The Impact of Weighted Football Training on the Skill Acquisition Processes of Place-Kicking in Sport

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The Impact of Weighted Football Training on the Skill Acquisition Processes of Place Kicking in Sport

Sam Jermyn
Department of Sport, Leisure & Childhood Studies

A thesis submitted in fulfilment of the requirements for the award of Doctor of Philosophy

Supervisors: Dr. Edward K. Coughlan and Dr. Cian O’Neill

Submitted to Munster Technological University (MTU) January 2023
Thesis Abstract

The Impact of Weighted Football Training on the Skill Acquisition Processes of Place Kicking in Sport

Sam Jermyn

Weighted implement training (WIT) involves performance of sport-specific motor skills with heavier-than-normal sporting implements. Typically, full range of motion (ROM) and similar kinematic characteristics of the respective motor skill are maintained concurrent to minimal changes in the force-velocity movement profile. While the majority of WIT research has been conducted in baseball, track and field, and cricket, there is a paucity of research conducted in the football codes, particularly Gaelic football. Existing observations of increased standard implement velocity and distance following the use of weighted implements infers potential benefits for Gaelic football performance, such as increasing kick-out ball velocity (BV) and distance, which can support ball retention downfield. The aim of this research was to investigate the acute and chronic effects of weighted Gaelic football training on markers of place kicking performance. A 600g (25% mass increase) weighted Gaelic football was used in four experiments, whereby this research investigated the effects of weighted football training on (i) kicking leg kinematic and ROM behaviours following a brief intervention, (ii) immediate place kick distance and BV following a weighted football warm up protocol, and (iii) inter-county goalkeepers’ BV following completion of a 4-week, 8-session intervention. Results showed that although kinematic and ROM behaviours were not altered, there were, albeit statistically insignificant, acute nominal improvements in kick distance and BV following the use of the weighted football which may positively impact ball retention further into opposition territory. The repeated use of weighted footballs also increased inter-county goalkeepers’ BV measures. The findings of this thesis suggest that weighted football training can be an effective means of acutely and chronically increasing BV and kick distance. Therefore, practitioners can utilise the provided weighted football warm up protocols and training programmes that enhance kick-out performance, which may ultimately support ball retention and the creation of scoring opportunities.
Definition of Terms

**Skill Acquisition** – the development of a functional relationship between the performer and the environment (Araujo & Davids, 2011).

**Weighted Implement Training** – performance of sport-specific motor skills with heavier-than-normal sporting implements where full range of motion of the respective motor skill is maintained concurrent to minimal changes in the force-velocity profile of the movement as a result of the overload applied (DeRenne, Buxton, Hetzler & Ho, 1994; 1995).

**Kinematics** – a branch of mechanics that deals with the geometry of movement of identified points of the body without reference to the forces that cause movement (Bartlett, 1996).

**Angular Velocity** – the rate of rotation around an axis usually expressed in radians or revolutions per second or per minute (Bartlett, 1996).

**Post-Activation Performance Enhancement (PAPE)** – the enhancement of transient, voluntary movements following conditioning contractions (Cuenca-Fernandez, Smith, Jordan et al., 2017; Prieske, Behrens, Chaabene, Granacher & Maffiuletti, 2020).

**Post-Activation Potentiation (PAP)** – the enhancement of acute, non-voluntary, electrically-evoked muscle twitch contractions following conditioning activities (Cuenca-Fernandez et al., 2017; Prieske et al., 2020).

**Retention of Learning** – the retention of performance of a particular skill following a sufficient time period of disengagement (Magill, 2007).
Author’s Declaration

The substance of this thesis is the original work of the author and due reference and acknowledgement has been made, where necessary, to the work of others. This research has complied with the University’s Code of Good Practice in Research. No part of this thesis has already been submitted for any degree and is not being concurrently submitted in candidature for any degree.

Candidate:         Date: 04/01/2023

Sam Jermyn

Supervisors:         Date: 04/01/2023

Dr. Edward K. Coughlan

Dr. Cian O’ Neill
Acknowledgments

I wish to express my sincerest gratitude to a number of people who have been an ever-present source of support, comfort and guidance throughout this PhD journey.

- Thank you to my supervisors, Dr. Edward Coughlan and Dr. Cian O’Neill. All that has been achieved over these recent years would not have been possible without your unwavering support, guidance and expertise.

- Kirsti – what can I say? A lot has been sacrificed for this milestone to be reached, and for that I am forever indebted. Thank you for your unconditional support and understanding since day one.

- Equally, thank you to my family – Mom, Dad, Peter, Hil, and co. – for being the constant source of support that you are. Simply, this would not have been possible without you all. G.F.L.GG.

- To Pat, Patti and all of the O’Flynn clan – thank you. I am forever grateful for your love and support throughout this journey.

- To all members of the postgrad office, past and present, thank you. All of those morning coffees, kick/throw-about, and everything else in between were as important as anything. My sincerest thanks for all of your support.

- Thank you to my extended family and friends. The importance of your companionship cannot be overstated.

- I also wish to express my gratitude to my colleagues in MTU, and a particular thank you to Dr. Seán Lacey for all of his statistical support and guidance throughout this journey.
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Chapter 1

Introduction
1.1. Introduction

Weighted implement training (WIT) involves the performance of sport-specific motor skills with heavier-than-normal sporting implements; for example, weighted baseball bats, weighted cricket balls, and weighted golf clubs (for review, see Jermyn, O’Neill & Coughlan, 2021a). Typically, full range of motion (ROM) and similar kinematic characteristics of the respective motor skill are maintained concurrent to minimal changes in the force-velocity profile of the movement as a consequence of the overload applied (DeRenne, Buxton, Hetzler & Ho, 1994, 1995; Jermyn, O’Neill, Dawson, Dunton & Coughlan, in press). Since the seminal research of the 1960’s (Brose & Hanson, 1967; Egstrom, Logan & Wallis, 1960; Straub, 1968; Van Huss, Albrecht, Nelson & Hagerman, 1962), a multitude of studies have investigated the effects of weighted implement protocols and programmes on the performance of sport-specific motor skills in sports such as baseball, cricket, and track and field, where acute and chronic improvements in implement velocity and distance have been observed. However, despite the promising findings of this research, and the concurrent desire for acute and chronic improvements in implement velocity and distance of a kicked football in Gaelic football, there is a dearth of research assessing the effects of weighted Gaelic football warm up protocols and training interventions on place kicking performance. Therefore, the research presented in this thesis aims to identify and evaluate the acute and chronic effects of weighted Gaelic football protocols and training programmes on markers of standard Gaelic football place kicking performance among university students and inter-county and club level male Gaelic football goalkeepers, with the ultimate aim of identifying whether the use of this weighted Gaelic football is an efficacious option for practitioners to improve athletes’ place kick distance, particularly among goalkeepers. Increasing kick distance is desirable for goalkeepers as long kick-outs (i.e., kick-outs that land outside the goalkeepers’ own
45m line; Mangan, Ryan, Devenney et al., 2017) are a prominent feature of match play (Daly & Donnelly, 2018; Mangan et al., 2017) due to the expansive playing surface and various match play rules that encourage distance kicking (see the ‘Mark’ rule and the new 20m line kick-out location; GAA, 2017; 2020).

1.2. Background to the Research and the Related Questions

The use of weighted implements in athlete’s physical preparation originates from the former Soviet Union’s (1922-1991) track and field strength and conditioning (S&C) practices. Under- and/or over-weighted discus, javelin, hammer and shot put exercises were a feature of their athletes’ physical preparation during specialised speed-strength programmes in the respective events (DeRenne & Szymanski, 2009). The seminal Soviet publications highlighted three proposed outcomes from WIT: (i) varied resistance training enhances power development, (ii) a weight increase or decrease of 5-20% relative to the standard implement should be employed, and (iii) a 2:1 frequency ratio of modified to standard implement utilisation should be incorporated (DeRenne & Szymanski, 2009).

Since this seminal research, the use of weighted implements has become a prominent feature in experimental and applied practice domains within the skill acquisition and S&C fields in other parts of the world. Specifically, weighted implements have been utilised for the purpose of enhancing key features of ballistic sport-specific motor skills. Examples include increased ball velocity when pitching a baseball (Van Huss et al., 1962), increased bat velocity when swinging a baseball bat (DeRenne, 1982; DeRenne, Ho, Hetzler & Chai, 1992), and increased distance travelled of a football when kicked from the hand (Ball, 2009). Studies have also investigated the effect of weighted implement use on other facets of sporting performance beyond the commonly assessed implement velocity, including injury risk (Reinold, Macrina, Fleisig, Aune & Andrews,
and movement pattern alterations (Southard & Groomer, 2003). Figure 1.1 (a-h) presents a multitude of sport-specific weighted implements currently available in the marketplace, designed to either ‘underload’ or ‘overload’ hitting and throwing movements in baseball, Olympic handball, track and field, golf, and rugby.

Figure 1.1 (a-h). A sample of weighted sporting implements available in the marketplace, such as the Driveline™ Leather Weighted Baseball range (a), the ERIMA® Handball G9 HEAVY Training weighted handball (b), the Rhino™ Storm Pass Developer weighted rugby ball (c), the SuperSpeed™ Speed Stick range of weighted golf clubs (d), the HEAVYBAT™ HeavySwing range of weighted baseball and softball bats (e), the Velaasa Weighted Discus (f), the Velaasa Weighted Shot-Put (g), and the Velaasa Over-Weighted Indoor Weight (h).

The early research of the 1960’s centred around investigations into the acute and chronic effects of weighted baseball utilisation on pitching performance. The first study by Egstrom et al. (1960), which investigated the transfer effects of training with a ball of a
particular mass to a ball of different mass among a university baseball cohort, found that
ten training sessions comprising of 50 throws with either a 2oz (60% mass decrease) or
6.5oz (30% mass increase) baseball resulted in practice with the under-weighted ball
being as effective as practice with the over-weighted ball in terms of developing post-
intervention throwing accuracy with the over-weighted ball. However, the effects of these
training programmes on performance with the standard ball were not assessed in this
study. Subsequently, Van Huss et al. (1962) reported that an over-weighted warm up
protocol (11oz, 120% mass increase) significantly increased standard baseball (5oz)
throwing velocity ($p = 0.01$) without significantly negatively impacting throwing
accuracy among a university baseball cohort. Brose and Hanson (1967) found that
training 3-times per week for 6-weeks with a 10oz (100% mass increase) baseball resulted
in significant improvements in standard baseball pitching velocity ($p < 0.05$), without any
change in pitching accuracy among a university baseball cohort. In contrast to the findings
of the aforementioned studies, Straub (1968) reported that high and low velocity throwers
(high school students ranked from fastest to slowest) experienced no significant chronic
improvements in standard baseball pitching velocity following use of 7-17oz (40-240%
mass increase) baseballs ($p > 0.05$), with no significant changes in pitching accuracy ($p
> 0.05$). Straub (1968) also found that pitching velocity and accuracy were not acutely
significantly altered after warm up throws with either 5oz, 10oz (100% mass increase) or
15oz (200% mass increase) baseballs ($p > 0.05$). Evidently, findings from this early
period of WIT research varied from improvements, regressions and absences of change
in motor skill performance.

In respect of this early research, subsequent empirical investigations into the acute effects
of weighted baseballs on pitching performance have shown that over- and under-weighted
baseball pitching protocols may increase pitching velocity, although pitching accuracy may not be improved (Morimoto, Ito, Kawamura & Muraki, 2003). Studies that have assessed the chronic use of weighted baseball programmes infer improvements in pitching velocity may be obtained (for a review specific to weighted baseball pitching interventions, see Caldwell, Alexander & Ahmad, 2019). However, the potential detrimental effects of chronic weighted baseball utilisation on injury rates and injury risk have been of concern in the literature (Reinold et al., 2018). Consequently, Reinold and Macrina (2021) recommend that careful consideration must be given to the development of individualised weighted baseball pitching programmes to ensure adequate, safe loading to decrease injury risk while supporting velocity improvements.

Research in baseball, golf, cricket, and track and field has revealed differing effects of WIT on immediate motor skill performance with the respective standard implement. However, it has been shown that protocols comprising of the use of weighted cricket balls (Wickington & Linthorne, 2017) and weighted indoor throwing implements (Bellar, Judge, Turk & Judge, 2012; Judge, Bellar & Judge, 2010) may be as effective as, if not more so than, protocols utilising the respective sport’s standard implement when aiming to enhance key performance metrics of the respective motor skill. Conversely, although the use of weighted bats (for reviews, see DeRenne & Szymanski, 2009; Jermyn et al., 2021a) and bats with a dynamic moment of inertia (Castonguay, Roberts & Dover, 2022; Liu, Liu, Kao & Shiang, 2011) may benefit standard bat velocity, it has been reported that the use of weighted bats negatively impacts bat velocity (DeRenne, 1982; DeRenne & Branco, 1986; Higuchi, Nagami, Mizuguchi & Anderson, 2013; Miller, Heishman, Freitas & Bemben, 2020; Montoya, Brown, Coburn & Zinder, 2009; Southard & Groomer, 2003). Further, detrimental effects on temporal accuracy of the swing have also
been reported, thus leading to the suggestion that weighted bats negatively impact competitive performance due to the creation and persistence of temporal accuracy decreases (Nakamoto, Ishii, Ikudome & Ohta, 2012; Ohta, Ishii, Ikudome & Nakamoto, 2014; Scott & Gray, 2010).

Similarly, weighted golf club research has identified an absence of positive acute effects on ball speed and total distance (Bliss, Livingstone & Tallent, 2021), with striking efficiency being negatively impacted (Hébert-Losier & Wardell, 2021), although ball speed and club acceleration may be chronically improved when including weighted club swings in S&C programmes (Alvarez, Sedano, Cuadrado & Redondo, 2012; Redondo, de Benito & Izquierdo, 2020). Contrastingly, weighted tennis racquet research has shown that the addition of 30g to a tennis racquet enhances forehand drive velocity ($p = 0.001$) without negatively impacting accuracy over a sustained period of time compared to regular tennis training (Genevois, Frican, Creveaux, Hautier & Rogowski, 2013). However, it should be noted that participants in this study had 30g of mass added to their own racquet, with the specific mass range of these racquets not stated by the authors. Therefore, the additional 30g of mass represented an $11.2 \pm 3.34\%$ mass increase with respect to the standard tennis racquets that were used in this study.

Although research has investigated the effects of under-weighted implements (i.e., lighter-than-normal sporting implements) on motor skill performance with the respective standard competition implement, the research discussed in this thesis focuses primarily on the use of over-weighted implements. However, the effects of under-weighted implements should be noted, whereby positive effects on standard implement motor skill
performance have been observed following use of under-weighted bats (DeRenne, 1982; DeRenne & Branco, 1986; Miller et al., 2020; Montoya et al., 2009), handballs (Skoufas, Mikhailidis, Bassa et al., 2003; van Muijen, Joris, Kemper & van Ingen Schenau, 1991), and volleyballs (Pellett, Henschel-Pellett & Harrison, 1994). Positive effects of under-weighted track and field implements have also been reported (Dinu, Houel & Louis, 2019; Dinu, Natta, Huiban & Houel, 2014; Emmerzaal, Hoogerbrugge & Janssen, 2017).

Although multiple sports have been the subject of WIT research, various sports, most notably football and its associated playing codes (for example, soccer, rugby union, rugby league), have yet to be the subject of investigations into the effects of weighted footballs on kicking performance metrics, such as ball velocity and kick distance (Reilly & Collins, 2008). Enhancing ball velocity is deemed desirable by the football literature, as enhanced ball velocity is a major contributor to increased kick distance (Sinclair, Fewtrell, Taylor et al., 2014). Only one such investigation has been conducted, whereby Ball (2009) showed that 4-weeks of weighted Australian football training significantly increased kick distance ($p < 0.05$). Remarkably, despite Gaelic football’s inherent requirement of goalkeepers to kick the ball over considerable distances (Figure 1.2), it has yet to receive empirical interest in assessing potential place kicking improvements that may be obtained following the use of weighted Gaelic footballs. Encouraging factors include (i) the size of the playing surface (GAA, 2017), (ii) playing rules, such as the ‘Mark’, which was introduced to encourage longer kick-outs, and (iii) the evidence and prominence of long kick-outs in match-play (kick-outs that land beyond the 45m line, i.e., >32m in respect of the 13m line kick-out location at the time of the study; Mangan et al., 2017).
To contribute to the training potential of this sport’s existing skill, the purpose of this thesis is to investigate the effects of a weighted Gaelic football, the ‘Green Ball’ (Figure 1.3a), on place kick ball velocity and distance of a standard Gaelic football (Figure 1.3b).
The ‘Green Ball’ was not necessarily selected from a range of differently weighted balls, rather this research project originated from an Enterprise Ireland grant that was specifically provided to support research that sought to investigate the effects of the ‘Green Ball’ on markers of maximal effort place-kick performance, namely kick distance. It is important to note, however, that although increasing kick distance is desirable in Gaelic football due to the prominence of long kick-outs in match play, the large playing surface, and playing rules that encourage long kick-outs, the importance of place-kick accuracy as it relates to the performance of kick-outs, and its associated enhancement, should not be overlooked. Nonetheless, as the ‘Green Ball’ was designed and developed with the aim of primarily increasing kick distance and the major contributing variables to kick distance (i.e., ball velocity), the body of research detailed in this thesis exclusively focuses on increasing such measures, although recommendations for future research as it pertains to including place kick accuracy as a dependent variable are included.

To understand the effects that a weighted Gaelic football has on (i) ball velocity and (ii) kick distance, the four studies within this novel thesis were conducted to assess (i) the acute effects of brief weighted Gaelic football place kicking protocols and (ii) the chronic effects of weighted Gaelic football training interventions, on various markers of place kicking performance, such as ball velocity, kick distance, kicking leg kinematic and range of motion behaviours, and participants’ subsequent perceptions of standard football mass and velocity. The findings provide empirical evidence to support or oppose the use of weighted Gaelic footballs in the applied setting when aiming to enhance markers of place kicking performance that may, ultimately, increase kick distance, and by extension, enhance individual and team performance.
1.3. Research Studies, Aims & Hypotheses

The overarching purpose of the research conducted in this thesis is to investigate the effects of place kicking a weighted Gaelic football on ball velocity and distance of a standard Gaelic football place kick. Therefore, this section states the aim(s) and null hypothesis/hypotheses of each of the four experimental studies that were conducted with respect to this overall purpose.

Experimental Study 1 (Chapter 3):

Aim: To investigate whether weighted Gaelic football place kicking alters how a maximal effort place kick with a standard Gaelic football is performed among inter-county and club level male Gaelic football goalkeepers.

- H01: There will be no significant changes in kinematic and range of motion behaviours of the kicking leg following the weighted Gaelic football place kicking intervention.

Experimental Study 2 (Chapter 4):

Aim: To examine the acute effects of a weighted Gaelic football place kicking protocol on standard Gaelic football place kick distance among male university students with Gaelic football playing experience.

- H02: There will be no significant difference in mean standard Gaelic football place kick distance following a weighted Gaelic football place kicking protocol compared to a control condition.
- **H₀3**: There will be no significant transient increase in kick distance across post-test trials following the weighted or standard Gaelic football place kicking protocol.

**Experimental Study 3 (Chapter 5):**

Aim: To investigate the acute effects of selected time intervals post-weighted Gaelic football place kicks on subsequent standard Gaelic football place kicking in order to identify the time period in which the greatest increase in standard football velocity occurs among male university students with Gaelic football playing experience.

Aim: To determine if participants’ subsequent perceptions of standard football mass and velocity post-weighted football warm up protocol, the different time intervals, or the warm up implement used, has the greatest impact on ball velocity.

- **H₀₄**: Following the weighted Gaelic football place kicking protocol, there will be no significant differences in ball velocity across the time points.

- **H₀₅**: There will be no significant difference in the magnitude of influence that the assigned warm up implement, various time intervals, perceptions of football mass, and perceptions of football velocity, have on ball velocity.

**Experimental Study 4 (Chapter 6):**

Aim: To investigate the chronic effects of a weighted Gaelic football place kicking protocol, akin to that utilised in Study 3, on place kicking performance among inter-county Gaelic football goalkeepers.
- H_06: There will be no significant intra-individual changes in ball velocity following the weighted Gaelic football intervention.

1.4. Significance of the Research

There is a dearth of research examining the effects of weighted footballs on markers of place kicking in Gaelic football, particularly ball velocity and kick distance, which are inextricably linked (Sinclair et al., 2014). Therefore, in light of WIT-induced performance improvements that are inferred from existing research in other sports (including Australian football), it is possible that weighted Gaelic football place kicking elicits positive place kicking effects. Due to (i) the absence of research into the effects of weighted Gaelic footballs on place kick performance, (ii) the requirement of Gaelic football goalkeepers to enhance their ability to distribute the ball over considerable distances, (iii) the positive inferences from the findings of existing WIT research that the use of weighted implements may enhance standard implement velocity and distance, (iv) the critical role of long kick-outs in setting up attacks in match play, and (v) the difficulty of generalising WIT programming to other sports and motor skills, research is required to examine the effects of weighted footballs on Gaelic football place kick proficiency.

Due to the absence of such research in the WIT literature, this thesis aims to contribute to the field by adding another sport to the domain where WIT currently has no evidence, despite the fact that the literature suggests it would positively impact performance of the place kick. In addition, this thesis could serve as the preeminent research into the acute and chronic effects of a weighted Gaelic football on multiple markers of Gaelic football place kicking performance. From an applied practice perspective, this research may provide skill acquisition specialists and S&C coaches with empirical support pertaining to the effects of weighted Gaelic football utilisation on place kick ball velocity and
distance. This may subsequently support practitioners in the development of effective warm up protocols that may be used prior to each playing half and/or as part of chronic training programmes aimed at enhancing place kicking performance among those who are required to kick the ball over considerable distances (i.e., goalkeepers performing long kick-outs). This research will also serve as a basis for future research to further investigate the effects of weighted Gaelic footballs on other markers of place kicking performance, such as kick-out accuracy and free-taking, and extend into other codes of football where kick distance is important. It may also serve as a foundation for future research to investigate the underlying mechanisms responsible for the observed acute and chronic effects of using weighted Gaelic footballs.

1.5. Thesis Overview

Chapter 1: Introduction

This chapter briefly discusses the extant WIT literature, with an emphasis placed on the seminal research and subsequent studies that have significantly shaped the domain to date. Previous investigations into the acute and chronic effects of WIT spanning multiple sports are also discussed. Consequently, the rationale for this thesis is presented as a consequence of the dearth of research into the effects of weighted Gaelic football training on place kicking performance. The aims of the current thesis and each individual study are stated, along with the related null hypotheses. Finally, the novelty of the thesis is discussed, as well as the potential impact it may have on future WIT research.
Chapter 2: Literature Review

In line with the stated purpose of this thesis, this chapter begins with a brief introduction to the domain of weighted implement training (WIT). In respect of the WIT modality, which requires athletes to interact with implements of differing mass, typically within a single session or across multiple sessions, the overarching theoretical concepts and underlying mechanisms that have been purported to justify the use of weighted implements and explain the observed performance improvements are discussed. A brief description of acute and chronic effects subsequently follows. This chapter then thoroughly reviews the WIT research from the seminal studies of the early 1960’s through to the latest contributions to the domain in 2022. This is presented in respect of each sport that has been the subject of WIT research, with the acute (i.e., single intervention experimental sessions) and/or chronic (i.e., multiple experimental sessions around a multi-session intervention) effects of weighted implement protocols and training interventions highlighted and interrogated. However, it is important to note that emphasis is placed on research that most directly implicates the motor skill of place kicking, such as studies that concern ‘whip-like’ motor skills that involve direct physical contact with a single implement. Therefore, research that is less relevant to the motor skill of place kicking, such as studies that investigated the effects of physical interaction with a weighted implement that is then used to contact another implement, are not included. Additionally, although a multitude of studies have examined the effects of the use of under-weighted implements on motor skill performance, emphasis is placed on studies that pertain to the use of over-weighted implements, as the research detailed in this thesis concerns the use of an over-weighted Gaelic football. As this review of the literature highlights an absence of research into the effects of WIT in Gaelic football, whereby increases in ball velocity and kick distance are desirable, this chapter culminates with a
review of research that has investigated kick-out distribution in Gaelic football. Due to the prevalence of studies that have investigated the acute effects of weighted implements on subsequent performance with the standard regulation implement, a systematic literature review was conducted and published in the Journal of Strength and Conditioning Research (Jermyn, et al., 2021a; see Appendix A). Thus, the reader is referred to Appendix A in order to review the full scope of literature pertaining to the acute effects of WIT on respective motor skill performance.

Chapter 3: The Impact of a Weighted Gaelic Football Intervention on Kicking Leg Kinematic and Range of Motion Behaviours when Place Kicking a Standard Gaelic Football

This preliminary, exploratory study examined the impact of a weighted Gaelic football training intervention on place kick performance with a standard Gaelic football. Twelve male Gaelic football goalkeepers of varied standard, ranging from inter-county to club level, were randomly assigned to one of three groups: Weighted Football (WF) (n = 4), Standard Football (SF) (n = 4), or Control (CON) (n = 4). The study design consisted of a pre-test, 5-day training intervention, post-test and 3-day retention test. In a motion analysis laboratory, this study analysed kinematic and range of motion behaviours of the kicking leg when performing a maximal effort place kick with the standard Gaelic football prior to, and upon conclusion of, the intervention phase. Mixed between-within ANOVAs were conducted to examine potential changes in kinematic and range of motion behaviours of the kicking leg across the experimental period. As this study was part of a two-study publication in the Journal of Sport Behavior (Jermyn et al., in press a), the reader is referred to Appendix B.
Chapter 4: An Investigation into the Acute Effects of a Weighted Gaelic Football Place Kicking Protocol on Subsequent Place Kick Distance

This chapter presents an original investigation that examined the acute effects of a weighted Gaelic football place kicking protocol on subsequent place kick distance of a standard Gaelic football place kick. Thirty male Sport & Exercise undergraduate university students with extensive Gaelic football experience (i.e., a minimum of ten years playing experience) were randomly assigned a weighted football (WF) (n = 15) or standard football (SF) (n = 15) following a 5-trial baseline test of place kick distance with a standard Gaelic football. With the randomly assigned implement, participants completed a 5-trial place kicking warm up protocol immediately prior to a post-test, the procedure of which was identical to that of the baseline test. An analysis of covariance (ANCOVA) was conducted to investigate differences in the effects of both warm up protocols on mean post-test place kick distance, while controlling for differences in baseline kick distance (i.e., the covariate). A repeated measures ANOVA per group was then conducted to investigate transient changes in kick distance across post-test trials. As this study was part of a two-study publication in the Journal of Sport Behavior (Jermyn et al., in press a), the reader is referred to Appendix B.

Chapter 5: The Acute Effects of a Weighted Football Training Intervention in Gaelic Football to Maximise Place Kick Ball Velocity

This chapter presents a study that investigated the acute effects of selected time intervals between weighted and standard Gaelic football place kicking protocols on ball velocity of a standard Gaelic football place kick. Fifty-two male Sport & Exercise undergraduate university students participated in this study. In a single experimental testing session,
participants completed a baseline test of ball velocity when performing a maximal effort place kick with a standard Gaelic football. Subsequently, participants completed a 15-minute wash out period in which no physical activity was permitted. Participants were then randomly assigned to one of two groups: Weighted Football (WF) (n = 26) or Standard Football (SF) (n = 26). Participants in each group performed a 5-trial place kicking warm up protocol with the respective implement, which was then followed by all participants performing a single place kick with a standard Gaelic football at 2-, 4-, 6- and 8-minutes post-warm up place kicks. Ball velocity was measured with a Bushnell radar velocity gun (Bushnell, Overland Park, Kansas), while participants also rated their perceptions of football mass and velocity for each post-warm up place kick. To examine whether significant differences in ball velocity were induced by the selected time intervals and warm up conditions (weighted or standard football place kicks), a linear mixed model including both groups (WF and SF) and each time point (mean baseline ball velocity, ball velocity at 2-, 4-, 6- and 8-minutes) was conducted. Another linear mixed model, with perception of football mass and perception of football velocity serving as fixed effects and participant as a random effect, was conducted to investigate how much of the variance in ball velocity was explained by the independent variables: time, group, perception of football mass, and perception of football velocity. The implications of the findings as they pertain to (i) the design of weighted football warm up protocols, (ii) the chronic programming of their use (for example, through complex training programmes), and (iii) the underlying mechanisms that potentially underpin the study’s results, are discussed.

As an original research article comprising of this study was recently accepted for publication in the Journal of Australian Strength and Conditioning (Jermyn, O’ Neill, Lacey & Coughlan, in press), the reader is referred to Appendix C. As the data collection phase of this study was interrupted by the COVID-19 pandemic, the reader is referred to
Appendix D, which is a methodological research report that details the process of amending the experimental design in order to facilitate a COVID-19 compliant study and provides recommendations to researchers for the design of laboratory-based sports science studies in light of the pandemic. The paper is published in The Sport Journal (Jermyn, O’ Neill & Coughlan, 2021b).

Chapter 6: The Effects of a Weighted Football Intervention on Ball Velocity of a Standard Football Place Kick among Inter-County Gaelic Football Goalkeepers: A Single-Subject Designed Study

This chapter presents a study that investigated the intra-individual effects of a 4-week, 8-session weighted Gaelic football place kicking intervention on ball velocity of a standard Gaelic football place kick, whereby the intervention-session protocol was directly informed by the findings of Study 3. Six inter-county male Gaelic football goalkeepers participated in this study. Following a baseline test of standard Gaelic football place kick ball velocity, each participant completed an 8-session weighted Gaelic football place kicking intervention across a 4-week period, comprising of a protocol akin to Study 3, i.e., five place kicks with a weighted Gaelic football followed by a single place kick with a standard Gaelic football at 2-, 4-, 6- and 8-minutes post-weighted football place kicks. A mid-test of ball velocity was performed between each participant’s fourth and fifth intervention sessions, with a post-test performed within 7-days of the final intervention session, and a retention-test performed within 7- to 14-days of the post-test. Details pertaining to participants’ S&C programmes in the lead up to, and during, this study are also presented and referred to in the discussion of the observed results. A linear mixed model, with time and participants as fixed effects and number of place kicks per testing
A session as a random effect, was conducted to investigate the intra-individual effects of the weighted Gaelic football intervention on ball velocity of standard Gaelic football place kicks. As an original research article comprising of this study was recently accepted for publication in Sports (Jermyn, O’Neill, Lacey & Coughlan, 2022), the reader is referred to Appendix E.

Chapter 7: Conclusions, Practical Applications & Recommendations for Future Research

This chapter comprises a detailed conclusion of the research conducted in this thesis and encompasses each study’s related aims, hypotheses and findings. The implications that the current thesis has on WIT research are also discussed. The practical applications of weighted footballs as a warm up and training tool are suggested for practitioners across football codes whereby enhanced ball velocity and kick distance are desirable. The limitations of the research in this thesis are also thoroughly discussed in this chapter. Finally, recommendations for future research into weighted implement training in Gaelic football and other domains are presented.
Chapter 2

Literature Review
2.1. Weighted Implement Training: An Introduction

Weighted implement training (WIT) involves the performance of sport-specific motor skills with heavier-than-normal sporting implements, whereby full range of motion (ROM) and similar kinematic characteristics of the respective motor skill are maintained concurrent to minimal changes in the force-velocity profile of the movement as a result of the overload applied (DeRenne et al., 1994, 1995; Jermyn et al., in press a). WIT is employed in practice and pre-competition settings as a means of enhancing sport-specific motor skill performance (DeRenne & Szymanski, 2009). As WIT maintains high biomechanical specificity between the weighted movement and the original movement, it has been categorised as a form of specific resistance training, in which the principle of force overload (or in some instances speed overload; i.e., the use of under-weighted implements) can be applied to the respective sport-specific motor skill while maintaining high representation of the fundamental action (for WIT reviews, see Caldwell et al., 2019; DeRenne & Szymanski, 2009; Escamilla, Speer, Fleisig, Barrentine & Andrews, 2000; Jermyn et al., 2021a; Szymanski, 2012; Szymanski, DeRenne & Spaniol, 2009).

2.1.1. Theoretical Backgrounds and Underlying Mechanisms

While the exact underlying mechanisms responsible for the acute effects of WIT on motor skill performance are unknown, research and theoretical frameworks from the physiology and motor learning and control domains attempt to do so (Prieske, Behrens, Chaabene, Granacher & Maffiuletti, 2020; Gibson, 1979). However, as the mechanisms responsible for chronic motor skill improvements following WIT programmes remain unknown, more diverse conclusions have been put forward, such as increased motor unit recruitment (Sale, 1988), firing frequency, and inter- and intra-muscular coordination (Cormie,
McGuigan & Newton, 2011), which may explain the observed motor skill improvements following chronic use of weighted implements.

Post-activation potentiation (PAP) and post-activation performance enhancement (PAPE)

As highlighted by Cuenca-Fernández, Smith, Jordan et al. (2017) and Sale (2004), there has been a substantial and consistent interest among those in the sporting domain in determining and identifying the warm up effects of high force, high intensity contractions on immediate, subsequent performance. As a result of the varied neuromuscular responses that have been observed immediately following a prior conditioning or warm up activity, and the different means of assessing and recording such responses, various phenomena and frameworks have been proposed to represent and explain enhanced neuromuscular performance immediately following a weighted implement protocol. Post-activation potentiation (PAP) has been routinely purported to explain observations of increased motor skill performance as a result of prior conditioning contractions (Sale, 2004). PAP is a distinct physiological phenomenon with a short window of action, generally a half-life of 28s, whereby enhanced contractile responses are observed immediately following a prior conditioning activity (Blazevich & Babault, 2019). In addition to PAP, a similar and somewhat interrelated phenomenon, referred to as post-activation performance enhancement (PAPE), has also been put forth to explain the observed performance effects of brief contractions. PAPE refers to the observed effect of a high-intensity conditioning protocol (dynamic or isometric contractions) resulting in acute neuromuscular improvements (Cuenca-Fernández et al., 2017).
Although PAP and PAPE represent and explain observed effects of enhanced contractile performance following prior conditioning contractions, the two terms have traditionally, and incorrectly, been used interchangeably, with PAP routinely being used to refer to observations of enhanced neuromuscular performance following a prior conditioning activity which would be more accurately categorised as a PAPE effect. Specifically, PAP involves the assessment of twitch torque responses to a prior conditioning contraction(s) via a controlled means of activation, such as electrical stimulation (MacIntosh, Robillard & Tomaras, 2012). A large initial enhancement of twitch torque, between 4% and 188% relative to pre-conditioning measures, is observed immediately following the conditioning contraction, which subsequently dissipates rapidly (Blazevich & Babault, 2018; Cuenca-Fernández et al., 2017; Prieske et al., 2020). PAP can be largely attributed to myosin light chain phosphorylation within type II muscle fibres that renders the actin-myosin complex more sensitive to calcium which then leads to an increase in cross-bridge formations rates and increased rates of muscular force development (Blazevich & Babault, 2019). While the PAP response is classified as a relatively immediate increase in twitch torque following a prior conditioning contraction(s) which is verified via controlled activation methods, PAPE is the correct framework to reference when measuring post-warm up performance via assessment of voluntary neuromuscular performance (i.e., without means of controlled activation), such as the use of weighted implements to enhance performance with the standard implement. Further, in comparison to the PAP response, observation of voluntary neuromuscular performance following a prior conditioning contraction typically illustrates a somewhat contrasting effect, whereby an initial decline in performance occurs immediately following the conditioning contraction, which is then followed by a subsequent and gradual increase in performance as time progresses post-conditioning contraction(s) (Prieske et al., 2020). Specifically,
the PAPE effect typically illustrates a 1-13% performance improvement compared to preconditioning measures, whereby the largest subsequent effect is observed ≥7-minutes post-conditioning contraction (Prieske et al., 2020). Elicited neuromuscular responses to the conditioning contractions, such as increases in muscle temperature, muscle and muscle fibre water content, and/or muscle activation, are suggested underlying factors responsible for PAPE (Blazevich & Babault, 2019). Therefore, because of (i) differing verification means (measurement of contractile performance via controlled versus voluntary means), (ii) typically opposing post-conditioning performance contraction profiles, and (iii) disparate mechanisms that are postulated to underpin the observed effect, the importance of delineating these phenomena in research and applied practice is imperative (Cuenca-Fernández et al., 2017).

In line with the collective body of PAP and PAPE literature, PAP has also been inaccurately used in the WIT literature (see Bellar et al., 2012; Judge, Bellar, Craig et al., 2016; Judge et al., 2010; Kim & Hinrichs, 2008; Reyes & Dolny, 2009). Specifically, these studies attribute immediate improvements in voluntary neuromuscular performance following a preceding WIT activity to PAP, without measurement of twitch responses via controlled methods of activation, such as electrical stimulation (MacIntosh et al., 2012). However, the PAPE framework has been accurately used by more recent WIT studies to serve as a means of justifying and/or explaining the observed effects as no direct assessments of twitch responses via controlled activation means were utilised (Bliss et al., 2021; Hébert-Losier & Wardell, 2021). While it is imperative to delineate PAP and PAPE, it is, however, suggested that it cannot be confirmed that any observed PAPE effect is not underpinned by, or interacting with, a PAP effect as both enhancement effects have been observed concurrently (Mitchell & Sale, 2011); although such concurrent
observations have been deemed inconsistent (Prieske et al., 2020). Nonetheless, as examination of the effects of weighted implement use on subsequent performance with the standard implement entails observations of voluntary neuromuscular performance, it is imperative that the PAPE framework, as opposed to PAP (unless directly measured via controlled activation), is referred to when explaining observed effects on performance.

Ecological Dynamics and Affordance Theory

The ecological dynamics theoretical framework of skill acquisition is a theory that integrates principles of ecological psychology, dynamical systems theory, and complexity and evolutionary science, in order to explain emergent movement coordination patterns and tendencies and, ultimately, skilled behaviour (Davids, Araújo, Vilar, Renshaw & Pinder, 2013; Woods, McKeown, Rothwell, Araújo, Robertson & Davids, 2020). Specifically, the ecological dynamics theory proposes that, in respect of Newell’s (1986) constraints classification, skilled behaviour emerges, or self-organises, as a result of the interaction between individual, task and environmental constraints, with significant consideration given to the interplay between individual constraints (for example, the performer or athlete’s own physical and physiological characteristics) and the affordances present in the environment on a moment-to-moment basis (Button, Seifert, Chow, Araújo & Davids, 2021). The term affordances, first proposed by Gibson (1979), specifically refers to opportunities or invitations for action in a particular environment, and has foundations in Gibson’s theory of direct perception (Gibson, 1979). It is proposed that detection of specifying information variables underpins the regulation of action, and the perception and realisation of affordances underpins functional and skilful behaviour in performance environments (Gibson, 1979; Woods et al., 2020). However, as ecological dynamics proposes that the athlete-environment relationship is the appropriate scale of
analysis as it pertains to emergent, coordinated behaviours, it is important to note that the perception of affordances in the competitive sporting environment is also regulated by exposure to representative learning opportunities that have been provided to the learner or performer in order to detect, and attune to, information variables that specify relevant properties of the respective affordance (Woods et al., 2020).

While it is bestowed upon the practitioner to enhance learners’ and athletes’ abilities to detect affordances that ultimately aid success in the performance environment, it is proposed that the detection of, and the ability to act upon, affordances is regulated by the performer’s individual constraints (Araújo, Dicks and Davids, 2019). While empirical research spanning the past four decades that has shown that the perception of, and enactment upon, affordances is dependent on body-scaled properties (i.e., the relation between some measurable dimension of the performer’s body in relation to a reciprocal property of the environment determines whether an action is possible (Fajen, Riley & Turvey, 2008), affordances present in the performer’s environment can also be defined by the performer’s own action capabilities (i.e., how the performer can behave relative to the environment (Fajen, Riley & Turvey, 2008)) (Fajen, 2005). For example, research has shown that perceiving an elevated surface as ‘climbable’ is regulated by the ratio between the climber’s own leg length and the height of the stair or step, where a ratio of greater than 0.88 would result in the elevated surface or stair being perceived as ‘unclimbable’ (i.e., body-scaled property) (Warren, 1984). However, it has also been shown that performers take the limits of their capabilities into account when guiding their movements on the basis of visual information, as Fajen (2005) showed that, in a deceleration task (joystick serving as a brake), participants perceived the required rate of deceleration in intrinsic units relative to their braking capabilities. It has also been shown that the
affordance of catching a projected ball is regulated by performer’s locomotor skills and capacities (Oudejans, Michaels, Bakker & Dolné, 1996). Therefore, as the WIT literature suggests that acute and chronic increases in standard implement velocity and distance can be obtained following weighted implement warm ups and chronic training programmes, it is suggested that potential increases in ball velocity and kick distance of standard football place kicks following use of the weighted football used in this thesis (i.e., the ‘Green Ball’) may result in the emergence of further affordances downfield when performing a kick-out which are regulated by the aforementioned action capacity alterations.

2.1.2. Acute Effects of WIT

Although the exact time-course that classifies an effect as ‘acute’ is not specifically defined, the sports and health sciences literature define acute exercise and corresponding effects as those that are elicited from a single bout of exercise (Sellami, Gasmi, Denham et al., 2018). Therefore, investigations into the acute effects of weighted implements on motor skill performance concern the relatively immediate effect of weighted implement ‘warm up’ or ‘conditioning’ protocols on subsequent standard implement motor skill performance within the same testing session. Although studies that compare motor skill performance with implements of differing mass typically do not include a subsequent analysis of performance with the standard implement, these investigations are, in the context of this thesis, categorised as studies concerned with the acute effects of WIT.

2.1.3. Chronic Effects of WIT

The sports and health sciences literature define chronic exercise and corresponding effects as those that are elicited from repeated bouts of exercise during a short or long-
term period (Sellami et al., 2018). Investigations into the chronic effects of weighted implements on motor skill performance concern the effect of a multiple session, multiple week WIT programme on subsequent performance of the same motor skill with the standard, regulation implement. Tests of motor skill performance are conducted prior to, and upon conclusion of, a training intervention.

2.2. The Effects of WIT on Sports Performance

The acute and chronic effects of WIT have been examined across a variety of sports, with the greatest prevalence in baseball, cricket, and track and field throwing events. While the predominant empirical interest in WIT concerns these sports, there has been research into the effects of WIT in other sports, such as softball and handball. Further, research has been conducted to examine the effects of WIT on the motor skill of kicking, whereby Ball (2009) reported positive effects of weighted Australian football use on markers of kicking performance following a chronic weighted football training intervention.

2.2.1. Baseball

*Acute effects of weighted baseballs*

Enhancing pitching velocity is deemed desirable in baseball to give batters less time to decide what to do when facing a pitcher (DeRenne & Szymanski, 2009; Escamilla et al., 2000). Therefore, multiple studies have examined the acute effects of a plethora of under- and/or over-weighted baseballs, ranging from 3.5oz (30% mass decrease) to 15oz (200% mass increase), on subsequent pitching velocity with a regulation 5oz baseball, with varied effects being observed (for a review, see DeRenne & Szymanski, 2009). In addition, assessments of the impact of weighted baseball use on throwing accuracy with
a regulation ball have been conducted, whereby improvements in throwing accuracy are deemed beneficial for pitchers, as well as outfielders, who both attempt to throw the ball to a specific location that increases the chances of obtaining an ‘out’ (Escamilla et al., 2000). In contrast to the ambiguity of the effects of weighted baseball use on subsequent pitching velocity, it has routinely been reported that weighted baseball pitching does not significantly alter pitching accuracy. In addition to assessing pitching velocity and accuracy effects, two studies have also assessed the effects of under- and over-weighted baseball warm up protocols on kinetics when pitching the different weighted balls and a regulation baseball (Choi & Shin, 2020; Shin & Choi, 2018).

Of the studies that have examined the acute effects of weighted baseballs on pitching velocity with the 5oz regulation baseball, two studies reported a significant increase in university pitchers’ subsequent pitching velocity with the 5oz baseball following pitches with 4.5oz (10% mass decrease – Morimoto et al., 2003) and 11oz (120% mass increase – Van Huss et al., 1962) baseballs. However, absences of significant pitching velocity changes have also been reported, whereby Shin and Choi (2018) showed that the use of 4oz (20% mass decrease) and 8oz (60% mass increase) baseballs did not induce significantly different pitching velocities compared to a standard implement condition among high school and university pitchers \( (p > 0.05) \). Straub (1968) found a similar effect, whereby warm up pitches with 10oz (100% mass increase) and 15oz (200% mass increase) baseballs did not significantly enhance velocity among high school students \( (p > 0.05) \). It is these differences in pitching velocity effects as a result of the use of weighted baseballs that leads to the ongoing ambiguity as it pertains to the efficacy of weighted baseball warm ups. However, methodological differences between the various studies should be considered as it relates to the creation of this ambiguity. For example,
substantial differences exist in relation to the participant samples across these studies, whereby eight male university students were in the study of Morimoto et al. (2003) compared to 60 male high school students in the study of Straub (1968). The number of warm up trials with the respective weighted implement also varied substantially, with ten pitches performed in the study of Shin and Choi (2018) compared to 25 pitches in the study of Van Huss et al. (1962). Finally, the time between weighted baseball pitches and subsequent pitches with the standard baseball also varied, with minimal time being implemented in the study of Morimoto et al. (2003) compared to 10-minutes of rest in the study of Shin and Choi (2018). In contrast to the uncertainty concerning the effects of weighted baseball pitching on subsequent velocity, Van Huss et al. (1962), Straub (1968) and Morimoto et al. (2003) have all reported absences of significant changes in pitching accuracy following use of the weighted baseballs that were used in each respective study. That is, the use of 4.5-15oz (10% mass decrease-200% mass increase) baseballs does not appear to induce significant detrimental effects on immediate pitching accuracy with the regulation baseball. Finally, with respect to kinetics, Shin and Choi (2018) concluded that, as a result of most upper extremity muscles displaying no significant differences in muscle activity following pitches with 4oz (20% mass decrease), regulation 5oz or 8oz (60% mass increase) baseballs ($p > 0.05$), the mass of a weighted baseball selected for use in warm up protocols may be selected based on a pitcher’s individual strength levels and preference. However, in a follow-on study with college pitchers whereby muscle activation during the pitching test was measured using a wireless TELEMyo™ 2400 EMG device (Noraxon, Scottsdale, Arizona, USA), Choi and Shin (2020) concluded that 8-10oz (60-100% mass increase) baseballs may be optimal to increase pitching velocity and strength of the rotator cuff and elbow muscles, while concurrently decreasing the risk of injury. This conclusion was based on the observation that, in comparison to pitching at
maximal effort with the standard 5oz baseball, 11oz and 12oz heavily weighted baseballs (120-140% mass increase) induced significantly greater amounts of muscle activity in the rotator cuff (for example, teres minor, supraspinatus and infraspinatus) and elbow muscles (for example, biceps brachii, triceps brachii, flexor carpi radialis and extensor carpi radialis) across various phases of the pitching action, with 6oz and 7oz baseballs inducing lower muscle activity levels compared to maximal effort pitches with the standard 5oz baseball.

Although immediate post-weighted baseball pitching warm up tests were not conducted in a multitude of weighted baseball studies, investigations into the acute effects of weighted baseballs have compared pitching performance among their respective cohorts with baseballs of differing mass in a within-subjects crossover design (Fleisig, Diffendaffer, Aune, Ivey & Laughlin, 2017; Fleisig, Phillips, Shatley, et al., 2006; O’Connell, Lindley, Scheffey, Caravan, Marsh & Brady, 2021; Okoroha, Meldau, Jildeh et al., 2021; Reinold, Macrina, Fleisig, Drogosz & Andrews, 2020). The findings of these studies provide skill acquisition specialists, S&C coaches and athletes with important information pertaining to the potential performance and injury effects that may result from the use of weighted baseballs. Fleisig et al. (2006) and Okoroha et al. (2021), who exclusively assessed the use of under-weighted baseballs on youth pitchers’ performance, observed positive effects on pitching performance. However, the majority of within-subjects crossover design studies include a range of weighted baseballs to include over-weighted baseballs. While Reinold et al. (2020) found that under-weighted warm ups with 2oz (60% mass decrease) and 4oz (20% mass decrease) baseballs resulted in no significant changes ($p > 0.05$), they reported that the over-weighted (6oz, 20% mass increase, and 9oz, 80% mass increase) and extremely over-weighted (16oz, 220% mass increase)
increase, and 32oz, 540% mass increase) warm ups resulted in significant increases of 3.3° ($p = 0.05$) and 8.4° ($p < 0.001$) in shoulder external rotation ROM, respectively, among high school pitchers. Shoulder external rotation ROM has been shown to correlate with pitching velocity, whereby maintaining an externally rotated shoulder angle of approximately 90° at delivery is postulated to maximise ball speed (Matsuo, Matsumoto, Mochizuki, Takada & Saito, 2002), but it also correlates with increased stress on the pitching arm (Camp, Tubbs, Fleisig, et al., 2017). Therefore, Reinold et al. (2020) concluded that over-weighted baseballs should be used with caution and ROM should be consistently monitored. Furthermore, the extremely over-weighted warm ups resulted in 58% of participants experiencing at least 10° external rotation increases, with some experiencing 15-18° increases. However, various studies have displayed contrasting results pertaining to weighted baseballs within the range of 3-7oz (40% mass decrease-40% mass increase), whereby altering mass within this range did not negatively affect elbow and shoulder torques and maximum shoulder external rotation position, with minimal differences in body position observed (Fleisig et al., 2017; O’Connell et al., 2021). In line with the studies that investigated the acute effects of weighted baseball pitching on subsequent pitching performance with the standard baseball, it is suggested that the differences in observed results between these studies may be the result of differences in the participant sample. For example, the participant sample in the study of Reinold et al. (2020) comprised of 16 male high school students between the ages of 15- to 18-years, whereas the participant sample in the study of O’Connell et al. (2021) comprised of 26 male collegiate and professional players. Similarly, Reinold et al. (2020) measured range of motion values manually with a goniometer, whereas O’Connell et al. (2021) used a multi-camera motion capture system (NaturalPoint/Optitrack, Corvallis, OR, USA).
Chronic effects of weighted baseballs

Since the seminal studies of the 1960’s (for example, Brose & Hanson, 1967), a multitude of empirical investigations have demonstrated that weighted baseball training programmes, typically 6- to 10-weeks in duration, induce increases in pitching velocity among various cohorts. For example, although Straub (1968) found that a 6-week weighted baseball programme, comprising of pitches with baseballs of incrementally greater mass across the intervention period (7oz, 40% mass increase to 17oz, 240% mass increase), did not significantly enhance pitching velocity among a high school cohort (14-19 years) \( (p > 0.05) \), several studies conducted by DeRenne and colleagues (DeRenne et al., 1994; DeRenne, Ho & Blitzblau, 1990; DeRenne, Tracy & Dunn-Rankin, 1985; DeRenne & House, 1993), and others (Brose & Hanson, 1967), report contrasting results. These studies have illustrated that 6- to 10-week weighted baseball pitching programmes, using baseballs between 4-10oz (20% mass decrease to 100% mass increase), result in significant increases in standard pitching velocity among high school and collegiate cohorts \( (p < 0.05) \), particularly when additional strength training and pitching practice is prohibited (DeRenne et al., 1990; DeRenne et al., 1994). However, although these studies show weighted baseballs may increase pitching velocity, pitching accuracy is unlikely to increase, or at least, be significantly altered (Brose & Hanson, 1967; Straub, 1968).

While WIT may benefit pitching performance in the form of increased pitching velocity, the efficacy of pitching weighted baseballs, and their contribution to overall baseball success, becomes more ambiguous when potential effects on injury risk and injury rates are considered. For example, Reinold et al. (2018) found that youth pitchers (12-18 years) who trained with 2oz (60% mass decrease) to 32oz (540% mass increase) baseballs across a 6-week intervention experienced a significant increase in pitching velocity of 1m/s.
(3.3%) \((p < 0.001)\), but there was a 24% injury rate among those who were assigned to the weighted baseball group, which represented injury to four participants, each of which required medical attention. The authors postulate that the significant increase \((p = 0.01)\) in shoulder external rotation ROM of 4.3° was a likely primary contributor to this injury rate. Contrasting findings with a collegiate and professional cohort are reported by Marsh, Wagshol, Boddy et al. (2018) as the implementation of a more expansive weighted baseball range (3.5oz, 30% mass decrease to 70.5oz, 1,310% mass increase) in individualised 6-week programmes resulted in an absence of significant increases in pitching velocity among the whole sample \((p > 0.05)\). However, even when the participant sample was split based on those who experienced insignificant increases in pitching velocity \((n = 9)\), it was found that there were no significant increases in shoulder external rotation ROM \((p = 0.65)\). Furthermore, the whole sample, and the velocity increase and decrease subgroups, did not experience significant increases in elbow varus torque \((p > 0.05)\). It was also revealed that the whole sample \((p = 0.006)\), and subgroups \((p > 0.05)\), experienced increases in shoulder internal rotation ROM, which the authors deem as advantageous to pitching performance and pitcher health. Ultimately, when comparing those who increased pitching velocity versus those who did not, there was predominantly an absence of significant detrimental changes in dominant arm joint kinetics and shoulder ROM measures \((p > 0.05)\). The findings of these two studies suggest that significant increases in pitching velocity may not just be accompanied by significant increases in shoulder external rotation ROM but may indeed be the result of such increases in external rotation (Reinold et al., 2018). However, as per the previously discussed weighted baseball studies, methodological differences between the studies of Reinold et al. (2018) and Marsh et al. (2018) may explain the contrasting findings. For example, differences exist particularly in relation to the included participant samples, whereby youth pitchers
were used in the study of Reinold et al. (2018) compared to collegiate and professional players in the study of Marsh et al. (2018). Furthermore, there were differences in the type of intervention used, whereby a non-individualised yet conservative weighted baseball programme was implemented in the study of Reinold et al. (2018) compared to an individualised but less conservative weighted baseball programme in the study of Marsh et al. (2018). Collectively, the inconsistent effects of weighted baseball use in these studies leads to the ongoing uncertainty surrounding the efficacy of the long-term use of weighted baseballs as, although weighted baseballs up to 32oz may significantly increase standard baseball pitching velocity, such increases may be the result of undesirable significant increases in shoulder external rotation ROM (Reinold et al., 2018). Therefore, per the recommendations of Reinold and Macrina (2021), it is suggested that weighted baseballs be programmed on an individual basis with careful consideration given to loading schemes, athlete monitoring, and the time of the season in which they are implemented (i.e., off-season, pre-season, and in-season phases).

2.2.2. Cricket

**Acute effects of weighted cricket balls**

Like baseball pitching and other sport-specific throwing skills, enhancing bowling velocity gives the batter less to time to obtain information from ball flight, potentially negatively impacting upon decision making, thus diminishing opponents’ performances (Maker & Taliep, 2021). Similarly, enhancing accuracy of delivery means bowlers can precisely deliver the ball to locations that may increase the likelihood of dismissal based on the batter’s technical faults (Feros, Young & O’Brien, 2020). Therefore, as both variables are integral to bowling performance, multiple studies have investigated the
acute effects of weighted cricket ball use on bowling performance. Similar to the baseball research, the collective findings of these investigations have resulted in ambiguity as it pertains to the efficacy of weighted cricket ball use. For example, Feros, Young and O’Brien (2013) found that an over-weighted cricket ball warm up with 250g (60.3% mass increase) and 300g (92.3% mass increase) balls resulted in no significant changes to bowling velocity ($p > 0.05$), but resulted in a significant decrement in bowling accuracy ($p = 0.049$) among sub-elite bowlers. Similar results were subsequently reported by Feros, Hinck and Dwyer (2021), whereby sub-elite bowlers experienced no significant effects of different weighted ball warm up conditions (standard 156g; 140.4g under-weighted, 10% mass decrease; 171.6g over-weighted, 10% mass increase) on bowling speed ($p = 0.174$) and accuracy ($p = 0.334$) of the standard ball. As the number of negative responders to the over-weighted warm up was greater than the other conditions, the authors suggest that participants were unable to overcome the level of fatigue induced by the over-weighted ball in the 3-minute window between weighted and standard ball trials. To potentially explain the observations of the two aforementioned studies, Feros, Young and O’Brien (2017) showed that, among sub-elite bowlers, a resistance training programme can result in a large improvement in the number of potentiated deliveries (i.e., a delivery that meets or exceeds the smallest worthwhile change of mean ball speed in match-intensity deliveries (2.2 km/h), or peak ball speed in maximal-effort deliveries (3.2 km/h)), with mean and peak bowling speeds also being largely improved. Interestingly, the participants in the studies of Feros et al. (2013) and Feros et al. (2021) had no resistance training and/or WIT experience. Therefore, in respect of the findings of Feros, Young and O’Brien (2017), it is possible that greater acute improvements in bowling performance may have been observed by Feros et al. (2013) and Feros et al. (2021) had the participants in both studies had greater resistance training experience. Although a
follow-on assessment of performance with the standard ball was not conducted, Wickington and Linthorne (2017) found that elite bowlers’ accuracy, as well as mechanics, were not adversely affected when bowling 156g (standard mass), 71g (54.5% mass decrease), 113g (27.6% mass decrease), 142g (9.0% mass decrease), 198g (26.9% mass increase) and 213g (36.5% mass increase) balls; therefore, consolidating the findings of Feros et al. (2021) and contrasting those of Feros et al. (2013). However, it is suggested that the reader carefully interprets the results of the study of Wickington and Linthorne (2017) due to the absence of analysis of subsequent pitching performance with the standard cricket ball which differs to that of the two aforementioned studies. Nonetheless, these contrasting results lead to the aforementioned ambiguity as it pertains to the efficacy of weighted cricket ball use, although it can be concluded that balls weighing ≤213g do not negatively impact accuracy (Wickington & Linthorne, 2017), whereas balls weighing ≥250g may negatively impact accuracy (Feros et al., 2013).

**Chronic effects of weighted cricket balls**

Research into the effects of weighted cricket ball training programmes on bowling performance has revealed conflicting reports as to whether integral performance markers, such as bowling speed and accuracy, are enhanced or degraded. Following the implementation of a 10-week weighted cricket ball programme (131g, 16% mass decrease-181g, 16% mass increase), Petersen, Wilson and Hopkins (2004) found that although sub-elite bowlers experienced a 4.0 ± 1.8km/h increase in bowling speed, it was not deemed worthwhile as the authors determined, in consultation with elite coaches, that a 5km/h improvement was required to justify the programme’s use in the applied setting as a 5km/h change was deemed to be the minimum practically important improvement. Furthermore, the authors stated that participants experienced negative effects on bowling
accuracy. Similarly, in a study that investigated the effects of an 8-week intervention comprising of over-weighted cricket balls (250g, 60.3% mass increase and 300g, 92.3% mass increase) on bowling performance, Feros et al. (2020) found that the weighted ball group experienced a ‘clear large’ significant decrease in markers of bowling accuracy ($p < 0.05$). Concurrent to these detrimental accuracy effects, the sub-elite bowlers who took part in this study experienced an, albeit insignificant ($p > 0.05$), ‘clear moderate’ change in peak bowling speed, therefore leading the authors to suggest that the use of weighted baseballs induces a speed-accuracy trade-off. Thus, the authors do not recommend heavy ball bowling for sub-elite bowlers.

Although the aforementioned studies do not report improvements in bowling accuracy, Wickington and Linthorne (2017) found that, through individual analysis, an 8-week intervention with balls weighing 71-213g (54.5 mass decrease-36.5% mass increase, respectively, compared to the 156g standard ball), resulted in one participant experiencing an ‘almost certainly beneficial’ effect on accuracy and another experiencing a ‘probably beneficial’ effect. Accuracy was measured with a target that consisted of three overlaying rectangles placed 0.5m beyond the stumps, whereby contacting a particular rectangle resulted in a score of 3, 2, or 1, with balls outside the largest rectangle receiving a score of 0. As stated by the authors, for the individual analysis, the mean value at both pre-test and post-test and the difference between the two test sessions was calculated for each variable. The magnitude of this difference was interpreted as ‘beneficial’, ‘trivial’, or ‘detrimental’ using the likely limits method for assessing a change in a performance test by an individual. The effect on the group’s other three participants was deemed ‘unclear’, but group analysis revealed an ‘almost certainly beneficial’ significant effect ($p < 0.01$) of the intervention on bowling accuracy. Although the elite bowlers who participated in
this study experienced only ‘possibly trivial’ significant increases in bowling speed of 1.0 m/s ($p = 0.07$; note: statistical significance was set at $p = 0.10$), individual analysis revealed two of the five participants in the experimental group experienced a ‘probably beneficial’ improvement in bowling speed. As this study displayed no differences in measures of bowling technique following completion of the intervention, concurrent to the absence of detrimental effects on bowling accuracy, the authors propose that use of these weighted balls may induce meaningful improvements in bowling accuracy, with some bowlers likely to experience meaningful increases in bowling speed. Interestingly, Maker and Taliep (2021) conducted a shorter combined resistance training intervention of 4-weeks with weighted cricket balls of less deviation from the standard 156g ball (133g, 14.7% mass decrease – 179g, 14.7% mass increase) compared to the aforementioned studies and found that sub-elite bowlers experienced a significant increase in bowling speed of 5.1 km/h (6%) ($p < 0.001$, effect size = 0.65). As the group experienced no significant changes in upper or lower body power that were used to assess the effects of general and special resistance training exercises ($p > 0.05$), it was concluded that the weighted balls resulted in the improved bowling performance. Although the findings of these four studies infer positive chronic bowling velocity effects following completion of weighted cricket ball interventions comprising of 71-300g weighted balls, the inconsistent effects on bowling accuracy lead to the ambiguity pertaining to the efficacy of weighted cricket ball use. Therefore, in line with the weighted baseball literature, it is likely that weighted cricket balls should be programmed on an individual basis in order to obtain performance improvements concurrent to an absence of detrimental effects. However, as per the previous sections, it is important to note the potential impact that methodological differences between the discussed studies had on the varied accuracy effects detailed. For example, although physical targets were used to
score bowling accuracy performance in the studies of Petersen et al. (2004) and Wickington and Linthorne (2017), a complex statistical approach was conducted in the study of Petersen et al. (2004) in order to control for potential confounding effects of bowling accuracy at baseline test, whereas a substantially different statistical approach was utilised in the study of Wickington and Linthorne (2017). Similarly, the accuracy target used in the study of Petersen et al. (2004) measured 4m x 2m x 5m, whereas the target used by Wickington and Linthorne measured 1.4m x 1m. Due to these methodological differences, it is suggested that the findings of these studies are interpreted with caution.

2.2.3. Olympic Handball

Acute effects of weighted handballs

In line with the related research in other sports, enhancing throwing velocity in handball gives defenders and goalkeepers less time to save a shot on goal (van Muijen, Joris, Kemper & van Ingen Schenau, 1991). Although there are no published studies that have investigated the acute effects of weighted handballs on immediate throwing performance with the standard handball, van den Tillaar and Ettema (2004) found that when experienced male handball throwers threw weighted balls of increasing mass (206g, 305g, 409g, 503g, 616g, 706g and 818g), there were significant increases in total throwing time \((p = 0.017)\) and significant decreases in ball velocity \((p = 0.001)\). Group and individual analyses revealed significant negative linear relationships between ball velocity and ball mass (group: \(r = 0.83, p < 0.001\); individual: \(r \geq 0.98, p < 0.001\)), and ball velocity and applied force (group: \((r = 0.64, p < 0.001; \text{individual: } r \geq 0.87, p < 0.012)\). It was also revealed that joint velocities of the arm significantly decreased as mass increased \((p < 0.05)\), with timing of the initiation of internal rotation and elbow extension occurring
significantly earlier as ball mass increased \((p < 0.05)\). The authors did, however, find that internal rotation of the shoulder and elbow extension account for 67% of ball release velocity, which has ultimately served to rationalise the use of weighted balls across a plethora of overarm throwing sports whereby increases in these variables have subsequently been observed post-weighted ball use (for example, see Marsh et al., 2018). Interestingly, a follow-on study by the same authors (van den Tillaar & Ettema, 2011) revealed that throwing 288g under-weighted (20% mass decrease), 360g standard, and 432g over-weighted (20% mass increase) balls resulted in significantly different throwing velocities between all balls among experienced female handball players \((p < 0.05)\), substantiating the findings of baseball and cricket studies. Furthermore, maximal velocity of elbow extension and internal rotation of the shoulder decreased significantly when throwing with the heavier ball compared to throwing the other two balls \((p < 0.05)\). As the findings of van den Tillaar and Ettema (2004) highlighted the importance of these variables to pitching velocity, these decreases in maximal velocity of elbow extension and internal rotation of the shoulder lead to uncertainty as it pertains to the use of over-weighted handballs. However, as Marsh et al. (2018) found that internal rotation velocity benefited from the use of over-weighted baseballs across an 8-week intervention, it is possible that the chronic use of over-weighted handballs would lead to increased internal rotation velocity when throwing the regulation handball, particularly as the overhand throw and baseball pitch are biomechanically similar actions.

**Chronic effects of weighted handballs**

While research into the chronic effects of weighted baseball and cricket ball use infers potential performance improvements as it relates to throwing velocity, research into the chronic effects of weighted handballs on subsequent throwing velocity illustrates
ineffective results. Van Muijen et al. (1991) and Skoufas et al. (2003) found that the use of over-weighted handballs (500g ball; 25% mass increase) and/or standard handballs (400-425g) did not significantly increase throwing velocity following 8- and 20-week interventions, respectively. However, it should be noted that Van Muijen et al. (1991) and Skoufas et al. (2003) found that training with under-weighted balls (20-25% mass decrease) resulted in significant throwing velocity increases among elite female handball players and inexperienced physical education students ($p < 0.05$), respectively. As these two studies are the only investigations into the chronic use of weighted handballs on throwing performance, further research is required in order to obtain a more comprehensive understanding of the effects of weighted handballs on throwing performance.

2.2.4. Track & Field

*Acute effects of track and field implements*

While WIT research in the aforementioned sports requires future research due to the ambiguity and inconsistency of empirical findings, investigations into the effects of weighted track and field implements consistently report positive effects on subsequent throwing performance (i.e., throw distance) with the standard implement. In an investigation into the acute effects of a 1kg over-weighted shot-put on the overhead back throw (a shot put training exercise) among NCAA Division-1 athletes, Judge et al. (2016) found the over-weighted implement resulted in significantly greater mean throw distance compared to the under-weighted ($p = 0.0015$; effect size = 0.472) and standard ($p = 0.0054$; effect size = 0.513) conditions concurrent to significantly greater sensations of fatigue compared to the under-weighted ($p = 0.0006$; effect size = 0.580) and standard ($p < 0.001$; effect size = 0.692) conditions. The authors conclude that the use of a 1kg over-
weighted shot-put enhances subsequent overhead back shot-put throw performance (1.5% greater improvement) among moderately strength-trained collegiate athletes. Judge et al. (2016) also concluded that those who experience greater levels of fatigue, or female athletes who possess less neuromuscular strength, may not experience as much improvement.

While the study of Judge et al. (2016) concerned the use of over-weighted shot-puts, two studies have investigated the effects of over-weighted indoor weight throw implements on throwing performance. The indoor weight throw is an indoor version of the hammer event. Judge et al. (2010) found that five throws with an over-weighted indoor weight throw implement weighing 1.37kg ($p = 0.004$) or 2.27kg ($p = 0.027$) heavier than standard male (11.4kg) and female (9.1kg) indoor weight throw implements significantly improved peak throw distance compared with that of a standard implement condition among high school weight throwers. The +1.37kg condition resulted in the male implement weighing 12.77kg (12% mass increase), whereas the female weight was 10.47kg (15.1% mass increase). The +2.27kg condition resulted in the male implement weighing 13.67kg (19.9% mass increase), whereas the female weight was 11.37kg (24.9% mass increase). There were no significant differences in peak distance between the two over-weighted conditions ($p > 0.05$), although mean distance was greatest following the +1.37kg condition. Although Judge et al. (2010) found that the +1.37kg ($p = 0.025$) and +2.27kg ($p = 0.007$) conditions resulted in significantly greater sensations of fatigue post-warm up, resultant throw distance indicated that this did not degrade performance. Indeed, the lighter of the two over-weighted implements induced a 0.9m increase in peak throw distance compared with the standard implement. As mean peak throw distance following throws with the standard implement was 14.15m, the 0.9m
increase (6.36%) following the lighter of the two over-weighted implements may have considerable performance implications in competition. Bellar et al. (2012) also found that over-weighted indoor weight throw implements weighing 1.37kg and 2.27kg heavier than standard male (15.87kg) and female (9.07kg) implements significantly improved throw distance among collegiate and elite weight throwers. The +1.37kg condition resulted in the male implement weighing 17.24kg (8.6% mass increase), whereas the female weight was 10.44kg (15.1% mass increase). The +2.27kg condition resulted in the male implement weighing 18.14kg (14.3% mass increase), whereas the female weight was 11.34kg (25% mass increase). The authors reported that mean throw distance following the +1.37kg condition ($p \leq 0.01$, ES = 1.49) and the +2.27kg condition ($p \leq 0.01$, ES = 1.09), compared with the standard warm up, was significantly greater during the first post-warm up throw. Mean throw distance of the second post-warm up throw was also significantly greater ($p = 0.007$, ES = 0.762) following the +1.37kg implement warm up condition compared with that of the standard condition. Mean distance of all post-warm up throws was significantly lower ($p < 0.02$, ES > 0.8) following the standard implement than the other conditions, with peak post-warm up throw distance being significantly greater than the standard condition following the +1.37kg ($p < 0.002$, ES = 1.01) and +2.27kg ($p < 0.044$, ES = 0.619) conditions. No significant differences were evident between the two over-weighted warm ups for peak ($p = 0.768$, ES = 0.08) and mean ($p > 0.05$) throw distance. Collectively, although the three studies span two events, their consistent findings of enhanced throwing following use of weighted track and field implements supports their use in the applied setting.
2.2.5. Softball

*Chronic effects of weighted softballs*

In line with the desire for increased pitching velocity in baseball, enhanced pitching velocity is also deemed desirable in softball in order to increase the likelihood of obtaining an ‘out’ (Brylinski, Moore & Frosch, 1992). In the only known published study to assess the effects of weighted softballs on pitching performance, Brylinsky et al. (1992) concluded that the use of an over-weighted softball does not offer additional benefits to pitching performance compared to that of a standard softball when incorporated into a training programme over a 6-week period among inexperienced university students. Although this study did not state the specific weight of the regulation softball, it was stated that the weighted softball weighed 2oz heavier than the standard weight. As a regulation softball must weigh a minimum of 6.5oz and a maximum of 7oz (NCAA, 2021), the weighted softball most likely weighed 8.5-9oz (28.6-30.8% mass increase). Results showed that there were no significant differences in post-test assessments of pitching velocity, grip strength and wrist strength between the weighted ball group and a regulation ball control group as a result of the 6-weeks of training ($p > 0.05$). Further research into the effects of chronic, as well as acute, weighted softball use is required in order to elucidate their effects on subsequent throwing performance with the standard softball.

2.2.6. Australian Football

*Chronic effects of weighted Australian footballs*

In the only known study to assess the effects of weighted footballs on kicking performance, Ball (2009) found that a 4-week intervention, which required elite football players to kick a 500g over-weighted football (11.1% mass increase) or a standard 450g
football, resulted in both groups experiencing significant improvements in kick distance from pre-test to post-test ($p < 0.05$). Increasing kick distance is critical to playing success, as it positively impacts passing and shooting and has been shown to be a major predictor of score differences in the Australian Football League (AFL) (Forbes, 2003). The standard football group experienced a 4.8m increase in kick distance, with the weighted football group experiencing a 5.6m increase. A control group (no specific kicking programme but completed at least the same number of kicks throughout the intervention period as the other two groups) did not experience a significant change ($p > 0.05$).

Although no significant between group effect was evident at pre-test ($p > 0.05$), it was revealed that the difference in kick distance between the two experimental groups and the control group at post-test was significant ($p < 0.05$), with no significant differences between the standard and weighted football groups at post-test ($p > 0.05$). The authors concluded that the results of this study infer that specific kick distance training is required to improve kick distance, but that standard football training may be more practical given the absence of significant differences between the two experimental groups. However, the authors acknowledge that a longer intervention may highlight greater advantages of weighted football training as the weighted football group experienced greater kick distance gains in the relatively short intervention period.

2.3. An Introduction to Gaelic Football

Gaelic football is a 15-a-side invasion-based field game and is one of the four national field sports of Ireland. A game consists of two 30-minute halves, although at the elite level (i.e., inter-county level), two 35-minute halves are played. Scores can be achieved by kicking the ball over the crossbar and between the posts for one point or between the posts, below the crossbar and into the net for a goal, which equals 3 points. In Gaelic
football, a wide range of in-game scenarios require players to kick the ball considerable distances (Reilly & Collins, 2008), particularly goal kicks (i.e., kick-outs). Additional factors, such as playing rules and environmental constraints including pitch dimensions (i.e., Gaelic football pitches are large – 145m x 90m), further promote the need for goalkeepers to be able to kick the ball over significant distances (Daly & Donnelly, 2018).

2.3.1. Kicking for Distance in Gaelic Football

Mangan et al. (2017) defined long kick-outs as those that land outside the goalkeeper’s own 45m line (i.e., a kick-out >32m). It is important to note, however, that the literature discussed in this section was conducted prior to kick-out rule changes that were implemented in 2020, whereby the kick-out is now taken from the 20m line as opposed to the 13m line at the time of each of the discussed studies (GAA, 2020). Hence, each subsequently referenced kick-out distance is relative to the 13m line.

From 52 inter-county Gaelic football matches (432 individual full-match player data sets from four teams across three years), Mangan et al. (2017) found that 70 ± 20% of kick-outs were kicked long, whereby the difference between the percentage of short and long kick-outs performed was classified as large ($d = 1.95$). From eight matches involving nine teams in the Ulster Men’s Senior Inter-County Championship (288 players, 351 kick-outs), Daly and Donnelly (2018) found a mean of 44.0 ± 9.9 kick-outs per match were performed, thus requiring goalkeepers to execute kick-outs frequently. Daly and Donnelly (2018) reported that, per match, 34.6% and 53.8% of kick-outs were kicked between the 45m and 65m lines (i.e., a kick-out 32m-52m in distance), and beyond the 65m line (i.e., a kick-out of >52m in distance), respectively, whereas only 8.8% of kick-
outs were kicked between the 20m and 45m lines (i.e., a kick-out 7-32m in distance). Per team, the most common kick-out distance was to the 65m line or beyond (57.0 ± 19.9%), followed by kick-outs to the 45m-65m zone (33.1 ± 16.6%), and then the 21m-45m zone (7.4 ± 7.2%). Of the nine teams included in this study, two teams opted to kick most kick-outs to the 45m-65m zone (44.1% and 64.7%), with the other seven teams opting to kick most of their kick-outs to the 65m line or beyond (46-91.7%). This tendency indicates a preference for a direct approach to score building (Daly & Donnelly, 2018; see also Gamble, McCarren, Bradley, & Moyna, 2020). These findings collectively underscore the frequent requirement of goalkeepers to kick considerable distances.

In support of Daly and Donnelly (2018), Gamble et al. (2020) state that long kick-outs can be used as an effective strategy to initiate an attack directly into the opposition’s defensive zone, bypassing multiple opposing players in the process. Gamble et al. (2020) also state that long kick-outs potentially reduce the risk of conceding a score in the event of a turnover (i.e., the unintended loss of possession), as the opposition must transfer the ball over a greater distance to score, thus increasing the potential of the opposition conceding a turnover. The aforementioned 2020 rule change further impacts this as kick-outs are now likely to land closer to the opposition’s goal line, provided a goalkeeper’s ability to achieve a constant kick distance is maintained. In addition to these match play kick-out statistics, and the referenced benefits of long kick-outs, the need to enhance the ability to kick considerable distances is further underscored by the addition of another newly introduced playing rule and existing embedded environmental constraints.
The ‘Mark’ rule, which was introduced in 2017, has the purpose of further encouraging long kick-outs, and increases the demands of goalkeepers to attain and enhance the ability to kick considerable distances (Mangan et al., 2017). Akin to the ‘Mark’ rule in Australian football, this rule states that when a player catches the ball cleanly from a kick-out without it touching the ground, on or past the 45m line nearest the kick-out point, the player shall be awarded a ‘Mark’ by the Referee. The player shall have the options of taking a free kick or playing on immediately (GAA, 2020). Gaelic football’s embedded environmental constraints, such as the pitch dimensions, which measure a maximum of 145m x 90m wide (GAA, 2017) representing a 40% increase in length and a 21% increase in total area compared to that of a soccer pitch (Reilly & Collins, 2008), additionally emphasises the inherent requirement to kick the ball over considerable distances, thus further enhancing the need to increase this ability.

Finally, although this review of the Gaelic football kick-out distribution literature highlights a clear rationale for the development and enhancement of long kick-outs due to the prevalence of long kick-outs in match play, the large playing surface, and playing rules that encourage distance kicking, it is important to note that enhancing place kick accuracy is also imperative, due to the evidence that shows that (short) accurate kick-outs result in high rates of possession retention (87%) and attack building (55%) (Daly & Donnelly). However, as previously stated, the ‘Green Ball’ was developed with the aim of primarily increasing kick distance and the major contributing variables to kick distance (for example, ball velocity), therefore, the body of research detailed in this thesis exclusively focuses on increasing kick distance and ball velocity.
2.4. Methodological Limitations of the WIT Literature

Although existing research has elucidated various effects of WIT, particularly in baseball, cricket and handball; the WIT domain displays several methodological limitations. Firstly, in regard to the WIT domain in its entirety, substantial differences in methodological design exist, including total number of intervention trials, implement weight and participant playing levels, therefore comparison between studies is a complex process. This further adds to the ambiguity as it pertains to the motor skills that may experience the greatest performance increases as a result of WIT, as well as the optimal implement weight, the optimal loading schemes, and the athletic populations that may be the most likely to experience performance increases as a result of WIT. However, it must be stated that existing resistance training research consistently shows that athletes with greater levels of resistance training experience and neuromuscular strength are likely to display the greatest acute performance increases following a preceding overload conditioning protocol (Wilson, Duncan, Marin et al., 2013). Secondly, regarding acute effects studies, not all investigations directly assessed the immediate effect of respective weighted implement use on markers of motor skill performance with the standard implement. As weighted implement protocols can potentially serve as an effective and time-efficient means of enhancing subsequent motor skill performance in competition settings, elucidating the subsequent, immediate effects of their use on performance with the standard implement may further refine the inclusion of weighted implements and warm up procedures in the design of preparatory activities for the applied setting. Among studies that have included an immediate assessment of subsequent performance with the standard implement, it has been clearly identified that time between weighted and post-weighted motor skill performance with the standard implement directly impacts subsequent standard implement performance, hence the reference to a PAPE effect and
the future need to assess subsequent post-weighted implement motor skill performance at different time points. Further, these studies have not applied statistical analyses to examine the relationship between the mass of the implement used, objective measures of subsequent performance with the standard implement, and potential alterations in participants’ perceptions of the standard implement’s physical properties (i.e., mass and velocity). Research into the chronic effects of WIT on motor skill performance displays minimal inclusion of retention tests and intra-individual analysis techniques to determine if WIT induces practice or learning effects and how such effects may vary per individual. Therefore, as there is a glaring omission of weighted football research in the WIT domain concurrent to a plethora of weighted footballs that are readily available in the marketplace, integration of these considerations into the design of seminal weighted Gaelic football training research is required in order to further understand the acute and chronic effects of their use and to refine their programming.

2.5. Conclusion

The WIT research to date provides researchers and practitioners (i.e., skill acquisition specialists and S&C coaches) with invaluable information and insights pertaining to the effects of a plethora of weighted implements on multiple sporting skills. In particular, although further research is needed in order to identify the optimal means of programming weighted implement training due to ambiguity that exists within particular sports as it pertains to the effects that WIT can have on respective integral performance variables, it has been shown that the use of weighted implements results in acute and chronic improvements in standard implement velocity and distance. However, there is a glaring absence of research into the effects of weighted footballs on kicking performance. Given the popularity of the various football codes (for example, Gaelic football, soccer, futsal,
and rugby), there is a need to expand research in this domain beyond the single study of Ball (2009), which infers potential benefits from the use of weighted footballs on kick distance. As highlighted, kick distance and ball velocity, which is a major contributor to kick distance (Sinclair et al., 2014), are particularly imperative to Gaelic football kick-out performance. This is due to (i) the prominence of long kick-outs in match play, (ii) the competitive benefits of kicking considerable distances from kick-outs, (iii) the addition of new playing rules to further promote distance kicking, and (iv) the expansive playing surface on which the game is played. With respect to these encouraging factors, maintaining and enhancing the ability to achieve considerable ball velocities and kick distances from kick-outs is resultantly desirable, and critical, to goalkeepers, outfield players, the implementation of team tactics and, ultimately, successful team performance. Therefore, it is the responsibility of sport scientists, in tandem with skill acquisition specialists, S&C coaches, Gaelic football coaches and players, to identify means of enhancing kick distance, and the variables that contribute to kick distance, such as ball velocity (Sinclair et al., 2014). As WIT has been shown to increase implement velocity and distance, empirical investigations into the effects of weighted football use may provide coaches and goalkeepers with preparatory means of enhancing kick-out performance and, ultimately, competitive success that are both effective and time-efficient in order to optimise execution in applied settings. Therefore, the purpose of the research conducted in this thesis was to investigate the acute and chronic effects of weighted Gaelic football warm up protocols and training interventions on markers of place kicking performance when place kicking a standard Gaelic football.
Chapter 3

The Impact of a Weighted Gaelic Football Intervention on Kicking Leg Kinematic and Range of Motion Behaviours when Place Kicking a Standard Gaelic Football

Publication: Journal of Sport Behavior as part of a two-study publication (Appendix B)
3.1. Abstract

Weighted implement training has been shown to alter kinematic and range of motion (ROM) behaviours when performing the respective motor skill with the standard competition implement. However, there is a dearth of research examining the effects of weighted football training on kinematic and ROM behaviours of the kicking leg when place kicking a standard Gaelic football. Therefore, the purpose of this study was to investigate the effects of a 5-session, 50-trial weighted Gaelic football (600g; 25% mass increase) place kicking intervention on hip and knee peak angular velocity, and ROM. Following a pre-intervention test that analysed participants’ kinematic and ROM behaviours when place kicking a standard Gaelic football, 12 male Gaelic football goalkeepers (23.5 ± 4.72 years), ranging from inter-county to club level, were randomly assigned to one of three groups: Weighted Football (WF: n = 4), Standard Football (SF: n = 4), or Control (CON: n = 4). The study design consisted of a pre-test, 5-day training intervention, post-test, and 3-day retention test. In the testing sessions, hip and knee peak angular velocity and ROM were analysed with a three-dimensional motion analysis system. Mixed between-within ANOVAs revealed that there were no significant interaction effects ($p > 0.05$), or main effects for time and group ($p > 0.05$), for each of the four biomechanical variables across the experimental phase. Therefore, it is concluded that a 5-session, 50-trial weighted Gaelic football training intervention does not induce detrimental effects on how a standard Gaelic football place kick is performed.

**Key Words:** Biomechanics, Gaelic Football, Overload, Skill Acquisition, Goalkeeper Training
3.2. Introduction

Recent trends in training techniques have emphasised efficiency and sport-specificity, leading to weighted implement training (WIT) becoming a prominent training method in applied settings (Caldwell et al., 2019). Some sports have embraced this training approach more than others; for example, baseball and track and field. In particular, baseball has been the subject of many research studies in the applied setting and with concurrent interest in injury risk. These baseball studies have been conducted with two primary purposes. Firstly, studies have investigated the effects of a multiple-session, multiple-week weighted implement intervention on kinematic and range of motion (ROM) behaviours of performance of the respective motor skill with the standard competition implement. The purpose of these studies has been to investigate if the chronic use of weighted implements alters how the respective motor skill with the standard implement is performed (for example, see Marsh et al., 2018). Secondly, rather than investigating subsequent effects on motor skill performance with the standard implement, several studies have also compared kinematic and ROM behaviours of the respective motor skill when using the standard competition implement to performance of the same motor skill with implements of varied mass (for example, Fleisig et al., 2006). These comparative, within-subject design studies have used their findings to infer potential, subsequent effects of using weighted implements based on the identified kinematic and ROM differences of performing the motor skill with the standard implement and the implements of varied mass (for example, Laughlin, Fleisig, Aune & Diffendaffer, 2016).

Marsh et al. (2018) explored potential changes in baseball pitching kinematic and ROM behaviours following a 6-week weighted baseball programme that comprised of baseballs
weighing 99.2g/3.5oz (30% mass decrease) to 1,998.6g/70.5oz (1,310% mass increase). Although there were no significant changes in pitching velocity ($p > 0.05$), kinematic analysis revealed significant increases in maximal shoulder internal rotation velocity during the acceleration phase ($p = 0.013$). In contrast, no significant changes in maximum pelvis angular velocity ($p = 0.586$), maximum torso angular velocity ($p = 0.129$), and maximum elbow extension velocity ($p = 0.499$) were evident during this phase, with no significant change in pelvis angular velocity occurring at ball release ($p = 0.564$). Shoulder internal rotation range of motion (ROM) ($p = 0.006$) and total shoulder ROM ($p = 0.031$) of the throwing arm significantly increased from pre- to post-test, with no significant change to shoulder external rotation ROM of the throwing arm ($p = 0.637$). While pitching velocity significantly increased from pre- to post-test ($p < 0.001$), Reinold et al. (2018) found participants’ arm angular velocities did not significantly change ($p > 0.05$) following a 6-week pitching programme. The programme included throws with under- and over-weighted baseballs ranging from 56.7g/2oz (60% mass decrease) to 907.2g/32oz (540% mass increase) in each session. Although significant increases in shoulder external ROM were evident ($p = 0.01$), no significant changes to shoulder internal rotation ROM, shoulder flexion ROM, elbow flexion ROM, and elbow extension ROM were evident following the weighted baseball programme ($p > 0.05$). The findings of these studies infer that WIT programmes have the potential to alter respective motor skill kinematic and ROM behaviours upon conclusion of the respective intervention, which could have positive or negative effects on subsequent performance with the standard implement in competition. For example, although increased shoulder external rotation ROM can increase pitching velocity, it can also increase the risk of injury (Camp et al., 2017). In addition to these multiple-session, multiple-week intervention studies, the findings of studies that have compared kinematics of motor skill performance with
weighted and standard implements in a within-subjects design have collectively reported alterations of the timing and magnitude of kinematic outputs with the use of weighted implements compared to the use of standard, competition implements (Fleisig et al., 2006; Laughlin et al., 2016; Van den Tillaar & Ettema, 2011). Although these studies did not include a training intervention with follow-on measures of performance upon return to the regulation implement, the respective findings provide potential implications for WIT and motor skill performance in other domains, such as Gaelic football, whereby the use of a weighted Gaelic football may induce altered kinematic and ROM behaviours of the kicking leg when subsequently striking a standard Gaelic football.

Implications may be inferred from the existing baseball WIT research, but without direct evidence of the effects of weighted football training on kinematic and ROM behaviours when place kicking a standard Gaelic football, such inferences must be considered with caution. Therefore, a preliminary investigation into the effects of weighted football training on how a place kick with a standard Gaelic football is performed was imperative. The purpose of this study was to investigate the effects of a 5-session, 50-trial, weighted Gaelic football place kicking intervention on hip and knee peak angular velocity, and ROM of the kicking leg when striking a standard Gaelic football. It was hypothesised that the weighted Gaelic football training intervention would lead to significant increases in hip and knee peak angular velocity and ROM. This study also served as the seminal body of work exploring the effects of a weighted football on place kicking in Gaelic football, and its findings have informed the efficacy of conducting subsequent research into the acute effects on weighted football place kicking on immediate kick distance of standard Gaelic football place kicks.
3.3. Methods

3.3.1. Participants

Twelve male Gaelic football goalkeepers of varying standard, ranging from inter-county to club level, were recruited to take part in this study. The mixed level of expertise was required in order to ensure a greater sample size due to the limited quantity of inter-county goalkeepers available to participate in the study. Participants were randomly assigned to one of three groups: Weighted Football (WF) (n = 4, age = 25.0 ± 6.16 years, body mass = 89.0 ± 12.27kg, height = 186.3 ± 6.17cm, number of playing years = 18.8 ± 3.30 years), Standard Football (SF) (n = 4, age = 21.3 ± 1.50 years, body mass = 80.0 ± 12.30kg, height = 180.6 ± 0.48cm, number of playing years = 15.3 ± 1.50 years), or Control (CON) (n = 4, age = 24.3 ± 5.56 years, body mass = 93.5 ± 6.14kg, height = 190.4 ± 3.25cm, mean number of playing years = 17.5 ± 6.24 years). Although an a priori power analysis was not conducted, the sample size was determined by the availability of participants to attend three 90-minute testing sessions in a motion analysis laboratory and five 30-minute intervention sessions across a 10-day period. Participants were required to refrain from any high intensity exercise or consumption of caffeine each morning of the testing period. They were encouraged to get 7-8 hours of sleep the night prior to each testing session and to avoid any substantial alterations to nutrition or fluid intake over the course of the testing period. All participants were free from injury and performed their normal Gaelic football training throughout. This research was approved by the Host Institution’s Research Ethics Committee.
3.3.2. Materials and Experimental Set-Up

The weighted Gaelic football (The Green Ball Co., Dublin, Ireland) used in this study weighed 600g, a 25% increase from the standard 480g game ball. The size and outer panelling of the weighted football was identical to that of a standard Gaelic football, with the additional mass due to a heavier inner bladder (Figure 1.3a). The standard football used in this study was a size-5 O’Neills All-Ireland Gaelic football (O’Neills Irish International Sports Co. Ltd., Belfast, Northern Ireland; Figure 1.3b), inflated to a pressure of 9.75-10 pound per square inch (PSI), resulting in the recommended mass of 480g (GAA, 2017). Kinematic data were collected using a three-dimensional motion capture system. A Vicon motion analysis system consisting of eight MX13+ cameras and Nexus v1.8.5 software was utilised (Vicon, Oxford, UK). Two digital video cameras were used for data quality and inspection purposes (Figure 3.1). A validated six degree of freedom (CAST technique) biomechanical model was used to provide accurate and valid kinematic data for analysis (Dawson, 2017). This system recorded motion within an approximate capture volume of 8.0m x 3.0m x 2.5m. However, based on the findings of the pilot research phase, it was found that this capture volume area was insufficient in order to capture biomechanical data of the upper body although the capture volume area was maximised in respect of dimensions of the motion analysis laboratory and the suspended frame in which the cameras were attached. Furthermore, as maximal effort place kicks were performed, foot and ankle coalescence provided an insurmountable challenge for the motion capture system, which only had a maximal frame rate of 100Hz. It has been reported that the foot is the fastest segment in the open kinetic chain during kicking performance (Young & Rath, 2011), which likely resulted in such challenges to the 100Hz cameras. Therefore, the marker trajectories for these structures were not analysed. Marker trajectories and model outputs were filtered with a 6Hz Butterworth
low-pass filter. This filter serves the purpose of smoothening the data by removing noise (i.e., inaccurate peaks and troughs in the data) due to signal interference and soft tissue artifact (i.e., differences between motion of the skin in which the markers are attached and the motion of the underlying skeletal structure).

Sixty-nine reflective markers, 14mm in diameter, were placed on anatomical landmarks that were palpated according to Van Sint Jan (2007). This is displayed in Figure 3.2. All test trials were executed in front of a Schutt training net (Litchfield, Ill, USA) measuring 2.1m high and 1.5m wide. As a result of a pilot research phase, the centre of the bottom frame of the net was placed 1.8m from the centre of the designated ball placement location, which was indicated by a 26cm² square of masking tape (Unibond Duct Tape, USA). Feedback from participants in the pilot research phase showed that a distance of 1.8m between the kicking location and the net was sufficient in order for participants to
not be at risk of making contact with the kicking net or its frame during the follow-through phase of each place kick. Figure 3.3 illustrates a participant performing a maximal effort place kick into the training net.

**Figure 3.2.** Full body marker set displaying the 69 anatomical markers (Van Sint Jan, 2007).

This study consisted of a pre-test, experimental phase, post-test, and 3-day retention-test. Each participant arrived for testing with their own pair of compression shorts. Participants were also required to wear indoor football shoes (Diadora Pichichi ID Indoor Football Boot, Caerano di San Marco, Italy) which were provided by the researcher. When in the required attire, participants’ body mass (kg) and height (cm) were measured for biomechanical modelling purposes. The reflective markers were then secured to the designated anatomical landmarks.
3.3.3. Procedure

Prior to the respective pre-test session in the motion analysis laboratory, participants were given a Participant Information Sheet, and subsequently completed a Consent Form and a Playing Experience Questionnaire. At the beginning of all testing sessions, the lead researcher and the in-house biomechanist prepared the Vicon system for the upcoming session. This included a preparation phase, which involved masking the cameras and preparing the Vicon Vantage Calibration Wand, and a calibration phase, which involved calibrating the masked cameras via use of the wand and subsequently applying a model to the wand in order to set the global origin of the system and the capture area. At the beginning of all testing and intervention sessions, participants were provided verbal instructions detailing the nature of the respective session’s procedure. Participants then completed a 5-minute warm-up including dynamic stretches for the quadriceps, hamstrings, hip flexors, adductors, gluteals, and gastrocnemius-soleus complex because of the maximal-effort nature of the testing and intervention sessions. All testing and
intervention place kicks were performed with an unused football, placed upon a standard 3cm kicking tee (The Green Ball Co., Dublin, Ireland). For all place kicks, participants were informed of the number of the upcoming kick and instructed to commence the trial. All place kicks were performed with the participants’ preferred leg, with each participant advised to approach each kick as they would in a game situation.

The testing procedure required participants to perform five maximal effort place kicks with a standard Gaelic football. Prior to the five maximal effort place kicks, two familiarisation place kicks were performed. Participants were specifically instructed to kick the ball with maximal effort for distance. Between trials, a member of the research team placed a new O’Neills All Ireland Gaelic football on the kicking tee. A 1-minute rest period was completed between each place kick, when communication was also not permitted. Recording of the trial commenced upon instruction to the participant and ceased when the football came to rest in the net. Testing concluded when five place kicks were successfully completed and recorded.

Upon conclusion of the pre-test, participants were randomly assigned to one of the three groups: Weighted Football (WF), Standard Football (SF), or Control (CON). While the CON group did not partake in an intervention phase, the WF and SF groups completed a training intervention between days two to six inclusive. Based on the time of the season in which this intervention took place and the corresponding availability of participants, it was determined that a training intervention duration of 5-days would be implemented in order to ensure participants would be exposed to a sufficient amount of weighted football place kicks without missing an intervention session. In each intervention session,
participants in the WF and SF groups completed ten maximal effort place kicks with the assigned football. Two familiarisation place kicks, with the randomly assigned football, were performed prior to the ten intervention trials. A 1-minute rest period was completed between each place kick. As this study was the seminal investigation into the effects of weighted implement training on place-kicking performance, it was hypothesised that ten maximal effort place kicks and a 1-minute rest period per intervention session would provide a potentially sufficient training stimulus without inducing an increase in injury risk. A pilot study also showed that a 1-minute period between place kicks was sufficient in order to allow the researcher to place a new football on the kicking tee and to allow the in-house biomechanist to save the recording of the previous place kick on the Vicon system and ready the system for the upcoming trial. All participants reported to the motion analysis laboratory for post-testing and retention-testing on Day 7 and Day 10, respectively. Both testing sessions followed an identical protocol to the pre-test.

3.4. Data Analysis

Four variables were selected for analysis: peak hip angular velocity (PHAV), hip range of motion (HROM), peak knee angular velocity (PKAV), and knee range of motion (KROM). Each of these variables were analysed in respect of their values through the flexion-extension axis. Prior to initiation of the study, it was also proposed that ball velocity would be analysed via the attachment of four circular pieces of reflective tape to the ball. However, the pilot research phase showed that, due the velocities in which the footballs were kicked, detection and analysis of these markers also provided an insurmountable challenge to the motion analysis system as 100Hz cameras were used. Analysis of the kicking motion began upon release of the kicking foot from the ground prior to planting of the support leg pre-foot-ball contact and ceased upon foot-ground
contact of both feet post-ball contact. Peak angular velocity was defined as the maximum value of the respective joint within the defined kicking motion. Range of motion (ROM) was defined as the difference between peak flexion and peak extension of the respective joint within the defined kicking motion.

A 3-Group x 3-Test repeated measures analysis of variance (ANOVA) was conducted to assess the effectiveness of the experimental phase on each of the selected kinematic and ROM variables of the kicking limb. The assumptions of distribution normality, homogeneity of variances and sphericity were assessed via Shapiro-Wilks, Box’s M Test of Equality of Covariance Matrices, and Mauchly’s Test of Sphericity, respectively. Outliers were assessed via visual inspection of a boxplot. A Bonferroni post-hoc test was conducted to examine the interaction, group, and time effects. For all analyses, the alpha level was set at \( p < 0.05 \). Partial eta squared (\( \eta^2 \)) was used to assess effect size (Small: \( 0.01 \leq \eta^2 < 0.06 \); Medium: \( 0.06 \leq \eta^2 < 0.14 \); Large: \( \eta^2 \geq 0.14 \); Cohen, 2013). This analysis was conducted with SPSS (Version 25, Chicago, Illinois, USA).

3.5. Results

The assumptions of outliers, distribution normality, homogeneity of variances and sphericity were satisfied across all four ANOVAs. Results of the 3-Group x 3-Test ANOVAs that were conducted on each kinematic and ROM variable are presented in Table 3.1. Pairwise comparisons were not performed when main and interaction effects were not statistically significant (i.e., \( p > 0.05 \)).
Table 3.1. Results of the 3-group x 3-test ANOVAs that were conducted on each kinematic and range of motion variable.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time (main effect)</th>
<th>Group (main effect)</th>
<th>Group x Time (interaction effect)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHAV</td>
<td>$F(2, 18) = 0.510$, $p = 0.609$, partial $\eta^2 = 0.054$</td>
<td>$F(2, 9) = 4.74$, $p = 0.039$, partial $\eta^2 = 0.513^*$</td>
<td>$F(4, 18) = 0.459$, $p = 0.765$, partial $\eta^2 = 0.093$</td>
</tr>
<tr>
<td>HROM</td>
<td>$F(2, 18) = 0.590$, $p = 0.564$, partial $\eta^2 = 0.062$</td>
<td>$F(2, 9) = 0.480$, $p = 0.634$, partial $\eta^2 = 0.096$</td>
<td>$F(4, 18) = 0.364$, $p = 0.831$, partial $\eta^2 = 0.075$</td>
</tr>
<tr>
<td>PKAV</td>
<td>$F(2, 18) = 1.322$, $p = 0.291$, partial $\eta^2 = 0.128$</td>
<td>$F(2, 9) = 1.633$, $p = 0.248$, partial $\eta^2 = 0.266$</td>
<td>$F(4, 18) = 0.737$, $p = 0.579$, partial $\eta^2 = 0.141$</td>
</tr>
<tr>
<td>KROM</td>
<td>$F(2, 18) = 1.216$, $p = 0.320$, partial $\eta^2 = 0.119$</td>
<td>$F(2, 9) = 1.506$, $p = 0.273$, partial $\eta^2 = 0.251$</td>
<td>$F(4, 18) = 0.413$, $p = 0.797$, partial $\eta^2 = 0.084$</td>
</tr>
</tbody>
</table>

*Pairwise comparisons did not reveal a significant difference between groups.

Kinematic and ROM values per group per testing phase are presented in Figures 3.4a-d.

![Figure 3.4a. PHAV in degrees/second for each group across the testing phase.](image-url)
Figure 3.4b. HROM in degrees for each group across the testing phase.

Figure 3.4c. PKAV in degrees/second for each group across the testing phase.
3.6. Discussion

This study had the aim of investigating if weighted Gaelic football place kicking practice alters how a subsequent place kick with a standard Gaelic football is performed among inter-county and club level male Gaelic football goalkeepers. Essentially, this study served as a preliminary kinematic and range of motion (ROM) analysis and investigated whether hip and knee angular velocity, and ROM, of the kicking leg, were altered when performing a place kick with a standard Gaelic football following a 5-session, 50-trial weighted Gaelic football place kicking intervention. Results revealed that all three groups (WF, SF & CON) experienced no significant changes in hip and knee angular velocity and ROM ($p > 0.05$), thus findings failed to reject the null hypothesis ($H_0$; Chapter 1). These findings suggest that a relatively short weighted Gaelic football training intervention does not alter how a subsequent place kick with a standard Gaelic football is performed. Previous kinematic analyses of place kicking performance have suggested
that velocities of the kicking leg joint structures strongly contribute to proficient place kicking (Lees, Asai, Andersen, Nunome, Sterzing, 2010; Young & Rath, 2011). In particular, it has been identified that velocities of the knee are a key contributor to desirable characteristics of place kicking, such as increased ball velocity, which is a contributor to increased kick distance (de Witt & Hinrichs, 2012; Sinclair et al., 2014). In the current study, the absence of significant decreases in lower limb angular velocities, as well as ROM, infer that this weighted Gaelic football training intervention does not induce detrimental effects upon place kicking. Therefore, it is suggested that 50 weighted Gaelic football place kicks across a 1-week period do not degrade maximal effort place kicking performance with the standard football.

The findings of the current study align with existing weighted implement training (WIT) literature pertaining to the effects of WIT on measures of joint velocities and ROM. Regarding angular velocities, Marsh et al. (2018), as previously stated, reported an absence of significant kinematic changes following 6-weeks of weighted baseball training. The authors observed an absence of significant changes in maximum elbow extension velocity, maximum torso angular velocity, and maximum pelvis angular velocity ($p > 0.05$) following completion of the intervention that comprised of throws with 3.5oz (30% mass decrease) to 70.5oz (1,310% mass increase) baseballs throughout programmes that were individualised per participant. Reinold et al. (2018) also found no significant changes in kinematics of the arm following a weighted baseball training intervention. Specifically, the authors found that following 6-weeks of training with a less expansive range of weighted baseballs compared to that of Marsh et al. (2018) (2oz, 60% mass decrease – 32oz, 540% mass increase), whereby 45-105 throws per week (across 3
weekly sessions) were performed, youth pitchers (12-18 years) experienced no significant changes in arm angular velocities ($p > 0.05$). Regarding ROM measures, Marsh et al. (2018) also reported an absence of significant changes following completion of their WIT intervention, whereby there was no significant change in dominant arm external rotation ROM ($p > 0.05$). Reinold et al. (2018) also reported an absence of significant changes as there were no pre- to post-test differences in ROM of shoulder internal rotation, shoulder flexion, elbow flexion, and elbow extension ($p > 0.05$) following the conclusion of their weighted baseball pitching intervention.

Although the findings from the current study showed no significant changes in kinematic or ROM values, it cannot be concluded that exposure to the weighted Gaelic football over a longer period of time would not lead to (i) changes in kinematic and ROM values, and (ii) an increased risk of injury. For example, although Reinold et al. (2018) observed the aforementioned absence of arm angular velocity changes, the authors observed a significant increase in pitching velocity (1m/s, 3.3%; $p < 0.001$) concurrent to four individual injuries representing a 24% injury rate, which was purported to be the result of a significant increase in shoulder external rotation ROM (4.3°; $p = 0.01$). Injuries occurred either (i) in the season in which the intervention was conducted, or (ii) the following season. Shoulder external rotation ROM has been shown to correlate with increased stress on the pitching arm (Camp et al., 2017), therefore Reinold et al. (2018) suggest that the use of weighted baseballs via the utilised means of programming among youth cohorts increases the risk of injury.
While the findings of Reinold et al. (2018) infer potential negative effects of WIT following an extended period of programming, which may ultimately lead to increased risk of musculoskeletal injury, contrasting results following an 8-week WIT programme have been reported by Wickington and Linthorne (2017). Upon conclusion of a weighted cricket ball bowling intervention, which comprised of between 108-126 weekly bowls (across 3-weekly sessions) with various cricket balls weighing 71g (54.5% mass decrease) to 213g (36.5% mass increase), results revealed that the use of weighted cricket balls did not induce detrimental changes to participants’ bowling mechanics on both individual and group analysis bases. It was found that one participant experienced an ‘almost certainly increased’ knee angle at front foot contact, with another experiencing a ‘possibly decreased’ back foot angle at contact. However, participants in the weighted ball group exclusively experienced either ‘possibly trivial’ or ‘probably trivial’ changes for all other kinematic measures (i.e., back foot angle at contact, front foot angle at contact, back leg knee angle at back foot contact, front leg knee angle at front foot contact, front leg knee angle at release, shoulder angle at back foot contact, and shoulder angle at front foot contact – Wickington & Linthorne, 2017). Collectively, these three studies (Marsh et al., 2018; Reinold et al., 2018; Wickington & Linthorne, 2017) display varied kinematic and ROM effects following completion of long-term WIT programmes. These contrasting findings represent the concern relating to the issue of generalising the results of WIT studies across different sports and implements, as nuanced effects relative to the utilised weighted implements, their means of programming, and the respective motor skill that is the subject of investigation, are evident. Considering the findings of this study in relation to those that have investigated the effects of WIT on motor skill performance over a longer time period, the current study suggests that 50 weighted Gaelic football place kicks performed across five practice sessions do not induce detrimental effects on
subsequent place kicking performance with the standard Gaelic football. However, future research is needed to elucidate the performance- and health-related effects of greater exposure to this implement.

Although the findings of the current study expand the WIT literature, several limitations should be considered. Findings led to the conclusion that multiple weighted Gaelic football training sessions do not alter how a subsequent place kick is performed. However, it cannot be concluded that additional metrics relating to the kicked football (for example, ball velocity and kick distance) are not altered as a result of completing this intervention. Further, it cannot be concluded that a weighted football training intervention of longer duration and a corresponding greater volume of place kicks would not result in kinematic and ROM alterations. Similarly, had the motion analysis system facilitated the biomechanical analysis of the ankle and foot, potential kinematic and ROM alterations may have been observed. However, as this motion analysis system was the only means of measuring biomechanics at the time of conducting the study, the in-house biomechanist was directly involved in the data collection and analysis phases throughout in order to ensure that no other issues pertaining to the motion analysis system arose. The small sample size (n = 12) is also considered a limitation, therefore it is recommended that future research increases sample sizes in respect to a priori power analysis. However, it is important to note that a total of 37 participants were originally recruited, with 25 of those participants failing to attend all experimental and intervention sessions, hence the final inclusion of just 12 participants. Therefore, although measures were put in place to increase the study’s attrition rate (for example, scheduling sessions to suit each individual’s daily schedule), the difficulty of ensuring a larger sample size across a 10-
day experimental period should be acknowledged. It may also be deemed a limitation of this research that the intra-individual effects of the intervention phase on angular velocity and range of motion values were not analysed. This may provide the practitioner with further information pertaining to the effects of weighted Gaelic football training that may be experienced in the applied setting. Similarly, the mixed level of expertise in this study may also be deemed a limitation, as significant changes in kinematic and ROM behaviours may have been observed if an exclusively inter-county or club level participant sample had been utilised. Finally, based on the content of the Information Sheet, participants were aware of the intervention groups that they could be assigned to. Therefore, it cannot be concluded that this knowledge did not impact upon performance throughout the intervention, as the participants were informed of the potential benefits of weighted football training, and participants in the WF group may have therefore exerted a greater amount of effort per place kick compared to those in SF group. If this were the case, the findings of this study infer that this did not impact upon place kick performance across the experimental period.

In conclusion, the purpose of this research was to investigate if the use of a weighted Gaelic football (600g; 25% mass increase) altered how a subsequent place kick with a standard Gaelic football was performed among inter-county and club level male Gaelic football goalkeepers. This study comprised of an exploratory biomechanical analysis to investigate the kinematic and ROM effects of a 5-session, 50-trial weighted Gaelic football intervention, whereby results revealed that kicking leg kinematics and ROM values of inter-county and club level male Gaelic football goalkeepers were not altered. While such effects were observed, the acute effects of weighted football place kicks on subsequent and immediate place kicking performance are unknown. As this study
identified that repeated use of the weighted football does not induce detrimental effects on subsequent maximal effort place kicking with a standard Gaelic football, concurrent to the aforementioned desire among Gaelic football stakeholders to increase kick distance, there is support for, and a need to, assess the effects of a weighted Gaelic football place kicking protocol on subsequent and immediate measures of place kick distance. There is also a need to compare these effects to a standard Gaelic football place kicking protocol. This research may provide players, and in particular goalkeepers, with an effective and efficient means of increasing kick distance which is desirable as (i) long kick-outs (i.e., kick-outs that land outside the goalkeepers’ own 45m line; Mangan et al., 2017) are a prominent feature of match play (Daly & Donnelly, 2018; Mangan et al., 2017), (ii) the expansive playing surface and various match play rules encourage distance kicking (see the ‘Mark’ rule and the new 20m line kick-out location; GAA, 2017; 2020), and (iii) long kick-outs play a critical role in setting up attacks in match play.
Chapter 4

An Investigation into the Acute Effects of a Weighted Gaelic Football Place Kicking Protocol on Subsequent Place Kick Distance

Publication: Journal of Sport Behavior as part of a two-study publication (Appendix B)
4.1. Abstract

Weighted implement training has been demonstrated to improve motor skills. However, there is a dearth of research examining the acute effects of weighted footballs on place kick distance, and in particular in the game of Gaelic football. The purpose of this study was to examine the acute effects of a weighted football (600g; 25% mass increase) place kicking intervention on subsequent place kick distance of standard Gaelic football place kicks among male university students with Gaelic football playing experience. On Day 1, 30 male Sport & Exercise university students (21.7 ± 1.55 years), each with a minimum of ten years playing experience, completed a 5-trial pre-test of place kick distance with a standard Gaelic football. On Day 2, participants were randomly assigned to a Weighted Football (WF: n = 15) or Standard Football (SF: n = 15) group, and performed five maximal effort place kicks with the assigned football immediately prior to a 5-trial post-test of place kick distance with a standard Gaelic football. An ANCOVA revealed that the WF group did not experience acutely enhanced mean kick distance compared to the SF group (p > 0.05). However, although repeated measures ANOVAs revealed no significant kick distance differences between pre-test measures and each individual post-test place kick (p > 0.05), there was a nominal transient distance increase from 30-seconds to 2-minutes post-weighted football engagement (i.e., post-test Trial 1 to 4). This suggests that a greater kick distance may be achieved with extended time periods between weighted and subsequent standard football place kicks. Albeit insignificant, this study provides practitioners with a means of inducing transient increases in kick distance, which is an integral aspect of Gaelic football performance due to the prominence of distance kicking in match play and the critical role it plays in a direct approach to creating scoring opportunities.
4.2. Introduction

Weighted implement training (WIT) has been the subject of research that concerns the identification and evaluation of the efficacy of using weighted implements as a pre-competition warm up strategy. This research was designed to provide practitioners with evidence to support the use of weighted implement warm up protocols comprising of relatively few repetitions that can lead to the realisation of acute performance enhancements (for a review, see DeRenne & Szymanski, 2009). The utilisation of WIT in this context aims to elicit a post-activation performance enhancement (PAPE) effect, with existing WIT research providing empirical support (for a review, see Jermyn et al., 2021a). PAPE represents the observed effect of a high-intensity conditioning protocol resulting in acute improvements in subsequent voluntary muscular contractions (Blazevich & Babault, 2019). Examples of WIT-induced PAPE effects exist within the literature, such as subsequent improvements in mean baseball pitching velocity (for example, Van Huss et al., 1962), mean baseball bat velocities (for example, DeRenne et al., 1992), and mean throwing distance (for example, Bellar et al., 2012), which have been observed following a weighted implement warm up protocol. These studies have attributed acute performance improvements to post-activation potentiation (PAP), which is defined as an enhanced muscle contractile response for a given level of stimulation following an intense voluntary contraction, and is measured as the maximum twitch force evoked by electrical stimulation (Blazevich & Babault, 2019; MacIntosh et al., 2012; Zimmerman, MacIntosh & Dal Pupo, 2019). However, as per its definition, verification of PAP requires confirmation of an enhanced muscle (i.e., twitch) contractile response
for a given activation via a controlled method of activation following voluntary contraction. Therefore, the term PAPE has been proposed to more accurately represent the observed effect of a high-intensity conditioning protocol resulting in acute improvements in voluntary muscular contractions (Blazevich & Babault, 2019), which explains observed acute performance improvements following a prior conditioning protocol (Prieske et al., 2020).

In addition to the observed effects of significantly increased mean motor skill performance following completion of weighted implement warm up protocols, transient increases in motor skill performance across individual post-warm up trials have also been observed (for example, Kim & Hinrichs, 2008; Wilson, Miller, Szymanski et al., 2012). This observation of transient increases accurately portrays the PAPE effect, whereby gradual increases in performance post-conditioning phase are a predominant characteristic of the effect (Prieske et al., 2020). In an investigation into the acute effects of weighted baseball bats on subsequent standard bat velocity, Kim and Hinrichs (2008) found that bat velocity 2-minutes post-over-weighted bat warm up was significantly lower than 3-minutes post-warm up ($p < 0.05$). This led the authors to conclude that a rest period of 3-minutes at minimum should be completed to enhance bat velocity. A similar study by Wilson et al. (2012), which investigated the acute effects of weighted bat implements and various rest periods, also found noticeable improvements in bat acceleration and velocity after 2-minutes compared to related baseline values, with further increases observed after 4- and 8-minutes. This finding influenced the suggestion that at least 2-minutes of rest is necessary to enhance bat acceleration and velocity. Wilson et al. (2012) suggested that their findings could potentially be explained by Banister’s Fitness Fatigue Model (Banister, Morton & Fitz-Clarke, 1992), which proposes that performance
is a balance between fitness and fatigue, whereby changes to the former outlast those of the latter following recent contractile activity. This implies maximal performance does not occur immediately following the training stimulus (Chiu & Barnes, 2003), an effect that was illustrated by the findings of Wilson et al. (2012) as bat velocity was significantly enhanced 4- and 8-minutes post-warm up compared to 1-minute post-warm up ($p \leq 0.05$).

The analysis of the WIT literature reveals that there is an abundance of studies investigating the acute effects of WIT on baseball skills and track and field performance, whereby improvements in standard implement velocity and distance are evident, thus illustrating the elicitation of a WIT-induced PAPE effect. However, this analysis concurrently reveals the dearth of research examining the acute effects of WIT on place kick distance in Gaelic football, which was highlighted as an integral performance indicator in Gaelic football in Chapter 2. Therefore, the prominence of WIT-induced PAPE effects in other sports and the absence of WIT research in Gaelic football presents an opportunity to examine the effects of training with a weighted football in order to acutely improve place kick distance. Further support for such an investigation is provided by existing research as it has been shown that (i) weighted football use does not detrimentally affect place kick kinematics (see Study 1, i.e., Chapter 3), and (ii) weighted footballs positively impact kick distance in Australian football (Ball, 2009). However, to avoid ambiguity, and to provide skill acquisition specialists and S&C coaches with empirical evidence pertaining to the effects of a specific weighted implement that is yet to be the subject of empirical investigation, it is deemed necessary to assess the effects of a weighted Gaelic football on place kick performance despite the plethora of positive WIT effects that exist within the literature, as it oftentimes suggests a specificity effect from one sport to the next (Wickington & Linthorne, 2017).
Therefore, the primary purpose of this study was to investigate the acute effects of a weighted Gaelic football place kicking protocol on subsequent mean place kick distance of standard Gaelic football place kicks among male university students with Gaelic football playing experience. It was hypothesised that the weighted football place kicking protocol would result in significantly greater mean post-warm up place kick distance compared to a standard Gaelic football control condition. The secondary purpose of this study was to investigate whether weighted football warm up place kicks resulted in a transient increase in post-test kick distance. It was hypothesised that the weighted football protocol would induce a significant transient increase in kick distance across post-warm up place kicks. The findings of this study have clear implications for practitioners, providing implement-specific empirical evidence for the support for, or opposition to, weighted football use in the applied setting leading to a time-efficient means of enhancing goalkeepers’ kick distance.

4.3. Methods

4.3.1. Participants
Thirty male Sport & Exercise undergraduate university students with Gaelic football experience (i.e., currently playing or previously played) were recruited to take part in this study. The participants were randomly assigned to one of two groups: Weighted Football (WF) (n = 15; age = 21.9 ± 1.73 years; number of playing years = 14.1 ± 1.81 years) or Standard Football (SF) (n = 15; age = 21.6 ± 1.40 years; number of playing years = 14.6 ± 2.35 years). Participants were required to refrain from any high intensity exercise or consumption of caffeine each morning of the testing period. A minimum of 7-8 hours of sleep the night prior to each testing session was encouraged, in addition to the avoidance
of any substantial alterations to nutrition or fluid intake over the course of the testing period. All participants were free from injury and performed their normal Gaelic football training throughout the testing period. This research was approved by the Host Institution’s Research Ethics Committee.

4.3.2. Materials and Experimental Set-Up

The weighted Gaelic football (The Green Ball Co., Dublin, Ireland; Figure 1.3a) used in this study weighed 600g, a 25% increase from the standard 480g game ball. The size and outer panelling of the weighted football was identical to that of a standard Gaelic football, with the additional mass due to a heavier inner bladder. The standard football used in this study was a size-5 O’Neills All-Ireland Gaelic football (O’Neills Irish International Sports Co. Ltd., Belfast, Northern Ireland; Figure 1.3b), inflated to a pressure of 9.75-10 pound per square inch (PSI), resulting in the recommended mass of 480g (GAA, 2017).

This study took place in the infield grass area of an outdoor athletics track as displayed in Figure 4.1. The kicking location was situated at the end of the javelin runway of a standard athletics track and field setting. At the apex of the arc indicating the end of the javelin runway, a kicking tee was placed on a mark on an artificial grass playing surface (Synthi Green Sports Surfaces Limited, Co. Cork, Ireland), which was placed over the runway. This surface served to replicate competitive playing surfaces as opposed to the tartan track below, thus providing a more representative surface of a football pitch for maximal effort place kicks to be performed. Further, it facilitated the participants being able to wear their regular football boots for each stage of data collection. Feedback from
participants in a pilot research phase highlighted the need for all participants to be afforded the opportunity to wear their own football boots in order for grip to maximised.

Figure 4.1. Experimental set-up including the 50m x 30m measurement grid, kicking location and evaluators.

The experimental set-up of Ball (2008, 2009) was modified in the current study to create a larger measurement area of a 50m x 30m (length x width) rectangular grid consisting of 1m² boxes. This grid was situated 25m into the outfield area from the kicking location as the pilot research phase showed that all 200 pilot trials were kicked substantially farther than a distance of 25m. The grid was painted onto the grass surface with a BeamRider CT Laser Line Marking System (Fleet Line Markers Ltd., Worcestershire, UK). The Host Institution’s groundsman, who is responsible for the marking of all lines on all playing pitches, created the grid with the line marker. The purpose of the measurement grid was to support the identification of the ball’s landing location, as illustrated in Figure 4.2, and had a measurement margin of error of one metre, as the recorded distance of all test trials
was rounded down to the nearest metre. Three evaluators were located at incremental distances across the marked area to ensure the exact box in which each place kick first made contact with the ground was accurately identified. The pilot research phase showed that three evaluators was sufficient in order for the point of ball-ground contact to be consistently identified and defined.

Figure 4.2. Measurement grid consisting of 1,500 1m² boxes.

A 100m measuring tape (San Tyau Co., Taiwan) fixed to the runway directly below the marked kicking location was then used to measure the distance between the origin of the kick and the first point of contact that the ball made with the ground. A video camera (Canon Legria HFR606, Tokyo, Japan) was positioned adjacent to the 50m line in the spectator stand to provide confirmatory analysis for the tape-recorded measurement of each trial. A Tenma 72-6638 anemometer (Tenma, Leeds, UK) was used to ensure a wind threshold of ≤ 2m/s was maintained for each test kick (Ball 2008, 2009).
4.3.3. Procedure

Prior to the commencement of this study, participants were given a Participant Information Sheet, and subsequently completed a Consent Form and a Playing Experience Questionnaire. At the beginning of all testing and intervention sessions, participants were provided verbal instructions detailing the nature of the respective session’s procedure. Participants then completed a 5-minute warm up including dynamic stretches for the quadriceps, hamstrings, hip flexors, adductors, gluteals, and gastrocnemius-soleus complex because of the maximal-effort nature of the testing and intervention sessions. All testing and intervention place kicks were performed with an unused football, placed upon a standard 3cm kicking tee (The Green Ball Co., Dublin, Ireland). For all place kicks, participants were informed of the number of the upcoming kick and instructed to commence the trial. All place kicks were performed with the participants’ preferred leg, with each participant permitted to approach each kick as they would in a game situation.

Prior to each intervention place kick on both days of the study, a member of the research team situated at the kicking location measured wind speed with the anemometer. If the threshold of ≤ 2m/s was violated, commencement of the respective trial was delayed until a measure of ≤ 2m/s was ensured. As data collection took place on days in which minimal wind was present (i.e., ≤ 2m/s), an extension of the 30-second inter-trial interval was never required. The role of the three evaluators was as follows: one evaluator identified the location outfield where the ball first contacted the ground, another evaluator, located nearest the primary evaluator for the given trial, corroborated the identified location to ensure accuracy of measurement, and the other evaluator remained in position awaiting the next place kick. For example, if the point of ball-ground contact was on the right-side
of the grid, the evaluators located on the right and in the centre of the grid identified, and agreed upon, the point of ball-ground contact. Upon identification of the ball-ground contact location, another member of the research team measured kick distance with the measuring tape and recorded the distance on a scoring sheet. For all test trials, the recorded distance was subsequently rounded down to the nearest metre to account for potential human error as identification of the exact point of ball-ground contact within the respective 1m² box was performed manually. In the event of a disagreement of the defined ball-ground contact location, the video recording from the camera in the spectator stand was consulted to identify the exact point of ball-ground contact. In the event that a player kicked the ball wide of the measurement grid, an additional trial was added to the testing protocol to ensure each participant completed five valid attempts.

Participants were required to attend two testing sessions separated by a minimum of 48 hours. On Test Day 1, baseline kick distance was measured from five maximal effort place kicks with the standard Gaelic football. A 30-second interval elapsed between all trials. A period of 30-seconds between trials has been used in multiple studies investigating the acute effects of weighted implements on immediate performance (for example, Miller et al., 2020; Reyes & Dolny, 2009). Furthermore, the pilot research phase indicated that 30-seconds allowed sufficient time to measure kick distance. For all trials, participants placed the tee on the identified kicking location on the synthetic grass surface. The testing protocol then commenced, requiring each participant to perform five maximal effort place kicks with the standard Gaelic football. Five seconds prior to each trial the researcher located in close proximity to the participant communicated the number of the respective trial and instructed the participant to perform a maximal effort place kick.
On Test Day 2, participants were randomly assigned to one of two intervention groups: the Weighted Football group (WF) or Standard Football group (SF). The place kicking intervention was then completed, which required participants to perform five maximal effort place kicks with the randomly assigned football. A period of 30-seconds elapsed between all intervention place kicks. Upon conclusion of the final intervention trial, the participant performed their first post-test trial after an interval of 30-seconds. The post-test protocol was identical to the baseline testing protocol. Five test-trials and five intervention trials (WF or SF) were used in this study as multiple studies in the WIT domain have incorporated this number of trials (for example, see Montoya et al., 2009; Wilson et al., 2012). More importantly, however, participant feedback from a pilot phase of research prior to initiation of this study showed that completion of five test-trials and five intervention trials did not result in perceptions of significant neuromuscular fatigue.

A period of 30-seconds between the intervention and post-test phase was utilised as the purpose of this study was to investigate the acute effects of the weighted football intervention on immediate, subsequent place kick distance of a standard Gaelic football place kick. In respect of this purpose, it could, however, be suggested that even less time should have elapsed between the intervention and post-test phases in order to ensure a more accurate understanding of the acute immediate effects of weighted football place kicking on standard football kick distance was obtained. However, it was important to ensure that some rest was achieved between the intervention phase and the post-test phase in order to ensure minimal risk of neuromuscular injury. Furthermore, as it was proposed that the findings of this study may potentially inform the development of acute weighted football protocols for use in the applied setting that directly and immediately impact upon place kicking performance with the standard football (for example, contrast or complex training protocols), a retention test was not included in the testing procedure.
4.4. Data Analysis

A one-way between groups analysis of covariance (ANCOVA) was conducted to compare the impact of the weighted football protocol and standard football protocol on post-test place kick distance after controlling for baseline kick distance. The independent variable was the type of intervention (WF, SF), the dependent variable was post-test kick distance, and pre-test kick distance served as the covariate. The assumptions of linearity, homogeneity of regression slopes, normality of distribution and homoscedasticity were initially assessed. A repeated measures analysis of variance (ANOVA) was then conducted to investigate if there were differences in kick distance between mean pre-test kick distance and the mean of each post-test trial for each group. The assumptions of outliers, normality of distribution and sphericity were initially assessed. However, as there was a need to ensure that there were no significant differences in baseline kick distance between the two groups before proceeding with the repeated measures ANOVAs, an independent samples t-test was initially conducted. The assumptions of outliers, normality of distribution and homogeneity of variances were initially assessed. The alpha level required for significance for all tests was set at $p < 0.05$, with the confidence interval level set at 95%. Partial eta squared ($\eta^2$) was used to assess effect size (Small: $0.01 \leq \eta^2 < 0.06$; Medium: $0.06 \leq \eta^2 < 0.14$; Large: $\eta^2 \geq 0.14$; Cohen, 2013). This analysis was conducted with SPSS (Version 25, Chicago, Illinois, USA).

4.5. Results

A one-way between groups ANCOVA was conducted to compare the impact of the weighted football protocol and standard football protocol on post-test place kick distance after controlling for baseline kick distance. In regard to the assumptions of the ANCOVA, there was a linear relationship between pre- and post-test kick distance for each group, as
assessed by visual inspection of a scatterplot. There was homogeneity of regression slopes as the interaction term was not statistically significant, $F(1,26) = 0.825$, $p = 0.372$. Standardised residuals for each group and the overall model were normally distributed, as assessed by Shapiro-Wilk's test ($p > 0.05$). There was homoscedasticity and homogeneity of variances as assessed by visual inspection of a scatterplot and Levene's Test ($p = 0.273$), respectively. There were no outliers in the data, as assessed by no cases with standardised residuals greater than ±3 standard deviations. The ANCOVA revealed no statistically significant difference in post-test kick distance between the WF and SF groups after adjustment for pre-test kick distance, $F(1, 27) = 2.56$, $p = 0.12$, partial $\eta^2 = 0.09$. Although not statistically significant, mean kick distance was greater following the weighted football protocol compared to the standard football protocol (45.4m ± 0.96m vs 43.2m ± 0.96m). Additionally, it was found that, of the 15 participants in the WF group, nine experienced mean kick distances increases from pre-test to post-test, with one participant experiencing an increase of 8.2m. It should, however, be noted that seven of the 15 participants in the SF group experienced increases in mean kick distance from pre-test to post-test, with one participant experiencing an increase of 6.4m. Adjusted and unadjusted means and variability for post-test kick distance are presented in Table 4.1. Adjusted means represent means that have been adjusted for the purpose of controlling for potential confounding effects of the covariate, i.e., baseline kick-distance.

Table 4.1. Adjusted and Unadjusted Means and Variability for Post-Test Kick Distance with Pre-Test Kick Distance as a Covariate.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weighted</td>
<td>15</td>
<td>46.1</td>
<td>6.03</td>
<td>45.4</td>
<td>0.96</td>
</tr>
<tr>
<td>Standard</td>
<td>15</td>
<td>42.4</td>
<td>7.02</td>
<td>43.2</td>
<td>0.96</td>
</tr>
</tbody>
</table>

N = number of participants; M = mean; SD = standard deviation; SE = standard error. Kick distance measured in metres (m).
Prior to conducting a repeated measures ANOVA per group in order to investigate whether there were differences in kick distance between the mean of the pre-test place kicks and each of the post-test place kicks, an independent samples t-test was conducted in order to ensure that there were no significant differences in baseline kick distance between the two groups. The assumptions of outliers and normality of distribution were satisfied via inspection of a boxplot and the Shapiro-Wilk’s test ($ p > 0.05 $), respectively. There was homogeneity of variances as assessed by Levene’s test for equality of variances ($ p = 0.562 $). The independent samples t-test showed that there was no significant difference between the two group’s baseline kick distance values, $ t(28) = 0.815, p = 0.422 $. For both ANOVAs, the assumptions of normality of distribution and sphericity were satisfied via the Shapiro-Wilk’s test ($ p > 0.05 $) and Mauchly’s Test of Sphericity ($ p > 0.05 $), respectively. Regarding outliers, the SF group had no outliers but there was one outlier among the WF group. However, as this was not a measurement or data entry error, this outlier remained in the subsequent analysis.

This analysis showed that the weighted football did not lead to any significant differences between the six time-points, $ F(5, 70) = 0.93, p = 0.47 $, partial $ \eta^2 = 0.06 $ (Figure 4.3). It was also shown that the standard football did not lead to any significant differences between the six time-points, $ F(5, 70) = 1.03, p = 0.41 $, partial $ \eta^2 = 0.07 $ (Figure 4.3). Therefore, pairwise comparisons were not conducted.
4.6. Discussion

The primary purpose of this study was to investigate the acute effects of a weighted Gaelic football place kicking protocol on subsequent kick distance of standard Gaelic football place kicks among male university students with Gaelic football experience. A further purpose of this study was to investigate whether the weighted football protocol induced a transient increase in post-weighted football kick distance across individual post-test trials to further elucidate the acute effects of the weighted football protocol. With respect to the former, results showed that there were no significant differences in mean post-test kick distance following completion of the weighted football protocol in comparison to
the control condition. Of interest upon further analysis of unadjusted kick distance means from pre- to post-test, slight improvements in mean post-test kick distance were evident following the weighted Gaelic football protocol (mean pre-test kick distance = 45.4m ± 7.15m; mean post-test kick distance = 46.1m ± 6.03m). Furthermore, at an individual level, descriptive statistics showed that some participants in the WF experienced substantial pre-test to post-test increases, ranging from +0.2m to +8.2m. With respect to the latter, analysis of kick distance means per individual post-test place kick revealed that although there were no significant differences, there was a nominal, transient increase in kick distance from Trial 1 (30-seconds) to Trial 4 (2-minutes), with kick distance at each time point being greater than mean baseline distance (Figure 4.3).

The findings of this study align with previous findings within the weighted implement training (WIT) literature, whereby the post-activation performance enhancement (PAPE) concept likely explains (i) the absence of significant difference in mean post-test kick distance, and (ii) the nominal, transient increase in kick distance across each individual post-test place kick following the weighted football protocol. Regarding the findings of the ANCOVA, which revealed no significant difference in mean post-test kick distance between groups, various studies investigating the acute effects of weighted baseball bats on bat velocity of a standard bat have exhibited similar effects, thus indicating the likely importance of implementing sufficient time periods between weighted and subsequent standard implement trials to experience enhanced mean motor skill performance (Montoya et al., 2009; Szymanski, Bassett, Beiser et al., 2012; Szymanski, Beiser, Bassett et al., 2011). Following a between-test-trial rest period of 20-seconds, whereby all post-test trials were completed within 1-minute of the weighted bat warm ups, Szymanski et al. (2011) found no significant improvement in mean bat velocity with a standard bat
following three swings with various weighted bats ($p > 0.05$). A similar finding was also reported by Szymanski et al. (2012) following an identical procedure with weighted bats among a softball cohort. Montoya et al. (2009) reported mean bat velocity of a standard bat to be significantly lower following an over-weighted bat warm up compared to other conditions following a 30-second rest period ($p < 0.05$). The cumulative findings of these studies, substantiated by the findings in the current study, highlight the likely implications of inadequate time intervals between weighted and standard implement trials, and corresponding increases in fatigue, on the elicitation of significant acute increases in mean post-weighted implement motor skill performance. Therefore, it is suggested that these findings are best explained by the PAPE concept (Blazevich & Babault, 2019). However, in regard to the findings of the current study, it is important to note that varied individual responses to the weighted football conditioning protocol were observed, thus illustrating that the optimal time period between the conditioning and subsequent post-test phase may be individual, the acknowledgement of which has been suggested to be of importance to the practitioner (Blazevich & Babault, 2019). Regarding practical implications of the current study, to induce significant and meaningful increases in subsequent mean standard implement performance, the skill acquisition specialist and S&C coach would, most likely, need to commence weighted football place kicks at a time that allows a greater time period to elapse prior to performance with the standard implement. For example, as the five post-test trials were completed 2.5-minutes after completion of the weighted football place kicks, it may be suggested to wait until the end of this time window before instructing the athlete to commence post-weighted football place kicks.
Although the findings of the ANCOVA, which specifically relate to mean post-test performance, do not infer an obvious benefit attributed to the use of the weighted football compared to the standard football control condition, the subsequent analysis of kick distance performance across each individual post-test place kick infers a performance advantage of weighted football use. It was found that there was a nominal enhancement of kick distance that increased transiently across post-test place kicks (Trial 1 to Trial 4) as greater time elapsed, relative to the conclusion of weighted football place kicks. An inverse effect was evident following the standard football control protocol (i.e., kick distance across the first four post-test trials was less than the related baseline value, with the fifth post-test trial measuring just 0.08m more than the related baseline value). Similar transient increases in motor skill performance following a weighted implement warm up protocol were also reported by Wilson et al. (2012) and Kim and Hinrichs (2008) with both studies concluding that 2-minute and 3-minute rest periods, respectively, were required between weighted and subsequent standard implement use in order to observe maximal motor skill increases. In line with the conclusions of Wilson et al. (2012) and Kim and Hinrichs (2008), as the current study also displayed a transient increase in motor skill performance as time intervals increased, the fitness-fatigue model may explain the findings following the weighted football protocol. The model also implies likely kick distance increases with a greater time period between weighted and standard footballs beyond that of the current study and possibly explains the findings of previous studies that used periods of 2-minutes or less resulting in an absence of mean bat velocity improvements (for example, Szymanski et al., 2012). The studies of Wilson et al. (2012) and Kim and Hinrichs (2008) have also referred to post-activation potentiation (PAP) as an explanation of their findings of transient performance increases post-WIT. However, as stated, performance enhancements cannot be attributed to PAP without confirmation.
that an evoked response or twitch potentiation occurred via controlled means at specific activation levels (MacIntosh et al., 2012). Therefore, the PAPE concept more accurately describes the observed transient increases in post-WIT performance in these studies and the current study.

The findings of the current study expand the WIT literature and provide skill acquisition specialists and S&C coaches with a means of eliciting transient increases in kick distance, which is an integral performance variable for Gaelic football goalkeepers. However, the limitations of the current study should be considered. Firstly, the time frame in which the post-test place kicks took place (i.e., 30-seconds to 2.5-minutes post-weighted football place kicks) is a possible limitation as it may not provide sufficient time for fatigue to dissipate. Thus, it is likely that a holistic understanding of the acute effects of this protocol cannot be fully determined from the results of this study. Further, the means of measuring kick distance is also considered a limitation. A more precise mode of measurement would have eliminated the requirement to round down to the nearest metre for each trial. This may have, therefore, resulted in the observation of a significant difference in the effectiveness of the weighted football protocol compared to the standard football. Significant acute improvements in kick distance at later time-points (i.e., post-test Trial 4 and 5) may also have been observed. Additionally, it is suggested that neuromuscular strength levels may augment the magnitude of enhanced performance that may be experienced following an over-weighted warm up protocol (Blazevich & Babault, 2019). Therefore, as participants were not required to be of inter-county playing level, whereby greater neuromuscular strength may be displayed, it is a limitation of this study that the weighted football protocol was not applied to an inter-county athlete population, whereby greater performance enhancements may have been experienced. Finally, although the
participants were experienced Gaelic football players, the fact that participants were not required to be goalkeepers is a potential limitation of this study. As a result of this, it is possible that the participants in the current study had minimal experience place-kicking off the tee as a large proportion of kicks performed in Gaelic football are from the hand.

In conclusion, this study found that the weighted football kicking protocol did not induce a significant (i.e., positive) acute effect on mean place kick distance compared to that of a standard Gaelic football. It is suggested that the time-period (30-seconds to 2.5-minutes) in which the post-test place kicks with the standard Gaelic football were performed did not provide sufficient recovery to facilitate dissipation of fatigue so that a significant mean difference was realised (Robbins, 2005). Therefore, a greater time-interval between weighted and standard Gaelic football place kicks may increase the potential for a significant difference in mean post-test kick distance to be observed. Although such findings are reported, the WF group experienced slight improvements in kick distance (unadjusted means for pre-test to post-test) and a likely meaningful, yet nominal, transient enhancement illustrated by a gradual increase from the 30-second time-point following the weighted football protocol, which peaked 1.5-minutes later. Although this increase was insignificant, these nominal increases in performance may have practical value for the practitioner and athlete in the applied domain. The PAPE concept, therefore, not only explains the absence of significant differences in mean post-test kick distance between groups, which is likely the result of collective post-test place kicks being performed at a time when fatigue had not sufficiently dissipated, but this concept also accurately explains the observation of nominal, transient kick distance increases across each individual post-weighted football place kick from Trial 1-4.
Although the observed acute effects can be explained by the PAPE concept, further research is required to specifically identify the underlying mechanisms responsible for such effects. This research should also assess the effects of a weighted football place kicking protocol on subsequent mean place kicking performance with greater time-intervals between weighted and standard football trials. A longer time-period (>2-minutes) may facilitate further dissipation of fatigue accumulated in the weighted football trials, allowing for potentiation to possibly dominate existing fatigue and subsequently significantly increase mean performance beyond baseline measures (Robbins, 2005). The identification of the optimal time-interval that results in the greatest place kicking performance improvements may further refine the protocol used in this study and provide coaches and goalkeepers with an even more efficient preparatory routine that can be completed prior to the beginning of each playing half. Therefore, identification of the optimal programming of a weighted Gaelic football protocol that significantly enhances acute place kicking performance may provide practitioners with an effective means of enhancing kick-outs that is grounded in high levels of training specificity relative to place kicking. This may potentially provide an alternative or additional warm up strategy for Gaelic football goalkeepers and provide an efficient mode of power development to induce chronic improvements to place kicking.

Additionally, although future research may further elucidate the training and acute effects (i.e., physical performance) of a weighted football on place kicking performance and refine means of implementation, it is also possible that this weighted football protocol can enhance psychological performance. Understanding that this weighted football place kicking protocol can enhance kick distance, it is possible that goalkeepers’ confidence in their kick-out ability may also be enhanced. As it has been reported that a mean of 44
kick-outs are performed per match (Daly & Donnelly, 2018), with long kick-outs playing a critical role in score building (Gamble et al., 2020), enhancing players’ confidence in their kick-out performance is integral as they are frequently and directly involved in match play. Therefore, it is recommended that future research also examines the psychological benefits that accompany physical performance enhancements as a result of weighted Gaelic football place kicking. The findings of the current study, and research that would seek to identify the optimal time interval between weighted and standard Gaelic football place kicks and the psychological benefits of the protocol’s completion, have implications for the practitioner regarding the implementation of a weighted football in complex or contrast training protocols to facilitate the long-term use of these footballs in the applied setting. More traditional means of inducing a PAPE effect on subsequent performance present a plethora of practical challenges to practitioners and athletes; for example, availability of strength training equipment, such as barbells and power racks, in the performance arena in order to perform PAPE inducing exercises such as back squats. Therefore, the findings of this study provide the practitioner and athlete with an efficient and effective means of enhancing goalkeeper kick-out performance that does not inherently present the same practical challenges as other performance enhancing means.
Chapter 5

The Acute Effects of a Weighted Football Training Intervention in Gaelic Football to Maximise Place Kick Ball Velocity

Publication: An original research investigation published in the Journal of Australian Strength and Conditioning (Appendix C)

Publication: A methodological research report published in The Sport Journal (Appendix D)
5.1. Abstract

Weighted implement training induces acute, transient improvements of standard implement motor skill performance. This study investigated the effects of various time intervals post-weighted Gaelic football place kicks on subsequent ball velocity (BV) of the standard football. Fifty-two male Sport & Exercise students’ (19.9 ± 2.29 years) baseline BV with a standard Gaelic football was determined from five maximal effort place kicks. Participants then performed five place kicks with a 600g (25% mass increase) weighted (WF: n = 26) or standard (SF: n = 26) football, with all participants’ standard football BV measured 2-, 4-, 6- and 8-minutes post-protocol. Participants’ perceptions of standard football mass and velocity for each post-weighted football place kick were recorded. A linear mixed model revealed no significant BV differences between- and within-groups. Consequently, with respect to further research, a post-hoc power analysis showed that a sample size of 70 is required for the difference observed to be significant at a 5% level of significance with 80% statistical power. Nevertheless, BV of all post-WF place kicks were greater than baseline, with greatest BV demonstrated at 8-minutes (a nominal 5.4% increase). A linear mixed model, with participants as a random effect, revealed that although none of the model’s independent variables were significant ($p > 0.05$), the WF protocol and time intervals made larger contributions to BV variance than participants’ perceptions of standard football mass and velocity post-warm up. Marginal and conditional $R^2$ values were 5.9% and 76.9%, respectively. Thus, BV variation is explained more by the variability between individual participants’ physical kicking skills than the perceptual measures. While further research with a greater sample size is needed, this weighted football protocol has practical implications for inter-county athletes, whereby maximum BV improvements occur 8-minutes post-weighted football place
kicks, thus serving to increase kick distance, a desirable performance outcome for goalkeepers.

**Key words:** Weighted Implement Training, Overload Principle, Skill Acquisition, Post-Activation Performance Enhancement, Specificity

### 5.2. Introduction

An empirical interest in the acute effects of weighted implements on subsequent motor skill performance with the standard implement has become increasingly evident over the past two decades (Miller et al., 2020). Previous research investigating the acute effects of weighted sporting implements has primarily focused on the effects of weighted baseball equipment on immediate performance of the respective motor skill(s) (for reviews, see DeRenne & Szymanski, 2009; Jermyn et al., 2021a). Many of these studies have identified acute improvements in batting and pitching velocity as a result of the use of such implements (DeRenne, 1982; DeRenne et al., 1992; Van Huss et al., 1962). Additionally, investigations into the acute effects of weighted indoor throws on subsequent standard implement throw performance demonstrated significant improvements in the distance the standard implement was projected compared to a standard implement warm up (p < 0.05) (Bellar et al., 2012; Judge et al., 2010). Although most of the research in this domain focuses on baseball and track and field, and striking sports such as softball, golf, and cricket, (see Szymanski et al., 2012; Hébert-Losier & Wardell, 2021; Feros et al., 2013, respectively), there is a dearth of related research examining the acute effects of weighted footballs on subsequent kicking performance. Enhancements of implement velocity and distance (i.e., how far a football travels), as reported in the aforementioned studies, are also of importance across the various football
codes (such as soccer, American football, rugby and Australian football) (Young & Rath, 2011), and particularly in Gaelic football as highlighted in Chapter 2.

Although research has illustrated the positive, immediate effects of weighted implement protocols, the findings of the previous study (i.e., Chapter 4) displayed the effects of various time intervals post-weighted implement warm up on subsequent performance with the standard implement as kick distance values increased transiently across post-weighted football place kicks with the standard football. Similar findings are also reported in the baseball literature. Following warm up protocols with various weighted bats, Wilson et al. (2012) and Kim and Hinrichs (2008) observed significant transient increases in various markers of batting performance across post-test trials, resulting in these studies suggesting that at least 2- to 3-minutes of rest post-weighted implement use is needed to experience significant bat velocity increases. These findings align with the post-activation performance enhancement (PAPE) literature, which was discussed in Chapters 2 and 4. Specifically, the PAPE effect represents the observation of increased voluntary contractile performance following a preceding conditioning activity. The PAPE literature has routinely reported increased post-conditioning voluntary contractile performance at later time intervals (for reviews, see Krzysztofi, Wilk, Stastny and Golas, 2021; Seitz & Haff, 2016; Wilson et al., 2013), with increased post-conditioning performance relative to baseline measures being observed up to 18.5-minutes post-conditioning protocol (Chiu, Fry, Weiss et al., 2003). Therefore, as the findings of Study 2 (Chapter 4) align with findings in the baseball and PAPE literature, there is a need to investigate the acute effects of various time intervals on subsequent place kicking with the standard football to identify when maximal performance increases are experienced following weighted football place kicks. This would support the development of weighted Gaelic football
warm up protocols that can be completed immediately prior to competition by players who are required to achieve considerable kick distances (i.e., goalkeepers), and may be implemented into long-term training programmes with the aim of achieving increased place kicking performance.

Weighted implement training (WIT) studies have also assessed the effect of weighted implement protocols on participants’ subjective measures of implement mass and velocity upon return to use of standard equipment (see Morimoto et al., 2003; Nakamoto et al., 2012; Otsuji, Abe & Kinoshita., 2002). Subsequent discrepancies between objective reality and subjective opinion upon immediate return to the standard implement have been identified, whereby participants perceive the standard implement to be moving faster, or feeling lighter, in comparison to previous interactions with the same implement; although objective measures indicate a performance decrement. This alteration in a performer’s perception of implement mass and/or velocity as a result of exposure to a previous object is referred to as a kinaesthetic aftereffect (Nakamoto et al., 2012). Altered perceptions of standard implement physical properties have traditionally been deemed advantageous to subsequent performance as it has been suggested that the performer may subsequently swing the standard bat or throw the standard ball with greater speed and force following use of the over-weighted implement, i.e., the performer is subsequently presented with an increased landscape of affordances (Scott & Gray, 2010). This suggestion further bolstered the belief that weighted implement protocols are an efficacious warm up strategy. However, recent research has demonstrated the degrading effect of weighted implements on subsequent motor skill performance with a standard implement in interceptive striking tasks with a dynamic target (Nakamoto et al., 2012). While place kicking involves intercepting a stationary target, thus decreasing temporal accuracy
demands, assessing the effect of a weighted Gaelic football place kicking protocol on participants’ perceptions of subsequent standard football mass and velocity post-weighted protocol would be informative for the practitioner and may potentially highlight positive psychological effects associated with weighted implement use that may benefit performance, in addition to potentially improved physical performance. Similarly, investigating the corresponding potential of eliciting a kinaesthetic illusion and its implications on objective measures of performance (i.e., standard football velocity), would further elucidate the effects of this tool’s use immediately prior to competition.

Findings from studies investigating the acute effects of weighted implement warm up protocols infer acute improvements of standard implement velocity and distance. Therefore, the primary purpose of the current study was to assess the acute effects of selected time intervals between weighted and standard Gaelic football place kicks on ball velocity (BV) to ensure that the greatest acute performance improvement of a standard Gaelic football place kick was observed and measured among male university students with Gaelic football playing experience. Due to data collection instrument requirements and measures of control of the environment, conducting data collection indoors in a more controlled setting was deemed essential for this study, hence BV served as the dependent variable. The current study, therefore, took place in the Host Institution’s Human Performance Laboratory. The secondary purpose of this study was to investigate whether participants’ subsequent perceptions of standard football mass and velocity post-weighted football warm up, the different time intervals, or the warm up implement used, had the greatest impact on BV. It was hypothesised that the weighted football protocol would induce greater acute improvements in BV compared to the standard football, with the greatest BV values observed with greater time intervals (i.e., 8-minutes). It was also
hypothesised that the weighted football and the various time intervals would have a greater influence on BV compared to the psychological after-effect of place kicking the weighted football (i.e., altered perceptions of football mass and velocity).

5.3. Methods

As this study took place during the COVID-19 pandemic, the experimental design was developed in full adherence to local, national and international health and safety guidelines (Jermyn et al., 2021b; Appendix D).

5.3.1. Participants

Fifty-two male Sport & Exercise undergraduate university students participated in this study. Participants were randomly assigned to a Weighted Football group (WF) (n = 26; age = 20.7 ± 2.88 years; number of playing years = 12.6 ± 5.43 years) or Standard Football group (SF) (n = 26; age = 18.6 ± 3.36 years; number of playing years = 10.0 ± 4.78 years). Participants were free from injury and provided written informed consent. Ethical approval was sought and granted by the Host Institution’s Research Ethics Committee.

5.3.2. Materials and Experimental Set-Up

The weighted Gaelic football (The Green Ball Co., Dublin, Ireland; Figure 5.3) used in this study weighed 600g, a 25% increase from the standard 480g game ball. The size and outer panelling of the weighted football was identical to that of a standard Gaelic football, with the additional mass due to a heavier inner bladder. The standard football used in this study was a size-5 O’Neills All-Ireland Gaelic football (O’Neills Irish International...
Sports Co. Ltd., Belfast, Northern Ireland; Figure 5.3), inflated to a pressure of 9.75-10 pound per square inch (PSI), resulting in the recommended mass of 480g (GAA, 2017). All experimental and intervention trials were performed with an unused football and a 3cm kicking tee (The Green Ball Co., Dublin, Ireland). This study took place in the Host Institution’s Human Performance Laboratory. Prior to initiation of this study, a pilot study was conducted with six participants to define features of the experimental set-up that are subsequently detailed, such as the placement of experimental apparatus, and obtain feedback from place kickers in order to ensure the experimental set-up did not impede upon the performance of a maximal effort place kick. A Schutt kicking net (Litchfield, Illinois, USA), measuring 2.1m high and 1.5m wide, was situated in the centre of the laboratory, therefore affording participants the ability to perform a full, unrestricted approach to the ball when performing a place kick. All kicks were executed from a distance of 1.5m from the centre of the net to ensure participants were not at risk of making contact with the kicking net or its frame during the follow-through phase of each place kick. A Bushnell Radar Velocity Gun (Bushnell, Overland Park, Kansas) was used to measure ball velocity (BV). The radar velocity gun was situated behind the goal at a height of 1m and a distance of 2.75m from the front of the kicking net to ensure a football would not contact the radar velocity gun as it was kicked into the net (Figure 5.2). However, pilot research showed that there was inconsistent detection of BV when the football entered the net at a height of 25cm or lower. Therefore, a 1m rope was interwoven horizontally into the net at a height of 0.65m, with additional 1m ropes interwoven vertically at either end of the horizontal rope. This rope formation (Figure 5.1) served the purpose of guiding ball trajectory towards the centre of the net in order to facilitate accurate and reliable measurement of BV. A video camera (Canon Legria HFR606, Tokyo, Japan) was placed adjacent to the kicking location to record all trials.
**Figure 5.1.** Experimental set-up in the Human Performance Laboratory.

**Figure 5.2.** Experimental set-up including the velocity gun, kicking location, kicking net, participant (P), footballs (F) and researcher (R) - adopted from Jermyn et al. (2021b), see Appendix D.
5.3.3. Procedure

In this study, all participants took part in a single experimental session. This was deemed necessary in order to support a large sample size and to avoid the risk of likely issues with participant attrition rates if multiple experimental sessions per participant were utilised to focus on each individual post-intervention time point per session. Upon arrival to the facility, participants completed a 5-minute warm up, comprising of dynamic stretches targeting the quadriceps, hamstrings, hip flexors, adductors, gluteals and gastrocnemius-soleus-complex, and bodyweight movements targeting the mobilised areas (two sets of: five bodyweight squats; three bodyweight lunges per leg). Upon completion, data collection commenced with participants performing five maximal effort place kicks with a standard Gaelic football in order to determine baseline BV. Prior to the five test-trials, participants performed two familiarisation trials with the standard Gaelic football. Between all trials, participants had 30-seconds to place an unused football on the kicking tee and prepare for the upcoming trial. A period of 30-seconds between trials has also been used in multiple studies investigating the acute effects of weighted implements on immediate performance (for example, Miller et al., 2020; Reyes & Dolny, 2009). Furthermore, the pilot research phase confirmed that a 30-second inter-trial period was a sufficient amount of time for a new football to be placed on the tee and for the lead researcher to note and save the BV value of the preceding place kick and to reset the radar velocity gun. Following the fifth and final trial to determine baseline BV, a 15-minute wash-out period was completed. Upon conclusion of the wash-out period, participants were randomly assigned to either the WF or SF group. Prior to a five-trial maximal effort place kick warm up protocol with the assigned football, participants performed two familiarisation trials with their respective football. As implemented in the baseline measure of BV, there was a 30-second time interval between all trials. Following the fifth
and final warm up trial, all participants performed a single maximal effort place kick with the standard Gaelic football 2-, 4-, 6- and 8-minutes post-warm up. Standard football place kick performance was analysed at these particular times as Wilson et al. (2012) showed that performance with the standard implement post-weighted implement use significantly increased across this time periods. BV of all trials (pre-test, intervention protocol and post-trials) was recorded with the radar gun.

Participants also made subjective judgments of the mass of the respective football and velocity of the corresponding place kick upon conclusion of each post-warm up place kick in comparison to the five baseline place kicks (i.e., place kicking a standard Gaelic football). A five-point scale was used to inform each judgment in a consistent manner: apparently lighter/faster (5), slightly lighter/faster (4), equal (3), slightly heavier/slower (2), and apparently heavier/slower (1), as per the methodologies of Nakamoto et al. (2012) and Otsuji et al. (2002). Upon completion of each place kick, participants verbally reported their perceptions of football mass and velocity, which was then written down by the lead researcher on a scoring sheet, and subsequently saved on an Excel spreadsheet following each experimental session. Following all place kicks (pre-test, intervention phase, and post-test), participants were informed of the BV of the respective trial prior to the subsequent place kick. The purpose of this was to encourage sustained maximal effort throughout the testing session. However, during the post-test place kicks, participants were informed of the respective place kick’s BV after stating their perception of football mass and velocity. This experimental procedure is detailed in Figure 5.3. For all place kicks, participants were instructed to: (1) “kick with maximal effort”, and (2) “kick within the rope formation”. Five seconds prior to each trial, the researcher gave the instruction:
“This is your (trial number) maximal effort place kick”. Participants were permitted to approach all place kicks as they would in a game situation.

<table>
<thead>
<tr>
<th>WF Group</th>
<th>SF Group</th>
<th>Velocity</th>
<th>Perceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Test</td>
<td>x5 kicks</td>
<td>x5 kicks w/ Standard Ball</td>
<td>N/A</td>
</tr>
<tr>
<td>15-minute wash-out period</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intervention</td>
<td>x5 kicks</td>
<td>x5 kicks w/ Standard Ball</td>
<td>N/A</td>
</tr>
<tr>
<td>Post-Test</td>
<td>1 kick performed 2, 4, 6 &amp; 8-mins post intervention</td>
<td>Ball Velocity Rated 1-5</td>
<td>Ball Weight Rated 1-5</td>
</tr>
</tbody>
</table>

Figure 5.3. Experimental Procedure, including the 600g weighted Gaelic football and the 480g standard Gaelic football.

5.4. Data Analysis

As there have been no independent investigations into the validity and reliability of the Bushnell radar velocity gun that was used specifically in this thesis, there was a need to assess the measurement accuracy of the radar gun. Therefore, the level of agreement of BV measures between the radar gun used in the study and a Bushnell Speedster III (Bushnell, Overland Park, Kansas) was assessed via Intra-class Correlation Coefficient (ICC). To assess the test-retest reliability of the radar gun used in this study, the level of agreement of the radar gun’s measurement of BV on three separate occasions was assessed via ICC. Each session consisted of 30 trials whereby a custom-built football projection machine, set at a speed of 1,000rpm, projected a standard size-5 O’Neills Gaelic football towards the speed guns. A customised black cover, with a 50cm slit down
the centre, was placed directly in front of the projection machine in order to occlude the spinning wheels from the radar guns to ensure the displayed BV value was that of the oncoming football. For both reliability analyses, ICC estimates and their 95% confidence intervals were calculated based on absolute-agreement and a 2-way mixed-effects model. For inter-device reliability, average measures results are reported. For intra-device reliability, single measures results are reported. The design of the reliability study and the subsequent reporting of its results are based on the recommendations of Koo and Li (2016).

To ensure that the use of mean pre-test BV did not neglect significant variation in BV among each respective group’s pre-test trials, a linear mixed model per group (WF or SF) was performed to investigate whether statistically significant differences existed within each group’s pre-test trials. A linear mixed model, including both groups (WF or SF) and each time point (mean baseline BV, BV at 2-, 4-, 6- and 8-minutes), was subsequently conducted to investigate if statistically significant differences in BV were present between the groups and across the time-points. Finally, a linear mixed model analysis was also carried out to investigate how much of the variation in BV was explained by the predictor variables: perception of football mass, perception of football velocity, group (WF, SF), and time (2-, 4-, 6-, and 8-minutes). Perception of football mass and perception of football velocity served as fixed effects with participant as a random effect. Variance Inflation Factor values were calculated for each of the respective predictor variables in order to ensure multicollinearity was not present in the model, where values >10 would be considered particularly problematic (Pallant, 2010). This was not the case in the present study. Marginal and Conditional R² were used to determine the percentage of variation in BV explained by the fixed effects only and by both fixed and random effects
together, respectively. The model assumptions of residuals being normally distributed and homoscedastic were checked using Shapiro-Wilk’s and Breusch-Pagan’s tests, respectively, for each linear mixed model. Data were assessed for outliers, as assessed by boxplot. All statistical test results were interpreted using a 5% level of significance. Partial eta squared ($\eta^2$) was used to assess effect size (Small: $0.01 \leq \eta^2 < 0.06$; Medium: $0.06 \leq \eta^2 < 0.14$; Large: $\eta^2 \geq 0.14$; Cohen, 2013). All statistical analysis was performed using R Statistical Software (version 4.0.4; R Foundation for Statistical Computing, Vienna, Austria).

5.5. Results

Results revealed that the inter-device reliability was 0.88 [95% CI, 0.75 – 0.94], indicating good to excellent reliability between the two devices (Koo & Li, 2016). Test-retest reliability was 0.85 [95% CI, 0.75 – 0.92], indicating good to excellent BV measurement reliability across all sessions (Koo & Li, 2016).

In regard to the initial linear mixed model analysis per group, the assumption of normality of distribution was satisfied via Shapiro-Wilk’s test ($p > 0.05$). Outliers were identified in both models, however, as these outliers were not data entry or measurement errors, they remained in the subsequent analysis. While the assumption of sphericity was satisfied via Mauchly’s Test of Sphericity when analysing the WF sample ($p > 0.05$), this assumption was violated when analysing the SF group ($p < 0.05$), therefore the Greenhouse-Geisser correction was applied. The initial linear mixed model analysis per group revealed that there were no significant differences in BV among the pre-test trials
for the WF $F(4, 100) = 1.61$, $p = 0.178$, partial $\eta^2 = 0.061$, and SF $F(2.7, 68.6) = 1.11$, $p = 0.349$, partial $\eta^2 = 0.042$, groups (Figure 5.4).

**Figure 5.4.** 95% confidence intervals of mean ball velocity (km/h) for the Standard Football group (left) and Weighted Football group (right) across the 5 pre-test trials (Pre1 – Pre5).

Consequently, mean baseline BV was used for the subsequent linear mixed model that investigated if statistically significant differences in BV were present between the groups and across the time-points. Outliers were present, however, as these were not measurement or data entry errors, the values remained in the subsequent analysis. The assumptions of residuals being normally distributed and homoscedastic were satisfied ($p > 0.05$). Sphericity was also assumed as indicated by Mauchly’s Test of Sphericity ($p > 0.05$). Results of the linear mixed model revealed no significant interaction effect between group and time, $F(4,200) = 2.22$, $p = 0.069$, partial $\eta^2 = 0.040$, while there was no significant main effect for time, $F(4,200) = 2.38$, $p = 0.053$, partial $\eta^2 = 0.050$, or group, $F(1,50) = 2.45$, $p = 0.124$, partial $\eta^2 = 0.160$. Therefore, pairwise comparisons were not conducted. As the interaction effect was insignificant, a post-hoc power analysis was conducted with respect to future research participant recruitment. This analysis found that a minimum sample size of 70 participants (not including withdrawals) would be required.
in order for the difference observed to be statistically significant at a 5% level of significance with 80% statistical power. Although there were no significant main or interaction effects, observation of BV mean scores across the four time points post-intervention revealed the WB group experienced increased BV at each of the four post-test time points relative to related baseline values (Figure 5.5).

The greatest BV value of the WB group occurred 8-minutes post-intervention. In contrast, observation of BV mean scores across the four time points following the SF intervention revealed decreased BV values at each of the first three post-test time points relative to related baseline values, with only a 0.1km/h increase observed at the 8-minute time point in comparison to SF mean baseline BV (Figure 5.5).

Finally, a linear mixed model, with participant as a random effect, was conducted to investigate how much of the variation in ball BV was explained by the predictor variables
(group, time, perception of football mass, and perception of football velocity). The resulting model satisfied the assumptions of residuals being normally distributed and homoscedastic ($p > 0.05$). One outlier was present, however, as this outlier was not a data entry or measurement error, it remained in the analysis. There was no evidence of multicollinearity, as assessed by Variance Inflation Factor with all values being less than 2. The Marginal and Conditional $R^2$ values were 5.9% and 76.9%, respectively. Thus, BV variation is explained more by variability between individual participants’ physical kicking skills as opposed to the perceptual measures. Regression estimates, confidence intervals and p-values are presented in Table 5.1.

Table 5.1. Linear mixed model ($n = 52$) results for ball velocity with time, group, perception of football mass and perception of football velocity as fixed effects and participants as a random effect. Marginal and conditional $R^2$ values were 5.9% and of 76.9%, respectively.

<table>
<thead>
<tr>
<th>Ball Velocity</th>
<th>Regression estimates</th>
<th>95% Confidence Intervals</th>
<th>p-value</th>
<th>Effect size (Partial $\eta^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>84.2</td>
<td>79.7 - 88.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perception of Mass</td>
<td>0.0</td>
<td>-1.2 - 1.2</td>
<td>0.971</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Perception of Velocity</td>
<td>0.5</td>
<td>-0.7 - 1.6</td>
<td>0.432</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>4-min time point†</td>
<td>-0.7</td>
<td>-2.2 - 0.9</td>
<td>0.408</td>
<td></td>
</tr>
<tr>
<td>6-min time point†</td>
<td>-0.2</td>
<td>-1.8 - 1.4</td>
<td>0.790</td>
<td>0.040</td>
</tr>
<tr>
<td>8-min time point†</td>
<td>1.3</td>
<td>-0.3 - 2.8</td>
<td>0.119</td>
<td></td>
</tr>
<tr>
<td>Group (Standard)*</td>
<td>-3.7</td>
<td>-7.7 - 0.3</td>
<td>0.074</td>
<td>0.060</td>
</tr>
</tbody>
</table>

†Time points are in reference to the 2-minute time point; * Group (Standard) is in reference to the Weighted Football group.

The effects of the footballs used in the intervention phase (WF or SF) on subsequent perceptions of standard football mass and velocity across the post-test phase are presented in Table 5.2. It is evident that the participants in the WF group subsequently perceived the standard football to weigh less and to be moving faster compared to the pre-test (i.e., normal conditions). In contrast, however, participants in the SF group subsequently perceived the standard football to be heavier and to be moving slower compared to normal conditions.
Table 5.2. Mean ± SD perceptions of standard football mass and velocity post-warm up.

<table>
<thead>
<tr>
<th>Perception of Football</th>
<th>2-minutes</th>
<th>4-minutes</th>
<th>6-minutes</th>
<th>8-minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weighted Football (WF) group (n = 26)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perception of Football Mass</td>
<td>3.5 ± 0.95</td>
<td>3.4 ± 0.80</td>
<td>3.2 ± 0.88</td>
<td>3.2 ± 0.98</td>
</tr>
<tr>
<td>Perception of Football Velocity</td>
<td>3.5 ± 0.71</td>
<td>3.5 ± 0.90</td>
<td>3.4 ± 0.95</td>
<td>3.4 ± 0.90</td>
</tr>
<tr>
<td>Standard Football (SF) group (n = 26)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perception of Football Mass</td>
<td>3.0 ± 0.82</td>
<td>2.8 ± 0.85</td>
<td>2.5 ± 0.81</td>
<td>2.8 ± 0.80</td>
</tr>
<tr>
<td>Perception of Football Velocity</td>
<td>3.2 ± 0.59</td>
<td>3.0 ± 0.89</td>
<td>2.9 ± 0.80</td>
<td>3.0 ± 0.75</td>
</tr>
</tbody>
</table>

5.6. Discussion

In response to the results of the Study 2 (Chapter 4) that showed acute transient increases in place kicking performance post-weighted football warm up, it was deemed necessary to investigate the acute effects of selected time intervals post-weighted Gaelic football place kicks on ball velocity (BV) of a standard Gaelic football place kick among male university students with Gaelic football playing experience. This served as the primary purpose of the Study 3. Further, as the use of weighted implements has been shown to subsequently alter performers’ perceptions of implement mass and velocity upon return to the standard implement, this study also explored whether participants’ subjective measures of standard implement mass and velocity post-weighted implement use, the different time intervals, or the mass of the implement used in warm up trials, had the greatest impact on post-warm up standard football velocity. Findings of this study showed that there were no significant BV differences across the various time points following the weighted and standard football conditions. Therefore, the post-hoc power analysis was conducted whereby findings suggested that an increase of 18 (i.e., n = 70) participants would have resulted in a statistically significant outcome of the intervention (at a 5% level of significance with 80% statistical power). In light of this analysis, further research with a larger sample is required. While results were insignificant, observation of BV values indicated that the 5-trial weighted Gaelic football place kicking protocol induced
subsequent acute improvements in standard football velocity at each of the four post-intervention time points (2- to 8-minutes), with each respective value being greater than mean baseline BV (Figure 5.5). Further, the increase observed 8-minutes post-weighted football place kicks represented a nominal 5.4% increase in standard Gaelic football velocity, the greatest increase across each of the four post-intervention place kicks. In contrast, the standard Gaelic football intervention primarily resulted in a subsequent decrease in standard Gaelic football velocity, with BV of the place kicks at 2-, 4- and 6-minutes being less than the SF group’s mean baseline BV. The place kick at 8-minutes represented just a 0.1km/h increase in BV compared to the group’s mean baseline BV. Therefore, although changes were insignificant, it is suggested that these findings have significance for practitioners in the inter-county setting, where performance of five place kicks with a weighted Gaelic football, followed by individual place kicks performed 2-, 4-, 6- and 8-minutes post-intervention with a standard Gaelic football, potentially result in the greatest increase in BV being observed at the 8-minute mark. As discussed in the Literature Review (Chapter 2), this may result in the emergence of additional passing affordances further downfield that may aid ball distribution to support the creation of scoring opportunities. The efficacy of utilising this protocol as a pre-competition warm up strategy, and its potential implementation into long-term training programmes is, therefore, supported. Additional support for weighted football place kicks is seen in the results of the post-hoc power analysis as findings suggest that the sample size in this study was the predominant factor that led to insignificant BV differences.

This finding of increased performance at delayed time points aligns with existing post-activation performance enhancement (PAPE) literature. For example, a systematic review with meta-analysis of 11 studies that investigated the PAPE effect showed that regardless
of the intensity of a bench/ chest press exercise, a greater effect on subsequent bench press	hrow performance is observed after 5- to 7-minutes (Krzysztofi et al., 2021). Similar
results are observed when considering varied intensities of the bench/ chest press,
with intensities below 85% 1-repetition maximum (1RM) having a greater effect on
subsequent performance after 5- to 7-minutes (effect size (ES) = 0.48) compared to after
15-seconds to 4-minutes (ES = 0.4). Considering intensities above 85% 1RM during the
conditioning activity, a similar effect is also observed where performance is greater after
5- to 7-minutes (ES = 0.3) and ≥8-minutes (ES = 0.29), whereas 15-seconds to 4-minutes
resulted in a negative effect (ES = -0.13) (Krzysztofi et al., 2021). While this review
article referred to upper body performance, systematic reviews with meta-analyses have
revealed similar effects when including studies that investigate PAPE effects in the upper
and lower body. For example, from 32 included studies, Wilson et al. (2013) showed that
a greater enhancement effect is observed between 7- and 10-minutes post-conditioning
protocol (ES = 0.7) compared to the enhancement at 3- to 7-minutes (ES = 0.54) post-
conditioning activity. Similarly, from 47 included studies, Seitz and Haff (2016) showed
that a greater enhancement effect is observed between 5- and 7-minutes post-conditioning
protocol (Overall ES = 0.49; ES = 0.62 for stronger individuals and 0.31 for weaker
individuals) compared to the enhancement observed immediately post-conditioning to the
4-minute mark (Overall ES = 0.17; ES = 0.15 for stronger individuals and 0.28 for weaker
individuals). Furthermore, these review articles have shown that a considerably superior
PAPE effect can be experienced in the lower body. Wilson et al. (2013) found a lower
body ES of 0.42 compared to just 0.17 for the upper body, with Seitz and Haff (2016)
showing an ES of 0.31 and 0.5 for jumping and sprinting, respectively, compared to 0.23
for upper-body ballistic activities.
With respect to studies that have investigated potential alterations in participants’ perceptions of standard implement physical properties post-weighted implement use, Otsuji et al. (2002) observed an absence of significant changes in standard bat velocity ($p > 0.05$), although participants perceived the standard bat to be of less mass and greater velocity compared to pre-test. In particular, the first swing post-weighted implement warm up was significantly lower than pre-test ($p < 0.05$), with participants concurrently perceiving bat mass to be lighter and bat velocity to be faster compared to pre-test, thus illustrating a kinaesthetic or sensory illusion. The authors concluded that the effect of the weighted bat warm up on subsequent performance with the standard bat was exclusively psychological. In contrast, Morimoto et al. (2003) found that six and 18 pitches with an under-weighted baseball, and an 18-trial combination warm up condition (throws with an over-weighted, standard, and under-weighted baseball), resulted in significant acute improvements of standard baseball pitching velocity ($p < 0.05$), concurrent to altered perceptions of standard baseball mass in post-warm up trials. Thus, this study observed that the weighted implement protocols induced positive physical and psychological effects. In the current study, analysis of mean BV scores across post-WF warm up trials, and the corresponding ratings of participants’ perceptions of football mass and velocity, show that the WF group experienced a physical performance improvement (i.e., increased BV at each time point) and perceptions of decreased standard football mass and increased standard football velocity compared to pre-test. Although these results collectively illustrate that weighted implement warm up protocols induce acute physical and psychological effects, previous studies have not statistically analysed whether it was the weighted implement induced physical effects or perceptual alterations that had the greatest impact on subsequent objective measures of motor skill performance with the standard implement. Findings from the linear mixed model suggest that the weighted
football condition contributed the most to BV, with the two perceptual measures contributing the least (Table 5.1). This suggests that it is likely that, in combination with time, the physical effect of the weighted football, and not the alteration of participants’ perceptions of standard football mass and velocity, results in acute improvements in subsequent standard football velocity, ultimately peaking 8-minutes post-warm up.

While the exact underlying mechanism responsible for the observed acute improvements in BV is unknown, research and theoretical frameworks from the motor control and physiology domains may describe what is responsible for the observed effects (Prieske et al., 2020; van Polanen & Davare, 2015). Research that has investigated the relationship between muscular force generation and physical interaction with objects of differing mass has revealed that force applied to the latter object is influenced by the physical interaction with the former object (Johansson and Westling, 1988). Specifically, Johansson and Westling (1988) showed that the rate profiles of the initial application of force to the latter object following an unexpected weight change were programmed on the basis of the mass of the object that was previously manipulated (i.e., application of forces to a subsequent lighter object were in excess of what was required to overcome gravity). Thus, the scaling of force to a current action is based on sensorimotor memory established as a result of a preceding physical interaction with an object of relative greater mass. It has also been identified that the initial stages of the dynamic phase of the preceding movement (i.e., not a stationary phase) are responsible for the creation of the sensorimotor memory effect experienced on subsequent trials (van Polanen and Davare, 2019). It should be noted, however, that the initial dynamic phase (1.2s lift prior to a stationary hold) in the study of van Polanen and Davare (2019) was larger than the 9.1 ± 0.7ms duration of foot-ball contact (Nunome, Lake, Gerogakis & Stergioulas, 2006). Nonetheless, these findings
suggest that minimal dynamic, physical interaction with an object of a heavier mass (i.e.,
kicking the weighted football where, theoretically, greater intra-individual force, relative
to kicking a standard football, is needed to achieve a constant (i.e., maximal) BV value
with both implements) may result in a subsequent sensorimotor memory effect when
interacting with an object of less mass. This may, therefore, potentially lead to
improvements in maximal effort place kicking performance. To further support the
findings of the current study, van Polanen and Davare (2015) found that not only force
scaling, but perceptual estimates of the physical properties of the object that was
subsequently manipulated, were influenced by the preceding lift. That is, an initial
physical dynamic interaction with heavier objects not only results in force scaling in
subsequent interactions with lighter weights being dependent on the preceding action, but
that an individual will perceive the mass of the lighter object to be of less mass than if the
preceding action involved manipulation of a lighter mass, or one that is equal to the mass
of the object subsequently manipulated. This concurs with the findings of the current
study, whereby participants in the WF group reported sensations of decreased standard
football mass post-weighted football warm up with mean perceptions of standard football
mass and velocity values of the SF group being closer to an ‘equal’ rating. Although the
findings of Johansson and Westling (1988) and van Polanen and Davare (2015, 2019)
may explain the observed effects within the current study, the fact that (i) there was an
absence of direct assessment of force generation when kicking both footballs, (ii) a series
of place kicks with a football of a particular mass preceded a series of place kicks with a
football of less mass, and (iii) participants were aware of when a potential weight change
occurred post-intervention, potentially degrades the possibility that it was, at least solely,
a sensorimotor memory effect as a result of the use of the weighted football that resulted
in BV improvements. This is further supported by the fact that BV improved trial by trial in the post-test phase, thus illustrating that time had some influence on post-warm up BV.

Due to the observed effect of time on BV, the PAPE effect framework may also explain the observed post-weighted football velocity effects in the current study. The PAPE framework states that post-conditioning improvements in voluntary performance typically represent a 1-13% performance enhancement (compared to pre-conditioning measures), whereby the largest subsequent effect is observed ≥7-minutes post-conditioning contraction (Prieske et al., 2020). As the design and subsequent results of the current study encompass each of the above features, it is reasonable to suggest that increases in muscle temperature, muscle and muscle fibre water content and/or muscle activation, each of which are suggested underling factors responsible for PAPE (Babault & Blazevich, 2018), may have resulted in the observed effects in the current study.

Although the observed effects of acute increases in BV following weighted Gaelic football place kicks support the efficacy of this protocol’s implementation in the applied setting, future research is needed to further refine the protocol’s design. Specifically, further research is required to identify the influence, or potential lack thereof, of the post-intervention place kicks that take place at the 2-, 4- and 6-minute time points. As the observed increase in post-weighted football BV infers a PAPE effect (Prieske et al., 2020), it is unknown if the place kicks performed at the 2-, 4- and 6-minute time intervals are required to sustain the underlying mechanisms proposed to support the PAPE effect, such as increased muscle temperatures, muscle and muscle fibre water content and/or muscle activation, so that increased BV values at the 8-minute time point can be obtained.
Therefore, it is proposed that future research is required to identify if BV of a standard Gaelic football 8-minutes post-weighted Gaelic football place kicks is enhanced, maintained, or degraded if the preceding place kicks with a standard Gaelic football at each of the previous time-points are removed. It is also suggested that future research examines the chronic training effect of the weighted Gaelic football protocol that was used in the current study on BV of a standard Gaelic football place kick, as well as the potential retention of improved BV beyond the conclusion of the respective weighted Gaelic football intervention. As the research detailed in this thesis to date has primarily included university students and club level players, it is also suggested that future research solely includes inter-county Gaelic football goalkeepers in the participant sample and analyses results on an individual basis which is purported to be the preferable statistical approach to the study of high performing athletes (Sands, Cardinale, McNeal et al., 2019).

While such results were observed and the aforementioned recommendations are provided for future research, the limitations of this study should be noted. Firstly, the level of expertise was not controlled for as participants were randomly assigned to one of two experimental groups. However, when referring to the descriptive statistics that detail the Gaelic football playing experience per group, both groups had at least ten years of playing experience. Furthermore, the addition of a non-training group, which is absent in the current study, may provide further insight into the efficacy of the weighted football protocol. Exclusion of a non-training control group does not allow for the determination of whether implemented experimental warm up protocols are unique in their ability to evoke observed immediate performance improvements of post-warm up protocol performance (Blazevich & Babault, 2019). However, as the aim of this study was not to assess the absolute effect of the task-specific practice, but to identify the acute effects of
selected time intervals between weighted and standard Gaelic football place kicks, only a standard Gaelic football control group was deemed necessary. An additional limitation of this study is the likely variance in ball trajectories and its impact on accuracy of BV measurement with the radar gun. Although the radar gun manufacturers state that the radar gun has a measurement accuracy margin of error of ±2.0km/h, and an angle of incidence of ≤12 degrees between object trajectory and the radar gun does not affect measurement accuracy, deviations in ball trajectory likely implicate measurement accuracy due to the relatively fixed direction that the radar gun was pointed. While attempts were made to control for this by requiring participants to kick within the rope formation so that ball trajectories closely aligned with the radar gun, it is suggested that additional accuracy constraints to control for trajectory deviations would have negatively affected participants’ intentions to place kick with maximal effort. Finally, it is important to note that participants were aware that they may subsequently use a weighted football in advance of commencement of this study. It was necessary for the physical properties of the weighted football to be detailed in the Information Sheet; therefore, it is possible that this prior knowledge may have impacted upon their place kick performance and the reported perceptions of standard football mass and velocity post-weighted football use.

In conclusion, this study identified that across an 8-minute time period post-weighted Gaelic football place kicks, the greatest increase in BV occurred at the 8-minute time point, with BV at each of the four post-intervention time points being greater than the WF group’s mean pre-intervention BV. Therefore, this protocol may be implemented in the minutes preceding each playing half, or in practice environments, to acutely improve goalkeepers’ kick-out BV. Acute improvements in BV may facilitate kick-outs of greater
distance (i.e., the emergence of additional affordances), a performance outcome deemed desirable in Gaelic football due to (i) the prevalence of long kick-outs (>32m) in match play, (ii) the expansive playing surface (145 x 90m), (iii) the introduction of the ‘Mark Rule’ to further encourage long kick-outs, and (iv) the potential to create scoring opportunities from long kick-outs. However, it has been shown that there can be substantial inter-individual recovery duration variability (Blazevich & Babault, 2018), thus making it difficult to generalise the effects of different time intervals between weighted and standard Gaelic football place kicks on subsequent standard football velocity. Therefore, it is suggested that skill acquisition specialists and S&C coaches identify the acute effects of each of the implemented time intervals per goalkeeper, if feasible, prior to implementing a protocol akin to that recommended in the current study. While the findings of the current study provide seminal and valuable insights into the use of weighted Gaelic footballs in the applied setting as a warm up activity, the absence of significant differences need to be carefully considered. However, the post hoc power analysis, which suggested that a sample size of 70 participants would result in a statistically significant outcome of the intervention, provides important information for researchers that seek to conduct similar research, which may ultimately provide even greater support for the use of weighted Gaelic footballs in the same manner as proposed in the current study.
Chapter 6

The Effects of a Weighted Football Intervention on Ball Velocity of a Standard Football Place Kick among Inter-County Gaelic Football Goalkeepers: A Single-Subject Designed Study

Publication: An original research investigation published in Sports’ Special Issue titled ‘Acute Resistance Exercise: Performance Effects on Competitive Athletes’

(Appendix E)
6.1. Abstract

Weighted football place kicking acutely enhances ball velocity (BV) of subsequent standard football place kicks. However, there is a dearth of research examining the long-term effects of such interventions, with less evidence in existence among high performing athlete cohorts. Therefore, the purpose of this study was to investigate the individual effects of a 4-week, 8-session weighted Gaelic football intervention on BV of standard Gaelic football place kicks among six inter-county male Gaelic football goalkeepers. This research design was based on a pre-, mid-, post- and retention-test design. A linear mixed model analysis was employed, with time and participants as fixed effects, and number of place kicks per testing session as a random effect. Post-hoc tests revealed significant changes in BV for five of the six participants ($p < 0.05$), with three participants experiencing significant BV increases from pre-test to post-test ($p < 0.05$), while no significant differences were found between post-test and retention-test. The remaining three participants experienced no significant BV differences from pre-test to post-test and retention-test. Among male inter-county goalkeepers during pre-season and in-season phases, the findings suggest that a weighted football place kicking intervention can be a time-efficient means of maintaining and enhancing BV, and resultantly kick distance.

Key words: Goalkeepers; Kick-Out; Overload; Skill Acquisition; Gaelic Football
6.2. Introduction

While weighted implement training (WIT) research has routinely investigated the acute effects of brief weighted implement protocols on immediate motor skill performance with the standard implement, there has also been a concurrent empirical interest in the chronic effects of WIT (for a baseball review, see Caldwell et al., 2019). A multitude of studies have investigated the effects of multi-week WIT interventions on motor skill performance with the standard implement across a variety of sports. For example, Marsh et al. (2018) found that although pitching velocity changes were insignificant, a multitude of participants experienced increases in pitching velocity with an absence of detrimental biomechanical effects following 8-weeks of pitching baseballs weighing 3.5oz (30% mass decrease) to 70.5oz, (1,310% mass increase). Similarly, Maker and Taliep (2021) found that 4-weeks of training with weighted cricket balls weighing 133g (15% mass decrease) to 179g (15% mass increase) resulted in sub-elite bowlers experiencing a significant increase in bowling speed of 5.1km/h (6%) ($p < 0.001$). As highlighted in the Literature Review (Chapter 2), the use of weighted footballs has also been shown to benefit kicking performance, as Ball (2009) found that eight training sessions across a 4-week period with a 500g over-weighted football (11.1% weight increase) resulted in significant improvements in kick distance from pre-test to post-test ($p < 0.05$), with kick distance at post-test being significantly greater than a control group.

Although there is an absence of research that has investigated the effects of a multi-week weighted Gaelic football training intervention on place kicking performance, the findings of the aforementioned studies infer that completion of such an intervention may lead to increased place kicking performance, whereby increases in football velocity and distance are also integral in Gaelic football, particularly at inter-county levels (Daly & Donnelly, 2021).
2018; Mangan et al., 2017), as highlighted in the previous chapters. However, while an investigation into the effects of a weighted Gaelic football training intervention on place kicking performance is required, recent WIT research has illustrated the intra-individual effects of chronic weighted implement use. Wickington and Linthorne (2017) reported varied responses to a weighted cricket ball training intervention with elite level bowlers. It was found that while some bowlers experienced beneficial increases in bowling speeds following completion of an 8-week intervention with balls weighing 71-213g (54.5% mass decrease - 36.5% mass increase, respectively, compared to the 156g standard ball), others who trained with these weighted cricket balls experienced only trivial changes in bowling speeds (Wickington and Linthorne, 2017). These findings support the recommendations of other sport science researchers to analyse participants individually, particularly at elite performance levels, as the prevalent group analysis techniques mask potential intra-individual differences in motor performance and learning akin to those observed by Wickington and Linthorne (2017) (Kinugasa, 2013; Kinugasa, Cerin & Hooper, 2004). Sands et al. (2019) specifically state that while analysis of group means may illustrate improved performance following completion of a training intervention, such group analysis techniques may hide detrimental effects to key performers which may ultimately degrade competitive performance and, for practitioners in the applied setting, deem the intervention unsuccessful despite group mean increases. This likely implicates the implementation of physical training practices in the applied athlete setting (Kinugasa et al., 2004; Martin, Andersen & Gates, 2000). A particularly underused, yet recommended, experimental design to assess intra-individual responses to physical preparation interventions is single-subject analysis, whereby analysis of multiple individuals’ personal responses to an intervention is conducted (Gorczynski, 2013; Kinugasa, 2013; Kinugasa et al., 2004). Furthermore, for high performance research, and
other populations whereby the recruitment of large sample sizes is challenging and typically impractical, it has been recommended that a single-subject methodology is not only an appropriate and effective approach to examine individual responses to physical training interventions, but is indeed recommended over other methodologies due to the need to study, and statistically analyse, individual responses of elite and high performing athletes to training interventions (Gorczyński, 2013; Kinugasa, 2013; Kinugasa et al., 2004; Sands et al., 2019; Skorski & Hecksteden, 2021). Critically, these study designs, and their respective findings, are deemed more flexible to incorporate into applied coaching practices and settings compared to group research designs (Kinugasa, 2013; Kinugasa et al., 2004).

Therefore, as (i) there is an absence of research into the effects of a multiple-week weighted Gaelic football intervention on markers of place kicking performance, (ii) WIT induces varied intra-individual effects, and (iii) the research conducted in this thesis to date has predominantly included university students with Gaelic football playing experience as participants, the purpose of Study 4 was to examine the intra-individual training and retention effects of a 4-week, 8-session weighted Gaelic football training intervention on ball velocity (BV) of a standard Gaelic football place kick among inter-county Gaelic football goalkeepers. As the protocol of Study 3 (Chapter 5) (i.e., five place kicks with the weighted football followed by a single place kick with a standard Gaelic football 2-, 4-, 6- and 8-minutes post-weighted football use) had positive effects on BV of standard Gaelic football place kicks, this protocol was completed in each intervention session in Study 4. It was hypothesised that the intervention would lead to significant BV increases across the testing period for each participant. As per Study 3 (Chapter 5), it was necessary to conduct this study indoors in a more controlled setting due to data collection
instrument requirements and measures of control of the environment. Therefore, the current study took place in the Host Institution’s Indoor Athletics Facility and, accordingly, BV served as the dependent variable.

6.3. Methods

This research took place during the COVID-19 pandemic; therefore, the experimental design was developed in full adherence to local, national and international health and safety guidelines (see Jermyn et al., 2021b; Appendix D).

6.3.1. Participants

Six inter-county male Gaelic football goalkeepers participated in this study (mean age = 21.8 ± 3.66 years; body mass = 89.2 ± 11.41kg; height = 190.1 ± 7.60cm; inter-county playing experience = 5.2 ± 3.60 years). This small sample size is reflective of the study’s aim to exclusively focus on inter-county level goalkeepers. However, as per Hecksteden, Kellner and Donath (2021) and Skorski and Hecksteden (2021), methodological recommendations to control for the small sample size were adhered to, such as collaboration with an expert statistician to lead the data analysis process. Descriptive statistics of each participants’ age and fundamental anthropometric scores, as well as a note of their Gaelic football goalkeeping background, are presented in Table 6.1. Participants were medically cleared to take part in the study and provided written informed consent. Furthermore, as this participant cohort comprised of inter-county athletes, unrivalled access to, and collaboration with, the participants’ Lead Strength & Conditioning (S&C) Coach was secured to define and implement physical preparation and warm up endeavours that were effective and familiar for participants so that the risk
of injury was minimised in each session. This research was approved by the Host Institution’s Research Ethics Committee.

**Table 6.1.** Participants’ anthropometric profiles and goalkeeping experience.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age (years)</th>
<th>Mass (kg)</th>
<th>Height (cm)</th>
<th>Gaelic football goalkeeping background</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>95.6</td>
<td>188.2</td>
<td>13 years of GK experience; 9 years of IC GK experience</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
<td>90.4</td>
<td>185.2</td>
<td>12 years of GK experience; 9 years of IC GK experience</td>
</tr>
<tr>
<td>3</td>
<td>23</td>
<td>102.4</td>
<td>196.5</td>
<td>8 years of GK experience; 5 years of IC GK experience</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>95.7</td>
<td>198.9</td>
<td>13 years of GK experience; 1 year of IC GK experience</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>78.1</td>
<td>178.6</td>
<td>9 years of GK experience; 6 years of IC GK experience</td>
</tr>
<tr>
<td>6</td>
<td>19</td>
<td>72.8</td>
<td>193.3</td>
<td>4 years of GK experience; 1 year of IC GK experience</td>
</tr>
</tbody>
</table>

Key: GK = Goalkeeping; IC = Inter-County.

### 6.3.2. Materials and Experimental Set-Up

The intervention took place in the Host Institution’s Indoor Athletics Facility, using a 9.5m x 3.4m (length x width) artificial grass playing surface (Synthi Green Sports Surfaces Limited, Co. Cork, Ireland), providing a more representative surface of a football pitch versus the tartan track below, for maximal effort place kicks to be performed (see Figure 6.1). A Schutt training net (Litchfield, Illinois, USA), measuring 2.1m x 1.5m (height x width), was situated at one end of the artificial grass, affording participants the ability to perform a full, unrestricted approach to the ball (Figure 6.2). As per the procedure of Study 3 (Chapter 5), all place kicks were executed from a distance of 1.5m from the centre of the net in order to ensure participants were not at risk of making contact with the training net or its frame during the follow-through phase of each place kick. A 1m rope was interwoven horizontally into the net at a height of 0.65m, with additional 1m ropes interwoven vertically at either end of the horizontal rope. This rope formation served the purpose of guiding ball trajectory towards the centre of the net to
facilitate accurate and reliable measurement of ball velocity (BV), which was attained via a Bushnell Radar Velocity Gun (Bushnell, Overland Park, Kansas).

The setting of the radar gun at a height of 1m, and the rope formation, ensured reliability and internal consistency of BV measurement. The radar gun was situated behind the goal at a distance of 2.75m from the front of the training net to ensure a ball would not contact the radar gun as it was kicked into the net. A video camera (Canon Legria HFR606, Tokyo, Japan) was placed adjacent to the kicking location to record all trials. Two RS PRO Halogen Work Light systems (400W, 220-240V; Radionics Ltd., Glenview Industrial Estate, Herberton Road, Rialto, Dublin 12, Ireland) were placed to the rear of the synthetic playing surface and angled upward to add greater light to the indoor facility.

The weighted Gaelic football (The Green Ball Co., Dublin, Ireland; Figure 1.3a) used in this study weighed 600g, a 25% increase from the standard 480g game ball. The size and

Figure 6.1. A scaled view of the experimental set-up. P = Participant; R = Researcher; F = Football.
outer panelling of the weighted football was identical to that of a standard Gaelic football, with the additional weight due to a heavier inner bladder. The standard football used in this study was a size-5 O’Neill’s All-Ireland Gaelic football (O’Neill’s Irish International Sports Co. Ltd., Belfast, Northern Ireland; Figure 1.3b), inflated to a pressure of 9.75-10 pound per square inch (PSI), resulting in the recommended mass of 480g (GAA, 2017).

Figure 6.2. The experimental set-up including the training net with rope formation within the net.

6.3.3. Procedure

Testing Session Procedure

Upon arrival to the facility for each testing session, participants completed a 10-minute warm up comprising of mobility, activation, and dynamic movement phases. While participants were encouraged to complete this warm up protocol, additional time was allocated so that they could include their own bespoke warm up and preparatory endeavours to facilitate maximal performance output in terms of their subsequent place kicks. This warm up protocol was developed in consultation with the players’ Lead S&C Coach to provide a familiar and effective warm up for all participants.
Upon conclusion of the warm up phase, the testing session began. In all testing sessions (pre-, mid-, post- and retention-test), participants performed five maximal effort place kicks with a standard Gaelic football. Prior to the five test-trials, participants performed two familiarisation trials with the standard Gaelic football. A minimum inter-trial time interval of 30-seconds was implemented. To respect the in-game kick-out ‘routine’ of each participant, a predetermined maximum inter-trial time interval was not imposed. As this study comprised exclusively of inter-county goalkeepers, it was agreed by the research team that this was essential as failing to respect each individual’s routine would likely result in the participant feeling rushed as a result of a set time point for each place kick to be performed, which would have potentially impacted upon subsequent performance. Across all testing sessions, the minimum inter-trial time interval per individual was 52s, with the maximum inter-trial time interval per individual being 76s. Participants were instructed to 1) “kick with maximal effort”, and 2) “kick within the rope formation”. Prior to each trial, participants received the following verbal instruction: “This is your (trial number) maximal effort place kick. You may proceed when ready”. Participants were permitted to approach all place kicks as they would in a match situation (i.e., there were no constraints on approach angle or number of approach steps).

*Intervention Session Procedure*

Upon conclusion of the pre-test, participants took part in a 4-week, 8-session training intervention, with the mid-test taking place between the fourth and fifth intervention sessions. A post-test took place within 7-days of the conclusion of the intervention, with a retention-test taking place 7- to 14-days after the participant’s respective post-test. The procedures of the mid-test, post-test and retention-test were identical to the pre-test.
During intervention sessions, participants completed an identical warm up to that of the testing sessions, followed by two familiarisation place kicks with the weighted football, prior to performing five maximal effort place kicks with the weighted Gaelic football. A 1-minute recovery period was situated between each weighted football place kick. This was followed by a single place kick with a standard Gaelic football approximately 2-, 4-, 6- and 8-minutes after the final weighted Gaelic football place kick as per the procedure of Study 3 (Jermyn et al., in press b). For each place kick with the standard Gaelic football (the phase following the weighted Gaelic football place kicks), participants were informed that they were permitted to commence the next trial 15-seconds prior to the respective time point. For example, for the standard Gaelic football place kick at the 2-minute time point, participants were informed that they could commence the trial 1-minute and 45-seconds after the final weighted Gaelic football place kick. A pilot research phase confirmed that informing participants that they were permitted to commence the next trial 15-seconds prior to the respective time point was sufficient time in order for the place kick to be performed in close proximity to the respective time point.

Season Schedules and Associated S&C Programmes

Concurrent to partaking in the weighted Gaelic football training intervention, participants continued their weekly on-field practice and match schedules, and associated S&C programmes. Upon commencement of the study, participants were beginning Phase-2 of their pre-season, with Phase-1 concluding one week prior. Phase-1 was defined as the phase in which participants were not permitted to perform on-field collective activities as per COVID-19 restrictions. Participants were, however, completing at-home S&C sessions. Phase-2, therefore, was defined as the phase in which on-field collective
activities recommenced. Across the experimental period, all goalkeepers participated in a minimum of two matches. The structure of participants’ S&C and on-field practice schedules at the time of the study (Phase-2), and immediately prior to the study (Phase-1), are detailed in Table 6.2. Due to the COVID-19 restrictions that were in place at the time of both phases of the participants’ pre-season, collective strength training sessions were not permitted. Therefore, across both phases, intensity was prescribed at 60 to 90% of 1 repetition-maximum to cater to the varied, and oftentimes limited, equipment and loads that each player had access to. Although loads varied, strength training session structures remained constant across all players and both pre-season phases (Table 6.2).

Table 6.2. Participants’ training activities prior to, and during, the current study.

<table>
<thead>
<tr>
<th>Training mode</th>
<th>On-field S&amp;C endeavours at the time of the study (i.e. pre-season Phase-2)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On-field collective practice</td>
<td>Kick-out practice</td>
<td>Strength training</td>
<td>Conditioning</td>
</tr>
<tr>
<td>Frequency</td>
<td>2-sessions per week</td>
<td>2-sessions per week</td>
<td>2-sessions per week</td>
<td>1-session per week (if not participating in a match)</td>
</tr>
<tr>
<td>Intensity</td>
<td>Session dependent</td>
<td>Session dependent</td>
<td>60-90% 1 repetition-maximum</td>
<td>Varied intensity; session dependent</td>
</tr>
<tr>
<td>Time</td>
<td>60- to 90-minutes</td>
<td>10- to 20-minutes</td>
<td>60-minutes</td>
<td>30- to 45-minutes</td>
</tr>
<tr>
<td>Type</td>
<td>Collective team training</td>
<td>Various types of kick-outs (10-20); varied direction &amp; distance</td>
<td>Upper &amp; lower body bilateral &amp; unilateral strength &amp; power exercises</td>
<td>Aerobic &amp; anaerobic running; ‘soft-skill’ activities focused on development of passing, soloing and first touch</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S&amp;C endeavours completed in the phase prior to the study (i.e. pre-season Phase-1)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>N/A</td>
<td>N/A</td>
<td>2-sessions per week</td>
</tr>
<tr>
<td>Intensity</td>
<td>N/A</td>
<td>N/A</td>
<td>60-90% 1 repetition-maximum</td>
</tr>
<tr>
<td>Time</td>
<td>N/A</td>
<td>N/A</td>
<td>60-minutes</td>
</tr>
<tr>
<td>Type</td>
<td>N/A</td>
<td>N/A</td>
<td>Upper &amp; lower body bilateral &amp; unilateral strength &amp; power exercises</td>
</tr>
</tbody>
</table>
6.4. Data Analysis

To assess the measurement accuracy of the radar gun, the level of agreement of BV measures between the radar gun used in the study and a Bushnell Speedster III (Bushnell, Overland Park, Kansas) was assessed via Intra-class Correlation Coefficient (ICC). To assess the test-retest reliability of the radar gun used in this study, the level of agreement of the radar gun’s measurement of BV on three separate occasions was assessed via ICC. Each session consisted of 30 trials whereby a custom-built football projection machine, set at a speed of 1,000rpm, projected a standard size-5 O’Neills Gaelic football towards the speed guns. A customised black cover, with a 50cm slit down the centre, was placed directly in front of the projection machine in order to occlude the spinning wheels from the radar guns to ensure the displayed BV value was that of the oncoming football. For both reliability analyses, ICC estimates and their 95% confidence intervals were calculated based on absolute-agreement and a 2-way mixed-effects model. For inter-device reliability, average measures results are reported. For intra-device reliability, single measures results are reported. The design of the reliability study and the subsequent reporting of its results are based on the recommendations of Koo and Li (2016). A linear mixed model analysis was carried out to examine the intra-individual effects of the 8-session weighted Gaelic football training intervention on BV of standard Gaelic football place kicks. Time and participants served as fixed effects, while number of place kicks per testing session served as a random effect. In order to control for the number of participants in the single-subject design, Tukey HSD post-hoc analysis was performed on the participant variable in order to assess intra-participant changes in BV across the testing period. The model assumptions of distribution normality and homoscedasticity were assessed via Shapiro-Wilks and Breusch-Pagans tests, respectively. Data were assessed for outliers, as assessed by boxplot. All statistical test results were interpreted
using a 5% level of significance. Partial eta squared ($\eta^2$) was used to assess the effect size of the linear mixed model (Small: $0.01 \leq \eta^2 < 0.06$; Medium: $0.06 \leq \eta^2 < 0.14$; Large: $\eta^2 \geq 0.14$; Cohen, 2013). Statistical analysis was performed using R Statistical Software (version 4.0.4; R Foundation for Statistical Computing, Vienna, Austria).

6.5. Results

Results revealed that the inter-device reliability was 0.88 [95% CI, 0.75-0.94], indicating good to excellent reliability between the two devices (Koo & Li, 2016). Intra-device test-retest reliability was 0.85 [95% CI, 0.75-0.92], indicating good to excellent BV measurement reliability (Koo & Li, 2016). The linear mixed model satisfied the assumptions of residuals being normally distributed and homoscedastic ($p > 0.05$). Outliers were identified, however, as these outliers were not data entry or measurement errors, the values remained in the subsequent analysis. Results revealed a large, significant interaction effect between participant and time ($F(15, 96) = 10.85, p < 0.0001$, partial $\eta^2 = 0.63$). Post-hoc analysis examining the participant variable revealed that, with the exception of Participant 3, all other participants ($n = 5$) experienced significant changes in BV across the testing period ($p < 0.05$). Mean BV values per testing period per participant are presented in Table 6.3.

Table 6.3. Mean Ball Velocity (BV) (km/h) per testing period per participant.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Pre-Test Mean ± SD BV (km/h)</th>
<th>Mid-Test Mean ± SD BV (km/h)</th>
<th>Post-Test Mean ± SD BV (km/h)</th>
<th>Retention-Test Mean ± SD BV (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100.4 ± 4.10</td>
<td>87.8 ± 3.27</td>
<td>99.8 ± 0.84</td>
<td>100.4 ± 3.51</td>
</tr>
<tr>
<td>2</td>
<td>100.8 ± 3.70</td>
<td>88.0 ± 3.16</td>
<td>97.0 ± 3.61</td>
<td>95.8 ± 2.77</td>
</tr>
<tr>
<td>3</td>
<td>110.4 ± 1.67</td>
<td>108.8 ± 4.09</td>
<td>110.8 ± 4.44</td>
<td>112.2 ± 2.86</td>
</tr>
<tr>
<td>4</td>
<td>101.0 ± 3.16</td>
<td>101.0 ± 5.66</td>
<td>107.0 ± 2.12</td>
<td>105.8 ± 1.30</td>
</tr>
<tr>
<td>5</td>
<td>86.2 ± 3.49</td>
<td>104.4 ± 3.97</td>
<td>101.8 ± 3.35</td>
<td>102.0 ± 1.87</td>
</tr>
<tr>
<td>6</td>
<td>96.2 ± 4.71</td>
<td>98.2 ± 1.79</td>
<td>102.0 ± 3.16</td>
<td>104.0 ± 1.22</td>
</tr>
</tbody>
</table>
Figures 6.3a-f display graphical representations of mean BV per test per participant.

**Figure 6.3a.** 95% confidence interval of mean ball velocity across the testing period for Participant 1. An asterisk and corresponding horizontal bracket indicate a statistically significant difference in ball velocity between the respective testing periods ($p < 0.05$).

**Figure 6.3b.** 95% confidence interval of mean ball velocity across the testing period for Participant 2. An asterisk and corresponding horizontal bracket indicate a statistically significant difference in ball velocity between the respective testing periods ($p < 0.05$).
Figure 6.3c. 95% confidence interval of mean ball velocity across the testing period for Participant 3.

Figure 6.3d. 95% confidence interval of mean ball velocity across the testing period for Participant 4. An asterisk and corresponding horizontal bracket indicate a statistically significant difference in ball velocity between the respective testing periods ($p < 0.05$).
Figure 6.3e. 95% confidence interval of mean ball velocity across the testing period for Participant 5. An asterisk and corresponding horizontal bracket indicate a statistically significant difference in ball velocity between the respective testing periods ($p < 0.05$).

Figure 6.3f. 95% confidence interval of mean ball velocity across the testing period for Participant 6. An asterisk and corresponding horizontal bracket indicate a statistically significant difference in ball velocity between the respective testing periods ($p < 0.05$).

Following the pre-test, Participant 1 experienced a significant decrease in BV at mid-test ($p < 0.0001$). However, BV significantly increased at post-test ($p < 0.0001$) and retention-
test \((p < 0.0001)\) relative to the mid-test, indicating BV returned to pre-test magnitudes as there were no significant differences in BV between pre-, post- and retention-tests \((p > 0.05)\) (Figure 6.3a). Similarly, Participant 2 experienced a significant decrease in mean BV from pre-test to mid-test \((p < 0.0001)\), followed by a subsequent significant increase at post-test \((p = 0.0002)\) and retention-test \((p = 0.0018)\) relative to the mid-test (Figure 6.3b). Participant 4 experienced a significant increase in BV from pre-test to post-test \((p = 0.0249)\), and mid-test to post-test \((p = 0.0249)\). These improvements in BV were maintained through the retention-test as no significant differences were observed between post- and retention-tests \((p > 0.05)\) (Figure 6.3d). Participant 5 experienced a significant increase in BV from pre-test to mid-test \((p < 0.0001)\), post-test \((p < 0.0001)\) and retention-test \((p < 0.0001)\). Participant 5 experienced no other significant differences in BV across the testing period (Figure 6.3e). Participant 6 experienced a significant increase from pre-test to post-test \((p = 0.0323)\) and retention-test \((p = 0.0018)\), and an additional significant increase from mid-test to retention-test \((p = 0.0323)\) (Figure 6.3f). Although the aforementioned five participants experienced significant changes in BV across the testing period \((p < 0.05)\), Participant 3 did not experience significant changes in BV. However, a statistically insignificant \((p > 0.05)\) mean BV increase of 1.8km/h was observed across the testing period for this participant (Figure 6.3c).

6.6. Discussion

Research suggests that WIT results in significant increases in standard implement velocity and distance (Ball, 2009; Bellar, Judge, Turk & Judge, 2012; DeRenne & Szymanski, 2009; Judge, Bellar & Judge, 2010; Wickington & Linthorne, 2017). The majority of this research evaluated the effects of weighted baseball equipment on the sport’s respective motor skills (i.e., batting and pitching). Although a single published
study has directly assessed the effects of a 4-week, 8-session weighted Australian football programme on place kicking performance, there is no research into the impact of weighted Gaelic footballs on place kicking performance of inter-county Gaelic football goalkeepers. Therefore, due to (i) the findings of previous studies that demonstrated that WIT induces increases in standard implement velocity and distance, (ii) the concurrent interest for improved ball velocity (BV) among Gaelic football goalkeepers as enhanced BV majorly contributes to increased kick distance (Sinclair et al., 2014), and (iii) the results of previous studies (including Study 2 and 3) that indicate positive acute effects of a weighted Gaelic football protocol on standard football place kick performance (Jermyn et al., in press a; Jermyn et al., in press b), an investigation into the effects of a 4-week, 8-session weighted Gaelic football place kicking intervention on BV of standard Gaelic football place kicks among inter-county goalkeepers was warranted. However, as a response to previous WIT research that highlighted varied intra-individual responses to WIT among elite and high performing athletes (Wickington & Linthorne, 2017), and the inherent difficulties in recruiting large samples of such athletes, a multiple participant single-subject design was applied. This experimental design has been deemed more suitable for the study of elite and high performing athletes compared to the more prominent group analyses techniques (Kinugasa, 2013; Sands et al., 2019).

The current study found that, in conjunction with participant’s return to weekly on-field team practice and S&C programmes, five of the six participants experienced significant increases and/or decreases in BV across the testing period ($p < 0.05$). Participant 1 and Participant 2 experienced the only significant decreases in BV across the testing period. Although Participant 1 did not report any injury or health-related issues prior to or during the current study, Participant 2 experienced a mild groin strain between the pre-test and
the first intervention session. This injury was not sustained because of the testing and intervention sessions. Although the participant was medically cleared to return to all football activities, the significant decrease in BV from pre-test to mid-test suggests this injury may have negatively impacted place kicking performance. However, as BV significantly increased from mid-test to post-test and retention-test, with no significant differences observed between pre-test, post-test, and retention-test, it is suggested that this training intervention may have supported his return to pre-injury performance levels. Participants 4, 5 and 6 all experienced significant increases in BV from pre-test to post-test. Although Participant 4 did not maintain significant differences in BV from pre-test to retention-test, retention-test BV was still greater than pre-test and mid-test measures, with no significant differences evident between post- and retention-test. In contrast, Participant 5 and Participant 6 experienced significant BV improvements at post-test and retention-test relative to pre-test scores, thus indicating that significant BV improvements incurred throughout the intervention period were retained. In particular, Participant 5 experienced the greatest BV increases among all participants, whereby relative to pre-test, an 18.2km/h (21.1% increase) improvement was observed at mid-test, a 15.6km/h (18.1% increase) improvement was observed at post-test, and a 15.8km/h (18.3% increase) improvement was observed at retention-test. However, caution is warranted when considering these substantial BV increases as the participant was dealing with an ankle injury just prior to commencement of the study. Although he was medically cleared to participate, any lingering effects of the injury may have impacted upon his performance in the pre-test, therefore leading to significant, and likely inflated, increases in BV at each of the other testing periods. Furthermore, the participant stated, post-data analysis, that place kicking on an artificial surface may have resulted in him performing submaximal effort place kicks in the initial testing session, although all participants were prompted to
kick with maximal effort prior to each experimental and intervention place kick. Indeed, previous WIT studies have emphasised that the use of artificial performance environments in experimental sessions (i.e., the current study’s use of the artificial playing surface), as well as the use of a net versus representative targets (i.e., teammates), may inhibit elite athletic performance (Hébert-Losier & Wardell, 2021). However, as the purpose of the current study was to investigate BV effects, these experimental apparatus were required. Nonetheless, as the only significant BV increases from pre-test to post-test were experienced by Participants 4, 5 and 6, it may be suggested that greater improvements in BV of standard football place kicks as a result of completing this weighted football intervention may be observed among younger, less experienced goalkeepers, as these three goalkeepers were members of the Under-20 inter-county team, with the other three goalkeepers being members of the Senior inter-county team.

Participant 3 was the only participant who did not experience significant changes in BV across the study’s duration. Analysis of mean BV values per participant across testing phases revealed that this participant displayed greatest mean BV values at each testing period compared to all other participants. Furthermore, this participant displayed the greatest mean BV value across all experimental trials (110.55km/h), with a maximum value of 117km/h. Observation of these results may indicate a ceiling effect. Similar results have been observed in studies that have incorporated the use of weighted golf clubs in training interventions, whereby golfers who had already established very high swing speeds experienced no significant improvements in swing speed post-intervention, thus illustrating a ceiling effect (Álvarez et al, 2012). Research that has investigated the effects of weighted baseballs on pitching performance has, however, inferred the need to identify velocity values at which a ceiling effect appears to occur, in order to further refine
the practical applications and programming recommendations of WIT (Erickson, Atlee, Chalmers et al., 2020; Hadley, Atlee, Chalmers et al., 2021). Although Sands et al. (2019) state that readers should be aware of the poor generalisability of single-subject analyses to other athletes and cohorts, it is suggested that findings of such study designs may be applicable to players that share similar characteristics to the single-subject study’s participants (Hecksteden et al., 2021). Based on Participant 3’s results, it may, therefore, be suggested that goalkeepers who display mean BV values of 110km/h may not experience significant BV increases as a result of implementing a weighted football intervention akin to the programme utilised in the current study. Nonetheless, as per the conclusions of Álvarez et al. (2012), it is important to note that WIT may facilitate the maintenance of previously achieved velocity gains among the most powerful and explosive athletes. Furthermore, albeit statistically insignificant, Participant 3’s BV values at post-test and retention-test were greater than pre-test values. As evidenced by Participant 3, Participant 6 also experienced a slight BV increase from post-test to retention-test. As participants were not exposed to the weighted football between the post-test and retention-test, it is suggested that these slight increases may have been the result of the participants’ on-field sessions, whereby a respective amount of time per session was allocated to kick-out distance.

The limitations of this study are acknowledged. Firstly, although the purpose of this research was to analyse individual responses to the weighted football intervention, an untreated or standard football control phase per individual was not included. This would have facilitated a determination of whether the weighted football intervention was unique in its ability to evoke the observed performance improvements among some of the participants. Furthermore, in single-subject research designs, a baseline testing period
should reflect a period (potentially multiple testing sessions as opposed to the utilised single session pre-test) whereby implementation of the intervention only occurs once performance across baseline sessions stabilises (Gorczynski, 2013). This, therefore, likely minimises the contribution of external factors to baseline performance (the contribution of which may be higher if only a single baseline session is conducted) so that a more accurate comparison can be made between post-intervention performance and true baseline performance (Barker, McCarthy, Jones & Moran, 2011). However, corresponding to the literature’s acknowledgement of the challenges presented in applied settings when endeavouring to implement chronic baseline phases (Barker et al., 2011), increased time constraints in the current study resulting from each participant’s forthcoming competitive season schedule meant that extending the study’s duration, to incorporate a control phase and/or an extended baseline phase, was not feasible. To combat this, Kinugasa et al. (2004) state that multiple baseline designs with multiple participants, as per the design of the current study, are an effective study design to control threats to internal validity.

The small sample size may also be deemed a limitation of the current study. However, as the aim of this research was to investigate the intra-individual effects of a weighted Gaelic football training intervention on place kicking performance among a specific population, specifically inter-county Gaelic football goalkeepers, and the corresponding limited amount of such athletes that meet this criterion, it was not possible to obtain a larger sample size. However, efforts were made to control for this limitation, including collaboration with an expert statistician for the purposes of ensuring use of appropriate data analysis techniques as per the recommendations of Hecksteden et al. (2021).
An additional limitation of this study is the likely variance in ball trajectories and its subsequent impact on accuracy of BV measurement with the radar gun. Although the manufacturers of the radar gun state that the radar gun has a measurement accuracy margin of error of ±2.0km/h, deviations in ball trajectory likely impact measurement accuracy due to the relatively fixed direction in which the radar gun was pointed. However, the manufacturers state that an angle of incidence of ≤12 degrees between object trajectory and the radar gun does not affect measurement accuracy, but a deviation of 20 degrees can result in a measurement accuracy margin of error of ±3.0km/h. While the authors attempted to control for this by requiring participants to aim their kick within the rope formation embedded in the net so that ball trajectories closely aligned with the positioning of the radar gun, it is suggested that additional accuracy constraints to control for trajectory deviations would have negatively affected participants’ intentions to place kick with maximal effort. Nonetheless, a reliability study showed that inter-device (ICC = 0.88, 95% CI = 0.75-0.94) and intra-device (ICC = 0.85, 95% CI = 0.75-0.92) test-retest reliability was good to excellent. Furthermore, in addition to the researcher manually operating the radar gun in order to align the trajectory of the radar gun toward the kicking location for each trial, the two familiarisation trials supported the researcher’s atunement to each participant’s typical kick execution and trajectory, therefore further refining the positioning of the radar gun in respect of the trajectory of the ball. Finally, similar to limitations of other WIT studies, whereby interventions were implemented at the beginning of the respective athlete cohort’s season (for example, Maker & Taliep, 2021), the current study was initiated immediately following a COVID-19 ‘lockdown’ period, whereby participants were returning to on-field practice and technical coaching for the first time in 14-weeks. The influence of these on-field team sessions on improvements in BV cannot, therefore, be excluded. Furthermore, as participants were also completing
their assigned S&C programmes, it cannot be confirmed that the significant intra-individual changes in BV across the experimental period were not the result of the S&C programmes. However, from a contrasting perspective, the implementation of a weighted football intervention would most likely never occur in isolation in the applied setting as such an intervention would most likely be implemented concurrent to, or as part of, an S&C programme and regular on-field practice. Therefore, the context within which the current intervention was implemented (i.e., in the middle of a high-performance pre-season) provides practitioners with authentic meaningful information relating to the interactions between this intervention, concurrent training activities, and the subsequent effects on place kicking performance.

To conclude, the findings of Study 4 suggest that a 4-week, 8-session weighted Gaelic football intervention, comprising a protocol akin to Study 3 (Chapter 5), increases BV of standard football place kicks and supports the maintenance of existing BV values among inter-county goalkeepers. Improvements in BV may facilitate kick-outs of greater distance (i.e., a perceptual-motor landscape of increased kick-out/passing affordances), a performance outcome deemed desirable in Gaelic football due to (i) the prevalence of long kick-outs in match play, (ii) the expansive playing surface, (iii) the recent introduction of the ‘Mark’ rule to further encourage long kick-outs, and (iv) the potential to create scoring opportunities from long kick-outs. As the utilised programme resulted in intervention sessions being completed within 25-minutes, this intervention provides practitioners, such as skill acquisition specialists and S&C coaches, with a time-efficient means of inducing intra-individual increases in standard football velocity among inter-county goalkeepers that can, therefore, be implemented as part of their training programmes.
Chapter 7

Conclusions, Practical Applications & Recommendations for Future Research
7.1. Introduction

The aims of this thesis were to (i) investigate the impact of weighted Gaelic football training on markers of place kicking performance, namely kinematic and range of motion (ROM) behaviours, ball velocity (BV) and kick distance, in addition to (ii) exploring perceptions of standard football velocity and mass following use of the weighted football. The rationale for this line of investigation emerged from the absence of objective evidence to inform skill acquisition specialists, strength and conditioning (S&C) coaches, and goalkeepers of the impact and practical applications of weighted Gaelic football training. This chapter serves to consolidate the findings of this body of original research and, further, suggests how these findings may impact the domains of weighted implement training (WIT) and skill acquisition, so as to positively influence the practice of place kicking in the applied setting.

7.2. Summary of Key Findings

7.2.1. Study 1

The purpose of Study 1 (Chapter 3) was to conduct a preliminary, exploratory investigation to determine whether a 5-session, 50-trial weighted Gaelic football place kicking intervention altered hip and knee peak angular velocity and ROM of the kicking leg when performing a place kick with a standard Gaelic football among inter-county and club-level male Gaelic football goalkeepers. Findings failed to reject the null hypothesis (H01) as, in addition to the standard football and non-training control groups, the weighted football group experienced no significant changes (p > 0.05) in peak hip angular velocity, hip ROM, peak knee angular velocity, and knee ROM. Although significant kinematic and ROM changes following WIT have been observed in baseball studies, these studies have also reported absences of significant changes to particular angular velocity and
ROM values (Marsh et al., 2018; Reinold et al., 2018). Similarly, WIT research in cricket has also reported absences of significant changes to technique variables following completion of a weighted cricket ball intervention (Wickington & Linthorne, 2017). Therefore, much of the WIT research to date suggests that the use of weighted implements is an efficacious training modality as it does not induce detrimental effects on the technical execution of the respective motor skill, provided that appropriate loading schemes are adhered to. The findings of Study 1 align with this as the absence of significant decreases in kinematic and ROM behaviours following the weighted football intervention may be deemed desirable as angular velocity measures of the kicking leg joint structures, particularly the knee, strongly contribute to markers of maximal effort place kicking (de Witt & Sinclair, 2012; Pereira Santiago et al., 2016; Sinclair et al., 2014; Young & Rath, 2011). In reference to the skill acquisition specialist and S&C coach’s use of weighted Gaelic footballs in the applied setting, findings from this study suggest that repeated use of the weighted Gaelic football across a one-week period, totalling five training sessions and 50-trials, does not alter how a subsequent maximal effort place kick with a standard Gaelic football is performed.

7.2.2. Study 2

The primary purpose of Study 2 (Chapter 4) was to examine the acute effects of a 5-trial weighted Gaelic football place kicking protocol on subsequent mean standard Gaelic football place kick distance among male university students with Gaelic football playing experience. The secondary purpose of Study 2 was to investigate whether kick distance increased transiently across place kicks following the weighted football protocol. Findings failed to reject the first null hypothesis of this study (H₀2) as results demonstrated that there was no significant difference in mean post-test kick distance.
between the weighted Gaelic football protocol and the control condition \( (p > 0.05) \). Findings also failed to reject the second null hypothesis of this study \( (H_02) \) as no significant transient increases in kick distance were found following the weighted football protocol. It warrants a mention, however, that in contrast to the control condition, the weighted football protocol induced a nominal increase in mean post-test kick distance compared to the related baseline value. Furthermore, nominal transient increases in kick distance across individual post-weighted football trials were evident, indicating the likely impact of time on subsequent performance. This finding suggests a post-activation performance enhancement (PAPE) effect, aligning with similar findings from the baseball domain that showed motor skill performance enhanced transiently post-weighted bat swings (Kim & Hinrichs, 2008; Wilson et al., 2012). As a consequence of this PAPE effect, it is suggested that skill acquisition specialists, S&C coaches, and goalkeepers wait until at least 2-minutes post-weighted football place kicks to commence subsequent standard football place kicks, with the duration of this complex training protocol deemed optimal and time-efficient for repeated use in practice settings.

7.2.3. Study 3

With respect to the finding that kick distance increased transiently across post-weighted football place kicks in Study 2, the primary purpose of Study 3 (Chapter 5) was to determine whether BV of a maximal effort place kick with a standard football peaked at 2-, 4-, 6- or 8-minutes after a 5-trial weighted Gaelic football place kicking protocol among male university students with Gaelic football playing experience. This served to aid the development of weighted football programming for warm up purposes. The secondary purpose of this study was to determine whether (i) the mass of the warm up implement used, (ii) the different time intervals, (iii) participants’ subsequent perceptions
of standard football mass, or (iv) participants’ subsequent perceptions of standard football velocity had the greatest influence on BV. The findings failed to reject the first null hypothesis of the study (H₀⁴) as results revealed that there were no significant differences in BV between- or within-groups (p > 0.05) and, therefore, that there would be no significant BV differences across the time points. As this result was insignificant, a post-hoc power analysis was conducted to inform future research. This analysis found that a minimum sample size of 70 participants (not including withdrawals) would be required for the difference observed to be statistically significant at a 5% level of significance with 80% statistical power. Therefore, it is suggested that the sample size was the predominant factor that led to insignificant BV differences. Additionally, future research that aims to replicate Study 3 should adhere to the findings of this post-hoc power analysis. While there were no significant changes, BV values across the post-weighted football protocol place kicks displayed a transient increase. Indeed, BV values of all post-weighted football time points were greater relative to the related baseline value, with the largest increase evident at the 8-minute time point, representing a nominal 5.4% BV increase. With regard to explaining the variance in BV, findings failed to reject the second null hypothesis of this study (H₀⁵) as results revealed that none of the predictor variables (mass of the warm up implement, various time intervals, perceptions of football mass and velocity) were significant (p > 0.05). Interestingly, however, it was found that the weighted football protocol, and the respective time intervals, had a greater influence on BV than the perceptual measures. Therefore, it may be inferred that, in combination with time, the physical effect of the weighted football protocol, and not the altered perceptions, resulted in acute subsequent BV improvements, which ultimately peaked 8-minutes post-warm up. Although results were insignificant, it is suggested that the 5.4% BV increase at the 8-minute time point post-weighted football protocol has practical significance for the skill
acquisition specialist and S&C coach in the applied setting, particularly as the post-hoc power analysis showed that a sample size increase of 18 would result in this meaningful 5.4% increase being significant, a finding that should be closely considered in the design of future research. Therefore, the efficacy of using this protocol as a warm up strategy immediately prior to the commencement of each playing half, and its implementation into chronic training programmes, is supported to enhance place kick distance. In respect of Affordance Theory as discussed in the Literature Review (Chapter 2), it is possible that completion of the place kicking protocol utilised in this study may result in the emergence of further affordances downfield as (acutely) increased action capabilities (i.e., increased BV) may facilitate longer kick-outs in match play.

7.2.4. Study 4
As the sample cohorts in the first three studies in this thesis predominantly comprised club level footballers, an investigation into the effects of weighted Gaelic football training on an exclusively inter-county Gaelic football cohort in the applied setting was warranted. As findings from Study 3 inferred nominal BV improvements following completion of the weighted football protocol, the purpose of Study 4 (Chapter 6) was to determine whether a 4-week, 8-session weighted football intervention, comprising an intervention protocol akin to the experimental procedure of Study 3, resulted in intra-individual changes in standard football velocity among inter-county Gaelic football goalkeepers (n = 6). The null hypothesis of this study (H$_0$) was rejected because results revealed varied significant BV changes following completion of the intervention ($p < 0.05$). Three participants experienced significant BV improvements from pre-test to post-test ($p < 0.05$), with no significant differences between post-test and retention-test. The remaining three participants experienced no significant BV differences from pre-test to post-test and
retention-test. These findings infer that among inter-county level Gaelic football goalkeepers, completion of a bespoke weighted Gaelic football intervention serves to not only maintain BV values, but can also increase BV when the intervention is completed in conjunction with goalkeepers’ regular pre-season on-field practice and S&C programme which may, subsequently, contribute to the emergence of further affordances as it relates to distributing the football to teammates further downfield from longer kick-outs. Additionally, this study also found that a baseline BV value of 110km/h appears to incur a ceiling effect. Collectively, these findings provide skill acquisition specialists and S&C coaches with information pertaining to a bandwidth of baseline BV values in which significant BV changes may potentially be achieved as a result of this intervention (i.e., mean baseline values between 86.2-101.0km/h). Most importantly, these findings provide practitioners with valuable evidence that support the use of weighted footballs in the maintenance and enhancement of BV in the applied setting, as this study was conducted at a time that was representative of when the practitioner would implement this intervention (i.e., when other athletic endeavours such as on-field practice and S&C programmes simultaneously take place).

7.3. Limitations & Strengths of the Thesis

Although the research findings in this thesis make a significant contribution to the domain of WIT, and specifically to place kicking in Gaelic football, it is important to note that several limitations inevitably arose throughout this research journey. As the specific limitations of each study have been discussed in the experimental chapters (Chapters 3-6), this section serves to emphasise the general limitations that apply to the research collectively.
Firstly, WIT has been rationalised as a particularly effective training modality due to the high level of sport-specific motor skill and biomechanical specificity that is embedded in its application, which is correspondingly purported to ensure a positive transfer of training effect to the respective sport-specific skill (DeRenne & Szymanski, 2009). Therefore, it may be considered a limitation of this research that those studies that investigated the chronic effects of weighted Gaelic football place kicking programmes (i.e., Study 1 and Study 4) did not include (representative) transfer tests. However, it is argued that the design and implementation of transfer tests is not always practical, as the creation, implementation and analysis of transfer tests would present a plethora of methodological challenges in the context of this thesis. For example, the dynamic complexity and interaction of other kick-out aims (for example, a short, highly accurate kick-out), and a multitude of team, task and environmental constraints, may result in the emergence of various place kicks that encompass alternative intentions other than achieving maximal BV and kick distance.

Secondly, although this thesis primarily concerned the effects of weighted Gaelic football training on kick distance and the major contributors to kick distance (for example, BV) as the ‘Green Ball’ was developed with the purpose of primarily increasing these variables, it is considered a limitation that this thesis did not investigate the effects of weighted Gaelic football training on place kick accuracy. Empirical investigations into kick-out distribution and effectiveness have highlighted the importance of kick-out accuracy as it pertains to integral performance metrics in Gaelic football. For example, in comparison to long kick-outs (kick-outs that landed between the 45-65m lines, and kick-outs that landed beyond the 65m line), Daly and Donnelly (2018) found that short, accurate kick-outs (kick-outs that landed between
the 21-45m lines) resulted in higher rates of possession retention (87% vs 58% (45-65m) and 53% (65m+)) and attacks started (55% vs 28% (45-65m) and 27% (65m+)) and lower rates of opponents scores (10% vs 13% (45-65m) and 13% (65m+)). Despite the importance of maintaining and enhancing the accuracy of kick-outs as displayed by these findings, this does not negate the importance of developing kick-out distance highlighted in the Literature Review (Chapter 2). However, as subsequently highlighted, there is a need for future research to investigate the acute and chronic effects of weighted Gaelic football training on place kick accuracy to provide skill acquisition specialists, S&C coaches and goalkeepers with further evidence to support or oppose the use of the ‘Green Ball’ in the applied setting.

- The absence of non-training and/or non-weighted Gaelic football control groups in Studies 2-4 are limitations within this research. The absence of such conditions does not allow for comparison of the effects of each implemented protocol with substantially different conditions that either (i) do not use the weighted Gaelic football (applicable to Study 4) or (ii) do not involve place kicking or any additional training endeavour(s) (applicable to Studies 2-4). The importance of including non-training and non-task-specific control groups was highlighted by Cuenca-Fernández et al. (2017), whereby the authors found that in addition to various training protocols that were implemented to induce a PAPE effect on subsequent performance, a ‘quiet standing’ non-training control condition also induced similar performance improvements to the other training protocols. These findings, therefore, infer that the absence of non-training and/or non-weighted Gaelic football groups in Studies 2-4 is a potential limitation of this research, as it cannot be determined whether their inclusion would also result in performance improvements.
• The absence of under-weighted footballs in the respective experimental designs may also be considered a limitation in this research. Existing studies in baseball (Miller et al., 2020) and handball (van Muijen, Joris, Kemper & van Ingen Schenau, 1991) have reported improved performance following under-weighted implement warm ups and long-term interventions. Therefore, while the current research suggests that use of an over-weighted football can induce positive kick-out effects, it remains unknown whether similar, if not greater, effects may be induced by use of an under-weighted Gaelic football. While the absence of under-weighted footballs is presented here as a limitation, it is important to note that this omission was a strategic decision as part of the research design process as the purpose of this thesis was to investigate the effects of an over-weighted football on place kicking. Therefore, the need to examine the effects of under-weighted footballs is discussed in the Recommendations for Future Research section.

• Finally, extant research has highlighted issues pertaining to the efficacy of generalising the effects of specific weighted implements and their means of implementation to other sports and motor skills. Previous WIT research has illustrated a large magnitude of deviation in (i) the mass of weighted implements relative to the respective sport’s standard implement and (ii) their means of programming, that have been reported to benefit performance. Therefore, in respect of this thesis, a degree of caution should be exercised in the generalisation of these findings to other sports and motor skills, thus warranting future research in such domains.

While it is important to note the aforementioned limitations of the research conducted in this thesis, it is also important to highlight the strengths of this body of research. As per
the limitations that have been detailed in this section, the subsequently discussed strengths of this research apply to this body of research in its entirety.

- Firstly, as the research conducted in this thesis was the seminal research to investigate the effects of weighted football training on markers of kicking performance in Gaelic football, novel research methodologies were developed and utilised. Specifically, novel experimental procedures (for example, the single-session experimental design of Study 3 and the experimental procedure of Study 4) and experimental apparatus were used (for example, the use of the Schutt training net and the rope formation to guide football trajectory). As a myriad of pilot research phases were completed that resulted in the development of these methodologies, this research provides a foundation for future experimental designs to expand research into the effects of weighted football training in Gaelic football and the other football codes.

- Secondly, as highlighted in the respective experimental chapters (Chapter 5 and Chapter 6), Study 3 and 4 were directly impacted by societal restrictions that were put in place as a result of the COVID-19 pandemic. Study 3, specifically, was directly interrupted, and temporarily suspended, due to the onset of the pandemic. Study 4 was designed in the midst of the pandemic, one year after the pandemic began. As a result of the severity of the disease and the subsequent need to ensure that health and safety guidelines were put in place in order to decrease the likelihood of further spread of the disease, the design of both studies was developed and amended in respect of local, national and international health and safety guidelines, which ultimately facilitated completion of both studies. As a
result of navigating the COVID-19 pandemic when amending and designing these two studies, this thesis, and the corresponding COVID-19 publication (Appendix D), provides researchers with clear guidelines that may aid future research that seeks to extend the research conducted in this thesis, as well as also supporting the development of other laboratory based sports science research projects.

- Finally, the findings of this thesis provide empirical evidence that supports the use of weighted football training in the applied Gaelic football domain. Therefore, skill acquisition specialists, S&C coaches and goalkeepers in Gaelic football are directly provided with weighted football protocols and programmes that can be readily used in the practice and competition environments. Providing the aforementioned practitioners with means of impacting place kicking performance in the applied setting was critical from the outset of this research project as the ‘Green Ball’ is a readily available skill acquisition tool in the marketplace, with a plethora of practitioners currently using the football in the applied setting. As a result of the research conducted in this thesis, practitioners are provided with empirical evidence that details the dose-response relationship regarding weighted football training and subsequent place kicking performance with the standard Gaelic football, and now have means of positively impacting kick-out distance that can be directly obtained from use of the ‘Green Ball’.

7.4. Practical Applications

As key findings from this thesis infer positive place kicking performance and learning effects, this body of work serves to provide skill acquisition specialists and S&C coaches with a methodology of acutely and chronically increasing place kicking performance as
a result of weighted football training. Of greatest significance, findings of this thesis demonstrate that weighted Gaelic football training can enhance BV and kick distance of standard Gaelic football place kicks, concurrent to inducing positive subsequent perceptions of standard football mass and velocity without inducing detrimental biomechanical effects.

- With regard to the enhancement of kick distance, the results of Study 2 provide skill acquisition specialists and S&C coaches with evidence that a 5-trial weighted football place kicking protocol, with a 30-second inter-trial recovery period across all trials, may increase immediate mean standard football place kick distance by 0.78m, with a nominal 2.25m increase in standard football place kick distance occurring 2-minutes after conclusion of weighted football place kicks. An enhanced ability to kick considerable distances is critical as it may directly contribute to ball retention downfield and the creation of scoring opportunities, therefore, an increase of 2.25m would potentially have a substantial effect on team performance, thus inferring a positive acute effect of weighted football place kicking. These findings provide support for the application of the weighted football protocol in complex training strategies in the practice setting as the time interval in which maximal kick distance improvements occur (2-minutes) is efficient in respect of typical overall session duration. It is posited that repeated performance of this ‘complex’ training protocol (five place kicks with the weighted football followed by five place kicks with the standard football with a 30-second inter-trial interval) across an extended timeframe may result in chronic improvements in kick distance.
• Study 3 provides evidence that upon completion of five place kicks with the weighted Gaelic football, goalkeepers can experience enhanced place kicking performance across a subsequent 8-minute time frame, with a nominal 5.4% increase in BV occurring 8-minutes upon conclusion of weighted football place kicks. Furthermore, it is possible that further increases in BV may be obtained with even greater time intervals (for example, 10- and 12-minutes). Therefore, it is likely that this time frame in which standard Gaelic football place kicking is enhanced has important implications for the practitioner and the athlete in respect of warm up activities in the competitive arena and in-game kick-out performance. Specifically, as a playing half at inter-county and club levels is 35- and 30-minutes respectively, completion of a 5-trial weighted Gaelic football warm up protocol immediately prior to throw-in of either playing half may result in enhanced BV across a time period that represents 22.9% (16-minutes out of a total of 70-minutes) (inter-county) to 26.7% (16-minutes out of a total of 60-minutes) (club level) of the entire match duration. As it has been shown that 44.0 ± 9.9 kick-outs are performed per inter-county level match (Daly & Donnelly, 2018), enhanced performance effects that may be experienced at the beginning of each playing half as a result of the weighted football protocol likely impacts a multitude of kick-outs. Therefore, it is suggested that skill acquisition specialists, S&C coaches and, ultimately, goalkeepers may particularly benefit from completion of five weighted football place kicks immediately prior to throw-in of each playing half.

• With regard to the chronic use of the weighted football, the findings of Study 4 suggest that completion of eight training sessions, comprising five weighted football place kicks and four subsequent standard football place kicks across a 4-week period,
may result in significant BV increases among inter-county Gaelic football goalkeepers. Skill acquisition specialists and S&C coaches are, therefore, provided with a means of inducing significant chronic increases in kick distance. However, the intra-individual analysis that was conducted in Study 4 highlights the unique differences in individual responses that are likely to occur. Specifically, Participant 3, who displayed the greatest baseline BV value (110.4km/h) did not experience subsequent BV increases upon conclusion of the intervention; therefore, displaying a ceiling effect. Correspondingly, with respect to applying the intervention used in Study 4, practitioners are advised to give careful consideration to the playing level of the goalkeeper and their existing BV values as goalkeepers who already exhibit high BV levels may not experience significant BV improvements following completion of the utilised intervention. Moreover, consideration should be given to the time of the season that the intervention is completed as it cannot be concluded that application of this intervention at a later stage of the season would result in significant BV increases. It is possible that the greater volume of kick-out practice accumulated as the season progresses would limit potential performance improvements that may be obtained from completion of the weighted football intervention.

7.5. Recommendations for Future Research
The key findings of the research presented in this thesis significantly contribute to the domains of skill acquisition and S&C, and WIT in particular. However, based on the scope, findings, and limitations of the current research, there remains a multitude of avenues where future research is recommended to investigate.
Firstly, the research in this thesis predominantly concerned the effects of weighted football training on the enhancement of BV and kick distance of maximal effort long kick-outs as the ‘Green Ball’ was designed to primarily impact upon kick distance and the major contributing variables to enhanced kick distance (i.e., BV). However, the effects of this football’s use on the accuracy of ‘short’ kick-outs is unknown. The literature that has investigated Gaelic football kick-out distribution and effectiveness has highlighted the performance benefits of short kick-outs. For example, short kick-outs (in respect of the new kick-out location rule, these are 13-25m kick-outs, i.e., kick-outs that do not go beyond the 45m line; Timmons, Collins & Mangan, 2022), which emphasise accuracy over distance, were shown to (i) be the most effective type of kick-out in respect of retaining possession, (ii) yield the greatest percentage of attack building plays, and (iii) lead to the greatest net difference of scores/scoring opportunities (Daly & Donnelly, 2018). Therefore, while the research in this thesis suggests that weighted Gaelic football use induces nominal and significant enhancements of BV and distance of long, maximal-effort place kicks, future research is warranted to investigate the effects of weighted football training on the ‘accuracy’ of kick-outs due to the integral role that such accuracy plays in retaining possession and creating scoring opportunities.

With respect to Study 1 (Chapter 3), it is recommended that future research investigates the effects of a longer weighted Gaelic football intervention on kinematic and ROM behaviours of place kicking a standard Gaelic football as it cannot be concluded that an intervention that lasts multiple weeks would not significantly alter these behaviours. Furthermore, given the limitations of the motion analysis system utilised in Study 1, it is recommended that a three-dimensional motion analysis
system, comprising cameras with a frame rate of 1,000Hz, is required. Previous studies that have investigated kicking kinematics have used cameras with higher frame rates from 240Hz (Atack, Trewartha & Bezodis, 2019; Bezodis, Atack, Willmott, Callard & Trewartha, 2019) to 1,000Hz (Nunome et al., 2006). Additionally, although it has been suggested that frame rates of 100-200Hz may be suitable for recording place kicks, Payton (2008) states that the appropriate frame rate for analysis of a respective action is determined by the dependent variable(s) in question. For example, with respect to a place kick, Payton (2008) states that although a frame rate of just 25Hz may facilitate accurate measurement of step length in the approach to foot-ball contact, a frame rate of 1,000Hz may be needed to analyse the dynamics of foot-ball interactions. In respect of the challenges faced in Study 1, it is proposed that future investigations into the kinematic and ROM effects of weighted football interventions of a longer duration use a motion analysis system comprising cameras of a higher frame rate than those used in Study 1. This would facilitate kinematic analysis of the foot, which is reported to be the fastest segment in the open kinetic chain during kicking (Young & Rath, 2011).

- It is also recommended that future research further examines how long the BV PAPE effect lasts as per the findings of Study 3 (Chapter 5). Albeit insignificant, as BV was consistently increasing across the four post-weighted football time points, it is possible that BV values would continue to increase beyond the enhancement observed at the 8-minute time point. The potential for this becomes particularly evident when consideration is given to existing PAPE literature that highlights performance improvements for up to 18.5 minutes following an over-weighted conditioning protocol (Chiu et al., 2003). Investigating BV values at later time points would
provide further information pertaining to the acute effects of the interaction of weighted football place kicks and time post-weighted football use on subsequent place kick BV. Findings of such an investigation may result in further value being placed on the performance of five weighted Gaelic football place kicks immediately prior to each playing half as enhanced BV values may be experienced for an even greater time period, thus further benefitting kick-out performance.

- Additionally, as the absence of individual time groups in Study 3 was deemed a limitation of this research, it is recommended that future research extends this research design whereby participants are assigned to time point specific groups that only perform post-weighted Gaelic football place kicks with the standard football at a single time point. For example, an ‘8-minute group’ would perform a post-weighted football place kick solely at the 8-minute time point and not at 2-, 4-, or 6-minutes as per the procedure of Study 3. Such a research design would provide an accurate insight into the specific time interval(s) that results in the greatest BV improvement post-weighted football use, and would correspondingly determine whether performance of preceding standard football place kicks at 2-, 4- and 6-minutes are required in order to induce maximal BV improvements at the 8-minute time point as observed in Study 3.

- It is recommended that future research investigates the effects of the intervention used in Study 4 (Chapter 6) at a time when goalkeepers are participating in a minimum of other training activities, such as in the off-season when on-field practice is at a minimum. This would further elucidate the impact of this intervention on each goalkeeper’s BV development. However, it is important to note that the manner in
which Study 4 was conducted provides great value to the skill acquisition specialist and S&C coach, as the study was conducted in an environment that was representative of what is encountered in the applied setting; that is, a weighted football intervention would rarely, if at all, be conducted in isolation of all other athletic endeavours.

- Based on the varied individual responses to the intervention that was conducted in Study 4, it is also suggested that future research investigates the effects of a 4-week, 8-session weighted football training intervention that comprises of a greater volume of weighted football place kicks, or an intervention that gradually increases the volume of weighted football place kicks as the intervention progresses. Such interventions may result in a larger proportion of participants experiencing significant pre-test to post-test improvements in place kick BV, particularly goalkeepers who have greater chronological and training ages.

- It is also recommended that future research that investigates the effects of weighted implement training in Gaelic football, and other football codes and sports, utilises other forms of data analyses in order to potentially observe some of the more subtle performance effects that may obtained from use of the respective weighted implement. For example, it is recommended that future research utilises a smallest worthwhile change analysis (Hopkins, 2000). This approach allows for determining and identifying meaningful changes in performance, therefore potentially adding to the practical significance of the respective research, and facilitating an accurate determination of whether a real change in performance has occurred as opposed to observed changes solely being the result of variation that is present within the dataset due to external factors (for example, the time of day in which the experimental test is
taking place) (Spencer, Fitzsimons, Dawson, Bishop & Goodman, 2006). However, it is important for researchers to embed this approach in the statistical analysis plan from the outset of the respective project as this form of analysis, and the validity and reliability of its findings, are dependent on particular methodological features. For example, it is imperative that the data is reliable and free from systematic bias (Turner, Brazier, Bishop, Chavda, Cree & Read, 2015).

- Finally, as per the Limitations section (see 7.3), it is advised that future research investigates the effects of the weighted football protocols and interventions that were applied in Studies 2-4 in comparison to non-training control conditions. As highlighted by Cuenca-Fernández et al. (2017), post-conditioning squat jump performance was not only significantly increased by task- and non-task-specific warm up protocols, but was also significantly increased by a ‘quiet standing’ condition. These findings illustrate that baseline testing activities, which are completed prior to the conditioning protocol(s), may have a substantial influence on post-conditioning motor skill performance and can potentially degrade the assumed influence of task- and non-task-specific training protocols on subsequent PAPE effects. Therefore, in respect of the protocols implemented in Studies 2-4 of this thesis, and the acute and chronic enhancement of place kicking performance, it is advised that future research replicates these studies but includes a non-training control condition. This would serve to determine whether the pre-conditioning warm up and preparatory endeavours contribute to potential increases in subsequent post-test place kicking.
7.6. Conclusion

WIT is used in the applied setting to attain acute and/or chromic enhancements of motor skill performance. Although a plethora of weighted implements spanning multiple sports are available in the marketplace, the majority of WIT research has been conducted in baseball, with a dearth of research investigating the acute and chronic effects of weighted Gaelic football place kicking on subsequent place kicking performance with the standard Gaelic football. Existing WIT research infers performance improvements may be experienced as a result of warming up and training with weighted implements. In light of this, and concurrent to a desire among Gaelic football stakeholders to enhance BV and kick distance, the aim of this thesis was to investigate the acute and chronic effects of weighted Gaelic football use on markers on place kicking performance. The efficacy of using the 600g (25% mass increase) weighted Gaelic football as a warm up and training tool to enhance place kick BV and distance was examined across four studies. The impact of the weighted football’s use on participants’ perceptions of standard football velocity and mass following use of the weighted football, as well as kinematic and ROM behaviours, was also explored. The key findings from this research suggest that repeated use of the weighted football does not chronically alter kicking leg kinematic and ROM behaviours and, further, the use of the weighted football serves as an efficacious warm up strategy to enhance kick distance and BV of place kicks with the standard football. The findings also suggest that a 4-week, 8-session intervention serves to significantly increase standard football velocity of inter-county level Gaelic football goalkeepers, thus benefiting kick-out performance. To conclude, this thesis addressed a significant gap in the WIT literature and provides skill acquisition specialists, S&C coaches, and Gaelic football goalkeepers with a strategy to enhance kick-out BV and distance, which are
critical in match play, particularly with regard to ball retention deeper into opposition territory.
References


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