1.36), pain (3.63 ± 1.43) and swelling/inflammation (3.50 ± 1.44) when ranked out of 5.

Massage

The massage section was completed by 333 players (28.3%). A significantly larger proportion of female players use massage when compared with male players (73.7% vs. 62.7%; $\chi^2[1]=4.638$; $\phi=-0.1$; $p=0.033$). Of the players who use massage, self massage using a foam roller or massage gun (72.5%), and massage by therapist (71.2%) were the most popular methods of use. Gaelic games players perceive massage as important for releasing tight connective tissue (4.17 ± 1.12), decreasing muscle soreness (4.16 ± 1.04) and relieving pain (3.89 ± 1.13 out of 5) when ranked out of 5.

Alternative Therapies

The alternative therapies section was completed by 415 players (35.2%). Music is commonly used as post-exercise therapy by a majority (60.4%) of Gaelic games players. Players perceive the importance of music for relaxation (3.68 ± 1.33), improved positive focus (3.75 ± 1.29) and reducing stress and anxiety (4.16 ± 1.04) when ranked out of 5. Additional strategies used to improve recovery such as yoga (19.3%), acupuncture (13.1%), reflexology (6.0%) and herbal therapy (5.8%) were also reported.

Discussion

This study identified that a broad range of post-exercise recovery strategies are commonly implemented by Gaelic games players to expediate the return of performance to pre-exercise levels. There were significant differences in recovery strategy use between different sports, biological sexes and playing standards. Notably, the current Gaelic games players reported a high prevalence of multi-team (51.2%) and multi-sport (51.1%) activity, while 31.6% reported an off-season of ≤ 2 -weeks duration (15.4% reporting no off-season), which directly corresponds with findings from a recently published national report (Kelly et al., 2018b).

The current results demonstrate that Gaelic games players use active cool downs, external cold application, a regular sleep routine, diet/hydration strategies and massage most commonly, which is similar to those utilised by other team sport athletes (Murray et al., 2017a, Tavares et al., 2017a, Pernigoni et al., 2022, Calleja-González et al., 2021a). Inter-county Gaelic games players appear to employ recovery strategies significantly more than their club/collegiate counterparts, also complementing work in other invasive team sports (Venter, 2014, Crowther et al., 2017, Tavares et al., 2017a). It's possible that elite level team sport athletes endure relatively more strenuous training/competitive demands than club/collegiate athletes, and subsequently seek modalities to expediate recovery more readily as a means to cope. Another possible explanation is that club/collegiate athletes may have limited access to recovery modalities or lack the knowledge about their appropriate implementation. Overall, the intense longitudinal demands faced by Gaelic players (particularly at inter-county level) may pose significant risks of cumulative and residual fatigue/muscle damage (Meeusen et al., 2013, Kellmann, 2010), mental fatigue (Russell et al., 2019) and symptoms of burnout (Langan et al., 2015). Indeed, inter-county

players within Gaelic games often join their club team following their inter-county team's elimination from the All-Ireland championship, and subsequently partake in an extensively long season (55.9% of players reported \geq 11-month long season; Table 7. 2) (Kelly et al., 2018b).

It's not surprising that most Gaelic games players (79.1%) in the current analysis implement a regular sleep routine to facilitate recovery, considering its governing influence on numerous psychobiological functions (Meeusen et al., 2013, Kellmann, 2010, Kirschen et al., 2020) and subsequent roles in physical and psychological recovery (Doherty et al., 2021, Halson, 2014). These include immunological function, energy metabolism, mood/cognitive function and muscular repair (Fullagar et al., 2015a, Claudino et al., 2019). Interestingly, a significantly larger proportion of female players employ a regular sleep routine compared to male players (82.6% vs. 75.1%). Evidence underlining the importance of sleep is highlighted by decrements in physical/cognitive performance following sleep deprivation (Fullagar et al., 2015b, Pallesen et al., 2017, Pilcher and Huffcutt, 1996) and improvements in markers such as running speed and shooting accuracy following sleep extension (Mah et al., 2011, Schwartz and Simon Jr, 2015). While a body of literature reinforces the importance of sleep in numerous regenerative processes (Watson et al., 2021, Kirschen et al., 2020), evidence highlighting its mechanistic underpinnings regarding post-exercise recovery remain somewhat unclear (Samuels, 2008, Milewski et al., 2014). In comparison, other components of recovery such as nutrition and hydration have more clearly defined physiological mechanisms underpinning their restorative effects (Halson, 2008, Williams and Rollo, 2015, Kovacs et al., 2002).

Notably, a significantly larger proportion of male players in the current cohort employed post-exercise nutrition strategies (77.6% vs. 67.5%), consumed a combination of carbohydrate and protein following exercise (62.1% vs. 28.0%) and used supplements

(28.8% vs. 15.8%) when compared with females. These findings support prior research suggesting that male team sport athletes demonstrate nutritional practices closer to consensus recommendations when compared with females (Baker et al., 2014) and more prevalently consume supplements (Jovanov et al., 2019). It's possible this disparity could be related to differences in the allocation of nutritional expertise/resources, which may be less accessible to female athletes, (Hoeber, 2008, Bowes et al., 2020) and/or lower levels of applied performance nutrition research extrapolated to female participants (Cowley et al., 2021). Interestingly, prior work has identified that female Gaelic players display 'poor' nutrition knowledge scores (Renard et al., 2020) and that female Gaelic players demonstrate lower total and sport specific nutrition knowledge scores when compared with males (Mitchell et al., 2021). On the same note, dietary practice at both inter-county and club/collegiate levels of Gaelic football have been exhibited to be suboptimal to support players performance and recovery (Ó Catháin et al., 2020, McCrink et al., 2021). Performance of the intensive and prolonged intermittent demands of Gaelic games match-play is heavily dependent upon both aerobic and anaerobic energy metabolism pathways (Malone et al., 2017d). These metabolic stressors imply a significant reliance on glycogen stores, and by virtue emphasise the gravity of peri-match nutritional intake (Ó Catháin et al., 2020). The importance placed on nutrition and hydration strategies by the current sample seems logical given their well-documented role in glycogen resynthesis, muscular structure/function recovery, fatigue dissipation, immune health and many other functions (Heaton et al., 2017, Renard et al., 2020, Ó Catháin et al., 2020). It should be noted that these strategies are regularly utilised as standalone practices and in combination with other regenerative strategies (Nédélec et al., 2012). However, this study and others (Murray et al., 2018, Field et al., 2021, Altarriba-Bartes et al., 2020) combine to suggest that team

sport athletes regularly strategize their post-exercise hydrational and nutritional intakes to aid recovery.

Supporting prior work (Altarriba-Bartes et al., 2020, Crowther et al., 2017, Venter et al., 2010), our results highlight an active cool down as the most commonly used recovery practice among Gaelic players. Notably, an active cool down was utilised significantly more in Camogie, hurling and Gaelic football when compared with Gaelic handball (56.3% vs. 77.3 to 94.3%). Amongst other possible reasons, this may suggest that players/coaches in the field-based Gaelic sports place a greater emphasis on an active cool down when compared with their court-based handball counterparts. The varying physical demands, indoor vs. outdoor environment and factors relating to sport culture (e.g., team vs. individual sport and/or between-sport differences in coaching infrastructure/educational initiatives) may contribute to these differences in active recovery use. Overall, despite extensive application, the practical efficacy of an active cool down is undermined by well-documented evidence demonstrating a trivial/non-significant impact on performance recovery in the day(s) following exercise (Van Hooren and Peake, 2018, Pooley et al., 2020, Andersson et al., 2010b). Many possible reasons such as ease of use, lack of equipment requirements and instruction from coaches/practitioners (Field et al., 2021) could explain the apparent mismatch between the widespread use of this strategy, and its limited scientific backing. Furthermore, prior work suggests that coaches prescribe recovery interventions based primarily on intuitive and experiential knowledge, rather than from academically verified sources of evidence (Simjanovic et al., 2009). Nevertheless, in the absence of sport-specific data it is difficult to infer how Gaelic games coaches or relevant practitioners (i.e., strength and conditioning staff, physiotherapists, nutritionists etc.) perceive active cool downs and other recovery techniques, and whether their perceptions influence the practices Gaelic players undertake.

Despite the current participants prevalent use of stretching to aid recovery (71.4%), several systematic analyses reported no clinically worthwhile benefit of stretching on muscle soreness (Herbert et al., 2011) or performance recovery (Afonso et al., 2021, Gremion, 2005). Also noteworthy, a significantly larger proportion of female players use post-exercise stretching when compared with males (66.4% vs. 76.5%). This finding complements previous work from Babault and colleagues (Babault et al., 2021), where the use of post-exercise stretching was demonstrated to be more prevalent in recreational female athletes when compared with male athletes (76.1% vs. 68.9%), and a significantly larger proportion of female respondents used stretching with the specific goal of assisting recovery when compared to males (81.0% vs. 69.3%). Despite its limited practical post-exercise recovery benefits (Pooley et al., 2017, Sands et al., 2013), post-training/competition stretching is routinely implemented by the current sample and previous runners (Shaw et al., 2017), rugby players (Tavares et al., 2017a) and soccer players (Nédélec et al., 2013). This may suggest a possible incongruence between (1) the perceived benefits and ubiquitous implementation of stretching in many sports, and (2) its limited empirically documented effectiveness to promote post-exercise recovery. On the other hand, stretching's pervasive use may be on account of its convenience, accessibility, ease of implementation and its cultural practice as part of a team-based warm up/cool down (Crowther et al., 2017). Indeed, while stretching may not confer clear performance recovery benefits (Gremion, 2005) or attenuate muscular soreness (Afonso et al., 2021), it could be conceived that coaches/athletes implement post-exercise stretching as a means to accelerate range of motion return (Judge et al., 2011). However, evidence for its utility in this context is also uncertain, with prior work demonstrating some post-exercise reductions in musculotendinous stiffness (Ryan et al., 2009) and others reporting mixed or non-significant findings (Afonso et al., 2021, Baxter et al., 2017, Herbert et al., 2011).

Complementing work in similar team sports, (Crowther et al., 2017) massage was used by a majority (68.8%) of the present respondents. Despite its popularity within the current Gaelic games cohort and among other athletes (Venter et al., 2010, Crowther et al., 2017), massage has demonstrated limited purposeful benefits regarding blood flow increase (Wiltshire et al., 2010), accelerated metabolite removal (Tiidus and Shoemaker, 1995) and the regeneration of physical performance (Tiidus and Shoemaker, 1995, Davis et al., 2020). In contrast, massage has demonstrated profound benefits on subjective measures of muscle soreness and recovery (Nédélec et al., 2013) which could prove beneficial in alleviating psychological stress or mental fatigue (Nunes et al., 2016).

The application of cold was significantly more prevalent in inter-county Gaelic games players when compared with their club/collegiate counterparts (77.2% vs. 81.7%). Possibly explaining this finding, the higher standard of play at inter-county level may provoke significantly more fatigue and muscle damage (as has been reported in rugby union) (Tavares et al., 2017b), thereby increasing the potential applicability/efficacy of recovery strategies in inter-county Gaelic players (Mangan et al., 2020, Malone et al., 2017c). Overall, cold exposure remains a popular regenerative technique in the current sample irrespective of playing standard, wherein the majority of respondents (79.5%) used the modality to consolidate recovery. This widespread utility is reinforced by many experimental studies and reviews demonstrating significantly beneficial effects of cold application on lowering acute markers of muscle damage/soreness and expediting performance recovery to pre-exercise condition (King and Duffield, 2009, Higgins et al., 2017). These effects are underpinned by many possible physiological mechanisms including increased cellular oxygen supply, metabolite efflux, lowered inflammation from muscle damage, reduced muscle spasm, analgesic effects and augmented muscle perfusion (Tipton et al., 2017, Ihsan et al., 2021). These mechanisms are relatively consistent with

the opinions of the current respondents, who perceived cold exposure as beneficial in decreasing swelling (4.23 out of 5), inflammation (4.21 out of 5) and muscle soreness (4.12 out of 5). Overall, based on current literature (Tipton et al., 2017, Ihsan et al., 2021) it may be suggested that Gaelic players possibly apply cold temperatures when acute readiness to play is the key objective and to avoid use when training loads are low or when the development of neuromuscular qualities (i.e., hypertrophy and strength) are primary targets (Tipton et al., 2017, Ihsan et al., 2021).

Remarkably, approximately a third (30%) of respondents periodised recovery strategies for exclusive or more frequent use during the foremost competitive phases. While it is unclear if this apparent recovery periodisation was achieved by accident or design, the open-ended responses demonstrate a clear link between the key phases of competition and initiated/increased recovery modality use (table 7.2). This premise corresponds with recommendations that athletes should periodise and prioritise such strategies (particularly cold exposure) for use when full recovery to an uncompromised psychophysiological level is required before competition, whilst limiting their utility when training adaptations are the most desired outcomes (Mujika et al., 2018, Kellmann et al., 2018).

As highlighted previously (Altarriba-Bartes et al., 2020, Field et al., 2021), some limitations in the current study exist and should be considered when interpreting results. Firstly, the instrument used (i.e., online questionnaire) means players may have misinterpreted some questions/sections and possibly provided inappropriate or inaccurate answers as a consequence (Crowther et al., 2017). Secondly, the questionnaires level of depth and detail may have meant ‘survey fatigue’ could have influenced responses (Egleston et al., 2011). Overall, an in-depth understanding of the numerous mechanisms underpinning the complex fatigue and muscle damage responses in Gaelic games players is incumbent for optimal prescription of recovery interventions (Calleja-González et al.,

2021b, Kellmann, 2010), and future work is necessary so this information can be gathered and disseminated to applied practitioners. Indeed, when considering the widespread implementation of recovery strategies among Gaelic games players, there is an apparent need to establish the efficacy of these modalities following Gaelic specific training/competition. Subsequently, future work is required to explore the effectiveness of various bespoke recovery modalities utilised in different Gaelic games populations and contexts in order to determine best practice. It would also be beneficial to explore players perceptions of various recovery strategies so as to account for potential placebo/nocebo effects when implementing an intervention (Hurst et al., 2020). Owing to promising findings of nutritional (Heaton et al., 2017), CWI (Higgins et al., 2017) and contrast water therapy (Higgins et al., 2017) interventions in other similar sports, experimental research outlining the effects of these strategies in Gaelic games players during or following periods of accentuated workloads/fixtures could provide practically meaningful insight for coaches/practitioners.

Conclusion

Gaelic games players face many challenges when attempting to maintain a synergistic stress/recovery equilibrium that would optimally facilitate the season long repeated performances crucial for success. Thus, the use of modalities to accelerate the time course and magnitude of physiological, perceptual and performance recovery may be a central factor in preparation for training and/or competition. Our results demonstrate that Gaelic games players regularly implement a range of post-exercise recovery strategies in an attempt to expediate the return of performance capacity and psychophysiological status to pre-exercise levels. This data may be used to (1) provide practical insight for coaches/support staff who seek to prescribe recovery interventions tailored to optimize preference/compliance, (2) enable targeted educational programmes outlining effective and periodized recovery strategies and (3) guide future research investigating the sport-specific efficacy of promising and logistically viable regenerative practices. These strategies should be carefully selected, implemented and manipulated with many factors in mind to optimally consolidate subsequent performances and avoid interference to physiological adaptations.

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Section Link

A preliminary assessment of Gaelic games players use of recovery strategies during the post-exercise recovery timeline was conducted in the previous chapter. While this study identified *what* Gaelic games players use to accelerate post-exercise recovery beyond passive measures, players perceptions of these strategies remain unknown. This is important to consider, as players practices may not align with their perceptions if they do not have access to the desired facilities/equipment, or if they have been specifically prescribed a given strategy by a practitioner working with their team. Additionally, given that prior work has suggested that the advice or instruction received from a practitioner significantly influences an athletes' perceptions (Murray et al., 2017a, Shell et al., 2020, Van Wyk and Lambert, 2009) it may be pertinent to also examine practitioners' perceptions. Collectively, profiling Gaelic games players and practitioners' perceptions is important to establish if beliefs align with evidence-informed recommendations and establish if evidence-based recommendations are being effectively communicated and translated into the applied field. Therefore, the forthcoming chapter and final study of this thesis will endeavour to examine players and practitioners' perceptions of recovery strategies.

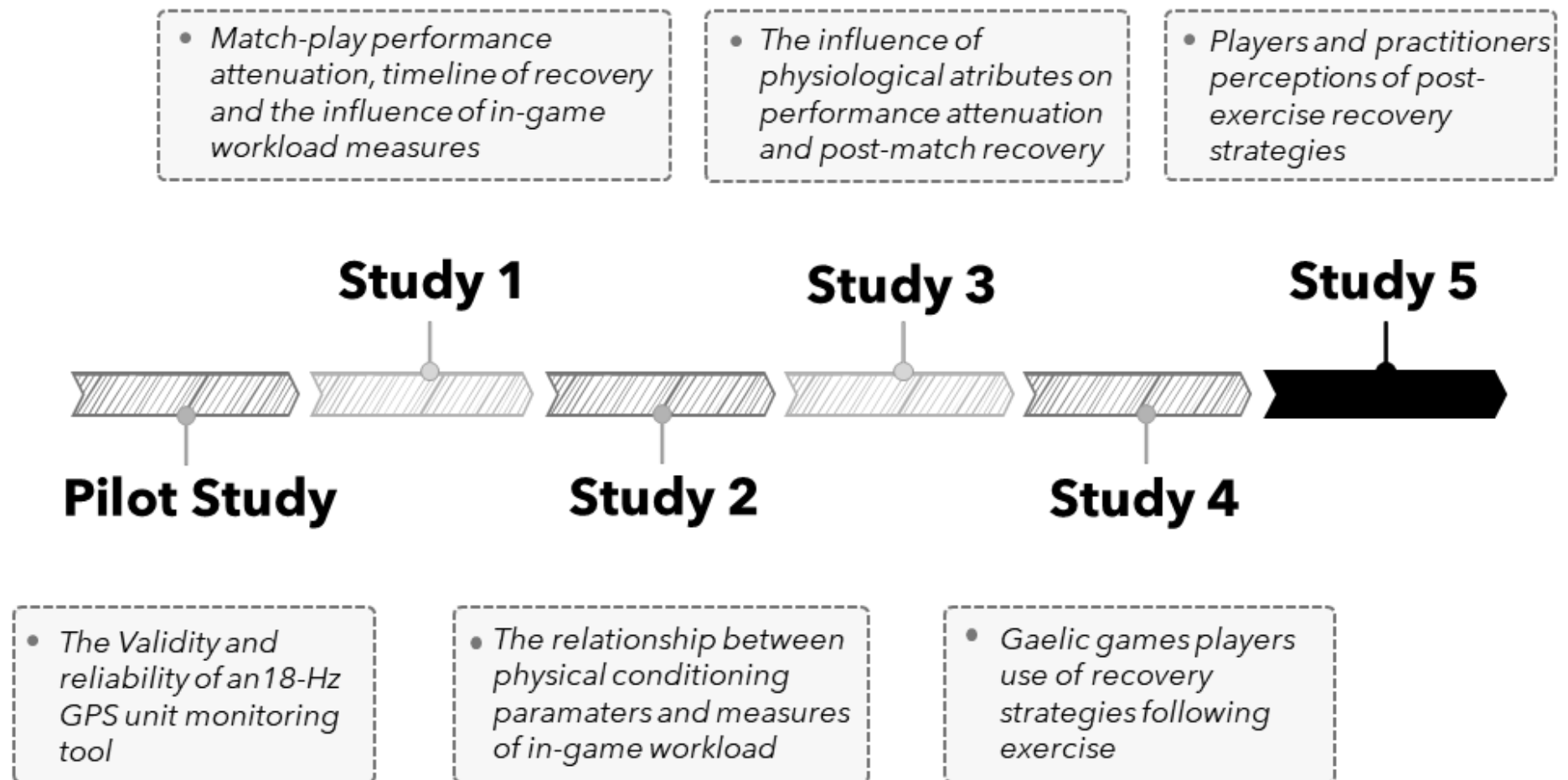


Figure 7. 4. Thesis timeline infographic highlighting study 5.

Chapter 8 – Study 5

Gaelic Games Players and Practitioners Perceptions of
Recovery Strategies: Guided by Evidence?

Abstract

Purpose: Athletes and practitioners' perceptions of recovery strategies are often incongruent with empirical evidence and have been demonstrated to illicit significant placebo/nocebo effects. As no data is yet available within Gaelic games, there is a need to identify the perceptions of players and practitioners in order to inform the design of recovery interventions and tailor future dissemination of evidence-based recommendations. Accordingly, this study aimed to examine and compare Gaelic games players and practitioners' perceptions of post-exercise recovery practices.

Methods: Gaelic games participants, categorised as players ($n = 1178$; age: 24.6 ± 6.6 years) and practitioners ($n = 148$; age: 35.9 ± 8.7 years), were recruited for this study. Gaelic football ($n = 813$; age 24.3 ± 6.5 years), Camogie/hurling ($n = 342$; age: 24.4 ± 7.3 years) and Gaelic handball ($n = 23$; age: 23.7 ± 10.1 years). Practitioners were categorised into sports coaches ($n = 71$; age: 39.3 ± 8.6 years), strength and conditioning coaches ($n = 34$; age: 31.2 ± 6.4 years), nutrition staff ($n = 15$; age: 32.7 ± 7.1 years) and athletic rehabilitation staff ($n = 35$; age: 34.5 ± 8.0 years). A questionnaire (Venter, 2014) was adapted and employed to determine players and practitioners perceptions of a range of psychological, physiological, social, alternative and complimentary recovery practices.

Results: Recovery strategies that were perceived to be most important (ranked out of 5) by Gaelic games players were sleep (4.52 ± 1.06), hydration (4.50 ± 1.06), nutritional intake (4.03 ± 1.22), stretching (3.98 ± 1.25), active cool-down (3.48 ± 1.22), massage by therapist (3.39 ± 1.28), foam rolling (3.33 ± 1.28) and cold-water immersion (3.29 ± 1.26). There were significant differences between sport, playing standard and biological sex for players perceptions of various recovery strategies ($p < 0.05$). Coaches/practitioners rated sleep (4.86 ± 0.56), fluid-replacement (4.77 ± 0.64), post-exercise meal (4.67 ± 0.70), daytime

naps (3.85 ± 1.09), discussion with teammates (3.56 ± 1.19), stretching (3.56 ± 1.16), getting out in nature (3.45 ± 1.10) and discussion with coach (3.44 ± 1.23) as the most beneficial practices. Here, there were also numerous significant differences between biological sex and playing standard ($p < 0.05$). Finally, players perceptions of numerous recovery strategies were significantly different when compared with the perceptions of practitioners ($p < 0.05$).

Conclusions: This work provides novel insight into the practices Gaelic games players and practitioners perceive as effective to enhance recovery from exercise. While strategies with established efficacy are rated as most important, a distinct and possibly problematic disconnect exists between the perceived importance of many regenerative practices and their empirically documented effectiveness. Thus, tailored education detailing optimal recovery practices could help redirect valuable time and resources towards more effective strategies.

Introduction

Gaelic games are a series of field-based (Gaelic football, hurling and Camogie) and court-based (Gaelic handball) sports native to Ireland which combine to form the largest amateur sporting body in the world (Crampsie, 2016). Field-based Gaelic sports are intermittent in nature, encompassing many high intensity accelerations, decelerations, changes in direction/speed, tackling/evading opponents, and the performance of many highly technical demands (Egan et al., 2021, Mangan et al., 2018b, Young et al., 2021). During competition, players cover most ground whilst walking and jogging, and intermittently run/sprint as the game regularly and rapidly transitions from defence to attack (Mangan et al., 2017b, Egan et al., 2021). Conversely, Gaelic handball necessitates the performance of many multi-directional turns, jumps, slides and changes of pace during short duration rallies (similar to other racquet sports) in a confined space (Kondrič et al., 2013, Sharp, 2002). These strenuous training/match-play demands (Mangan et al., 2020) combined with lengthy seasons, multi-team/sport activity (Kelly et al., 2018b), signs of burnout (Woods et al., 2020) and residual fatigue (Daly et al., 2020) could collectively compromise players post-exercise recovery.

Bereft of adequate recovery, fatigue/muscle damage emanating from these stressors may not be fully compensated (Kellmann et al., 2018, Dellal et al., 2015) and performance during forthcoming training sessions and/or matches may subsequently become compromised (Hunkin et al., 2014, Julian et al., 2021). While similar team sport athletes and coaches perceive a wide range of regenerative strategies as effective to consolidate recovery kinetics (Shell et al., 2020, Crowther et al., 2017, Venter, 2014), the perceptions of Gaelic games players and practitioners remain unknown. An exponential growth in research assessing the efficacy of recovery strategies (Argus et al., 2013, Gill et al., 2006),

the widespread implementation of recovery interventions (Field et al., 2021, Altarriba-Bartes et al., 2020, Shell et al., 2020) and the high prevalence of pseudoscientific beliefs held by athletes and coaches (Bailey et al., 2018, Halson et al., 2016) makes it challenging to surmise what strategies may be perceived to be effective within Gaelic games. This uncertainty may become magnified when considering the intricate and multifactorial nature of recovery from exercise (Kellmann et al., 2018, Kellmann, 2010, Simjanovic et al., 2009), the lack of research exploring recovery within Gaelic games (wherein demanding sport and non-sport stressors could amplify players perceptions of recovery interventions) (Woods et al., 2020, O'Connor et al., 2016b, Daly et al., 2020) and the extensive sources of information with which athletes and coaches form their perceptions and base their training and recovery practices on (Stoszkowski and Collins, 2016, Jovanov et al., 2019, Froiland et al., 2004).

The interplay between (1) physical training and competition loads overlaid with work/academic stressors and (2) the subsequent fatigue, muscle damage and regenerative response is highly complex (Dupuy et al., 2018, Kellmann et al., 2018) and regulated by many factors during the recovery timeline (Tavares et al., 2017b, Argus et al., 2013). An exemplar model of post-exercise recovery is suggested to be multifactorial, context dependant and individualised (Kellmann et al., 2018, Kellmann, 2010). The latter may be particularly pertinent within Gaelic games when accounting for potentially large variations in external load (e.g., via possible multi-team/sport activity) (Kelly et al., 2018b) and life stressors (e.g., via diverse career/academic pursuits) (Woods et al., 2020, Kelly et al., 2018b). Practitioners who seek to navigate the complex interactions of this stress-recovery relationship are impeded by the lack of information available exploring the perceptions of post-exercise recovery strategies within Gaelic games. Investigating players and practitioners' perceptions and opinions of recovery modalities could deliver valuable insight into the possible compliance, understanding and beliefs surrounding various

recovery practices, which are likely to influence responses via placebo/nocebo effects (Hurst et al., 2020). Indeed, a negative opinion on the efficacy of an ice bath has been demonstrated to significantly reduce the reported post-exercise recovery benefits of the modality (Higgins et al., 2011), possibly inferring an athletes perceptions can meaningfully impact the effectiveness of a recovery intervention. On the same note, prior experience of a recovery modality has also been exhibited to adjust an athletes perceptions of its effectiveness (Juliff et al., 2014), implying that it would be beneficial to first identify a players perceptions of a given strategy before prescribing its use, so as to account for biases such as these. Furthermore, knowledge of possible differences in perceived effectiveness between Gaelic games sports, playing standards and biological sexes (as demonstrated in other team sports) (Venter, 2014, Tavares et al., 2017a) could guide tailored recovery interventions for specific Gaelic games populations.

Many post-exercise recovery practices are prevalent and believed to be effective in professional invasion team sports (Field et al., 2021, Altarriba-Bartes et al., 2020) such as cold water immersion (CWI), active cool downs, massage, rehydration and stretching (Venter et al., 2010, Field et al., 2021). Indeed, athletes perceive a diverse range of post-exercise recovery strategies as beneficial in offsetting the effects of fatigue, inflammation and muscle damage emanating from training and match-play (Venter, 2014, Shell et al., 2020, Crowther et al., 2017). Crucially, given suggestions that failing to integrate scientific evidence when implementing recovery interventions may have detrimental effects (Field et al., 2021, Dupuy et al., 2018), there is a need to assess the contemporary perceptions players and relevant support staff have about various post-exercise regenerative strategies. Interestingly, the instructions or advice received from a practitioner (Murray et al., 2017a, Shell et al., 2020, Van Wyk and Lambert, 2009) is suggested to significantly influence an athlete's beliefs of a recovery strategy. It has been previously identified that practitioners

perceive a range of post-exercise recovery strategies as effective, such as dietary practices, sleep, CWI and active recovery (Querido et al., 2022, Field et al., 2021). Therefore, it is pertinent to understand practitioners beliefs of recovery strategies (in addition to players), and whether their perceptions are supported by peer-reviewed data or based on experiential/intuitive knowledge as has been reported previously (Simjanovic et al., 2009). Consequently, this study sought to investigate and compare Gaelic games players and practitioners of the importance of post-exercise recovery strategies.

Methods

Participants

In total, 1326 Gaelic games participants were recruited for this study. These were categorised as players ($n = 1178$; age: 24.6 ± 6.6 years) and practitioners ($n = 148$; age: 35.9 ± 8.7 years). Players were categorised into each Gaelic sport; Gaelic football ($n = 813$; age 24.3 ± 6.5 years), Camogie/hurling ($n = 342$; age: 24.4 ± 7.3 years) and Gaelic handball ($n = 23$; age: 23.7 ± 10.1 years). Players whose highest level of Gaelic games participation was at inter-county level were identified as inter-county (national; $n = 309$; age: 23.2 ± 6.0 years), while players at club/collegiate level were identified as developmental ($n = 869$; age: 25.0 ± 6.8 years). Players under 18-years of age or with less than 6-months experience of competitive training/match-play in Gaelic games were excluded from this analysis. Practitioners were categorised into sports coaches ($n = 71$; age: 39.3 ± 8.6 years), strength and conditioning staff ($n = 34$; age: 31.2 ± 6.4 years), athletic rehabilitation staff ($n = 35$; age: 34.5 ± 8.0 years) and nutrition staff ($n = 15$; age: 32.7 ± 7.1 years). Informed consent was obtained from all participants, and ethical approval was granted for this research by the Technological University of the Shannon Research Ethics Committee (code 20200304).

Questionnaire Development

A questionnaire previously used to assess team sport athletes perceptions of recovery strategies (Venter, 2014) was adapted for use with Gaelic games players (Appendix D) and practitioners (appendix E) using the same methods to establish validity and reliability as outlined in chapter 7 of this thesis. Briefly, the questionnaire was adapted to limit respondent fatigue and was tested and reviewed to assess validity and reliability. Here, ten reviewers (i.e., two Gaelic games sports coaches, six qualified sport scientists and two athletic rehabilitation therapists) with ≥ 5 years' experience working with Gaelic games

players appraised, critiqued and subsequently provided feedback on the proposed questionnaire. To determine validity, the questionnaire was circulated to reviewers using an online format (SurveyMonkey, San Mateo, CA, USA). Changes the reviewers sought to address were identified and suggested corrections were provided on a supplementary Google forms document (Microsoft Corporation, Redmond, WA, USA). Similarly, any potential issues relating to relevance, understanding, spuriousness or sequence that the reviewers identified were highlighted and amended in accordance with suggested recommendations (Querido et al., 2021). Following completion of the suggested edits the survey was prepared for the reliability assessments. Here, the stability of players and practitioners' responses were examined by implementing a test re-test reliability assessment over a short-duration time interval (i.e., 12-days). This time interval adheres with prior recommendations (i.e., 10 to 24 days separating each assessment) and was selected to evaluate random discrepancies that may characterise the questionnaires responses, without allowing sufficient time for attitudes or opinions to change (Pedhazur and Schmelkin, 2013). Players ($n = 34$) and practitioners ($n = 31$) completed each respective population-specific survey with a 12-day interval interspersed between both assessments (i.e., all players and practitioners completed each respective population-specific survey during each timepoint). These results were compared using Cohens kappa agreement test, whilst observing the previously recommended sample size (more than 20 participants) (Bujang and Baharim, 2017). The questionnaire was subsequently circulated to Gaelic games players and practitioners. Once the data collection phase was completed, the internal consistency of the players and practitioners responses were assessed using the Cronbach alpha statistic (Bland and Altman, 1997).

Questionnaire Overview

The player and practitioner surveys both comprised two key sections, wherein section 1 assessed demographics and section 2 assessed their perceptions of the importance of various recovery strategies. The introductory demographic section of the players questionnaire assessed their playing participation details (i.e., age, playing standard, biological sex, sport etc.) while the practitioners demographic section assessed background (i.e., age, biological sex) and Gaelic games career details (i.e., their profession and an overview of the team(s) they work with). Next, a list assessing the importance of various recovery modalities (e.g., sleep, fluid-replacement, daytime naps, stretching, active cool-down, supplements, foam rolling, sauna, cryochamber etc.) was completed by the players and practitioners (please see appendix c [players] and d [practitioners] for the full list of recovery strategies). This list was based off previous works profiling athletes use and perceptions of recovery strategies (Venter, 2014, Venter et al., 2010, Crowther et al., 2017) and was adapted for Gaelic games participants. Players and practitioners indicated on a 5-point Likert Scale how important they perceived each modality was to support post-exercise recovery, with '1' not important at all and '5' extremely important. Participants also had the choice to indicate that they were not familiar (NF) with the modality. The NF choice served as a filter in the prevention of inaccurate or erroneous responses (Beatty and Herrmann, 2002).

Statistical Analysis

This research followed a cross-sectional and observational study design. The data was extracted from the online survey platform (Survey Monkey, San Mateo, CA, USA) on to Statistical Package for Social Sciences (Statistics for Windows, SPSS, Version 27.0, Chicago, IL, USA) for analysis. For descriptive purposes, means with standard deviations were reported for ordinal (Likert Scale) measurements and frequencies were used to

describe categorical data. One-way analysis of variance (ANOVA) with Bonferroni post-hoc testing was used to compare Likert Scale ordinal data between respondents from the different sports (camogie, hurling, Gaelic football and Gaelic handball) and sub-groups of practitioners (sports coaches, strength and conditioning staff, nutrition staff and athletic rehabilitation staff). Independent samples t-tests and Hedges *g* effect size (ES) statistic were used to examine any differences between populations (i.e., between practitioners and players) or within-population analysis for biological sex (between male and female players and practitioners respectively) or playing standard (between inter-county and club/collegiate players and practitioners respectively). Effect sizes of 0.20–0.60, 0.61–1.19, and >1.20 were considered small, moderate, and large respectively (Hopkins et al., 2009). Cronbach alpha was calculated to assess the internal consistency of the Likert scale survey responses. The score was interpreted as good in the range of 0.80 to 0.89 and excellent if ≥ 0.90 . Weighted Cohen's kappa coefficient agreement was used to assess test-retest reliability. Weighted Kappa (κ_w) values were used to interpret the degree of reliability and were characterised according to the scale proposed by Landis and Koch (Landis and Koch, 1977): poor agreement (<0.00); slight agreement (0.00–0.20); fair agreement (0.21–0.40); moderate agreement (0.41–0.60); substantial agreement (0.61–0.80); almost perfect agreement (0.81–1.00). An alpha level of $p < 0.05$ was considered as statistically significant.

Results

The Cronbach alpha result of the current survey was 0.88 for the players and 0.87 for the practitioners, demonstrating a high level of internal consistency for all scale data. Responses to all questions presented significant agreement in the test-retest assessment ($p < 0.05$), with 87.7% of questions demonstrating substantial to almost perfect agreement (average κ_w for players $[0.71 \pm 0.08]$; average κ_w for practitioners $[0.71 \pm 0.10]$; Table 8.1).

Table 8. 1. Test-retest reliability outcomes for each section of the questionnaire.

Questionnaire section	Players (<i>n</i> = 34)		Practitioners (<i>n</i> = 31)	
	Weighted kappa (κ_w)	Degree of agreement	Weighted kappa (κ_w)	Degree of agreement
Active cool-down	0.75	Substantial	0.68	Substantial
Cold water immersion	0.65	Substantial	0.62	Substantial
Warm water immersion	0.57	Moderate	0.56	Moderate
Acupuncture	0.72	Substantial	0.57	Moderate
Breathing exercises	0.82	Almost perfect	0.68	Substantial
Cold shower	0.65	Substantial	0.77	Substantial
Compression garments	0.71	Substantial	0.58	Moderate
Contrast therapy	0.79	Substantial	0.68	Substantial
Cryochamber	0.93	Almost perfect	0.72	Substantial
Daytime naps	0.83	Almost perfect	0.94	Almost perfect
Discussion with coach	0.73	Substantial	0.73	Substantial
Discussion with teammate	0.76	Substantial	0.71	Substantial
Post exercise meal	0.70	Substantial	0.68	Substantial
Floataion tank	0.72	Substantial	0.61	Substantial
Rehydration	0.71	Substantial	0.54	Moderate
Fluid intake after match	0.81	Almost perfect	0.71	Substantial
Foam rolling	0.75	Substantial	0.74	Substantial
Ice bath	0.86	Almost perfect	0.82	Almost perfect
Imagery/visualisation	0.58	Moderate	0.86	Almost perfect
Massage by therapist	0.64	Substantial	0.56	Moderate
Meditation	0.68	Substantial	0.71	Substantial
Music	0.63	Substantial	0.86	Very good
Prayer	0.72	Substantial	0.62	Substantial
PMR	0.70	Substantial	0.77	Substantial
Sauna	0.70	Substantial	0.67	Substantial
Self-massage	0.65	Substantial	0.78	Substantial
Sleep	0.70	Substantial	0.73	Substantial
Socialise with friends	0.66	Substantial	0.69	Substantial
Stretching	0.80	Very good	0.82	Almost perfect
Supplements	0.58	Moderate	0.78	Substantial

Abbreviations; κ_w : weighted Kappa; CWI: cold water immersion; PMR: progressive muscle relaxation

Descriptive data for ratings of recovery modalities for the sub-groups of inter-county, club/collegiate, male and female players are summarised in Table 8. 2. Here, and in subsequent tables detailing comparisons between sub-groups of participants, an arbitrary cut off was used to determine the top 8 ranked recovery modalities similar to prior work (Venter, 2014, Shell et al., 2020, Crowther et al., 2017).

Gaelic games players

When comparing playing status, inter-county players rated CWI (+6.7%; ES = 0.17; $p = 0.044$), warm water immersion (+8.4%; ES = 0.18; $p = 0.048$) contrast temperature therapy (+7.2%; ES = 0.19; $p = 0.045$) compression garments (+14.6%; ES = 0.37; $p < 0.001$), daytime naps (+10.7%; $p = 0.010$) and massage by therapist (+8.2%; ES = 0.23; $p = 0.009$) as significantly more beneficial when compared with club/collegiate participants (Table 8. 2). Female athletes rated an active cool down (+13.5%; ES = 0.39; $p < 0.001$), discussion with coach (+24.3%; ES = 0.55; $p < 0.001$) and teammates (+21.7; ES = 0.53; $p < 0.001$), foam rolling (+13.0%; ES = 0.34; $p < 0.001$), massage by teammates (+19.6%; ES = 0.30; $p < 0.001$) and stretching (+10.0%; ES = 0.32; $p < 0.001$) significantly higher than males. Finally, male athletes rated daytime naps (+14.4%; ES = 0.30; $p < 0.001$) and supplements (+7.7%; ES = 0.17; $p = 0.024$) as significantly more important than females.

Table 8. 2. Participant's perceptions of recovery strategies importance as dichotomised by playing standard and biological sex.

Group	Recovery Practice	Score out of 5
Inter-county (<i>n</i> = 309)	Sleep	4.56 ± 1.11
	Fluid replacement	4.49 ± 1.11
	Post-exercise meal	4.16 ± 1.21 †
	Stretching	3.89 ± 1.26
	Massage by therapist	3.61 ± 1.22 †
	Cold water immersion	3.45 ± 1.34 †
	Active cool down	3.39 ± 1.25
	Ice bath	3.39 ± 1.29 †
Club/collegiate (<i>n</i> = 869)	Fluid replacement	4.48 ± 1.07
	Sleep	4.48 ± 1.09
	Stretching	4.00 ± 1.26
	Post-exercise meal	3.94 ± 1.31 †
	Active cool-down	3.49 ± 1.24
	Foam rolling	3.27 ± 1.37
	Discussion with teammates	3.13 ± 1.47
	Massage by therapist	2.97 ± 1.59
Male (<i>n</i> = 604)	Sleep	4.55 ± 1.02
	Fluid replacement	4.50 ± 1.03
	Post-exercise meal	4.01 ± 1.19
	Stretching	3.78 ± 1.26
	Cold water immersion	3.33 ± 1.25
	Massage by therapist	3.31 ± 1.32
	Ice bath	3.29 ± 1.29
	Active cool down	3.24 ± 1.26
Female (<i>n</i> = 574)	Fluid replacement	4.50 ± 1.08
	Sleep	4.49 ± 1.10
	Stretching	4.18 ± 1.20 †
	Post-exercise meal	4.04 ± 1.23
	Active cool down	3.71 ± 1.13 †
	Discussion with teammates	3.61 ± 1.40 †
	Foam rolling	3.56 ± 1.30 †
	Massage by therapist	3.47 ± 1.23

Data presented as mean ± SD († indicates a significantly higher rank when comparing playing standard; ‡ indicates a significantly higher rank when comparing sex).

Descriptive data for the top 8 most highly rated recovery modalities for each Gaelic sport are summarised in Table 8. 3. Descriptive data for the top 8 most highly rated recovery modalities for each Gaelic sport are summarised in Table 8. 3. Perceptions of the importance of an active cool down ($F_{(2,775)}5.115$; $p = 0.006$) and CWI ($F_{(2,667)}3.077$; $p = 0.047$) were significantly different between sports. Here, Gaelic football (+29.1%; ES = 0.70; $p = 0.024$) and camogie/hurling (+33.2%; ES = 0.91; $p=0.007$) participants rated an active cool down significantly higher than handball. Additionally, camogie/hurling players rated CWI significantly higher than Gaelic football players (+32.2%; ES = 0.71; $p=0.040$).

Perceptions of the importance of discussion with coach ($F_{(2,751)}10.472$; $p = 0.005$) was also significantly different between sports, wherein camogie/hurling players rated the practice significantly higher than Gaelic football players (+11.3%; ES = 0.25; $p=0.006$). Finally, perceptions of the importance of a post-exercise meal was significantly different between sports ($F_{(2,774)}3.823$; $p = 0.013$) whereby Gaelic football (23.1%; ES = 0.68; $p = 0.022$) and camogie/hurling (25.3%; ES = 0.76; $p = 0.010$) rated the practice significantly higher than handball players.

Table 8. 3. Participant's perceptions of recovery strategy importance across Gaelic sports.

Sport	Recovery Practice	Score out of 5
Gaelic football (<i>n</i> = 813)	Sleep	4.52 ± 1.07
	Fluid replacement	4.49 ± 1.05
	Post-exercise meal	4.02 ± 1.21 †
	Stretching	3.95 ± 1.28
	Active cool-down	3.45 ± 1.25 ‡
	Massage by therapist	3.40 ± 1.29
	Foam rolling	3.30 ± 1.34
	Ice bath	3.29 ± 1.28
Camogie/hurling (<i>n</i> = 342)	Sleep	4.53 ± 1.03
	Fluid replacement	4.53 ± 1.03
	Post-exercise meal	4.27 ± 1.11 †
	Stretching	4.14 ± 1.20
	Active cool down	3.80 ± 1.25 †
	Foam rolling	3.78 ± 1.00
	Discussion with teammates	3.70 ± 1.28
	Discussion with coach	3.61 ± 1.17 ‡
Handball (<i>n</i> = 23)	Fluid intake	4.27 ± 1.39
	Sleep	4.00 ± 1.73
	Stretching	3.67 ± 1.05
	Massage by therapist	3.58 ± 1.38
	Discussion with coach	3.50 ± 1.54
	Post-exercise meal	3.33 ± 1.45
	Foam rolling	3.33 ± 1.18
	Compression garments	3.30 ± 1.49

Data presented as mean ± SD († indicates significantly higher than Gaelic football; * indicates significantly higher than hurling; ‡ indicates significantly higher than handball).

Gaelic games practitioners

Descriptive data for practitioners' perceptions of recovery strategy importance across playing standard and biological sex are summarised in Table 8. 4. When comparing playing status, inter-county practitioners rated fluid replacement (+4.8%; ES = 0.36; $p = 0.038$) and supplements (+13.1%; ES = 0.38; $p = 0.028$) as significantly more important than club/collegiate practitioners. When comparing biological sex, female practitioners rated post-exercise meal consumption significantly higher than males (+6.9%; ES = 0.88; $p = 0.028$).

Table 8. 4. Practitioners' perceptions of recovery strategy importance as dichotomised by the practitioner's biological sex and teams playing standard.

Group	Recovery Practice	Score out of 5
Inter-county (<i>n</i> = 71)	Sleep	4.91 ± 0.33
	Fluid replacement	4.88 ± 0.32 †
	Post-exercise meal	4.72 ± 0.60
	Daytime naps	3.97 ± 1.04
	Discussion with teammates	3.59 ± 1.14
	Stretching	3.46 ± 1.27
	Get out in nature	3.52 ± 1.14
	Discussion with coach	3.46 ± 1.27
Club/collegiate (<i>n</i> = 77)	Sleep	4.80 ± 0.72
	Fluid replacement	4.65 ± 0.83
	Post-exercise meal	4.62 ± 0.80
	Daytime naps	3.72 ± 1.14
	Discussion with teammates	3.53 ± 1.21
	Stretching	3.52 ± 1.18
	Discussion with coach	3.41 ± 1.19
	Get out in nature	3.38 ± 1.09
Male (<i>n</i> = 118)	Sleep	4.83 ± 0.62
	Fluid replacement	4.76 ± 0.66
	Post-exercise meal	4.60 ± 0.77
	Daytime naps	3.87 ± 1.07
	Discussion with teammates	3.57 ± 1.18
	Stretching	3.51 ± 1.17
	Discussion with coach	3.46 ± 1.23
	Get out in nature	3.45 ± 1.09
Female (<i>n</i> = 30)	Sleep	4.96 ± 0.19
	Post-exercise meal	4.93 ± 0.26 ‡
	Fluid replacement	4.79 ± 0.57
	Daytime naps	3.79 ± 1.23
	Stretching	3.71 ± 1.12
	Discussion with teammate	3.54 ± 1.26
	Socialise with friends	3.54 ± 1.17
	Get out in nature	3.46 ± 1.17

Data presented as mean ± SD († indicates a significantly higher rank when comparing the playing standard involved with; ‡ indicates a significantly higher rank when comparing coaches/practitioner biological sex).

Descriptive data for practitioners' perceptions of recovery strategy importance across practitioner sub-groups (i.e., sports coaches, strength and conditioning staff, nutrition staff and athletic rehabilitation staff) is summarised in Table 8. 5. Perceptions of the importance of contrast therapy was significantly different between sub-groups of practitioners ($F_{(3,123)}4.484$; $p = 0.005$). Sports coaches rated the modality significantly higher than nutrition (+22.8%; $ES = 0.62$; $p = 0.041$) and athletic rehabilitation staff (+32.9%; $ES = 0.83$ $p = 0.001$). Perceptions of the importance of foam rolling ($F_{(3,129)}7.651$; $p < 0.001$), self-massage ($F_{(3,125)}4.759$; $p = 0.004$), massage by a therapist ($F_{(3,129)}9.132$; $p < 0.001$) and cryochambers ($F_{(3,116)}4.646$; $p = 0.004$) were also significantly different between sub-groups of practitioners. Specifically, sports coaches rated these modalities as significantly more beneficial when compared with all other practitioners (+19.5 to +85.2%; $ES = 0.50$ to 0.98 ; $p < 0.05$). Finally, perceptions of the importance of stretching was significantly different between sub-groups of practitioners ($F_{(3,129)}4.772$; $p = 0.003$). Here, sports coaches rated stretching as significantly more important than athletic rehabilitation (+23.1%; $ES=0.73$; $p = 0.003$) and strength and conditioning (+20.3%; $ES = 0.62$; $p = 0.005$) staff. Finally, nutrition staff rated stretching as significantly more important when compared with athletic rehabilitation staff (+21.1%; $ES = 0.71$; $p = 0.045$).

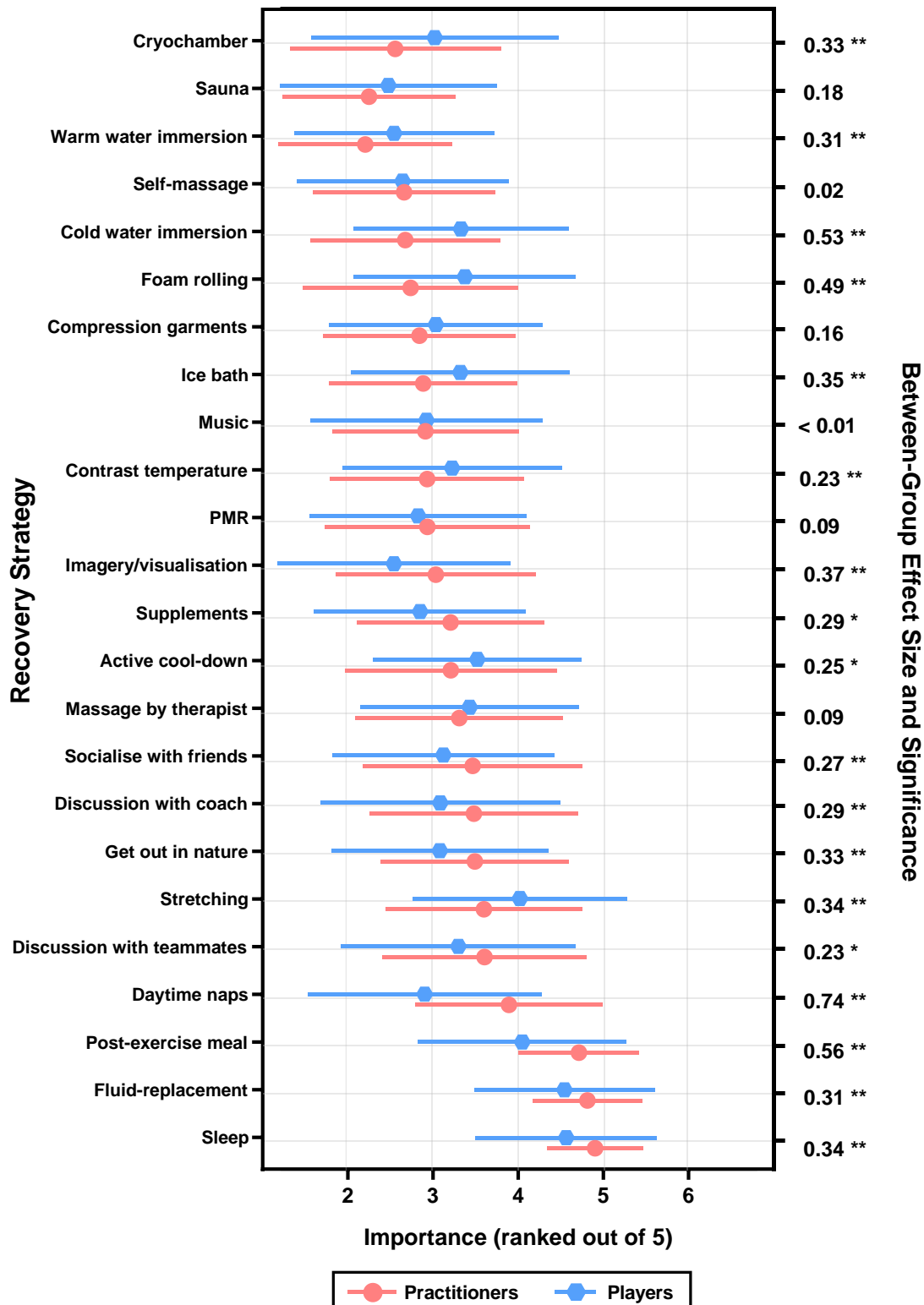
Table 8. 5. Participant's perceptions of recovery strategy importance across groups of practitioners.

Sport	Recovery Practice	Score out of 5
Sports coaches (<i>n</i> = 71)	Sleep	4.78 ± 0.65
	Fluid replacement	4.73 ± 0.67
	Post-exercise meal	4.68 ± 0.74
	Stretching	3.88 ± 1.10 * †
	Daytime nap	3.79 ± 1.12
	Massage by therapist	3.77 ± 1.05 † * ‡
	Discussion with Teammate	3.54 ± 1.31
	Get out in nature	3.48 ± 1.09
Strength and conditioning coaches (<i>n</i> = 34)	Sleep	4.80 ± 0.75
	Fluid replacement	4.74 ± 0.77
	Post-exercise meal	4.45 ± 0.89
	Daytime nap	3.87 ± 0.97
	Socialise with friends	3.45 ± 1.41
	Discussion with team	3.41 ± 1.06
	Get out in nature	3.34 ± 1.11
	Discussion with coach	3.26 ± 1.21
Nutrition staff (<i>n</i> = 15)	Sleep	5.00 ± 0.00
	Post-exercise meal	4.93 ± 0.26
	Fluid replacement	4.87 ± 0.52
	Discussion with teammates	4.00 ± 1.00
	Daytime naps	3.80 ± 1.08
	Stretching	3.80 ± 0.94 †
	Discussion with coach	3.67 ± 1.11
	Get out in nature	3.60 ± 1.24
Athletic rehabilitation staff (<i>n</i> = 35)	Sleep	4.97 ± 0.18
	Fluid intake	4.81 ± 0.48
	Post-exercise meal	4.74 ± 0.74
	Daytime naps	3.97 ± 1.20
	Discussion with teammate	3.53 ± 1.19
	Discussion with coach	3.43 ± 1.16
	Socialise with friends	3.54 ± 1.31
	Get out in nature	3.42 ± 1.09

Data presented as mean ± SD († indicates significantly higher than athletic rehabilitation staff; * indicates significantly higher than strength and conditioning coaches; ‡ indicates significantly higher than nutrition staff).

Descriptive data for players and practitioners' perceptions of recovery strategy importance (and the statistical significance and effect size of these differences) are summarised in Figure 8. 1.

Figure 8. 1. Comparisons of Gaelic games players and practitioners' perceptions of recovery strategy importance.



Abbreviations: CWI: cold water immersion, PMR: progressive muscle relaxation. Note: Data are presented as mean \pm SD and ES. Significantly higher rating of importance for players or practitioners: * $P \leq 0.05$, ** $P \leq 0.001$.

Discussion

The primary aim of this study was to investigate Gaelic games players and practitioners' perceptions of the efficacy of various recovery strategies. This research also aimed to compare possible differences between the perceptions of players and practitioners, and between sport, playing standard and biological sex.

Gaelic games players rated sleep, rehydration, nutritional strategies, stretching, an active cool-down, massage, foam rolling and CWI as the most important regenerative practices, similar to work in other team sports (Murray et al., 2017a, Tavares et al., 2017a). Gaelic games practitioners rated sleep, hydration strategies, nutritional strategies, daytime naps, discussion with teammates/coach, stretching and getting into nature as the most beneficial strategies. Although there were some similarities, differences between practitioners and players perceptions surrounding the importance of recovery strategies were also highlighted, whereby the majority of modalities were rated significantly differently between groups (Figure 8. 1). Previous research in other team (i.e., hockey, netball, soccer and rugby union) (Scantlebury et al., 2018) and individual (i.e., swimming and running) (Shell et al., 2020, Foster and Porcari, 2001) sports have reported similar differences between the perceptions of athletes and practitioners.

Inter-county Gaelic games players perceived almost all modalities to be more beneficial than their club/collegiate counterparts, reflecting data in similar invasive team sports (Venter, 2014, Crowther et al., 2017, Tavares et al., 2017a). This dichotomy in perceptions according to playing standard is reinforced by the current practitioners working at inter-county level, who perceive rehydration (+4.8%) and supplements (+13.1%) as significantly more important than their counterparts working at club/collegiate level. In Gaelic games, the higher standard of play at inter-county inter-county level is associated

with greater high intensity running demands and intermittent workloads (Keane et al., 2021, Young et al., 2018, Mangan et al., 2018a). Indeed, the relative efficacy of recovery strategies could conceivably improve as a means to cope with these elevated loads (which possibly impose greater post-match/training disturbances) when compared with club/collegiate players (Tavares et al., 2017a, McLellan et al., 2011, Johnston et al., 2015b). Thus, the increasingly burdensome demands reported at inter-county level could amplify players and practitioners' perceptions of the importance of recovery strategies (Mangan et al., 2020, Malone et al., 2017c). Additionally, it's possible that inter-county level players have a superior knowledge of recovery strategies when compared with club/collegiate players, as has been previously demonstrated in nutrition knowledge among female Gaelic games players (Renard et al., 2020).

Players and practitioners identified sleep as the most important post-exercise recovery strategy, complementing published reports (Venter, 2014, Shell et al., 2020, Crowther et al., 2017). Similar to findings in swimming (Shell et al., 2020), practitioners in the current analysis rated both sleep and daytime naps as significantly more important for recovery than players. Nonetheless, players perceive sleep as the most important component of recovery from exercise (rating sleep 17.4% higher than previous work in team sport athletes) (Venter, 2014). Emerging evidence and recommendations as to the importance of sleep in recent years, may help explain the disparity in results (i.e., 2014 (Venter, 2014) vs 2022). Overall, these results present further evidence that sleep is widely acknowledged as the primary factor in the post-exercise regenerative process in team and individual sports (Doherty et al., 2021, Samuels, 2008, Halson, 2008). The importance of sleep for the development, maintenance and regeneration of physical performance, well-being, academic/career performance and injury prevention is well documented (Filipas et al., 2021, Bolin, 2019, Lastella et al., 2014, Trockel et al., 2000). Indeed, sleep is

demonstrated to dissipate symptoms of fatigue, sustain immune health, repair structural damage to muscle tissues and facilitate numerous other psychophysiological functions through a myriad of biological mechanisms (Kirschen et al., 2020, Fullagar et al., 2015a, Lastella et al., 2014, Zielinski et al., 2016).

Strategic post-exercise fluid and nutritional intake were collectively perceived by players and practitioners as the second most important recovery practice (ranked only behind sleep), supporting prior work in swimmers (Shell et al., 2020), runners (Shaw et al., 2017), team sport athletes (Crowther et al., 2017) and sports coaches/athletic trainers (Shifflett et al., 2002). Noteworthy, male players in the current research perceived supplements to be significantly more important (+7.7%) for recovery when compared with females, which supports previous evidence (Shaw et al., 2017, Venter, 2014) highlighting greater consumption of dietary supplements by male athletes when compared with female athletes (Aguilar-Navarro et al., 2021). Overall, the highly taxing intermittent demands (McGahan et al., 2018b) and significant metabolic cost of Gaelic games match-play (caloric expenditure \approx 1300 kcal per game; 18.6 kcal \cdot minute $^{-1}$) (Malone et al., 2017d) infer that peri-match dietary intake is a central aspect of maximising performance, alleviating fatigue and healing muscle tissues (Beck et al., 2015, Ranchordas et al., 2017). In addition to the availability of fuel, low muscle glycogen content has also been reported to depress the release rate of calcium in the muscles sarcoplasmic reticulum, which may contribute to increased fatigue and delayed recovery (Gejl et al., 2014). Hence, this evidence suggests the current samples preeminent perceptions of nutritional intake seem congruous with its pivotal role in post-exercise recovery (Ó Catháin et al., 2020). Interestingly, the perceptions of the current Gaelic players contrast with previous team sport athletes, wherein nutritional and rehydration strategies were not perceived to be among the most beneficial recovery practices listed (Venter, 2014). Differences in sporting culture, ethnicity or country,

competitive demands or the more recent availability/dissemination of scientific evidence or recommendations could help to explain these between team sport population discrepancies.

An active cool down and stretching were perceived to be highly beneficial by the players in the present analysis, both of which were also perceived as significantly more important when compared with practitioners (+11.1% and +9.3% respectively). These findings, particularly when combined with similar results in other athletes (Crowther et al., 2017, Venter, 2014, Shell et al., 2020), support the premise that an active cool down and stretching are commonly believed to be highly effective in assisting post-exercise recovery. However, their properties are suggested to be quite limited in the context of accelerating the regeneration of psychophysiological outcomes to an uncompromised status following exercise (Van Hooren and Peake, 2018, Pooley et al., 2020, Andersson et al., 2010b). This imbalance between perceived and applied effectiveness may suggest educational incentives could be beneficial to avert time and resources towards more effective strategies within Gaelic games. Interestingly, Gaelic games sports coaches rated stretching and an active cool down as significantly more important when compared with athletic rehabilitation and strength and conditioning staff (10.8% to 23.3%). Amid the complex landscape of post-exercise recovery, which presents ambiguous empirical findings regarding the efficacy of recovery strategies (Calleja-González et al., 2019), it is challenging to identify appropriate, effective and situationally viable strategies to implement when seeking to accelerate post-exercise performance recovery (Dupuy et al., 2018). This understanding coupled with the suggestions that coaches may (1) be susceptible to misinformation and/or pseudoscience (Bailey et al., 2018) and (2) rely more heavily on experiential, intuitive and anecdotal information when compared with robust scientific data sources when choosing recovery strategies to prescribe to athletes (Simjanovic et al., 2009) may help to explain some of the

reported differences. Furthermore, while the current questionnaire did not specifically enquire about educational background or coaching qualifications, it could be reasonable to speculate that the athletic rehabilitation and strength and conditioning staff may have a more comprehensive knowledge base of human physiology obtained via their respective qualifications (which likely encompass post-exercise recovery) when compared with the sports coaches (Stoszkowski and Collins, 2016) who tend to have less physiology-specific qualifications (NASh and Sproule, 2012).

While massage has been demonstrated to improve psychometric outcomes (Davis et al., 2020, Kerautret et al., 2020, Micklewright et al., 2005), its scientifically documented effects with regard to accelerating performance return to pre-exercise condition are generally reported as either trivial or non-significant (Davis et al., 2020, Poppendieck et al., 2016). In the present analysis, massage by a therapist and foam rolling were among the most highly perceived recovery strategies, which contrasts prior work in South African team sport athletes (Venter, 2014) and complements data collected in Australian team sport athletes (Crowther et al., 2017). Inter-county Gaelic games players also rated massage by a therapist as significantly more important than their club/collegiate counterparts, which is consistent with other reports (Field et al., 2021, Altarriba-Bartes et al., 2020, Shell et al., 2020). Amongst other potential factors, this could be related to the possibility that inter-county players may have increased access to physiotherapists and athletic/massage therapists (Crowther et al., 2017).

In line with prior evidence highlighting the effectiveness of CWI to aid recovery (Ihsan et al., 2021, Pooley et al., 2020), this modality was correspondingly perceived as highly beneficial by the present cohort. This was especially evident in the inter-county-level players, who perceive CWI as significantly more important than their club/collegiate counterparts. On a similar note, inter-county Gaelic games players also appraised each

temperature related technique (i.e., all hot, cold and contrast therapy modalities) as significantly more important than their club/collegiate counterparts. It's possible that greater logistical issues and/or resource constraints (e.g., lack of access to cryochambers, plunge pools or saunas) at club/collegiate level may be factor in the relatively lower popularity of these modalities among club/collegiate players when compared with their inter-county level counterparts. Taken together, these findings suggest that temperature-based recovery strategies may be emphasised and/or implemented more routinely at inter-county level when compared with club/collegiate level. However, Gaelic games players perceived CWI, cryochambers, contrast therapy and ice baths as significantly more beneficial to assist recovery when compared with practitioners (-9.6 to -22.3%). These findings may suggest a misalignment between players and practitioners' perceptions (which may subsequently imply a possible disconnect between the recovery interventions being prescribed by practitioners and those being executed by players). Indeed, a similar incongruence between the training plans being prescribed by coaches and the training executed by athletes has been previously identified (Foster and Porcari, 2001, Brink et al., 2014, Scantlebury et al., 2018). Overall, while temperature related recovery strategies (principally the application of cold) are generally perceived as beneficial in the current sample, it should be noted that the repeated blunting of post-exercise physiological stressors and anabolic signalling associated with cold exposure may diminish training adaptations over prolonged periods (Tavares et al., 2017b, Tipton et al., 2017), in particular hypertrophy and strength outcomes (Ihsan et al., 2021). However, cold exposure may indeed be effective when readiness to perform and/or recovery are the primary goal, especially at a time of the season when neuromuscular development is not the principal objective (Ascensão et al., 2011, Tipton et al., 2017).

Strategies of a psychosocial nature (such as music and discussion with coaches/teammates) were also perceived as highly beneficial by the current cohort and among previous team sport athletes (Venter, 2014), and these strategies have been reported to buffer psychological stressors, alleviate mental fatigue and improve self-confidence and skill-based performance (Rees and Freeman, 2010, Abrahamsen et al., 2008, Coimbra et al., 2021). Notably, practitioners perceive many psychosocial modalities (e.g., socialising, meditation, discussion with teammates/coaches) as significantly more useful for recovery than players (Figure 8. 1). As is the case with other strategies (Table 8. 2 and Table 8. 4), significant differences in the perceptions of psychosocial modalities (i.e., discussion with coach/teammates and massage by teammates) were observed between biological sexes, as female players rated these practices as more important for recovery than males. As highlighted by Venter (2014), female athletes may be more likely to reach out for social support or help than their male counterparts (O’Keeffe et al., 2021). Hence, our work provides further support for this premise, in that biological sex influences players perceptions of the importance of psychosocial recovery strategies.

There are a number of limitations existing in the current study and should be considered when interpreting results, as highlighted in similar works (Altarriba-Bartes et al., 2020, Field et al., 2021, Braun-Trocchio et al., 2022). Firstly, the data from this study was completed during pandemic-based restrictions, whereby collective training and match schedules were either interrupted or not taking place. This disruption to routine may have impacted players and practitioners’ training/recovery regimens and could have subsequently altered their acute perceptions of various recovery modalities. Importantly, in some sections the questionnaire did not enquire as to the extensive or specific details surrounding players and practitioners’ perceptions of a given recovery strategy (e.g., the questionnaire did not specifically seek to identify which specific dietary supplements were

perceived to be (in)effective). On the contrary, the questionnaire was adapted to maximise time efficiency and user-friendliness (and subsequently maximise completion rates), and a more in-depth analysis may have detracted from these goals (e.g., via increased survey fatigue) (Egleston et al., 2011). Finally, future work should aim to spotlight the specific sources of information with which Gaelic games players and practitioners acquire their knowledge about recovery strategies. An understanding of where players and practitioners gain their information could help identify an effective pathway by which to disseminate evidence-based recommendations, and subsequently narrow the research-practice gap within Gaelic games.

Conclusion

This study has identified that Gaelic games players and practitioners perceive numerous post-exercise recovery modalities as being highly advantageous when seeking to promote the recovery of physical readiness beyond passive measures. Notably, many significant differences were reported between players and practitioners' perceptions of the importance of various recovery techniques. Our results also suggest that playing standard, biological sex and sport should be considered when designing recovery interventions within Gaelic games in order to account for population-specific differences in preferences and beliefs (and consequent placebo/nocebo effects) (Hurst et al., 2020). Differences in perceptions exhibited between sub-groups of practitioners possibly indicates that the recovery interventions being prescribed to players may be dependent on a team's coaching and/or support staff infrastructure. While players and practitioners perceive strategies with proven efficacy as most important (i.e., sleep, diet, rehydration), the current results indicate a clear and possibly problematic disconnect between players and practitioners' perceptions of the effectiveness of many regenerative practices and their empirically documented

evidence supporting them. Thus, tailored education detailing optimal practices may be vital so that valuable time and resources could be redirected towards more effective and/or efficient recovery strategies. This may be particularly incumbent when considering Gaelic games amateur status, which is already likely to magnify time and resource constraints to a greater extent than professional organisations. In concluding, this data could be used to inform future intervention studies, facilitate custom player/coach education incentives and guide practitioners who seek to optimally prescribe post-exercise recovery strategies.

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**Chapter 9 – Thesis Summary, Limitations,
Conclusions, Directions for Future
Research and Practical Applications**

Summary

It has been well established that team sport athletes' responses to competitive match-play are highly complex and multifactorial phenomena (Hader et al., 2019, Hagstrom and Shorter, 2018, Twist et al., 2012) which are governed by many factors (Abbott and Clifford, 2021, Lievens et al., 2020, O'Donnell et al., 2018, Barrett et al., 2018, Johnston et al., 2015b, Juliff et al., 2014). Importantly, information characterising Gaelic games players responses to match-play and the influence of key factors likely to modulate these responses, such as physical conditioning, workload indices and recovery strategy use, had not been available at the time of this research. As such, the aim of the present body of work was to investigate performance attenuation and recovery in Gaelic games players, and assess how principal moderators influence these responses with a view to informing training practices, guiding talent identification processes, functioning as an operational framework for practitioners and providing direction for future work in the area.

The literature review presented in chapter 2 examined bioenergetics, the aetiology of neuromuscular fatigue and muscle damage, psychophysiological and performance attributes, in-game workloads and their mutual interconnection. This review identified a number of gaps in the research, highlighting that there was much uncertainty regarding Gaelic games players psychophysiological responses to competition. Furthermore, it was also apparent that the impact of physical conditioning parameters and possible selection and implementation of recovery strategies following exercise remained unclear in both Gaelic games and team sport populations, thereby limiting practitioners' potential to optimally plan responsive and sensitive reactive training programmes and monitor players psychophysiological status. Subsequently, the need for empirical evidence to explore these pertinent areas and address the extensive information deficit was emphasized in this review.

Both the literature review and sport science industry practice guided the selection of a new and already widely used GPS unit for the purpose of monitoring in-game workload demands in the then forthcoming studies of the current research programme. However, it was identified that the device in question required analysis in relation to its validity and reliability to quantify team sport specific movements, in order to account for the devices performance while interpreting its collected data. Therefore, the work outlined in chapter 3 was conducted to examine the validity and reliability of an 18-Hz GPS unit (Apex, STATSports, Newry, Northern Ireland) while measuring speed and distance over linear and non-linear courses at varying speeds. This research was completed prior to the data collection phases of the primary studies of this thesis. In summation, the results of this pilot study suggested that the device was highly valid and reliable at lower speeds over both straight and curvilinear courses. Nonetheless, increases in speed and course complexity were accompanied with a progressive increase in recorded errors, wherein the results specifically imply that high intensity change of pace may be a key factor in reducing the GPS unit's accuracy.

As emphasised within the literature review of chapter 2, profiling the responses of Gaelic games players to competition was a requirement to inform practitioners who seek to optimally design training programmes. Consequently, Chapter 4 outlined acute changes in markers of fatigue and performance attenuation during and following a competitive senior club-level Gaelic football match. This work demonstrated that there are large decrements in performance and substantial multidimensional fatigue experienced by players during and following Gaelic football match-play. Specifically, neuromuscular and biochemical markers presented with the greatest disturbances 24 h post-match, while perceptual markers were lowest at full-time. Additionally, the recovery of neuromuscular and perceptual measures was observed 48 h post-match in the presence of continued biochemical

disturbance. The results outlined in this chapter illustrated the need to investigate potential factors that may influence these psychophysiological responses.

Chapter 5 examined the influence of Gaelic football players physical conditioning and body composition on in-game workload measures during competitive match-play and endeavoured to provide further context for practitioners by building on the conclusions of the previous chapter. The results demonstrated that Gaelic football players competitive running and acceleration profiles are influenced by a range of physical conditioning markers. More specifically, markers of physical conditioning such as lower-body power, short distance running speed, body composition, aerobic capacity and blood lactate responses appear to be particularly important in modulating players on-field work capacity. Furthermore, when players were dichotomised using a median split into higher-standard and lower-standard groups based off each respective conditioning marker, the higher-standard group almost always displayed larger workloads than their lower-standard group counterparts.

Chapter 6 examined the influence of Gaelic football players components of fitness on measures of performance attenuation and recovery during and following competitive match-play. The findings presented in this chapter suggest that well-developed neuromuscular-related performance measures (i.e., muscular strength, power and running speed) and markers of aerobic function (i.e., maximal aerobic capacity and running economy) are also likely to limit the development of neuromuscular fatigue, perceptual disturbances and accrual of muscle damage during Gaelic football match-play. Taken together, the key message from the collective works of phase 1 of this project is that players with well-developed components of fitness express comparatively lower fatigue and muscle damage responses, even despite undertaking larger external workloads during competition.

Chapter 7, the first study of phase two, provided a preliminary examination into Gaelic games players use of post-exercise recovery strategies. This chapter identified that a broad range of post-exercise recovery strategies are commonly implemented by Gaelic games players to expediate the return of performance to pre-exercise levels. Specifically, Gaelic games players most commonly use active cool downs, external cold application, a regular sleep routine, diet/hydration strategies and massage. Significant differences were also identified in the recovery strategy practices of different Gaelic sports, biological sexes and playing standards. Moreover, the high prevalence of additional multi-sport and multi-team activity identified in this study may further illustrate the importance of fatigue management within Gaelic games. This research was the first work to examine recovery strategy use in Gaelic games players and identified that a wide range of practices are utilised by players, thus providing impetus for further research for *why* these strategies are employed.

Building on the findings of the previous chapter, Chapter 8 examined and compared Gaelic games players and practitioners' perceptions of post-exercise recovery practices. Gaelic games players rated sleep, rehydration, nutritional strategies, stretching, active cool-downs, massage, foam rolling and CWI as the most important regenerative practices. Additionally, Gaelic games practitioners rated sleep, hydration strategies, nutritional strategies, daytime naps, discussion with teammates or a coach, stretching and getting into nature as the most beneficial strategies. Although there were a lot of similarities in players and practitioners' perceptions, the majority of regenerative modalities were rated significantly differently between groups. Furthermore, there were differences between playing standard, biological sex and sport identified among the players. With regards to the practitioners, there were also a number of differences identified based on their specific practice and the playing standard of the players they worked with.

Limitations

While the findings outlined in this body of work have the potential to guide team sport practitioners and direct future research, a number of methodological limitations have been identified throughout this research programme, and these are largely discussed within each of its respective studies. Nevertheless, there are some limitations associated with the overall project that warrant the attention of readers, and with which our findings must be accordingly viewed.

- Firstly, the data of phase 1 studies was exclusively collected from a convenience sample of senior level club Gaelic football players participating with a number of Westmeath, Galway and Roscommon clubs respectively. Despite a high likelihood of commonality and relevance with other similar club teams, it is difficult to accurately surmise the between-population applicability of this research. Therefore, the extrapolation of the findings to other athletes should be made with a degree of caution. Nonetheless, the current body of work may be used to guide relevant practitioners and may present a framework with which future research may be conducted on other team sport populations.
- The data collected in phase 1 of this project detailed players responses to one competitive match during the mid-season period. Therefore, caution should be exercised when applying the findings of this work during other phases of the season, as factors such as in-game demands (Egan et al., 2021) and physical conditioning parameters (Kelly and Collins, 2018) may significantly change as the season progresses, subsequently altering players responses when compared with the current analysis.
- In studies 1 – 3, participant commitment and compliance with the testing procedures was reliant on many factors, such as individual occupational and/or study

circumstances, coach support and encouragement to participate in the research, training or match cancellations, logistical issues, which influenced the sample that was analysed. Consequently, there were many cases of incomplete data collection due to participant absenteeism which could not be used for analysis.

- The validity and reliability of the numerous equipment and monitoring tools used in this thesis to profile participants physiological attributes, performance attenuation and recovery markers, in-game workloads and recovery strategy use and perceptions should be considered. For instance, the pilot study reported errors in the data collected using the GPS unit that was subsequently employed to monitor players in-game workloads during the remaining studies of phase 1. Specifically, the magnitude of errors was reported to increase when paralleled with an increase in velocity, change of direction, accelerations and decelerations. As such, the reported inaccuracies of the devices may have resulted in an underrepresentation of the magnitude and/or number of high intensity actions recorded, particularly high intensity velocities and/or changes of pace. Nevertheless, the units present high levels of reliability and validity when measuring distance, suggesting their utility and applicability in this context.
- Finally, study 4 reported that multi-team and multi-sport activity are prevalent within Gaelic games. These findings, albeit ecologically valid within the studied population and therefore bearing significant relevance, may elicit co-founding factors that may warrant a large sample to sufficiently account for possible within-sample variations. For example, the interplay between possible multi-team and multi-sport activity and the highly variable work and/or study commitments may have caused large between-participant variation in workload, performance attenuation and recovery parameters. Therefore, a very large sample of Gaelic games participants may be necessary for such

research when compared with other professional sports, in order to account for the potential variability in responses emerging from non-sport or external sport stressors.

Thesis Conclusion

This programme of research contributes to the field of team sport physiology by extending current understanding of the factors underpinning match-play demands and responses, on-field work capacity, performance attenuation and recovery. While the efficacy of hypothetico-deductive methods employed in the team sport domain, which is innately characterised by a highly complex and unpredictable nature, poses certain limitations (Mackenzie and Cushion, 2013, Ade et al., 2016), the present work attempted to address a range of pertinent topics, utilise large samples in real world conditions and answer practically meaningful research questions. The results demonstrate that Gaelic football match-play imposes significant demands on players, provoking multifactorial performance attenuation, fatigue and muscle damage responses. Specific in-game demands, such as accelerations, sprint distance and the number of sprints completed are also reported to be positively correlated with greater post-match disturbances of psychophysiological outcomes. Therefore, monitoring these selected high intensity running variables during match-play may help contribute to tailored training load management during the day(s) following competition. Players were observed to endure significant biochemical, neuromuscular and perceptual disturbances during and following match-play which persist 24 to 48 hours post-match. Furthermore, our data demonstrates that players neuromuscular and perceptual outcomes appeared to recover at 48 hours, while biochemical disturbances persisted at this timepoint. Bearing these findings in mind, multiple monitoring tools may be required to effectively establish players' preparedness to perform during subsequent training sessions or matches (Figure 9. 1).

Targeting the effective development of players physical conditioning with the goal of maximising sport-specific work capacity and mitigating performance attenuation is challenging when considering the multifactorial physiological, psychological and tactical-technical elements necessary for successful match-play. Indeed, our data suggests short distance running speed, lower-body power, aerobic conditioning and body fat levels impose a significant influence on players competitive external outputs. Consequently, the appropriate development of these performance attributes may deliver a positive transfer effect to Gaelic footballs specific demands.

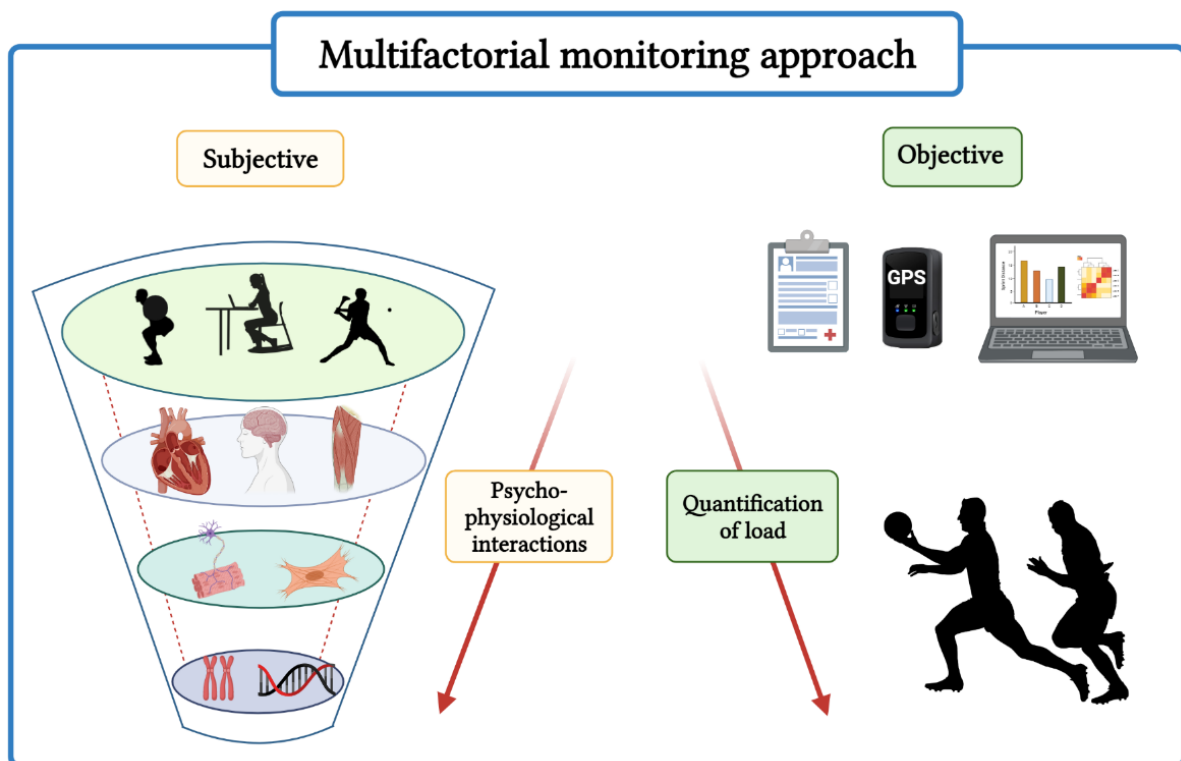


Figure 9. 1. Overview of a possible multifactorial monitoring approach. Adapted from the work of Montull et al. (2022) with permission.

Our results also suggest that physical conditioning attributes influence players performance attenuation and recovery responses. Here, Gaelic football players with well-developed muscular power, strength and aerobic capacity display less psychophysiological

disturbances and present with an accelerated recovery response following exercise. Players with superior physiological attributes may display an increased metabolite efflux, lower neuromuscular fatigue responses and a higher resilience against the accrual muscle damage during the intense actions of match-play. In contrast, players with poorly developed physical conditioning attributes are likely to experience an exacerbation of acute and residual neuromuscular fatigue, muscle damage and perceptual disturbances when compared with their physiologically superior counterparts, and may consequently present with compromised readiness to perform during subsequent training sessions and/or matches.

It is not unusual for Gaelic games players to play more than one match during a week alongside other training commitments, due to the frequently reported multi-sport and multi-team activity over a lengthy season. In an attempt to mitigate the neuromuscular fatigue, inflammation and muscle damage likely to stem from these demands, players commonly use active recovery, regular sleep routines, cold showers, ice baths and strategically consume food and/or fluids. Similarly, players and practitioners perceive a range of recovery modalities, such as sleep, nutrition and hydration strategies, as important to modulate the post-exercise recovery process. Of note, our results indicate that biological sex, sport and playing standard should be appraised when designing and implementing recovery interventions in order to account for population-specific differences within Gaelic games. Furthermore, differences observed between groups of practitioners indicates that the recovery interventions being prescribed to players may be adjusted depending on the team's practitioner infrastructure. Finally, while players use and perceive strategies with well- effectiveness, the results of this thesis indicate many other strategies with limited documented efficacy are perceived as effective and used regularly, which may indicate a dissension between empirical research and applied practice. Overall, the results presented

in this research programme deliver novel and potentially useful information for practitioners who are concerned with the holistic preparation of players for competition; ultimately aiming to maximise player availability and performance.

Future Work

The studies of this PhD project have provided novel findings pertaining to performance attenuation and recovery in Gaelic games. In the process of conducting this work and in view of its findings, a number of unanswered questions remain, potentially representing promising avenues for future research to improve our understanding and deliver further layers of nuance when attempting to develop best practice within the domain. In turn, the below recommendations have been prompted to deliver insight and improve our understanding within the domain.

- Exploring players responses to match-play during different phases of the competitive season is important in assessing possible physiological, biochemical or perceptual differences or interactions across the year. Similarly, establishing whether or not markers of residual fatigue are evident during the early or late phases of the season may better inform the training systems and recovery practices of Gaelic games players. Obtainment of such information could be particularly beneficial for practitioners designing players training programmes across the in-season, as these interactions may behave differently as players physiological attributes (Reilly and Keane, 2001), and the games demands (Egan et al., 2021, Mangan et al., 2018b), change over the competitive year. Soccer players speed, agility and power have been reported to decline as the season progresses, while aerobic capacity has been observed to increase (Noon et al., 2015). If such a phenomenon occurs in Gaelic games, research should

consider assessing the changes of in-game workloads and recovery responses that may emanate from these alterations in different physiological attributes.

- Study 1 observed evidence of an incomplete recovery status in players 2-days post-match (i.e., continued creatine kinase efflux) wherein the subsequent training session is often scheduled. Therefore, it may be of particular interest for practitioners if players responses were assessed during an extended period of high training density and/or fixture congestion. Indeed, extended periods of elevated loads have been previously demonstrated to result in negative training responses (Jaspers et al., 2017, Slattery et al., 2012) and elevated psychophysiological disruptions (Thorpe et al., 2015, Thorpe et al., 2016), and it would provide valuable insight if similar research was conducted within a Gaelic games setting.
- Whilst the findings of studies 2 and 3 demonstrate that various physiological attributes coincide with superior match-specific work capacity and protect against neuromuscular fatigue and muscle damage, it is difficult to surmise whether improvements in these physiological parameters would elicit meaningful increases in these outcomes. To the best of the authors knowledge, this has yet to be examined in any team sport population, as the contemporary work in the area exclusively employs cross-sectional and observational study designs. Hence, causality may not be assumed from the present work or the previous collation of analyses, and future work should seek to investigate if the further development of physical conditioning measures provides additional benefits. Furthermore, if this is indeed reported to be the case, it would be useful for practitioners to understand: (1) does the magnitude of enhanced responses reflect the magnitude of physiological improvements? or (2) is there a ‘ceiling’ effect, whereby increases in physical conditioning beyond a certain point may present diminishing returns? Critically, these effects may be governed by numerous

factors such as biological sex, playing standard, stage of season and the players initial physical conditioning levels and subsequent rate and magnitude of a given attributes improvement. Thus, work is needed to explore this complex and mediator-entangled area in order to guide practitioners who are tasked with the design of perceptive training, injury mitigation and recovery interventions.

- Considering the gender gap in sports science literature where female participants are generally underrepresented, a replication of the current research from phase 1 conducted on female participants is required for a more specific application. Furthermore, examining the physical conditioning characteristics of female samples across each of the Gaelic games codes (camogie, handball and Gaelic football) and relating these to workload, performance attenuation and recovery responses may yield novel findings with potentially important implications for practice. Such data would enable valid and population-specific guidance for relevant coaches and players to better inform their training practices and preparation for competition. Physical differences between biological sexes are well established, and these complex physiological discrepancies are suggested to be primarily governed by hormonal and genetic differences (Ansdell et al., 2019). Indeed, between-sex differences have been previously documented in fatigue characteristics and recovery timelines (Purvanova and Muros, 2010), responses to resistance training (Staron et al., 1994, Lindle et al., 1997) and cardiovascular adaptations to endurance training (Seals et al., 1984). Furthermore, differences between biological sexes in-game workload have been demonstrated in Gaelic games specifically, whereby large differences in match workloads are evident when comparing Camogie (Young et al., 2021) and hurling (Young et al., 2019). Thus, future work assessing female players physical and psychological responses to the demands of Gaelic games is required to assist

prescription of biological sex-specific recovery practices, training programmes and training load management.

- The relative effectiveness of the recovery strategies that Gaelic games players prevalently use remains to be demonstrated in an applied and Gaelic games specific setting. Indeed, the orchestration and conduction of intervention-based research may be necessary to assess how a range of such recovery modalities (or a combination of strategies) may impact players recovery status and readiness to perform in Gaelic games players. Using the results of this thesis to identify players and practitioners' perceptions (which may result in consequent nocebo/placebo effects) (Hurst et al., 2020) and uses (which may provide a surrogate identification of practically viable and preferred strategies) (Simjanovic et al., 2009) of recovery strategies may inform and help streamline future recovery intervention studies. Sound experimental work in this area is needed and collection of such information could help identify the most effective and efficient recovery strategies and subsequently facilitate guidelines for Gaelic games players in a context-appropriate setting.
- Finally, there is a sparsity of experimental data assessing longitudinal recovery strategy use among team sport athletes, and work within and/or outside of Gaelic games players would be valuable in helping researchers and practitioners understand how best to plan recovery interventions, when they are necessary and their long-term effects on training adaptations. Translatable and applied research findings are needed to generate evidence-informed recommendations for all types of athletes, including Gaelic games players.

Practical Applications

The current body of work has demonstrated how Gaelic games players respond to match-play, the influence of physical conditioning on these responses, and the timeline and strategies of recovery with many implications for applied settings. Considering the findings presented, questions emerge as to how we may best prepare players for the sporting demands they face, with a view to increasing competitive performances, reducing injury risk, promoting wellbeing and preparing players for the rigours of training and match-play. Through this lens, the collective evidence of this project may yield the following practical applications:

- Gaelic football players neuromuscular and perceptual outcomes appeared to recover at 48 hours, while biochemical disturbances persisted at this timepoint. This outcome suggests several possible implications for practitioners. Firstly, a multifactorial monitoring approach is required to obtain a range of an athlete's response constructs and in turn generate holistic overview of a player's psychophysiological status. Secondly, in circumstances where important matches are a few days apart, neuromuscular performance may have recovered in the presence of continued biochemical disturbances. This may be sufficient in the short-term, provided that full recovery is afforded after this period of fixture congestion. In contrast, if a high density of matches ensues for a prolonged period, a reduction of training load and/or the implementation of recovery strategies may be needed to avoid cumulative muscle damage and fatigue. Thirdly, players may not be completely recovered 48 hours post-match, where the subsequent training session is often scheduled. Indeed, players who display lower levels of strength and aerobic function may present with ongoing fatigue and muscle damage at this timepoint, while stronger and fitter players may present

with little/no psychophysiological disturbances. Therefore, training loads may be manipulated according to the players psychophysiological status (for instance, a player may sit out of a certain drill etc.), and this status may be indirectly characterized by their aerobic fitness and muscular strength levels.

- Sport scientists, coaches and other relevant practitioners utilising a holistic monitoring approach, similar to that of current body of work, should be cognisant of the inter-individual variability that may be presented for some of the markers. Indeed, when considering the potential for large distinctions in both the external (e.g., positional demands, minutes played, tactical roles etc.) and intrinsic (e.g., physical conditioning status, psychobiological factors and non-sport stressors) factors likely to influence these markers, Gaelic games players responses to imposed loads are likely to be correspondingly variable. Therefore, comparisons of intra-individual values, rather than averaged group-based observations, over time may be recommended in order to examine players responses, track changes in fitness and permit informed adjustments of training loads.
- Given the logistical burdens, requirement of specialist equipment and trained personnel, players willingness (or lack thereof) to participate, cost-ineffectiveness and the invasiveness of metabolic and/or biochemical assessments of fatigue and muscle damage (Carling et al., 2018); their utility in a practical Gaelic games setting may be limited. In contrast, neuromuscular assessments, such as a countermovement jump, may deliver a faster and easier to administer alternative when attempting to monitor a player's capacity to perform. However, similar challenges relating to time-constraints, (un)availability of equipment and reluctance from coaching staff or players regarding their regular implementation may serve as a collective barrier for their real-world application. On the other hand, perceptual questionnaires are cost-effective, time-

efficient, non-invasive, scientifically verified and easily administered to a large cohort of players (e.g., via an online platform). Nonetheless, possible issues relating to compliance and buy-in may arise with their routine administration in the field. All considered, Gaelic games practitioners may be advised to specifically employ question-lead monitoring objectives and weigh up the benefit-cost and specific necessity of such endeavours prior to their use.

- Players and practitioners may be recommended to adopt a periodised concurrent training approach that appropriately integrates (1) strength and/or power training to develop neuromuscular force and velocity capacity, (2) endurance related training associated with regular team training and match-play, and where necessary (3) additional work to trigger an increase in the muscular systems capacity to access and utilise aerobically and/or anaerobically generated energy. Indeed, the development of these components of fitness are likely to concomitantly reduce players performance attenuation and enhance post-exercise recovery, even despite these players simultaneously undertaking elevated external loads.
- While well-proven regenerative strategies are commonly used by Gaelic games players, the prevalence of sub-optimal and/or under researched recovery practices may have implications in the days following match-play. This premise may be emphasised given that the findings from study 1 highlighted that players are not fully recovered two days post-match, wherein the next training session is often scheduled. Accordingly, practitioners may be advised to continue to promote the use and optimisation of strategies with well-documented effectiveness (e.g., sleep, rehydration, strategic nutritional intake). Furthermore, attention should be paid to how the implementation of any given strategy following training or match-play effects players markers of psychophysiological status on both an individual and squad level.

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Appendices

Appendix A

Study 1 Publication: Daly, L.S.; Catháin, C.Ó.; Kelly, D.T. Gaelic Football Match-Play: Performance Attenuation and Timeline of Recovery. *Sports* **2020**, *8*, 166.

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Article

Gaelic Football Match-Play: Performance Attenuation and Timeline of Recovery

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Abstract: This study investigated acute changes in markers of fatigue and performance attenuation during and following a competitive senior club-level Gaelic football match. Forty-one players were tested immediately pre-match, at half-time, full-time, 24 h post-match and 48 h post-match. Creatine kinase, drop jump height and contact-time, reactive strength index, countermovement jump height and perceptual responses were assessed at the aforementioned time-points. 18 Hz global positioning system devices were used to record players in-game workload measures. Compared to pre-match, perceptual responses (−27.6%) and countermovement jump height (−3.9%) were significantly reduced at full-time ($p < 0.05$). Drop jump height (−8.8%), perceptual responses (−27.6%), reactive strength index (−15.6%) and countermovement jump height (−8.6%) were significantly lower 24 h post-match ($p < 0.05$). Pre-match creatine kinase was significantly increased (+16.2% to +159.9%) when compared to all other time-points ($p < 0.05$). Total distance, total accelerations, total sprints, sprint distance and average heart rate were all correlated to changes in perceptual responses ($r = 0.34$ to 0.56 , $p < 0.05$). Additionally, maximum speed achieved ($r = 0.34$) and sprint distance ($r = 0.31$) were significantly related to countermovement jump changes ($p < 0.05$), while impacts ($r = 0.36$) were correlated to creatine kinase increases ($p < 0.05$). These results demonstrate that Gaelic football match-play elicits substantial neuromuscular, biochemical and perceptual disturbances.

Keywords: Gaelic football; fatigue; post match; muscle damage; countermovement jump; recovery; post-match fatigue; match-play; GPS; monitoring

1. Introduction

Gaelic football is a field-based team sport native to Ireland which is contested on a grass pitch with two teams of 15 players [1]. It is an intermittent invasion field sport, whereby intensive anaerobic efforts occur in a cyclical nature behind a background of light aerobic activity [1]. The game is fast paced, with frequent turnovers of possession, necessitating players to have well developed components of fitness and technical skills [1,2]. During competitive matches, players typically cover large total distances (5 km to 11 km) with variation in workloads and physical demands depending on the playing level, player position, tactics and many other factors [3,4]. Elite-level players are reported to cover 1563 ± 605 m of high-speed running distance (≥ 4.7 m·s^{−1}), 524 ± 190 m of very high speed running distance (≥ 6.1 m·s^{−1}) and perform 166 ± 41 m of accelerations [2].

During Gaelic football match-play, workloads following intensive periods of play are temporarily impeded due to performance attenuation, while work rates progressively decline over the course of a game [4]. In elite-level Gaelic football, a significant progressive reduction in total and high speed running distance (≥ 5.5 m·s^{−1}) is reported across the final three quarters when compared with the first quarter [3]. While such research is beneficial in quantifying the workloads which players undertake

Study 3 Publication: Daly, L.S., Catháin, C.Ó. and Kelly, D.T., 2022. Does Physical Conditioning Influence Performance Attenuation and Recovery in Gaelic Football? *International Journal of Sports Physiology and Performance*, 1(aop), p.1-9. DOI: [10.1123/ijsp.2021-0342](https://doi.org/10.1123/ijsp.2021-0342)

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Human Kinetics
ORIGINAL INVESTIGATION

Does Physical Conditioning Influence Performance Attenuation and Recovery in Gaelic Football?

Lorcan S. Daly, Ciarán Ó Catháin, and David T. Kelly

Purpose: This study investigated the influence of components of fitness on measures of performance attenuation and recovery following Gaelic football match play. **Methods:** Measurements of players' anthropometric characteristics, body composition, running speed, lower-body strength and power, blood lactate concentrations, running economy, and maximal aerobic capacity (VO_2max) were taken over 2 separate days 1 week prior to a competitive match. Creatine kinase, countermovement jump height, drop jump height, contact time, reactive strength index, and perceptual responses were tested prematch, at full time, 24 hours postmatch, and 48 hours postmatch. **Results:** Multiple components of fitness were associated with reduced performance attenuation and improved recovery responses (adjusted $R^2 = 9.8\% - 27.6\%$; $P < .05$). Players were divided into higher-standard and lower-standard VO_2max (higher standard: $57.4 [4.2] \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; lower standard: $45.3 [3.8] \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and relative squat (higher standard: $1.46 [0.11] 1\text{-repetition-maximum kg}\cdot\text{body mass}^{-1}$; lower standard: $1.20 [0.08] 1\text{-repetition-maximum kg}\cdot\text{body mass}^{-1}$) groups. After adjusting for prematch baseline differences, there were significant differences between VO_2max groups in drop jump height at 24 hours postmatch ($\eta_p^2 = .078 - .154$; $P < .05$) and countermovement jump height at 48 hours postmatch ($\eta_p^2 = .134$; $P < .05$), where the lower-standard group displayed larger decrements. In addition, there were significant differences between relative squat groups at all postmatch time points in contact time ($\eta_p^2 = .156 - .194$; $P < .05$) and reactive strength index ($\eta_p^2 = .127 - .223$; $P < .05$) and in perceptual responses at 24 hours postmatch ($\eta_p^2 = .152$; $P < .05$), where the lower-standard group expressed larger decrements. **Conclusion:** Coaches should prioritize the development of aerobic capacity and neuromuscular function as an effective method of reducing performance attenuation and enhancing recovery kinetics in Gaelic football.

Keywords: team sport, fatigue, muscle strength, creatine kinase, neuromuscular monitoring

Gaelic football is a physically demanding contact team sport indigenous to Ireland.¹ The game is characterized by intermittent and short-duration high-intensity actions interspersed with light aerobic activity.^{1,2} While the sport requires significant aerobic energy provisions to cover large distances (6–11 km), a broad range of components of fitness are essential to undertake frequent high-intensity efforts of sprinting, changes of direction, rapid accelerations/decelerations, tackling, and contesting for possession.² These demands inevitably result in a multifaceted fatigue and muscle damage response, modulated by numerous physiological, psychological, and metabolic processes.³ Well-developed components of fitness are necessary to cope with the intense physical demands of Gaelic football match play and training across the competitive season,⁴ as match play results in immediate and prolonged neuromuscular, perceptual, and biochemical disturbances. More specifically, 48 hours following match play is sufficient to restore neuromuscular and perceptual measures, but not biochemical measures of players.⁴ Owing to the competitive schedules of Gaelic football players, an adequate postmatch recovery time period may not always be afforded between successive training sessions/matches.⁵

While well-developed components of fitness have been associated with reduced fatigue and muscle damage in team sports such as soccer⁶ and rugby league^{7,8}; Gaelic football's distinctive match play demands, recovery profiles, and the sport's

amateur status may yield different results.^{3,9,10} The progressive and significant declines in workloads recorded during Gaelic football match play allude to the impact of accumulated fatigue and subsequent performance attenuation.² Gaelic football players are exposed to considerable demands during match play, and this likely causes significant central and peripheral fatigue, manifesting through metabolite accumulation, reduced muscle contractility potential, impaired nervous system control, and depleted glycogen stores.^{2,4} In addition to the acute demands surrounding competitive match play, Gaelic football players have been reported to regularly participate in congested match and training schedules over extended periods, oftentimes in combination with multiteam and multisport commitments during the season.^{11,12} Many possible factors may influence Gaelic football players' capacity to cope with these acute and longitudinal demands, such as sleep quantity and quality, nutritional status, and physical conditioning attributes.^{6,13}

The influence of anthropometric characteristics, neuromuscular function, running economy (RE), blood lactate responses, and aerobic capacity on markers of performance attenuation and recovery in Gaelic football is currently unknown. Well-developed aerobic capacity has been associated with reduced biochemical disturbances in Australian rules,¹⁰ while positively influencing the restoration of neuromuscular function in rugby league.¹⁴ Athletes with a greater aerobic capacity are reported to endure lower metabolic disturbances following frequent bouts of high-intensity running when compared with their less conditioned counterparts, consequently limiting fatigue and subsequent performance attenuation.^{8,14} Although more speculative due to a lack of research, other markers of endurance performance, such as lactate threshold and

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Appendix B

Participant Information Sheet



Performance Attenuation, Post-Match Fatigue and Timeline of Recovery in Senior Club Level Gaelic Football Players

Investigators: Lorcan Daly BSc, David Kelly PhD and Ciarán O' Catháin PhD

Dear participant,

An invitation below is to take part in a Gaelic football research project.

What is this project about?

This study aims to investigate the effect of fatigue and timeline of recovery in Gaelic football. The information collected throughout this study will aid sport scientists and coaches and other practitioners in planning effective injury prevention strategies and training schedules to both improve performance and minimize the accumulation of fatigue, while reducing disruption to competition and training.

What is required from you?

Baseline Screening

1. You will need to make two visits to the High Performance gym and Sports Science lab in AIT so some baseline fitness test results can be established. During visit 1 you will be required to undergo a brief physical examination and perform a squat strength and an aerobic endurance test. Your body composition will also be assessed using a skinfold callipers. This testing session should last approximately two or so hours.

2. During visit two will be used to measure muscle power in vertical jumps and hip thrust strength. You will be wearing reflective markers during the jumps on 2 points of your lower-body in order to gather biomechanical data regarding your jumping performance. This session should also last approximately two hours.

Match day

1. Partake in a competitive Gaelic football club match.
2. You will complete tests before, at half time, full time and 24 hours and 48 hours after the competitive game.
3. You will be provided with a GPS unit attached in a sports vest for the match in order to track a variety of locomotion metrics.
4. Perform a number of jump tests to examine your neuromuscular status (less than five minutes).
5. During these jump tests you will wear reflective markers throughout so as to obtain biomechanical data during the jumps.
6. Provide a fingertip blood sample to record your markers of muscle damage status (Creatine Kinase) before, during and at time points after the game (less than two minutes).
7. This testing will be completed at the venue of the competitive match.

Are there any potential risks associated with involvement in this study?

All forms of exercise carry some degree risk of injury or discomfort. However, there are specific measures which are put into place to help avoid these risks and prevent any injury from occurring to you. You will also be advised of the potential risk of delayed onset muscle soreness following testing. Your previous experience of training and playing Gaelic football will limit these risks. Aside from the small fingertip blood sample before, during and after the game every other test should be familiar to you from previous training and gym experience.

The GPS tracking units which are supplied are regularly used by different elite level Gaelic football players and have been also been approved for use according to the Gaelic Athletic Association. For this you will be provided with a specifically designed padded sports vest that you can comfortably wear under your jersey. The GPS unit in this vest is highly unlikely to cause any obstruction to the player or come into contact with the ground or another player.

The jump tests that you will need to perform are very low in risk. These tests will be carried out in a on a stable surface in a safe environment, clear of any potentially obstructive objects. You also will complete a standardised warm up prior to the jumps to further minimise the risk of injury.

The blood collection procedure only requires a finger prick and a minor amount of blood. Here, appropriate measures will be implemented to minimise all risks associated with any infection as the investigators taking the sample will be wearing rubber gloves and will thoroughly clean the finger with an alcohol wipe prior to making contact with the fingers skin. All of the material and samples gathered through this sampling process will be placed in either a biohazards bin or a sharps bin.

Benefits associated with involvement in this testing

You will receive very useful written and verbal information regarding the wide ranging components of fitness, anthropometry and body composition. In addition to this, the GPS devices used will provide you with a detailed analysis of your competitive match activity profile. You will also be an integral part of investigating and discovering novel research and information in connection with Ireland's native sport. The findings gathered through this research project will help coaches advance preparation for subsequent matches, training and guide appropriate recovery strategies. The findings may allow coaches create guidelines to reduce the accumulation of fatigue and the lower the risk of different fatigue related injuries. With this research it is intended to publish in a peer reviewed scientific journal. This would allow many other athletes within the area of Gaelic football to benefit from the information acquired during this research study.

Statement that involvement in the assessment is voluntary

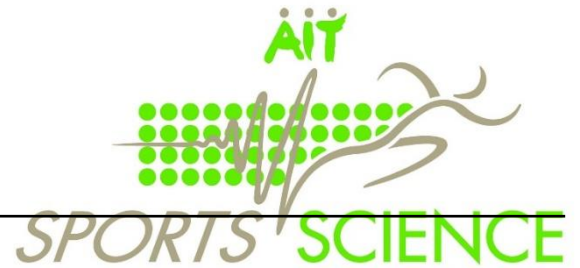
If you feel at any point during your participation in this research project the need to drop out, this is by no means a problem. You are under no obligation to take part in this study if you do not wish too, and can leave without any issue.

Feel free to contact any of the research projects investigators:

Mr. Lorcan Daly (MSc Student)	l.daly@research.ait.ie or 0876152751
Dr. David Kelly (Supervisor)	davidkelly@ait.ie
Dr. Ciarán O'Catháin (Supervisor)	ciarancathain@ait.ie

Department of Sport and Health Sciences, Athlone Institute of Technology, Co. Westmeath, Ireland.

Consent Form



Project Title: Performance Attenuation, Post-Match Fatigue and Timeline of Recovery in Senior Club Level Gaelic Football Players

Research Investigators: Lorcan Daly BSc, David Kelly PhD and Ciarán O’ Catháin PhD

The purpose of this research project is the examination of the effect of fatigue and timeline of recovery in competitive Gaelic football. You will be tested on two separate screening days and at a competitive match. All of the information and data relating to the testing will be both non-verbalized and kept confidential. You as a participant will have full privacy and it will only be the researchers involved in the study present. The study will take place in the High-Performance gym and Sport Science laboratory in Athlone Institute of Technology while match day testing will be completed in Gaelic football clubs all over the region.

Participant – please complete the following (Circle Yes or No for each question)

- | | |
|--|--------------|
| I have read the Plain Language Statement (or had it read to me) | Yes / |
| No | |
| I understand all of the information provided | Yes / |
| No | |
| I have had a chance to ask questions and discuss this study | Yes / |
| No | |
| I have received acceptable answers to all my questions | Yes / |
| No | |

If at any point throughout this study you feel as if you don't wish to continue taking further part, this is not an issue. You are under no pressure to stay involved with this project and can leave without any issue.

The investigators will protect all the information about me, and my full part in the assessments. All of the records and information will be securely stored. Additionally, the findings from this research may be published in a scientific journal and presented at conferences in a way that does not show my identification.

I understand that the investigator Lorcan Daly, Athlone Institute of Technology (Tel: 0876152751) will answer any question I have regarding the research project. If I have questions or issues around the study, I am free to get in touch with any of the investigators via phone call or email.

I have read and fully understood the information in this consent form. My concerns and questions have been fully answered and I have received a plain language form. Therefore, I consent to take part in this research project.

Participants Signature: _____.

Date: _____.



Email to Manager

Dear Manager,

As part of a PhD research programme in Athlone Institute of Technology, I am undertaking a project investigating the effect of fatigue and timeline of recovery in Gaelic football. Fatigue is commonplace with Gaelic football as players are often involved with numerous teams, at different ages and at different playing levels. Many of the training sessions and games over a season are separated by short rest times which does not allow for comprehensive recovery. This may have a long-term negative effect on playing performance and may also alter movement patterns, potentially resulting in an injury. The immediate 24 hr recovery period following competitive match play presents quite a challenging dilemma for modern Gaelic football coaches. A greater recognition of the fatigue and recovery response to Gaelic football match play and the relationship of different components of fitness that directly influencing this response will assist greatly practitioners and coaches in planning more effective schedules, reduce disruption to training and improve recovery strategies. This will both minimise the occurrence of fatigue related injuries and improve performance of club football players. There is currently no information in this area available to coaches regarding fatigue and recovery among club level Gaelic football players.

The project will take place in the AIT Sports Science laboratory and at the venue of a competitive club match. Each of the participants will undergo testing on 5 different occasions and will make visits to AIT on two separate occasions for screening days prior to the match. Here, they will undergo tests to measure leg strength, speed, jumping ability, aerobic fitness and body composition. On the day of a game, participants will undergo tests pre match, at half time and post-match. Muscle damage, jumping ability, GPS analysis, and different biomechanical variables will be monitored.

If you would consider suggesting to players on your team to partake in this study, or if you require further information on the testing please don't hesitate to contact me on 087-6152751.

Looking forward to hearing back from you.

Best regards,

Lorcan Daly, MSc Student

Athlone Institute of Technology

Physical Activity Readiness - Questionnaire



Department of Sport and Health Science

PRE-TEST QUESTIONNAIRE

NAME

Ref. No.

Date of Birth

Age:

Test procedure

As you are to be a subject in this laboratory/project, would you please complete the following questionnaire. Your cooperation in this is greatly appreciated.

Please tick appropriate box

NO

YES

Has the test procedure been fully explained to you?

Any information contained herein will be treated as confidential

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

2. Do you feel pain in your chest when you do physical activity?

3. In the past month, have you had chest pain when you were not doing physical activity?

4. Do you lose your balance because of dizziness or do you ever lose consciousness?

5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?

6. Is your doctor currently prescribing drugs for your blood pressure or heart condition?

7. Do you know of any other reasons why you should not undergo physical activity? This might include severe asthma, diabetes, a recent sports injury, or serious illness.

8. Have you any blood disorders or infectious diseases that may prevent you from providing blood for experimental procedures?

- If you have answered **NO** to all questions then you can be reasonably sure that you can take part in the physical activity requirement of the test procedure

I..... declare that the above information is correct at the time of completing this questionnaire Date/...../.....

Please Note: If your health changes so that you can then answer YES to any of the above questions, tell the experimenter/laboratory supervisor. Consult with your doctor regarding the level of physical activity you can conduct.

- If you have answered **YES** to one or more questions:

Talk with your doctor in person discussing with him/her those questions you answered yes. Ask your doctor if you are able to conduct the physical activity requirements.

Doctor's signature.....

Date/...../.....

Signature of Experimenter.....

Date/...../.....

Appendix C

Data Collection Sheet



Data Collection Information

<u>Participant Name</u>	
<u>Address</u>	
<u>Mobile number</u>	
<u>Date</u>	
<u>Club/team involved with</u>	
<u>Playing Position</u>	
<u>Current Occupation</u>	

Match Day Testing

Date of Testing: ____/____/____

Name: _____

ID#:

Pre

Jump tests:	1	2	3	Mean
DJ (cm)	_____	_____	_____	_____
CMJ (cm)	_____	_____	_____	_____

Blood sample:

Creatine Kinase (ul) _____

Half time

Jump tests:	1	2	3	Mean
DJ (cm)	_____	_____	_____	_____
CMJ (cm)	_____	_____	_____	_____

Blood sample:

Creatine Kinase (ul) _____

Full time

Jump tests:	1	2	3	Mean
DJ (cm)	_____	_____	_____	_____
CMJ (cm)	_____	_____	_____	_____

Blood sample:

Creatine Kinase (ul) _____

Perceptual Questionnaire Sheet – Pre Match

	5	4	3	2	1	Record score
Fatigue	Very fresh	Fresh	Normal	More tired than usual	Always tired	
Sleep Quality	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia	
General Muscle Soreness	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore	
Stress Levels	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed	
Mood	Very positive mood	A generally good mood	Less interested in others &/or activities than usual	Snappiness at team-mates, family and co-workers	Highly annoyed/irritable/down	
						Score

Perceptual Questionnaire Sheet - Post Match

	5	4	3	2	1	Record score
Fatigue	Very fresh	Fresh	Normal	More tired than usual	Always tired	
Sleep Quality	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia	
General Muscle Soreness	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore	
Stress Levels	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed	
Mood	Very positive mood	A generally good mood	Less interested in others &/or activities than usual	Snappiness at team-mates, family and co-workers	Highly annoyed/irritable/down	
						Score



24 Hour Post Match Testing

Date of Testing: ____/____/____

Name: _____

ID#:

24 Hours Post

Jump tests:	1	2	3	Mean
DJ (cm)	_____	_____	_____	_____
CMJ (cm)	_____	_____	_____	_____

Blood sample:

Creatine Kinase (ul) _____

Perceptual Questionnaire Sheet – 24 Hours Post

	5	4	3	2	1	Record score
Fatigue	Very fresh	Fresh	Normal	More tired than usual	Always tired	
Sleep Quality	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia	
General Muscle Soreness	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore	
Stress Levels	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed	
Mood	Very positive mood	A generally good mood	Less interested in others &/or activities than usual	Snappiness at team-mates, family and co-workers	Highly annoyed/irritable/down	
					Score	



48 Hour Post Match Testing

Date of Testing: ____/____/____

Name: _____

ID#: _____

48 Hours Post

Jump tests:	1	2	3	Mean
DJ (cm)	_____	_____	_____	_____
CMJ (cm)	_____	_____	_____	_____

Blood sample:

Creatine Kinase (ul) _____

Perceptual Questionnaire Sheet – 48 Hours Post Match

	5	4	3	2	1	Record score
Fatigue	Very fresh	Fresh	Normal	More tired than usual	Always tired	
Sleep Quality	Very restful	Good	Difficulty falling asleep	Restless sleep	Insomnia	
General Muscle Soreness	Feeling great	Feeling good	Normal	Increase in soreness/tightness	Very sore	
Stress Levels	Very relaxed	Relaxed	Normal	Feeling stressed	Highly stressed	
Mood	Very positive mood	A generally good mood	Less interested in others &/or activities then usual	Snappiness at team-mates, family and co-workers	Highly annoyed/ irritable/ down	
Score						



Screening Day 1

Name:

Date of testing:

Anthropometrics

Age	
Height	
Weight	

Body Fat Analysis

Site	mm	mm	mm	Average mm
Chest				
Abdominal				
Thigh				
Tricep				
Subscapular				
Suprailiac				
Midaxillary				
			Total (mm)	

Body fat (%)	
Body fat (Kg)	
Lean body weight (Kg)	

Squat Strength

1RM strength (Kg)	
--------------------------	--

VO₂Max Result

VO₂max (ml/kg/min)	
--------------------------------------	--



Screening Day 2

Name:

Date of testing:

Jump Tests Results

Jump	Height (cm)
Countermovement jump	

Jump	Height (cm)	Contact time (s)	RSI
Drop jump			

Running Speed Results

Sprint	Sprint 1 (s)	Sprint 2 (s)	Best sprint time (s)
5 m speed			
10 m speed			

Hip Thrust Strength

1RM strength (Kg)	
-------------------	--

Appendix D



Recovery Strategies in Gaelic Games

Informed Consent

Aim: This study aims to investigate the recovery practices of Gaelic games athletes.

Procedures: The study will involve completing a short questionnaire which will assess various practices used to enhance post-exercise recovery. The questionnaire will take on average 17-minutes to complete.

Questions: For any concerns or questions with regards to the study and its procedures please contact: l.daly@research.ait.ie

Data Protection: All data will be anonymised, handled confidentially and retained for a duration of 5 years. Data will be securely stored online and protected by 2-step verification and password encryption. Personal data from which you can be identified, will not be shared with any third party.

Withdrawal: Consent can be withdrawn at any stage throughout the data collection period by contacting: l.daly@research.ait.ie. Upon such request any personal data will be deleted and excluded from further processing within 48-hrs, you are not legally obliged to follow any of the procedures outlined above.

1. To proceed with the questionnaire please that you understand the requirements of the study, you understand the procedures that will take place and you are satisfied with the information provided and therefore willingly agree to participate. To participate **click yes to proceed.**

Yes

No



Recovery Strategies in Gaelic Games
Section A: Biographic Information

2. Age in Years

3. What is your sex?

- Male
- Female

4. What is your sport in Gaelic Games?

- Gaelic football
- Hurling
- Camogie
- Handball

5. What is your highest current level of participation?

- Club/collegiate
- Inter-county

6. How many hours per week do you typically spend training for your sport during the competitive season? (Team and individual sessions)

- less than 4 hours 6 - 7 hours
 4 - 5 hours 7 - 8 hours
 5 - 6 hours More than 8 hours

7. Do you participate in other sports outside your primary Gaelic games sport?

- Yes
 No

8. Do you participate in multiple teams in your primary Gaelic games sport?

- Yes
 No

9. How long, if any, is your off-season without sport activity?

- No off season
 2 weeks or less
 4 weeks or less
 Over 4 weeks

10. Do you have a rest day/day off training/competition during the week?

- Yes
 No



Recovery Strategies in Gaelic Games

Section B: Post-Match Recovery Timeline and Influencing Factors

11. When do you feel fully recovered following match-play?

- 12 hours or less
- 24 hours
- 48 hours
- 72 hours
- More than 72 hours

12. Please rank the in-game demands that you believe make you feel most tired/sore following match-play.

Rank in order from 1 (largest contributor) to 4 (smallest contributor)

	1	2	3	4
Total Workload (Total distance covered)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
High intensity workload (Total sprints, distance covered sprinting)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Physical Contact (Impacts and tackling)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Changes of pace (Accelerations or decelerations)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

13. From the below list, please rank the attributes you believe help you recover quicker following match-play.

(1 being the most important and 4 the least important)

	1	2	3	4
Strength	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Aerobic Fitness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Power	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Running Speed	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

14. Do your recovery practices following match-play/training change depending on the time of season?

Yes

No

If yes, please provide detail of how your practices change during the season

6



Recovery Strategies in Gaelic Games

Section C: Recovery Techniques

15. Athletes can use a number of recovery techniques to assist them with their physical and psychosociological recovery during the competitive season. The following are examples of such methods. Please indicate how important you rate the contribution of **each** of these to recovery and regeneration by ticking the corresponding block.

NF = Not familiar with technique, 1 = Not important at all, 5 = Extremely important

	1	2	3	4	5	NF
Active cool-down by slow jogging	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Active cool-down in cold swimming pool	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Active cool-down in heated swimming pool	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Acupuncture	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Aromatherapy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Breathing exercises	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Cold shower	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Compression garments	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Contrast temperature (hot+cold)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

	1	2	3	4	5	NF
Cryochamber (extreme cold chamber)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Daytime naps	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Discussion with coach after training/match	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Discussion with teammates after training/match	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Eat shortly after training	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Eat shortly after match	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Floatation tank	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fluid intake after training	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fluid intake after match	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Foam rolling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Gaming	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Get out in nature	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Go to an entertainment/fun park or mall	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ice bath	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Imagery/visualisation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Massage by teammate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Massage by therapist	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Meditation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Music	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Prayer	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

	1	2	3	4	5	NF
Progressive muscle relaxation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reflexology	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sauna	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Self-massage	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sleep	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Socialise with friends	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Stretching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supplements	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Watch mood-lifting videos/movies	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>



Recovery Strategies in Gaelic Games
Section D Overview: Active Cool Down

16. Do you ever perform an active cool down?

Yes

No



Recovery Strategies in Gaelic Games
Section D: Active Cool Down

17. Do you perform an active cool down after training sessions?

- Sometimes
- Regularly
- Always
- No

18. Do you perform an active cool down **between training** sessions on the same day?

- Sometimes
- Regularly
- Always
- No

19. Do you perform an active cool down after matches?

- Sometimes
- Regularly
- Always
- No

20. The active cool down I perform consists of...

- Slow jogging
- Stretching
- Low-intensity activities in a cold swimming pool
- Low-intensity activities in a heated swimming pool
- Other (please specify)

21. Reasons why an active cool down could be performed are listed below. Please read the list and then rate the reasons why you personally perform the active cool down by allocating a score from 1 to 5 to each item.

1 = least important reason 5 = most important reason

I perform an active cool down, because it...

	1	2	3	4	5
Speeds up removal of waste products from muscles	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to wind down	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

	1	2	3	4	5
Gives me time to socialise with team mates	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Decreases muscle soreness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Assists in countering the negative effects of intense training on the immune system	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Gives me time to reflect on the training session or match	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel good	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something the coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other (please specify)	<input type="text"/>				



Recovery Strategies in Gaelic Games

Section E: Nutrition Overview

22. Do you ever apply a specific strategy for **fluid** or **food intake** around **training sessions** or **matches**?

Yes

No



Recovery Strategies in Gaelic Games
Section E: Nutrition

23. Do you apply a specific strategy for fluid intake **after training sessions**?

- Sometimes
- Regularly
- Always
- No

24. Do you apply a specific strategy for fluid intake **after matches**?

- Sometimes
- Regularly
- Always
- No

25. Do you apply a specific strategy for food intake after training sessions?

- Sometimes
- Regularly
- Always
- No

26. Do you apply a specific strategy for food intake after matches?

- Sometimes
- Regularly
- Always
- No

27. Do you use the glycaemic index (GI) of food to determine your food/fluid choices?

- Sometimes
- Regularly
- Always
- No

28. If you answered Yes to any of the questions, please proceed to the following sections.

- | | |
|--|--|
| <input type="checkbox"/> I drink within 30 minutes after a training session | <input type="checkbox"/> I eat foods with a high to moderate GI after training and matches |
| <input type="checkbox"/> I drink within 30 minutes after a match | <input type="checkbox"/> I drink sports drinks after training |
| <input type="checkbox"/> I eat within 30 minutes after a training session | <input type="checkbox"/> I only drink water after training |
| <input type="checkbox"/> I eat within 30 minutes after a match | <input type="checkbox"/> I drink sports drinks after matches |
| <input type="checkbox"/> I drink/eat only protein after training or match | <input type="checkbox"/> I only drink water after matches |
| <input type="checkbox"/> I drink/eat only carbohydrates after training or match | <input type="checkbox"/> I prefer a drink with alcohol after matches |
| <input type="checkbox"/> I combine carbohydrates and protein after a hard training session (e.g., weights, sprinting, tackling) or competition | <input type="checkbox"/> I prefer a drink with caffeine after matches |
| <input type="checkbox"/> I eat and drink within 2 hours after I training | <input type="checkbox"/> I use supplements |
| <input type="checkbox"/> I eat and drink within 2 hours after a match | <input type="checkbox"/> I use vitamins and minerals |

29. Reasons why nutrition can be important in recovery are listed below. Please read the list and then rate the reasons why you personally think it is important by allocating a score from 1 to 5.

1 = least important reason 5 = most important reason

Optimal fluid and food intake ...

	1	2	3	4	5
Helps me to replace the fluids I've lost	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps to build glycogen stores	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to be able to train hard again in the next training session	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Builds the immune system	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Repairs muscles	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Gives energy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)



Recovery Strategies in Gaelic Games

Section F: Sleep

30. Do you have a regular sleep routine? (Going to bed and getting up at more or less the same time)

- Yes
- No

31. How many hours per night do you sleep during the week?

- Less than 6 hours
- 6 - 8 hours
- More than 8 hours

32. How many hours per night do you sleep during the weekend?

- Less than 6 hours
- 6 - 8 hours
- More than 8 hours

33. Do you take a nap during the day?

- Sometimes
- Regularly
- Always
- No

34. Do you experience problems falling asleep?

- Sometimes
- Regularly
- Always
- No

35. Do you experience problems waking in the morning?

- Sometimes
- Regularly
- Always
- No

36. Please proceed to the following sections.

- | | |
|---|--|
| <input type="checkbox"/> I use sleeping pills to sleep better | <input type="checkbox"/> I am affected by noise in the environment when I sleep |
| <input type="checkbox"/> I use alcohol to sleep better | <input type="checkbox"/> I am affected by light in the environment when I sleep |
| <input type="checkbox"/> Caffeine before bedtime keeps me awake | <input type="checkbox"/> I use melatonin for jet lag |
| <input type="checkbox"/> I know how to manage jet lag | <input type="checkbox"/> I do something to relax before going to sleep |
| <input type="checkbox"/> I take a warm bath before bedtime to sleep better | <input type="checkbox"/> Exercise before bedtime interferes with my sleeping pattern |
| <input type="checkbox"/> I am affected by the colour of the room in which I sleep | |

37. Some of the reasons why sleep can be important in recovery are listed below. Please read the list and then rate the reasons why you personally think it is important by allocating a score from 1 to 5.

1 = least important reason 5 = most important reason

Good quality sleep ...

	1	2	3	4	5
Helps maintain normal body rhythms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is essential for growth and repair of the body	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is important for memory processing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increases the secretion of growth hormone	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is important for emotional well-being	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Plays a role in countering depression due to a lack of sleep	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)



Recovery Strategies in Gaelic Games
Section G: External Cold Overview

38. Do you ever apply external cold (e.g. Ice Pack, Cold water Immersion, Ice Bath etc)?

Yes

No



Recovery Strategies in Gaelic Games

Section G: External cold

39. Do you apply external cold **after training** sessions?

- Sometimes
- Regularly
- Always
- No

40. Do you apply external cold **between training** sessions on the same day?

- Sometimes
- Regularly
- Always
- No

41. Do you apply external cold on non-training days?

- Sometimes
- Regularly
- Always
- No

42. Do you apply external cold after matches?

- Sometimes
- Regularly
- Always
- No

43. The external cold applications after training or a match consists of...

- | | |
|--|---|
| <input type="checkbox"/> Ice packs or ice bags | <input type="checkbox"/> Cold water whirlpool |
| <input type="checkbox"/> Cryocuff or cold water circulating unit | <input type="checkbox"/> Sitting, standing or lying in cold water |
| <input type="checkbox"/> Cooling jacket | <input type="checkbox"/> Sitting, standing or lying in ice water |
| <input type="checkbox"/> Ice massage | <input type="checkbox"/> Cold shower |
| <input type="checkbox"/> Activities in cold swimming pool | |
| <input type="checkbox"/> Other (please specify) | |

44. Reasons why the application of cold could be used are listed below. Please read the list and then rate the reasons why you personally apply cold by allocating a score from 1 to 5.

1 = least important reason 5 = most important reason

I apply external cold , because it ...

	1	2	3	4	5
Assists in faster removal of waste products from the muscles	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces swelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces inflammation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Decreases muscle soreness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Decreases pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel good	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces muscle spasms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increases muscle performance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something my coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other athletes do it	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)



Recovery Strategies in Gaelic Games
Section H: External Heat Overview

45. Do you ever apply external heat (e.g. sauna, hot bath, steam room, heat pack)?

Yes

No



Recovery Strategies in Gaelic Games
Section H: Heat Application

46. Do you apply external heat **after training** sessions?

- Sometimes
- Regularly
- Always
- No

47. Do you apply external heat **between training** sessions on the same day?

- Sometimes
- Regularly
- Always
- No

48. Do you apply external heat **after matches**?

- Sometimes
- Regularly
- Always
- No

49. Do you apply external heat **on non-training days**?

- Sometimes
- Regularly
- Always
- No

50. The external heat applications after training or a match consists of...

- Warm water whirlpool
- Sauna
- Activities in a heated swimming pool
- Ultrasound
- Hot bath
- Hot water bottle
- Hot shower
- Other (please specify)

51. Reasons why the application of heat could be used are listed below. Please read the list and then rate the reasons why you personally apply cold by allocating a score from 1 to 5.

1 = least important reason 5 = most important reason

I apply external heat, because it ...

	1	2	3	4	5
Assists in faster removal of waste products from the muscles	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces swelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces inflammation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Decreases muscle soreness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Decreases pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to feel good	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes stretching more effective	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces muscle spasms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Will increase muscle performance	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something the coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)



Recovery Strategies in Gaelic Games
Section I: Contrast Treatment (Heat and Cold) Overview

52. Do you ever apply contrast treatment (heat and cold)?

- Yes
- No



Recovery Strategies in Gaelic Games
Section I: Contrast Treatment (Heat and Cold)

53. Do you apply contrast treatment (heat and cold) **after training** sessions?

- Sometimes
- Regularly
- Always
- No

54. Do you apply contrast treatment (heat and cold) **between training** sessions on the same day?

- Sometimes
- Regularly
- Always
- No

55. Do you apply contrast treatment (heat and cold) after matches?

- Sometimes
- Regularly
- Always
- No

56. Do you apply contrast treatment (heat and cold) on non-training days?

- Sometimes
- Regularly
- Always
- No

57. The contrast treatment (heat and cold) after training or a match consists of...

- | | |
|--|--|
| <input type="checkbox"/> Hot and cold showers | <input type="checkbox"/> More time spent on heat application than cold application |
| <input type="checkbox"/> Heated pool and cold shower | <input type="checkbox"/> More time spent on cold application than heat application |
| <input type="checkbox"/> Cold pool and hot shower | <input type="checkbox"/> Start and finish with cold |
| <input type="checkbox"/> Heated pool and cold pool | <input type="checkbox"/> Start and finish with heat |
| <input type="checkbox"/> Other (please specify) | |

58. Reasons why contrast treatment could be used are listed below. Please read the list and then rate the reasons why you personally apply cold by allocating a score from 1 to 5.

1 = least important reason 5 = most important reason

I apply contrast treatment, because it ...

	1	2	3	4	5
Assists in faster removal of waste products from the muscles	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces swelling and inflammation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Creates a pumping action in the muscles	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Decreases muscle soreness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Decreases pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel good	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces muscle spasms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something the coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>



Recovery Strategies in Gaelic Games
Section J: Massage Overview

59. Do you ever apply massage?

- Yes
- No



Recovery Strategies in Gaelic Games
Section J: Massage

60. Do you apply massage **after training** sessions?

- Sometimes
- Regularly
- Always
- No

61. Do you apply massage **between training** sessions on the same day?

- Sometimes
- Regularly
- Always
- No

62. Do you apply massage after matches?

- Sometimes
- Regularly
- Always
- No

63. Do you apply massage on non-training days?

- Sometimes
- Regularly
- Always
- No

64. How many massage sessions do you have per week during the competitive season?

65. Massage after training or a match consists of...

- | | |
|---|---|
| <input type="checkbox"/> Self Massage | <input type="checkbox"/> Deep, intense strokes |
| <input type="checkbox"/> Massage by teammate | <input type="checkbox"/> Squeezing, wringing, kneading of muscles |
| <input type="checkbox"/> Massage by a therapist | <input type="checkbox"/> Rapid tapping, chopping-like movements |
| <input type="checkbox"/> Light, smooth strokes | |
| <input type="checkbox"/> Other (please specify) | |

66. Reasons why massage could be used are listed below. Please read the list and

then rate the reasons why you personally apply cold by allocating a score from 1 to 5.

1 = least important reason 5 = most important reason

I apply massage, because it ...

	1	2	3	4	5
Makes muscles more supple or flexible	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces swelling and inflammation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Releases tight connective tissues	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Decreases muscle soreness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increases deep muscle temperature	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Improves lymphatic circulation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Relieves pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel good	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces muscle spasms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Increases blood circulation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces stress and anxiety	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me with awareness of my body	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

	1	2	3	4	5
Helps with elimination of waste products	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Provides me with a sense of caring touch	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something the coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Other (please specify)	<input type="text"/>				



Recovery Strategies in Gaelic Games
Section K: Aromatherapy Overview

67. Do you ever use aromatherapy (use of aromatic plant extracts and essential oils)?

- Yes
- No



Recovery Strategies in Gaelic Games

Section K: Aromatherapy

68. Do you use aromatherapy **after training** sessions?

- Sometimes
- Regularly
- Always
- No

69. Do you use aromatherapy **between training** sessions on the same day?

- Sometimes
- Regularly
- Always
- No

70. Do you use aromatherapy after matches?

- Sometimes
- Regularly
- Always
- No

71. Do you use aromatherapy on non-training days?

- Sometimes
- Regularly
- Always
- No

72. Aromatherapy after training or a match consists of...

- A bath with oils added
- Showering with oils on a face-cloth or sponge
- Fragrancing a room
- Other (please specify)

73. Reasons why the aromatherapy could be used are listed below. Please read the list and then rate the reasons why you personally apply cold by allocating a score from 1 to 5.

1 = least important reason 5 = most important reason

I use aromatherapy, because it ...

	1	2	3	4	5
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel good	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Relieves stress and anxiety	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to sleep better	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to concentrate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Activates the mind	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something the coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)



Recovery Strategies in Gaelic Games
Section L: Music Therapy Overview

74. Do you ever use music as a therapy?

- Yes
- No



Recovery Strategies in Gaelic Games
Section L: Music Therapy

75. Do you use music as therapy *after* training sessions?

- Sometimes
- Regularly
- Always
- No

76. Do you use music as therapy *between* training sessions on the same day?

- Sometimes
- Regularly
- Always
- No

77. Do you use music as therapy after matches?

- Sometimes
- Regularly
- Always
- No

78. The type of music I use is...

- | | |
|---|--|
| <input type="checkbox"/> Classical | <input type="checkbox"/> Jazz |
| <input type="checkbox"/> Electronic | <input type="checkbox"/> Rap |
| <input type="checkbox"/> Rock | <input type="checkbox"/> Vocal/singing |
| <input type="checkbox"/> Nature sounds (waves, birds, etc.) | <input type="checkbox"/> Non-vocal/instruments |
| <input type="checkbox"/> Gospel/religious/spiritual | |
| <input type="checkbox"/> Other (please specify) | |

79. Some of the reasons why music therapy could be used are listed below. Please read the list and then rate the reasons why you personally use music by allocating a score from 1 to 5.

1 = least important reason 5 = most important reason

I use music, because it...

	1	2	3	4	5
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel energetic	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to fall asleep	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces feelings of anger	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces stress and anxiety	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Produces a positive attitude	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to concentrate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Can improve healing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel good	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something the coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)



Recovery Strategies in Gaelic Games
Section M: Complementary and Alternative Therapy

80. Do you ever use any complimentary therapies, namely **yoga, acupuncture, reflexology, herbal therapy** or **shiatsu**?

- Yes
- No



Recovery Strategies in Gaelic Games
Section M: Complimentary and Alternative Therapy

81. Do you use acupuncture?

- Sometimes
- Regularly
- Always
- No

82. Do you use reflexology?

- Sometimes
- Regularly
- Always
- No

83. Do you use herbal therapy?

- Sometimes
- Regularly
- Always
- No

84. Do you use yoga?

- Sometimes
- Regularly
- Always
- No

85. Do you use shiatsu?

- Sometimes
- Regularly
- Always
- No

86. Some of the reasons why the above-mentioned therapies could be used are listed below. Please read the list and then rate the reasons why you personally use it by allocating a score from 1 to 5 for each therapy.

1 = least important reason 5 = most important reason

I use acupuncture, because it...

	1	2	3	4	5
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Prevents illness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel energetic	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to fall asleep	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces stress and anxiety	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Has a positive effect on the immune system	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to concentrate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Balances energy fields	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Relieves pain	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Gives a personal touch	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something the coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

87. Some of the reasons why the abovementioned therapies could be used are listed below. Please read the list and then rate the reasons why you personally use it by allocating a score from 1 to 5 for each therapy.
 1 = least important reason 5 = most important reason

I use reflexology, because it... ..

	1	2	3	4	5
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel energetic	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to fall asleep	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces feelings of anger	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to concentrate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Can improve healing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something the coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something a teammate told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

88. Some of the reasons why the abovementioned therapies could be used are listed below. Please read the list and then rate the reasons why you personally use it by allocating a score from 1 to 5 for each therapy.

1 = least important reason 5 = most important reason

I use herbal therapy because it... ..

	1	2	3	4	5
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel energetic	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to fall asleep	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces feelings of anger	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to concentrate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Can improve healing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something the coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

89. Some of the reasons why the abovementioned therapies could be used are listed below. Please read the list and then rate the reasons why you personally use it by allocating a score from 1 to 5 for each therapy.

1 = least important reason 5 = most important reason

I use yoga because it...

	1	2	3	4	5
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel energetic	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to fall asleep	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces feelings of anger	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to concentrate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Can improve healing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something the coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

90. Some of the reasons why the abovementioned therapies could be used are listed below. Please read the list and then rate the reasons why you personally use it by allocating a score from 1 to 5 for each therapy.

1 = least important reason 5 = most important reason

I use shiatsu because it...

	1	2	3	4	5
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel energetic	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to fall asleep	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces feelings of anger	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to concentrate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Can improve healing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is something the coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)



Recovery Strategies in Gaelic Games

Section N: Relaxation Overview

91. Do you ever use any relaxation therapies, namely **progressive muscle relaxation, breathing exercises, imagery/visualization, autogenic training or prayer?**

- Yes
- No



Recovery Strategies in Gaelic Games
Section N: Relaxation

92. Do you use progressive muscle relaxation?

- Sometimes
- Regularly
- Always
- No

93. Do you use breathing exercises?

- Sometimes
- Regularly
- Always
- No

94. Do you use meditation?

- Sometimes
- Regularly
- Always
- No

95. Do you use imagery/visualization?

- Sometimes
- Regularly
- Always
- No

96. Do you use autogenic training?

- Sometimes
- Regularly
- Always
- No

97. Do you use prayer?

- Sometimes
- Regularly
- Always
- No

98. If you answered Yes to any of the questions, please proceed to the following

sections.

Reasons why the abovementioned therapies could be used are listed below. Please read the list and then rate the reasons why you personally use it by allocating a score from 1 to 5.

1 = least important reason 5 = most important reason

I use it, because it...

	1	2	3	4	5
Helps me to relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps with emotional recovery	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Prevents illness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to fall asleep	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reduces stress and anxiety	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Has a positive effect on the immune system	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to focus on positives	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lowers heart rate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Helps me to switch off	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Makes me feel good	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lowers blood pressure	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Creates an awareness of muscle tension	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

	1	2	3	4	5
Is something the coach told me to do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

Appendix E



Gaelic Games Coaches and Practitioners Perceptions of Recovery Strategies

Section A: Biographic Information

2. What is your age in years?

3. What is your sex?

- Male
- Female
- Prefer not to say

4. Which of the below roles best describes your involvement in Gaelic games?

- Sports coach
- Strength and conditioning coach
- Nutritionist / dietitian
- Physiotherapist / rehabilitation
- Other (please specify)

5. What is the sex of the Gaelic athletes you currently work with at adult level?

- Male
- Female
- Both male and female

6. What Gaelic games sport (s) are you currently involved with at adult level? (tick all that apply)

- Gaelic football
- Hurling
- Camogie
- Handball

7. What is the highest level of participation of Gaelic games athletes you currently work with?

- Club / collegiate
- Inter-county



Gaelic Games Coaches and Practitioners Perceptions of Recovery Strategies

Section B: Recovery Techniques

8. Athletes can use a number of recovery techniques to assist them with their physical and psychosocial recovery during the competitive season. The following are examples of such methods. Please indicate how important you rate the contribution of **each** of these to recovery and regeneration by ticking the corresponding block.

NF = Not familiar with technique; 1 = Not important at all; 5 = Extremely important

	1	2	3	4	5	NF
Active cool-down by slow jogging	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Active cool-down in cold swimming pool	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Active cool-down in heated swimming pool	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Acupuncture	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Breathing exercises	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Cold shower	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Compression garments	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

	1	2	3	4	5	NF
Contrast temperature (hot and cold)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Cryochamber (extreme cold chamber)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Daytime naps	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Discussion with coach after training/match	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Discussion with teammates after training/match	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Eat shortly after training / match	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Floatation tank	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fluid intake after training / match	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Foam rolling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Get out in nature	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ice bath	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Imagery / visualization	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Self massage	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Massage by therapist	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Meditation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Music	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Prayer	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Progressive muscle relaxation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sauna	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sleep	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

5

	1	2	3	4	5	NF
Socialise with friends	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Stretching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supplements	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Appendix F

Table 10. 1 below summarises the anthropometric characteristics of all participants.

Table 10. 1. Anthropometric characteristics

Age (y)	23.3 ± 4.2
Height (cm)	178.3 ± 7.9
Weight (kg)	80.6 ± 9.5
Body fat (%)	13.1 ± 4.2

Values are mean ± SD

A summary of all participants' speed, power and strength characteristics can be seen in Table 10. 2.

Table 10. 2. Speed, Power and Strength.

5 meter (s)	1.1 ± 0.1
20 meter (s)	3.1 ± 0.1
CMJ (cm)	34.6 ± 4.6
DJ (cm)	33.4 ± 5.2
DJ Contact Time (s)	0.35 ± 0.1
RSI	1.1 ± 0.4
1RM Squat (kg)	106.5 ± 14.3
1RM Hip Thrust (kg)	131.9 ± 4.2

Values are mean ± SD

Table 10. 3 below summarises the physiological responses at maximal exercise.

Table 10. 3. Physiological responses during the maximal aerobic capacity test

$\dot{V}O_2\text{max}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	51.3 ± 7.9
Heart rate ($\text{beats}\cdot\text{m}^{-1}$)	199.4 ± 6.1
RPE	19.6 ± 0.5

Values are mean \pm SD

Table 10. 4 summarises the running economy variables of participants at five different running velocities.

Table 10. 4. Running economy expressed as $\dot{V}O_2$ in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$

Running Speed	$\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$
8.0 ($\text{km}\cdot\text{h}^{-1}$)	26.8 ± 4.7
9.0 ($\text{km}\cdot\text{h}^{-1}$)	30.7 ± 4.5
10.0 ($\text{km}\cdot\text{h}^{-1}$)	33.4 ± 5.3
11.0 ($\text{km}\cdot\text{h}^{-1}$)	36.8 ± 5.7
12.0 ($\text{km}\cdot\text{h}^{-1}$)	40.2 ± 5.8

Values are mean \pm SD

Table 10. 5 describes the running economy blood lactate variables of the participants during the treadmill run at the lactate threshold (LT), 2.0 mmol.L⁻¹ and 4.0 mmol.L⁻¹ fixed blood lactate concentrations. Table 10. 6 illustrates the GPS collected metrics of the overall cohort and sub-divisions of in-game workload measures based on positional lines.

Table 10. 5. Blood Lactate Concentrations during Running Economy Test

Treadmill velocity at LT	10.1 ± 1.2
Treadmill velocity at 2.0 mmol.L ⁻¹	9.3 ± 0.7
Treadmill velocity at 4.0 mmol.L ⁻¹	12.2 ± 0.8
% $\dot{V}O_2$ at LT	77.2 ± 7.4
% $\dot{V}O_2$ at 2.0 mmol.L ⁻¹	71.2 ± 8.6
% $\dot{V}O_2$ at 4.0 mmol.L ⁻¹	89.9 ± 4.1

Values are mean ± SD

Table 10. 6. GPS metrics during competitive play across three positional lines (Values are mean \pm SD).

	Combined	Full Back/Forward Line	Midfield	Half Back/ Half Froward Line
Max Speed (km·h⁻¹)	28.9 \pm 2.3	27.8 \pm 2.7	29.2 \pm 2.3	29.5 \pm 1.9
Distance (m) (1st)	3834.7 \pm 654.0	3380.4 \pm 681.1	4250.1 \pm 0.6	4007.4 \pm 521.0
Distance (m) (2nd)	3300.1 \pm 714.2	2892 \pm 698.1	3627.2 \pm 449.9	3471.2 \pm 690.5
Distance Total (m)	7132.4 \pm 1194.9	6272.5 \pm 1035.0	7877.5 \pm 868.4	7473.6 \pm 1078.6
Accelerations (1st)	20.7 \pm 6.7	18.5 \pm 6.9	23.7 \pm 8.3	21.2 \pm 5.8
Accelerations (2nd)	15.4 \pm 5.5	15.2 \pm 5.6	18.5 \pm 6.6	14.5 \pm 5.1
Sprints (1st)	17.8 \pm 8.3	16.2 \pm 11.0	17.7 \pm 6.4	18.9 \pm 6.9
Sprints (2nd)	12.8 \pm 5.9	11.7 \pm 5.5	14.4 \pm 7.2	13 \pm 6.0
Total Sprints (\geq19.8 km·h⁻¹)	29.3 \pm 11.9	24.2 \pm 10.6	32.4 \pm 13.0	31.9 \pm 11.9
Total Impacts	133.5 \pm 122.4	64.7 \pm 31.3	200 \pm 184.0	158.4 \pm 120.2
Explosive Distance (m) (1st)	426.4 \pm 137.7	351.1 \pm 120.4	472.3 \pm 109.1	463.1 \pm 141.1
Explosive Distance (m) (2nd)	315.5 \pm 119.7	294.4 \pm 116.0	309.5 \pm 118.2	332.5 \pm 126.2
Total Explosive Distance (m)	745.3 \pm 229.9	640.3 \pm 217.8	781.9 \pm 191.5	806.0 \pm 234.0
Average Heart Rate (beats·m⁻¹)	167.9 \pm 8.3	162.7 \pm 9.6	170.5 \pm 9.2	170.7 \pm 5.1

Appendix G

Exercise & Sports Science Australia Twitter Conference Proceedings 2021.

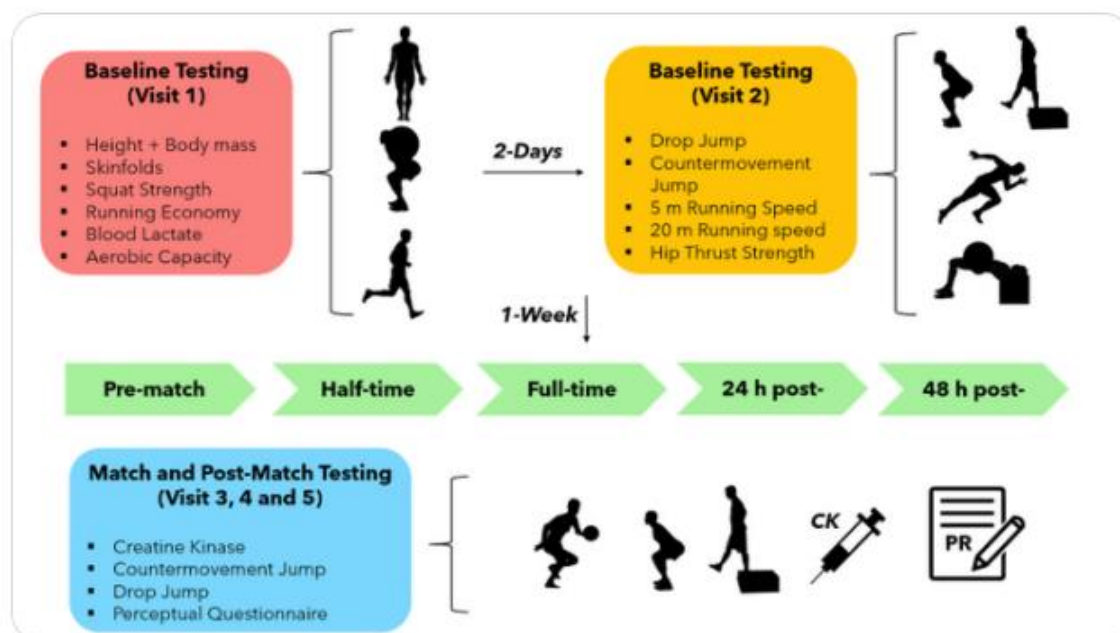
1) Does physical conditioning influence fatigue and recovery in Gaelic football? While superior physical conditioning has been suggested to moderate fatigue and muscle damage in other team sports (1,2) Gaelic footballs' unique demands may provoke different responses 🧵

#ESSTC21



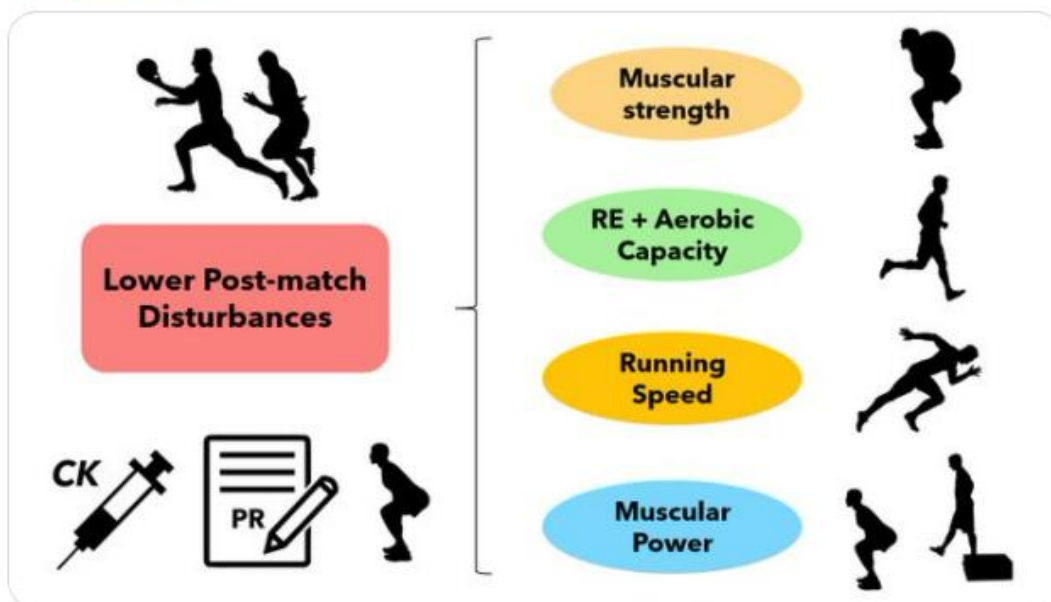
2) Fifty-two senior club level Gaelic football players components of fitness and peri-match neuromuscular, perceptual and biochemical markers were monitored. Possible associations between physical conditioning and markers of fatigue and muscle damage were assessed

#ESSTC21



3) Our data suggests that well-developed neuromuscular-related performance measures (strength, power and running speed) and markers of aerobic function (running economy and aerobic capacity) protect against fatigue and muscle damage, and accelerate post-match recovery

#ESSTC21



4) Possibly explaining these findings, well-developed physical conditioning attributes (particularly aerobic capacity and muscular strength) may facilitate increased metabolite clearance, reduced neuromuscular fatigue and provide higher resilience against muscle damage

#ESSTC21



5) Overall, our results suggest incorporating appropriately periodised training to increase aerobic capacity and muscular strength may:

📈 Reduce the magnitude of fatigue and muscle damage during and following match-play

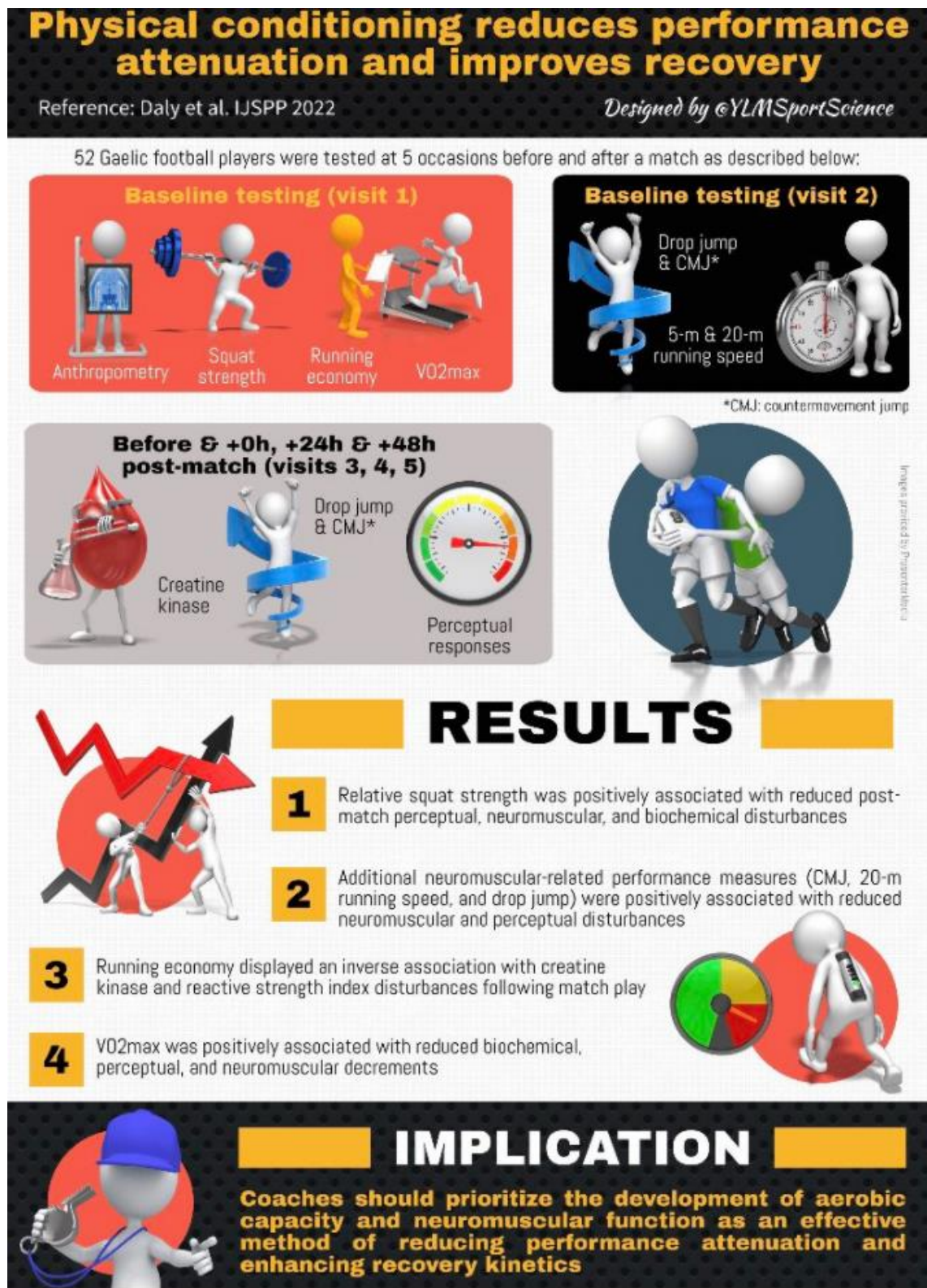
✅ Accelerate the post-match recovery timeline

#ESSTC21



Appendix H

Infographic of study 3 designed and created by Dr. Yann Le Meur.



Appendix I

Poster of study 3 presented at the SHE Research symposium 2022.



Do Superior Physiological Attributes Enable Players to Outwork their Less-Conditioned Counterparts? A Study in Gaelic Football

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Introduction

In order to provide objective data for coaches to design effective training programmes with the goal of increasing competitive workloads, it may be necessary to address these interactions in an ecologically valid context. Therefore, this study aims to investigate the influence of players components of fitness on in-game workload measures in Gaelic football.

Methods

Fifty-two male Gaelic football players (mean ± SD; age: 22.9 ± 3.8 years; stature: 179.2 ± 7.5 cm) underwent measurements of anthropometric characteristics, running speed, muscular strength and power, blood lactate responses, running economy and aerobic capacity. One week following baseline testing, 18-Hz Global Positioning System units were used to record players in-game workloads during competitive match-play.

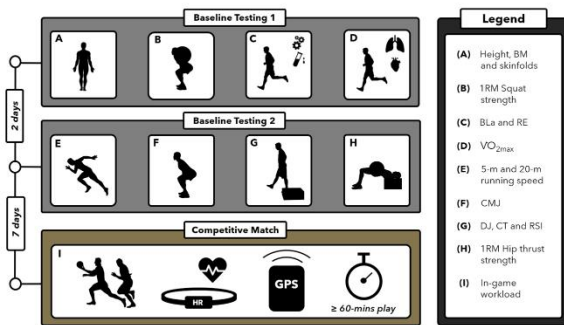


Figure 1. Schematic overview of study methodology.



Figure 2. Possible physiological mechanisms underpinning results.

Results & Conclusions

Our results reflect the multifaceted physical and metabolic loads players face during match-play, highlighting a significant influence of body composition, running speed, muscular power and aerobic conditioning on players competitive workload measures.

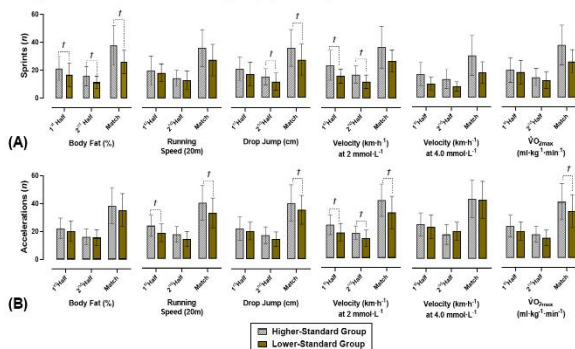


Figure 3. Differences in the number of accelerations (A) and sprints (B) completed during match-play between higher-standard (HS) and lower-standard (LS) component of fitness groups. † Denotes a significant difference between groups.

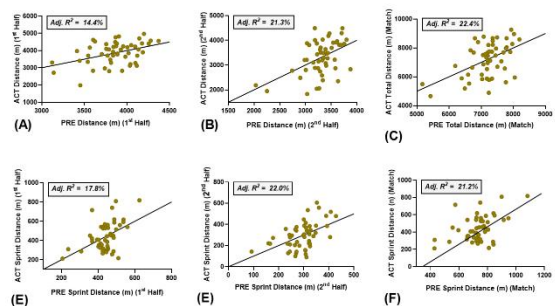


Figure 4. Plot of actual (ACT) vs. predicted (PRE) values for (A) 1st half distance, (B) 2nd half distance, (C) full match distance, (D) 1st half sprint distance, (E) 2nd half sprint distance and (F) full match sprint distance covered during match-play. Total distance dependant variables: VO_{2max} and body fat (%). Sprint distance dependant variables: body fat (%), drop jump and 20 m running speed.

From a programming perspective, concurrent endurance training to develop players markers of aerobic function combined with strength and/or power training to target the neuromuscular system will likely translate into increased external workloads. Furthermore, coaches should aim for high transferability from training induced adaptations to meet the specific mechanical, metabolic and technical demands of Gaelic football match-play. This may be best achieved using appropriate training strategies that drive physical conditioning adaptations during the general preparatory phases of the season, while limiting disruptive magnitudes of fatigue and muscle damage during the competitive in-season period.

