CARDIFF METROPOLITAN UNIVERSITY
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CARDIFF SCHOOL OF SPORT

DEGREE OF BACHELOR OF SCIENCE (HONOURS)

SPORT CONDITIONING, REHABILITATION AND MASSAGE

2015-6

# THE RELATIONSHIP BETWEEN MUSCULAR POWER, SPRINT PERFORMANCE AND SPATIOTEMPORAL SPRINT CHARECTERISTICS

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| | |
|---|---|
| **CMJ** | Counter Movement Jump |
| **FT** | Flight Time |
| **GCT** | Ground Contact Time |
| **GRF** | Ground Reaction Force |
| **IMTP** | Isometric Mid-Thigh Pull |
| **PF** | Peak Force |
| **PV** | Peak Velocity |
| **RFD** | Rate of Force Development |
| **RSD** | Relative Standard Deviation |
| **SD** | Standard Deviation |
| **SF** | Step Frequency |
| **SJ** | Squat Jump |
| **SL** | Step Length |
| **SSC** | Stretch Shortening Cycle |
| **VJ** | Vertical Jump |

# ACKNOWLEDGEMENTS

First and foremost, I would like to express gratitude towards my dissertation supervisor Rob Meyers. His continuous support, knowledge and guidance was invaluable throughout.

I would like to thank Tom Osmond, Will Pinnell and Louis Simms for there help during the data collection process. Furthermore, I would like to acknowledge all the participants that took part on a voluntary basis, making this study possible. Finally, I would like to thank my friends and family for their encouragement throughout my final year of study.

# ABSTRACT

It is well established that muscular power is essential for sprint performance. However, the mechanism by which muscular power facilitates faster running speeds is weakly reported. The aim of this study was to identify the missing links between muscular power and sprint performance, playing specific attention to spatiotemporal sprint characteristics. The study hoped to create the missing links between cause and effect, understanding how the more powerful athlete alters their step length, step frequency and ground contact time to attain greater velocities.

18 undergraduate sports students from Cardiff Metropolitan University (age 19 ± 1.04 years, stature 175.5 ± 8.54 cm, body mass 77 ± 11.74 kg) volunteered to take part in the study. Both dynamic and isometric tests of muscular power were performed and correlated against maximal velocity sprint performance. The findings report a strong significant relationship ($p$ <0.01) between countermovement jump (CMJ) height and sprint performance; 30-40m split time ($r$ = -.759) and average velocity ($r$ = -.759). CMJ performance was found to be an accurate predictor of maximal velocity sprint performance, step length (SL) and step frequency (SF) through multiple stepwise regression. The justification of this relationship has been explored, suggesting a likeness in exercise nature as the associated factor.

In contrast, rate of force development (RFD) from the isometric mid-thigh pull (IMTP) only conveyed weak to moderate relationships with sprint performance (30-40m split time and average velocity) and spatiotemporal sprint characteristics; SL, SF and ground contact time (GCT). The strength of these findings were increased when the data was made relevant to body weight, identifying moderate significant ($p$ <0.05) relationships between relative RFD 0-250ms and sprint performance; 30-40m split time ($r$ = -.499) and average velocity ($r$ = .492). Despite only being moderate in strength this supports the existing literate, holding greater correlations with sprint performance than absolute force production.

Future investigations could look to implement the same methodology within a more specific population, allowing greater confidence when applying the findings. In addition to this, an investigation into horizontal force production as a predictor of sprint performance would be of value given its importance to the manifestation of sprint speed.

**KEY WORDS:** *Muscular Power, Sprint Performance, Rate of Force Development, Spatiotemporal Sprint Characteristics*

# CHAPTER I

# INTRODUCTION

### *1.1 The Importance of Sprint Speed*

Be it through direct or indirect application, sprint speed is an invaluable attribute in numerous sports (Taylor, 2003). In its simplest of forms, running fast can produce success in specialized track events such as the 100m sprint – an event offering its successor the title of the “fastest man or woman on earth.” Since the inaugural Modern Olympic Games in Athens 1896, sprint athletes have progressed dramatically, with the current 100m world record held by Usain Bolt in a time of 9.58 seconds. In addition to this, the possession of speed has been found beneficial amongst multiple sports; Rugby League (Gabbett, Kelly and Sheppard., 2008), Field Hockey (Spencer *et al*., 2004) and Basketball (Abdelkrim, El Fazaa and El Ati., 2007) to name a few. Sprint speed is held in such high regard that is proposed as the determining factor between sportspersons playing at the elite and sub-elite level (Layden, 2012; Cronin and Hansen, 2005; Young *et al*., 2008); again reinforced by the inclusion of speed testing in talent identification schemes, designed to evaluate athletic potential for world-class sport (Meylan *et al.,* 2010).

### *1.2 Defining Speed*

Speed can be defined “the skills and abilities required to achieve high velocities” (DeWesse & Nimphius 2008, p. 522). Within this definition ‘ability’ refers to individual physiological and anthropometric characteristics, whilst ‘skill’ is the adoption of an idealistic technique, both efficient and economic; this begins to highlight the fundamental relationship between physiological and biomechanical function when looking to achieve sprint performance. Speed is the product of SL and SF, with both parameters directly influencing one’s speed (Dintiman & Ward, 2003).

$$\text{Velocity} = \text{Step Length} \times \text{Step Frequency}$$

Despite appearing simple, multiple factors influence this equation. SL is quantified as the distance travelled between consecutive footfalls and SF the rate of steps within a given time. In this article we regard the term “step” as half a running cycle, the placement of one foot to the other. Hunter, Marshall and McNair (2004) found SL was influenced by flight and stance distance, the distance travelled by the centre of mass when in flight or ground contact respectively. Similarly, SF is comprised of flight and stance time, used interchangeably with GCT in this instant. Jarver (2000) classified the drive phase as the period of time in which the athlete is in contact with the floor, immediately followed by a recovery phase in which the limb is repositioned; occurring in a cyclic nature throughout the entirety of the sprint.

The assessment of speed can be undertaken simply by performing a basic sprint, covering a given distance in the quickest time possible. Sprint performance is underpinned by one’s ability to accelerate, their magnitude of velocity and ability to maintain velocity regardless of fatigue. Accelerative running occurs as the athlete sets into motion, lasting until the attainment of peak velocity (PV), their greatest speed of running (Gaffney, 1995).

### *1.3 The Importance of Muscular Power*

Forces underpin locomotion, allowing us to run, jump and throw. When sprinting great forces must be produced and applied effectively to propel the athlete down the track. The ability to produce a large ground reaction force (GRF) is beneficial to sprint speed (Cavagna, Komarek, and Mazzoleni, 1971; Mero *et al*., 1981; Weyand *et al*., 2000), with linear relationships found between maximal force production and PV (Peterson, Alar and Rhea, 2006). It is now understood that absolute forces play a greater role in the initial stages of the sprint, where athletes are looking to overcome inertia and set the body into motion (Brechue *et al*., 2010). In contrast to this, at maximal velocity athletes are faced with brief periods of ground contact, preventing them from producing maximal force (Weyand *et al.,* 2000). For this reason, forces must be produced and applied rapidly. Relative force production is now thought to be a key determinant of sprint performance (Meyers *et al.,* 2015; Hunter, Marshall and McNair*,* 2005) and gains greatest justification for further investigation. Despite a wealth of existing knowledge in this area, most studies fail to investigate how the more powerful athlete alters their spatiotemporal sprint characteristics to achieve quicker speeds. For this reason, an investigation into muscular power and sprint performance is necessary, with a detailed analysis of its effects upon spatiotemporal sprint characteristics such as SL, SF and GCT.

# CHAPTER II

# REVIEW OF LITERATURE

### *2.1 Biomechanics of Sprint Performance*

A successful sprinter is built upon sound biomechanics, allowing great forces to be produced and applied effectively (Weyand *et al*., 2000; Morin *et al*., 2012). When investigating the biomechanics of sprint performance both kinetic and kinematic variables must be considered.

The study of kinetics relates to forces, produced by and acting upon an athlete in motion. When sprinting, athletes experience three external forces: GRF, gravitational force and wind resistance. With gravity being an unchangeable constant and the effects of wind resistance negligible, GRF can be influenced most readily and is often the focus of sprint speed development (Cavagna *et al*., 1971). GRF can be broken into two components - braking and propulsive. In order to accelerate, one must minimise braking and maximise propulsive force development. The ability to produce large GRF is vital for sprint speed (Cavagna, Komarek, and Mazzoleni, 1971; Mero *et al*., 1981; Weyand *et al*., 2000). Mero *et al*. (1992) found a greater net horizontal force ($F_y$) over the course of the drive phase resulted in faster acceleration. Suggesting that sprint speed could be maximised through reduced vertical force ($F_z$) production; limited to the necessary value that supports sufficient FT yet allowing all remaining force to be transposed horizontally. Similarly, Morin *et al.* (2012) found the ability to maintain a horizontal orientation of GRF despite increasing speed through acceleration beneficial. This was described as ones “index of force application technique” and reported it to be a main mechanical determinant of 100m sprint performance; predicting both mean and peak running speeds.

Athletes are only able to influence their velocity during ground contact, creating momentum in response to the production of an impulse; force x time. For this reason, athletes must apply large forces rapidly in brief periods of ground contact to allow them to increase or maintain velocity (Weyand *et al*., 2000; Hunter, Marshall and McNair, 2005; Cissik, 2005). This notion suggests a focus upon front side sprint mechanics is beneficial, helping to maximise impulse expression through quality technical execution. Whilst the physical capacity to generate large force is necessary for sprint performance, the study of kinetics alone gives a limited insight into the way in which theses forces are expressed, equally as important.

Kinematics is the assessment of movement, motor patterns and technique, the fundamental link between force production and application. Technique is a major limiting factor of sprint performance with MacFarlane (1993, p. 35) suggesting “an athlete can only run as fast as his/her technique allows”. Accelerative and maximal velocity running place different demands on an athlete, influencing their spatiotemporal characteristics in response. SL, SF, FT and one’s centre of mass changes dramatically as acceleration manifests into maximal velocity running (Coh *et al*., 2006); also seeing transition to a more vertical torso (Young, Benton, and Pryor, 2001). Regardless of the many differences, a forceful triple extension (proximal-distal hip, knee and ankle sequencing) is evident and necessary throughout (Delecluse, 1997). Encouraging full triple extension helps to increase the impulse generated during the drive phase, applying forces for longer and increasing running velocity in turn. Differentiating between the kinematic qualities of elite and amateur athletes is vital in the training of sprint speed, helping identify areas of weakness for further development.

### *2.2 Spatiotemporal Sprint Characteristics*

SL and SF are mutually dependent, directly influencing one’s speed. Hunter, Marshall and McNair (2004) proposed a negative interaction during maximal velocity sprinting, with alterations to either SL or SF potentially detrimental to its counterpart. This suggests an optimal interaction is apparent where the improvement of one parameter must be directly proportional to, or greater than, the reduction in the other to achieve faster speeds. The Coaching Education Committee (2001) attempted to predict optimal SLs, measuring the distance between the greater trochanter and floor and multiplying it by the relevant value; 2.5-2.7 and 2.3-2.5 for men and women respectively. Salo *et al*. (2011) found individual dominance in SL or SF did not inhibit the performance of elite sprinters; nine of who had run sub-10 second 100m times. This makes evident how ‘optimal’ interactions are highly individual and can vary between all athletes - even those performing on the world’s biggest stages.

Both SL and SF change dramatically over the course of the sprint. In the accelerative phase SL and SF remain low, helping to generate large forces, overcome inertia and set the body into motion (Brechue *et al*., 2010). As the sprint progresses the two parameters then grow. Previous literature looking at the development and effects of longer SLs and greater SFs has been inconclusive. Both SF (Mero *et al*., 1981; Mero, Komi, and Gregor, 1992; Bezodis, Salo, and Kerwin, 2008) and SL (Hunter *et al*., 2004; Mackala 2007; Armstrong, Costill, and Gehlse, 1984) have been suggested as the ‘speed-limiting factor’ when looking to increase

PV. Greater impulses facilitate a greater SL, yet may cause one to over-stride if increased beyond its optimum value; increasing GCT, breaking forces and reducing one's resultant velocity in consequence (Morin *et al*., 2012). Conversely, dramatic increases in SF reduce GCT, limiting the time available to apply force and negatively influencing PV (Morin *et al*., 2012).

Similarly, GCT and FT change dramatically as sprint speeds manifest. In acceleration, GCTs are greater as the athlete spends time overcoming inertia, applying large concentric forces through the track (Salo, Keranen, and Vitasalo, 2005). In the maximal velocity phase, GCT is significantly reduced, with FT growing in turn (Salo, Keranen, and Vitasalo, 2005); this can be comprehended as the athlete increases momentum, short and sharp ground contacts essentially propel them along the surface of the track. Interestingly, Weyand *et al.* (2000) found FTs were consistent throughout participants, proposing their interaction with the floor at the determining factor of sprint speed as oppose to a rapid leg turnover. Astonishingly, Weyand *et al*. (2000) found only 8% (0.03s) variance in FT between those running the fastest and slowest sprint times.

### *2.3 Physiology of Sprint Performance*

The expression of kinetics and kinematics is underpinned by physiological function, the 'engine' of force production. Morphological factors have been investigated recurrently, with muscle structure and composition found to influence sprint speed (Cissik, 2005). Correlations between muscle mass and PV have been found, suggesting a greater muscle cross sectional area facilitates sprint performance through increased force potential (Kumagi *et al*., 2000; Bosch & Klomp, 2005). Kumagi *et al*. (2000) found greater fascicle length, the length of muscle bundles between the proximal and distal tendons, in faster athletes, allowing the muscle to contract more rapidly (up to 22%). Additionally, Costil *et al*. (1976) found elite sprinters possessed a greater quantity of Type II (fast-twitch) muscle fibres; holding the capacity to contract rapidly with greater force (Kawamori & Haff, 2004). The ability to generate larger forces in shorter times is beneficial to sprint performance ((Weyand *et al*., 2000; Hunter, Marshall and McNair, 2005; Cissik, 2005;) suggesting athletes should aim to improve muscle mass and composition.

The neuromuscular system can be trained to 'coordinate' our contractile tissues, producing greater forces in consequence (Duchateau, Semmler, and Enoka, 2006). This is addressed via intermuscular and intramuscular coordination variables. Intramuscular coordination is the ability to organise fibres within a given muscle, increasing motor unit recruitment, synchronisation and rate coding. Synchronizing motor units allows an accumulative contractile affect and the attainment of greatest force. However, some individuals do not posses the ability to recruit all muscle fibres collectively when performing voluntary contractions; thus limiting the quantity of force produced and likelihood of sprint success (Suter, Herzog, and Huber, 1996). Increased motor unit recruitment can be achieved through task-specific training modalities (Ross, Leveritt, and Riek, 2001); replicating triple extension patterns under load for example, transferable from weight room to track. Well trained sprint athletes do not only possess greater quantities of fast-twitch muscle fibres (Costil *et al*., 1976), but have a greater ability to recruit them (Saplinskas, Chobatas, and Yashchaninas, 1980). This suggests the ability to selectively recruit muscle fibres capable of rapid contraction and relaxation is beneficial to sprint performance and may occur in response to the demands of sprint exercise.

Rate coding or nerve contraction velocity refers to the speed at which a nerve impulse travels along the motor axon to stimulate muscle contraction; closely linked to muscle contraction time (Kupa *et al*., 1995). High nerve contraction velocity is indicative of a short refractory period (Borg, 1980), allowing subsequent impulses to be generated more readily. When impulses are fired rapidly one after another, the signals summate with the resultant force of contraction accumulating. A state of tetanus, continuous innervation of a muscle fibre through overlapping impulses, is therefore facilitative of maximal force production through this given mechanism. Increased nerve contraction velocity was found to improve force transmission and could be developed in response to a period of sprint training (Sleivert, Backus, and Wenger, 1995).

Intermuscular coordination refers to the relationship between agonist and antagonist. Co-contraction is the simultaneous activation of agonist and antagonist, apparent when tasks demand motor coordination and joint stability (Frost *et al*., 1997). In situations where the antagonist is stimulated beyond the necessary level for joint stability, the movement will be performed at a greater metabolic cost, reducing efficiency through opposing muscular tension. Ross, Leveritt and Riek (2001) found the efficiency of coordinated movement could be improved by altering the temporal sequencing of muscle recruitment and reducing co-contraction. The ability to create limb ‘stiffness’ through pre-activation of the tendomuscular system helps reduce deformation, avoid ‘force leakage’ and allows energy reutilisation through the stretch shortening cycle (SSC) (Chelly & Dennis, 2001; Ross, Leveritt, and Reik, 2001). Stiffness within the tendomuscular system has found to facilitate shorter GCTs, greater peak force (PF) and improved RFD, making it highly correlated with maximal velocity running and speed maintenance (Chelly & Dennis, 2001).

The SSC is a passive system that helps store and reutilise elastic energy from eccentric loading (Nicol, Avela, and Komi, 2006). The mechanism helps augment greater efficiency in concentric force production (Gamble, 2013; Markovic & Javic, 2005; Kotzamanidis, 2006) with the Achilles tendon for example providing an energy return rate of up to 93% following eccentric loading (Bosch, 2005). The SSC can be broken in to fast and slow categories, classified as greater or lesser than 250 milliseconds (Hennessy & Kilty, 2001). Komi (2000) found SSC actions changed in response to the GCT at each stage of the sprint - slow during acceleration and fast in maximal velocity. The SSC plays a greater role as the sprint progresses due to to greater eccentric loading, not present in the initial accelerative phase (Cronin & Hansen, 2005; Coyle & Yule, 2009). Sprint performance is a highly complex yet trainable quality, influenced by physiological capacity and technical ability. To attain greater running speeds athletes must have the ability to produce large relative forces and apply these with sound technical execution during limited periods of ground contact.

## *2.4 Mechanical Determinants of Sprint Performance*

### *2.4.1 Strength*

Absolute strength is the “maximal amount of force developed during a voluntary contraction” (Sale 1991, p. 21). Previous literature identifies the importance of a large GRF for sprint performance (Cavagna *et al*., 1971; Mero *et al*., 1981; Weyand *et al*., 2000). Peterson, Alar and Rhea (2006) deemed great force capacitates critical in the attainment of high velocity running speed; finding linear relationships between maximal strength and PV. More specifically lower limb strength, measured using the back squat, has been found to correlate strongly with both 20m (Seitz *et al*., 2014) and 40m (Baker & Nance, 1999) sprint time. Cormine, McBride and McGaulley (2009) gave support for this, finding 1RM back squat correlated with 10 ($r = -0.544$, $p = 0.024$) and 40m ($r = -0.605$, $p = 0.010$) dash times in a population of American Football players. Interestingly, concurrent improvement occurred between lower body strength and sprint performance following resistance training interventions (Comfort, Haigh, and Matthews, 2012). Lorturco *et al*. (2014) found improvements in strength and power (1RM back squat and CMJ height) were also reflected in sprint performance (20m dash time) amongst a moderately trained sample. De Villarreal *et al*. (2013) found complex training methods, incorporating both heavy resistance training and ballistic power activities were more successful in developing maximal strength and sprint speed when compared to either method in isolation. The findings of De Villarreal *et al*. (2013) may be limited however due to their given sample; made entirely of non-competitive individuals with no previous strength training. For this reason, we may assume that such vast improvements were associated with increased motor coordination and neuromuscular control, common in those beginning any form of structured training (Häkkinen & Häkkinen, 1994; Häkkinen *et al*., 2000).

Absolute force is now understood to play a greater role during accelerative running with large PFs helping to overcome inertia and set the body into motion (Brechue *et al*., 2010). As the sprint progresses, GCT reduces significantly, even noticeable over the first four steps (Salo, Keranen, and Vitasalo, 2005). For this reason, the ability to produce greater force in lesser time is ever important as the athlete's velocity increases.

### *2.4.2 Power*

Power is the product of force and velocity; defined as "the rate at which one can perform work" (Sale 1991, p. 21). Power can be calculated by multiplying force and velocity or conversely the amount or work performed in a given time (Kawamori & Haff, 2004). With sprint performance in primary focus, athletes must apply large forces in a limited time to accelerate or maintain velocity, measured through RFD.

$$\text{Rate of Force Development} = \Delta\text{Force} / \Delta\ \text{Time}$$

Weyand *et al.* (2000) suggested those who had greater RFD attained faster running speeds. As the sprint progresses into maximal velocity GCT reduces significantly, making the rate at which forces are expressed increasingly important (Macintosh *et al.,* 2000). When investigating the limiting factors of sprint performance, Weyand *et al.* (2010) found athletes were unable to produce forces reflective of their contractile maximum due to the brief GCTs experienced. He suggested an increase in limb extensor strength and RFD would improve running speeds when one's body mass was maintained.

The relationship between muscular power and sprint performance has been shown to varying degrees of strength. Young, James and Montgomery (2002) found no relationship between muscular power (isokinetic squat), reactive strength index (drop jumps) and 8m sprint times. Similarly, Cronin and Hansen (2005) found no correlation between PF and split times of 5, 10 and 30m. However, significant correlations ($r$ = -0.43 to -0.66, $p$ <0.05) were found between vertical jump (VJ) height, a ballistic measure of power and the three given distances. Markström and Olsson (2013) used a CMJ and found jump height correlated positively ($r$ = -0.158, $p$ <0.05) with PV. Sleivert and Taingauhue (2004) implemented a loaded squat jump (SJ) and recorded significant correlations ($r$ = −0.64, $p$ <0.01) between concentric force development and sprint start performance (5m dash), whilst Maulder, Bradshaw and Keogh (2006) found relative power output achieved during a SJ could predict 10m sprint performance. Young *et al*. (1995) found force production in the initial 100ms of a loaded SJ to be the best predictor of PV, again reflecting the success of those who can produce great forces in brief periods of time.

Baker and Nance (1999) investigated strength and power in a sample of Rugby League Players, looking at its relationships with sprint performance over 10 and 40m. They found significant correlations ($p$ <0.05) between 3RM back squat ($r$ = -0.39), 3RM hang power clean ($r$ = -0.56) and loaded JS ($r$ = -0.52 to -0.61) when data was made relative to body weight. Despite this, no significant correlations were found when values were left absolute. Support for this was given by Meyers *et al*. (2015) reiterating the importance of relative force production, found to be a key predictor of youth sprint speed. Similarly, Hunter, Marshall and McNair (2005) found relative horizontal impulse to be the greatest predictor of sprint velocity, recorded at the 16m mark. This suggests that absolute force is a weak predictor of sprint speed when compared to relative values. Whilst numerous authors have looked to explore the relationship between muscular power and sprint speed, they have failed to investigate its direct affect upon spatiotemporal characteristics of sprint performance. Looking at how these entities differ dependent upon muscular power will be beneficial, helping to understand how athletes run faster, not simply appreciating that they do.

### *2.5 Methodology Support*

Sprint performance can be measured using laboratory and field assessments. Despite the availability of 'gold standard' equipment it is worth noting without the necessary funding, training and facilities available this becomes irrelevant to the majority of practitioners. For this reason, procedures that are innately reliable, affordable and easy to implement have become prevalent in the assessment of speed, strength and power.

### *2.5.1 Sprint Speed Assessment*

Three dimensional (3-D) computerised gait analysis systems such as the Cartesian Optoelctronic Dynamic Anthropometer (CODA mpx30) can provided extensive kinetic, kinematic and spatiotemporal descriptions of sprint performance. CODA mpx30 is an invasive, active motion analysis system that tracks marker position via a sensory unit. Birch and Dechamps (2011) reported CODA mpx30 could accurately report the location of a marker to a single millimetre. They also found it had the ability to accurately estimate a known right angle in all planes other than the yz plane; in which the mean prediction was 92.47°. Piotter, Post and Vanden-Berg (1999) also found high repeatability recording gait pattern data over nine consecutive days. The ability to investigate the interaction between joints and change in joint angles helps coach's compare the athlete in front of them to a model of best practice, addressing flaws in technique to develop sprint performance. However, such complicated systems lack feasibility in real life application, requiring participants to be fitted with battery packs and markers, extremely time consuming when dealing with large quantities of athletes. Furthermore, wearing these markers may alter their natural sprint mechanics, reducing the validity of its findings. Innately being deemed a 'gold-standard' method of assessment this equipment comes with a substantial cost, outside of the reach of most athletes, coaches and other practitioners.

OptoJump (Microgate, Bolzano, Italy) allows an automatic assessment of spatio-temporal sprint characteristics such as GCT, FT, SL and SF, with an accuracy of 1/1000s of a second (Meyers *et al*., 2015). The OptoJump kit consists of two parallel bars that fire infrared beams to one another, allowing the breaking of the beam to be recorded and analysed instantaneously. The OptoJump has been found to report acceptable reliability for both speed and spatiotemporal determinants of sprinting (SL, SF and GCT) over single and repeat steps (Meyers *et al*., 2015), with Debaere, Jonkers and Deleculuse (2013) reiterating its ability to measure SL and SF accurately. The OptoJump track also gathered support when used to asses VJ performance (Glatthorn *et al*., 2011). Although cheaper than CODA, OptoJump systems are costly and unaffordable for the average practitioner. Furthermore, OptoJump tracks are time-consuming to initially set up, making them impractical for regular application.

Infrared timing gates are the method of choice in settings that require high levels of precision, virtually eliminating timing errors (Hetzler *et al*., 2008; Brechue *et al*., 2008). Being easy to implement and relatively affordable they offer an ecologically valid measure of sprint performance. Such timing gates work in a similar fashion to the OptoJump system, where split times are recorded instantaneously following the breaking of an infrared beam. The data is then fed back to the control unit allowing live data analysis, beneficial for coaches gaining immediate feedback. Implementing timing gates removes the influence of reaction time upon sprint speed measurement, a major floor of the hand held stopwatch alternative (Hetzler *et al*., 2008; Brechue *et al*., 2008); Participants are able to start on their own accord with the timer commencing upon the breaking of the first beam, rather than reacting to a given stimulus and relying upon a coach pressing to record split times as they progress. Hetzler *et al*. (2008) suggested the faster the participant, the greater the inaccuracy of the stopwatch method; making it an invalid measure of elite sprint performance. D'Auria *et al*. (1996) compared the reliability of SMARTSPEED gates using false signal processing to that of standard dual beam gates over 6 sprints with splits at 5, 10, 20 and 30m. They found typical error was almost half that of standard dual beam gates at the 5m mark, within an error of 0.03 seconds, satisfying the National Sport Science Quality Assurance (NSSQA) guidelines. Reliability in sprint assessment is essential, with elite athletes making improvements of miniscule margins these cannot be lost through the inaccuracy of equipment. Despite their reliability, timing gates provide no understanding of kinematic data, restricting insight into how speeds are actually achieved. However, data can be paired with video footage of the given trial, allowing retrospective video analysis to take place. This aids in the calculation of average spatiotemporal sprint characteristics and helps paint a more rounded picture of athlete performance.

### *2.5.2 Muscular Power Assessment*

Muscular power is a desirable attribute in numerous sports, found to be a predictor of sports specific speed (Cronin & Hansen, 2005). The function of skeletal muscle can be assessed through isometric and dynamic means. A dynamic assessment of power ordinarily requires participants to jump for maximal heights or distances. VJs have been found to exhibit similar neuromuscular performance qualities to that of running tasks (Bosco *et al*., 1987) and be reflective of the explosive characteristics in both sedentary (Bosco & Komi, 1979) and elite (Bosco & Vitasalo, 1982) populations. Furthermore, Shalfawi *et al*. (2011) found strong correlations ($r$ = 0.75) between CMJ height and sprint speed (40m split). Similarly, Young *et* *al*. (1996) and Mero *et al*. (1981) found CMJ height and 30m split time were strongly related (*r* = 0.66 and 0.65 respectively). CMJs allow the greatest force expression and consequent jump heights as the are able to recruit the SSC through countermovement (Markovic & Jaric, 2005). Cormie, McBride, and McCaulley (2009) found the CMJ facilitated maximal muscle contraction amongst the Quadriceps, the primary agonist responsible for jump performance.

Data can be collected most simply using a 'jump and reach' test, where athletes are asked to leap in and 'slap' the highest point possible; however, this method clearly lacks reliability and precision (Leard *et al*., 2007). Contact mats are used more commonly, allowing a reliable and relatively inexpensive assessment of VJ performance. Force plates may be used to gather a more in depth analysis of force development throughout the sequential phases of the jump however these are expensive and may be more time consuming to implement when compared to the instantaneous results gathered using jump mats. Harmen *et al*. (1990) found high test-retest reliability using the CMJ, yet his sample size was limited. Markovic *et al*. (2004) concluded, in a study of a greater sample size, that the CMJ was the most reliable and valid jump tests for the estimation of explosive power in the lower limbs. However, made evident that a consistent landing technique must be acquired, with the legs and hips remaining extended until contact is made with the mat; as suggested by Klavora (2000). A number of variables heavily influence the performance of a CMJ including arm swing, timing of segmental actions and the speed and amplitude of countermovement (Young, MacDonald, and Flowers, 2001), yet Domire and Challis (2007) found adopting a self-selected squat depth made no difference in subsequent jump heights when compared to a fixed 90-degree depth – reducing hassle of measurement and encouragement of natural movement.

An isometric muscle action sees the production of force against a greater external resistance, causing it to remain at constant length. An IMTP is a multi-joint test commonly implemented to assess both strength and power (Murphy *et al*., 1995; Hunter, Marshall, and McNair, 2004; Haff *et al*., 2015). The IMTP requires participants to stand above a force plate and pull in maximal effort against an immovable bar. The IMTP mirrors the second pull of the clean, where the athlete should have an upright trunk and soft knees (Enoka, 1985). This position is favourable as it allows the greatest force and power output of all the weightlifting positions (Garhammer, 1993). Hunter, Marshall and McNair (2004) supported the inclusion of IMTP whilst assessing sprint performance and hailed its specificity. This was reasoned by its great posterior chain muscle recruitment and replicable mechanics to that of sprint performance – force generated through triple extension of the hip, knee and ankle to create large vertical impulse through the floor.

The reliability of this test is heavily influenced by the positions and cueing of participants. Murphy *et al*. (1995) found the joint angle of the hip and knee was able to greatly affect one's force-generating capacities due to the quantity of cross-bridge formation avaliable. For this reason, joint angles should be standardised to ensure more reliable comparisons. Another factor deemed influential was the 'cueing' and instruction of the subjects (Haff *et al*., 2015). Commanding participants to "pull as hard and as fast as possible" was shown to encourage maximal effort (Garhammer, 1993). Grip strength can also influence IMTP scores, to reduce this a women's bar can be used due to its narrower circumference, helping to minimise this factor.

A number of authors criticise the IMTP and claim that is seldom seen in the sporting environment (Komi, 2000); discounting its transferability to triple extension patterns seen extensively throughout sport. With this noted, isometric measures have shown strong potential to predict dynamic capabilities in activities involving strength and explosive power (Juneja, Verma and Khanna, 2010). Using a dynamic and isometric measure of muscular power offers a more rounded assessment of one's force profile, understanding their ability to create and apply force.

### *2.6 Rationale*

The aim of this study is to investigate and quantify the relationship between muscular power and sprint performance. Whilst it is well established that maximal velocity sprinting is heavily influenced by an athlete's capacity to produce and apply force effectively, there is little research investigating its direct effects upon spatiotemporal sprint characteristics. The study will aim to strength a wealth of existing knowledge whilst investigating the effect of muscular power upon SL, SF and GCT.

The hypotheses predict that producing great forces rapidly is advantageous to sprint performance and facilitates greater running speeds. In addition to this, those with a greater RFD capacity will record larger SLs, smaller SFs and spend less time in contact with the floor. The findings will be of benefit to strength and conditioning practitioners, coaches and athletes alike, helping them to understand the multi-faceted nature of sprint performance and promote the development of athletes in alignment with scientific justification rather than anecdotal evidence.

Hypotheses

1. CMJ height will have a significant correlation with sprint performance, making it an accurate predictor of sprint speed.
2. Greater RFD during an IMTP will have a significant correlation to sprint performance, making it an accurate predictor of sprint speed.
3. CMJ height will have a significant correlation with spatiotemporal sprint characteristics, helping to predict SL, SF and GCT at maximal velocity.
4. IMTP RFD will have a significant correlation with spatiotemporal sprint characteristics, helping to predict SL, SF and GCT at maximal velocity.

Null Hypotheses

1. CMJ height will have no significant correlation with sprint performance making it an inaccurate predictor of sprint speed.
2. Greater RFD during an IMTP will have no significant correlation with sprint performance making it an inaccurate predictor of sprint speed.
3. CMJ height will have no significant correlation with spatiotemporal sprint characteristics, failing to predict SL, SF and GCT at maximal velocity.
4. IMTP RFD will have no significant correlation with spatiotemporal sprint characteristics, failing to predict SL, SF and GCT at maximal velocity.

# CHAPTER III

# METHODOLOGY

### *3.1 Experimental Design Overview*

The aim of this study was to investigate the relationship between muscular power, sprint performance and average spatiotemporal sprint characteristics. Participants attended two testing sessions held on consecutive Thursdays. In testing session one informed consent was gathered, basic anthropometric data (body mass and stature) recorded and individual participant numbers designated, followed by sprint familiarisation and testing. A standardised 10-minute warm-up was performed and then followed by three 40m sprint trials. In testing session two the standardised warm-up was repeated, followed by three CMJ and IMTP trials. The data collected was analysed to explore the relationship between muscular power and average spatiotemporal sprint characteristics, depicted via a Pearson's and Spearman's Rho correlation. To identify the most accurate predictor of average velocity, SL and SF a multiple stepwise regression was also implemented.

### *3.2 Participants*

18 undergraduate sports students (age 19 ± 1.04 years, stature 175.5 ± 8.54 cm, body mass 77 ± 11.74 kg) from Cardiff Metropolitan University volunteered to take part in the study. All participants were deemed eligible to partake in this study through the successful completion of a Physical Activity Readiness Questionnaire (PAR-Q; Appendix A) and having previous exposure to resistance training. A convenience sample of undergraduate sports students was recruited following personal communications and approaches during scheduled lectures. Each participant was given the opportunity to read and question the information sheet (Appendix B) prior to formally agreeing to the study through written consent (Appendix C). At this moment it was emphasised that participation was voluntary and they obtained the right to withdraw at any time. Participants were told to avoid the consumption of alcohol and participation in strenuous exercise in the 24 hours prior to testing. Approval from the Cardiff Metropolitan University ethics committee was obtained prior to the study being advertised.

### *3.3 Procedures*

In testing session one, upon giving consent, each individual was prescribed a participant number that would be used to identify them for the duration of the study. Basic anthropometric data (body mass and stature) was then recorded, accurate to a single decimal place. Height was measured using a stadiometer (Seca 213, Hamburg, Germany) and weight with digital scales (Seca 770, Hamburg, Germany); shoes were removed along with any additional clothing. Participants then took part in a standardised 10-minute warm-up (Appendix D), reflecting the procedure used by Till and Cooke (2009) in preparation for sprint testing. This consisted of a 'heart raise' period, followed by progressive dynamic exercises helping to globally mobilise and activate the body. The movements selected were deemed reflective of the subsequent activity as suggested by Jeffreys (2007).

#### *3.3.1 Sprint Trials*

All sprints took place at the National Indoor Athletic Centre (NIAC), Cardiff, on an indoor synthetic surface. The sprint was 40m in length and recorded using infra-red timing gates (Smartspeed, Fusion Sport, Brisbane, Australia). Gates at 0, 30 and 40ms allowed numerous split and elapsed sprint times to be recorded telemetrically. Data was collected using a personal digital assistant and later processed using an Excel spreadsheet (Microsoft, Washington, USA). Extreme care was taken to ensure the accurate placement and height (1.2m) of each gate. To encourage maximal effort throughout the entirety of the trial an additional gate was paced upon the 45m mark, the data collected from this gate was used to motivate participants then later disposed during analysis. Waldron *et al*. (2010) deemed infra-red timing gates a reliable (CV 1-1.54%) method for the testing of linear movement over 10m intervals, also found to satisfy the NSSQA guidelines (D'Auria *et al*., 1996).

To conclude the warm-up, three progressive sprint trials (60, 70 and 80% perceived effort) were performed, also acting to familiarise the participants with the procedure. Stood in a split-stance 30cm before the first gate, participants were instructed to begin at their own accord. Each participant was given three attempts to record their fastest 30-40m split time, given a minimum of three minutes rest to ensure sufficient recovery (Robinson *et al*., 1995). The 30-40m split was used to measure maximal velocity running (Cronin & Hansen, 2006) where participants were assumed to be travelling at constant velocity. Hennessy and Kilty

(2001) found maximal velocity sprinting could be measured reliably over a 40m test, with Young *et al*. (2008) stating 99% of their subjects (*n* =65) attained maximal velocity by the 40m mark. Young *et al*. (2008) used an elite sprint population who reach PV at a later stage in comparison to novice athletes (Letzelter, 2006; Mackala, 2007). As our sample is relatively untrained, we may assume they had reached PV by this point.

In order to gain a more extensive understanding of the spatiotemporal sprint characteristics, retrospective video analysis was performed. An iPad Mini (Apple, California, USA) was used to record video footage of the 30-40m split, set to film at a 120 frames per second. The iPad remained fixed on a tripod perpendicular to the sprint track and was not moved during data collection in an effort to minimise perspective and parallax errors. To calculate each spatiotemporal sprint characteristics, the video was replayed in slow motion in intervals of 0.04s, thus giving 0.08s margin of error. Firstly, the elapsed time between initial and final foot contact (toe down) was recorded then multiplied by average velocity (30-40m split time divided by the 10m distance); thus giving us distance travelled. Distance travelled could then be divided by the number of steps taken, giving average SL (2). Finally, average velocity was divided by average SL giving average SF (3), based on the knowledge that velocity is equal to stride length multiplied by stride frequency (1). All video footage was erased following its analysis to ensure participant confidentiality.

Velocity = Stride Length x Stride Frequency (1)
Average Step Length = Distance travelled/Steps taken (2)
Average Step Frequency = Average Velocity/Average Step Length (3)

### *3.3.2 Dynamic Power*

The CMJ is a dynamic action found to be the most valid and reliable measure of lower body power (Cronbach’s Alphas = 0.97; Markovich *et al*., 2004). Participants began stood on a contact mat (SmartJump Mat, Fusion Sport, Brisbane, Australia) with knees fully extended; then squatting to a self-selected depth and jumping for maximal height. Hands were kept on hips throughout the entirety of the jump, with legs remaining fully extended in flight. Each participant was given two opportunities to practice and familiarise themselves with the procedure, followed by three maximal attempts. Again, three minutes rest was given between trials (Robinson *et al*., 1995). The contact mat recorded jump height using the following equation, set to record at a frequency of 50Hz.

$$\text{Jump Height} = (FT^2 \times G)/8$$

FT = flight time (s)
G = acceleration due to gravity (9.81ms.$^2$).

### 3.3.3 Isometric Power

An IMTP is a multijoint measure that reflects both strength and power. The test requires participants to pull in maximal effort against an immovable barbell (Eleiko Sport, Halmstad, Sweden), overloaded within a power rack (Conner Athletic Products Inc, Jefferson, USA) and fastened using ratchet straps. To perform the test participants stood with feet hip width apart on top of the force plate (PASCO PS-2142, Roseville, U.S.). Participants were encouraged to hold the bar using their normal clean grip, keeping their chest up and backs tight. To ensure continuity between individual's knee angles of 141±10° were measured using a goniometer (Biometrics F35, Newport, UK) and vertical trunks attained (Kawamori, 2006). Upon hearing "Ready" and 'GO!' participants were instructed to pull as hard and as fast as possible. Manipulating the recording conditions allowed a five second trial to be triggered once force values exceeded body weight plus 10%. A minimum of three minutes rest was given (Robinson *et al*., 1995) and repeated for a total of three trials. The data was recorded onto a laptop with PASCO Capstone software (PASCO, Roseville, U.S.) and later reviewed using Microsoft Excel (Washington, USA).

To allow suitable familiarisation three progressive practice pulls took place, gradually progressing from sub-maximal to maximal effort. Investigators gave coaching cues and tactile positioning (following verbal consent) in order to achieve the correct position. Our procedure was similar to that of James *et al*. (2015) given his reported level of reliability (CV = 3.1% and ICC 0.96, 90%). Each participant aimed to produce the greatest force possible throughout the five second trial; recording the peak value at 0-50, 0-100, 0-150, 0-200 and 0-250ms intervals over the course of three trials. Force data was not inclusive of body weight, only representing the force generated by each participant. RFD amongst each of the time intervals above was calculated using the following equation:

$$\text{Rate of Force Development (N.S-1)} = \Delta\text{Peak Force (N)} / \Delta\text{Time (s)}$$

### *3.4 Data Analysis*

Firstly, the data for analysis was selected as stated, then tested for normality using SPSS (Version 22, SPSS, Chicago, Illinois). This dictated weather a Pearson's or Spearman's Rho correlation was performed, assessing the strength of relationships between muscular power and spatiotemporal sprint characteristics. '*r*' values depict the strength of such relationships on a scale of -1 to +1, with -1 showing a negative linear relationship and +1 a positive (Curran-Everett, 2010). In order to determine the strength of correlations, Hopkins model (2002) was implemented; <0.1 trivial, 0.1-0.3 small, 0.3-0.5 moderate, 0.5-0.7 large, 0.7-0.9 very large, >0.9 nearly perfect (Hopkins, 2002). The significance of all statistical tests was set at a level of $p < 0.05$. In addition to this, a multiple stepwise regression was run to identify the best predictor of sprint performance, SL and SF.

# CHAPTER IV

# RESULTS

### *4.1 Descriptive Statistics*

Table 1 shows the means and standard deviations (SD) for the groups anthropometric, sprint performance and spatiotemporal sprint characteristics (*n* = 18). In addition to this, minimum, maximum and relative SD (RSD) is listed for each parameter, helping to identify the level of variation amongst the sample. All participants were of similar height (175.5 ± 8.54) and age (19.4 ± 1.04) yet varied greatly in weight (77.0 ± 11.74). Sprint performance is also displayed in Table 1, making a large range in sprint ability evident with 30-40m split times range by 0.68s. Using SD alone average GCT looked to vary least (±0.02) however, it holds a RSD of 14%, the second largest of table 1. With average GCT taking place over a 12ms window, small deviations from the mean would result in a large percentage variance due to the sensitivity of the measure.

**Table 1**. Descriptive statistics and RSD values for the groups (*n* =18) age, height, weight, sprint performance and average spatiotemporal sprint characteristics

| | Mean | SD (±) | Minimum | Maximum | RSD (%) |
|---|---|---|---|---|---|
| Age (years) | 19.40 | 1.04 | 18.00 | 21.00 | 5 |
| Height (cm) | 175.50 | 8.54 | 157.50 | 186.00 | 5 |
| Weight (kg) | 77.00 | 11.74 | 49.30 | 93.80 | 15 |
| 30-40m (s) | 1.20 | 0.15 | 0.95 | 1.58 | 12 |
| Average Velocity (m.s$^2$) | 8.43 | 0.95 | 6.33 | 10.53 | 11 |
| Average SL (m) | 1.57 | 0.13 | 1.32 | 1.87 | 8 |
| Average SF (Hz) | 5.40 | 0.29 | 4.79 | 5.80 | 5 |
| Average GCT (s) | 0.12 | 0.02 | 0.10 | 0.15 | 14 |

Table 2 depicts the means, SDs, RSD, minimum and maximum values for the CMJ and IMTP. There is a large range amongst CMJ height, with scores reported between 22.15 and 52.59cm amongst the population.

Table 2 also demonstrates the IMTP RFD data at numerous time intervals. This clearly shows a reduction in RFD as the interval increases; greatest at 0-50ms (27988.6 N) and least between 0-250ms (8123.46 N). Despite this, RFD 0-50ms has the greatest SD (±6149.22) and range between minimum and maximum values showing a great mix in ability during this initial window. Greater variance is shown throughout table 2 with all RSD values exceeding those in table 1 (17 to 56% variance). Peak RFD and time to peak RFD report the greatest RSD, 39 and 56% respectively. Time to peak RFD suffers a similar fate to that of average GCT as it takes place over such small intervals the level of variation can manifest rapidly.

**Table 2.** Means, standard deviations (SD), relative SDs, minimum and maximum values for CMJ jump height and IMTP RFD (*n* =18)

| | Mean | SD (±) | Minimum | Maximum | RSD(%) |
|---|---|---|---|---|---|
| CMJ Jump Height (cm) | 42.39 | 7.04 | 22.15 | 52.29 | 17 |
| RFD 0-50 (N) | 27988.60 | 6149.22 | 15206.00 | 39140.40 | 22 |
| RFD 0-100 (N) | 16607.07 | 3613.88 | 8242.90 | 22456.60 | 22 |
| RFD 0-150 (N) | 12208.39 | 3033.48 | 6172.53 | 16744.87 | 25 |
| RFD 0-200 (N) | 9596.49 | 2522.07 | 4282.10 | 13110.60 | 26 |
| RFD 0-250 (N) | 8123.46 | 2130.82 | 3757.92 | 11588.96 | 26 |
| Peak RFD (N) | 9057.83 | 3548.81 | 2858.80 | 15718.00 | 39 |
| Time to Peak RFD (s) | 0.09 | 0.05 | 0.05 | 0.25 | 56 |

### *4.2 Correlation Analysis*

The aim of this study was to identify the strength of relationships between muscular power and sprint performance, whilst exploring its effect upon spatiotemporal sprint characteristics. In order to do so, performance measures from a CMJ and IMTP were correlated against 30-40m split time, average velocity and spatiotemporal sprint characteristics using a Pearson's correlation. The only exception to this was CMJ height and average GCT, requiring a Spearman's Rho upon failing tests of normality (Kolmogorov-Smirnov and Shaprio-Wilk).

CMJ height is shown to have a very strong relationship ($p$ <0.01) with sprint performance (30-40m split $r$ = -.759 and average velocity $r$ = -.759), whilst the IMTP failed to display any significant relationships with sprint performance.

When looking at the relationship between muscular power and the spatiotemporal sprint characteristics CMJ held a very large significant ($p$ <0.01) correlation with average GCT ($r$ = -.740), a large significant ($p$ <0.05) relationships with average SL ($r$ = .679) and a moderate insignificant relationship with average SF ($r$ = .449). The IMTP displayed a moderate relationship between average SF and time to peak RFD ($p$ <0.05, $r$ = .477). All other relationships were insignificant and moderate at best ($r$ = 335 to -.454).

**Table 3.** A correlation coefficient between muscular power, sprint performance and spatiotemporal sprint characteristics

| | 30-40m (s) | A.Vel (m.s$^2$) | A.SL (m) | A.SF (Hz) | A.GCT (s) |
|---|---|---|---|---|---|
| CMJ JH (cm) | -.759$^{**}$ | .759$^{**}$ | .679$^{**}$ | .449 | -.740$^{**}$ |
| RFD 0-50 (N) | -.360 | .316 | .210 | .300 | .048 |
| RFD 0-100 (N) | -.383 | .334 | .236 | .335 | .060 |
| RFD 0-150 (N) | -.353 | .309 | .214 | .283 | .100 |
| RFD 0-200 (N) | -.370 | .333 | .248 | .273 | .119 |
| RFD 0-250 (N) | -.454 | .419 | .293 | .342 | .000 |
| PRFD (N) | -.348 | .326 | .296 | .236 | .003 |
| TT.PRFD (s) | -.187 | .166 | -.055 | .477$^{*}$ | -.155 |

**Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

A.Vel = Average Velocity
A.SL = Average Step Length
A.SF = Average Step Frequency
A.GCT = Average Ground Contact Time

Table 4 demonstrates the relationship between relative RFD, sprint performance and average spatiotemporal characteristics. Relative RFD 0-250 presented significant moderate relationships ($p$ <0.05) with average velocity ($r$ =.492) and 30-40m split time ($r$ =.499). Relative RFD 0-100 held a moderate significant ($p$ <0.05) relationship with average SF whilst all other relationships were insignificant and moderate at best.

**Table 4.** A correlation coefficient between relative RFD and spatiotemporal sprint characteristics

| | 30-40m (s) | A.Vel (m.s$^2$) | A.SL (m) | A.SF(Hz) | A.GCT (s) |
|---|---|---|---|---|---|
| RRFD 0-50 (N.Kg) | -0.389 | 0.383 | 0.228 | 0.449 | -0.221 |
| RRFD 0-100 (N.Kg) | -0.404 | 0.389 | 0.247 | .495* | -0.183 |
| RRFD 0-150 (N.Kg) | -0.370 | 0.357 | 0.225 | 0.397 | -0.110 |
| RRFD 0-200 (N.Kg) | -0.393 | 0.385 | 0.270 | 0.375 | -0.019 |
| RRFD 0-250 (N.Kg) | -.499* | .492* | 0.324 | 0.449 | -0.163 |

* Correlation is significant at the 0.05 level (2-tailed)

RRFD = Relative Rate of Force Development

A correlation coefficient between sprint performance (30-40m split time and average velocity) and average spatiotemporal sprint characteristics (SL, SF and GCT) is displayed in Table 5. Average SL showed a very strong significant relationship ($p$ < 0.01) with both 30-40m split time ($r$ = -.861) and average velocity ($r$ =.886). Average SF presented a large correlation with sprint performance; 30-40m split time ($p$ <0.01, $r$ = -.603) and average velocity ($p$ <0.05, $r$ = .590). Finally, average GCT showed major significant relationships ($p$ <0.05) with 30-40m split time ($r$ = .627) and average velocity ($r$ = -.643).

**Table 5.** A correlation coefficient between sprint performance and spatiotemporal sprint characteristics

| | 30-40m (s) | A. Velocity (m.s$^2$) |
|---|---|---|
| Average SL (m) | -.861** | .886** |
| Average SF (Hz) | -.603** | .590* |
| Average GCT (s) | .627** | -.643** |

**Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

### *4.3 Multiple Stepwise Regression Analysis*

A multiple stepwise regression helped to identify the best predictor of sprint performance and specific spatiotemporal characteristics. CMJ height was found to be a strong predictor of average velocity, accounting for 66% of the explained variance. In addition to this CMJ was also found to account for 41% and 45% of the explained variance in SL and SF respectively. In summary, this helps to identify CMJ height as the most accurate predictor of average velocity, average SF and average SL.

**Table 6.** A multiple stepwise regression identifying the most accurate predictor of average velocity, average SL and average SF

| | Best Predictor | Adjusted $R^2$ | β |
|---|---|---|---|
| Average Velocity ($m.s^2$) | CMJ Jump Height | 0.658 | 0.823 |
| Average SL (m) | CMJ Jump Height | 0.406 | 0.664 |
| Average SF (Hz) | CMJ Jump Height | 0.453 | 0.697 |

# CHAPTER V

# DISCUSSION

### *5.1 Major Findings*

The primary aim of this study was to investigate the relationship between muscular power and sprint performance, paying specific interest to its effect upon spatiotemporal sprint characteristics. It is well established that athletes who produce greater force in less time are predisposed to sprint performance (Weyand *et al.,* 2000; Hunter, Marshall and McNair, 2005). For this reason, it was hypothesised that muscular power expressed during a CMJ and IMTP would be significantly correlated with sprint speed. In addition to this, we predict that CMJ height and IMTP RFD would have a significant relationship with SL, SF and GCT.

The major findings of this study were threefold; Firstly, CMJ height was highly correlated with 30-40m split time and average velocity. Showing a strong relationship between CMJ height and maximal velocity sprint performance. Secondly, CMJ height was found to be the most accurate predictor of average velocity, SL and SF by implementing multiple stepwise regressions. Finally, the IMTP RFD data showed weak-moderate relationships with all spatiotemporal and performance variables however, a significant relationship was found between RFD 0-250ms and sprint performance (average velocity and 30-40m split time) when made relevant to body weight; reinforcing the importance of relative force production as suggested in previous studies.

### *5.2 The Relationship Between Muscular Power and Sprint Speed*

The first meaningful finding was the very strong significant relationship ($p$ <0.01) between CMJ height and sprint performance; both 30-40m split time ($r$ = -.759) and average velocity ($r$ = -.759). Our findings are in support of the existing literature identifying CMJ height as an accurate predictor of sprint speed (Young *et al.,* 1996; Shalfawi *et al.,* 2011).

Markovic *et al*. (2004) found VJ tests were a valid and reliable measure of lower body power, holding similar neuromuscular demands to that of running tasks (Bosco *et al.,* 1987). The 40m sprint and CMJ could both be classified as vigorous and short lived in nature and for this reason dependent upon the same physiological functions. We may assume individuals with the favourable adaptations found to facilitate maximal sprint performance would also benefit maximal jump height. An example of this is a greater muscle cross sectional area, beneficial to sprint performance through increased force potential (Kumagi *et al*., 2000; Bosch & Klomp, 2005). Similarly, possessing a greater quantity of fast twitch (type II muscle fibres) promotes rapid and more forceful contractions, with trained individuals having the capacity to selectively recruit these during intense activities (Saplinskas, Chobatas, and

Yashchaninas 1980). This would suggest these individuals could perform at a greater intensity during the 40m sprint and CMJ by activating these ballistic and explosive fibres. Despite the strength of our findings, we must implement them with caution. With such a large variation in jump height ability, ranging from 22.15 to 52.29cm, the spread of data may act to exaggerate the relationships between CMJ height and sprint performance.

Another substantial discovery was the weak correlations between the IMTP and sprint performance, showing no significant relationship throughout. These findings are in direct contrast to that of Juneja, Verma and Khanna (2010) who suggested the IMTP was a strong predictor of explosive power and sprint performance. However, this discrepancy may be explained my flaws in our methodology. A major limitation of our study was the IMTP recording frequency of 20Hz, substantially reducing the sensitivity of our data. This meant force values were recorded in 0.05s increments, reducing disparity between participants and failing to accurately represent force potential. In addition to this, the position of the participant heavily influences the reliability of the test (Murphy *et al.,* 1995) and may have played a significant role. Despite dictating starting positions and standardising joint angles, it was hard to ensure participants remained in the given position throughout, commonly slipping out of place when taking strain on the bar. Komi (2000) suggested the IMTP was seldom seen in the sporting environment and rarely practised, potentially rationalising its weakness when compared to the CMJ, a common sporting movement.

Furthermore, isometric tests occur in a static position, with muscle fibres remaining at constant length. Conversely, the CMJ is a dynamic action with both eccentric and concentric components, mimicking the force-velocity profile of sprinting (Cronin & Hansen, 2005). This creates a dynamic correspondence with similar motor unit recruitment patterns in each task (Cronin & Hansen, 2005). In addition to this, a SSC mechanism is evident in the CMJ unlike the IMTP. This plays a great role in maximal velocity sprinting in which the athlete experiences large eccentric load (Cronin & Hansen, 2005; Coyle & Yule, 2009), helping to increase efficiency and magnitude of force.

Despite these limitations, RFD was then made relevant to body weight with some degree of success. In a similar fashion to Baker and Nance (1999) this appeared to strengthen the relationship, with relative RFD 0-250ms holding moderate significant relationships ($p$ <0.05) with average velocity ($r$ = .492) and 30-40m ($r$ = .499) split times. Whilst not entirely convincing, these relationships are in support of the existing research suggesting relative force production as a more successful indicator of sprint performance (Baker & Nance, 1999; Meyers *et al*., 2015) than absolute values alone. A potential explanation for moderate the relationships presented could be due to the poor body composition and power to body weight ratios within the sample. Athletic performance may have been limited as those with greater mass supported more adipose tissue than lean body mass.

Our findings heavily favour dynamic tests of muscular power when looking for relationships with sprint performance. The CMJ showed strong relationships with sprint performance and is more practical to implement than the IMTP; being more affordable, less time consuming and easier to perform. However, it must be noted that IMTP date was of greater strength when made relevant to body weight, supporting the existing.

### *5.3 The Relationship Between Muscular Power and Spatiotemporal Sprint Characteristics*

Again, CMJ height was related to all spatiotemporal sprint characteristics and the most accurate predictor of SL and SF. Large significant relationships ($p$ <0.01) were found between CMJ height and average SL ($r$ = .679). SL is influenced by flight and stance distance, in response to the generation of an impulse (Hunter, Marshall and McNair, 2004). The greater the impulse produced by the athlete, the greater the SL in result (Morin *et al.,* 2012). Essentially, the CMJ is governed by the ability to produce force and therefore, fitting that those who performed better were found to have longer SLs. Force production is again underpinned by physiological function; muscle cross sectional area, muscle composition and neural drive all contributing (Kumagi *et al*., 2000; Bosch & Klomp, 2005, Costill et al., 1976, Saplinskas, Chobatas, and Yashchaninas, 1980). As well as this, an insignificant moderate relationship was found between CMJ height and average SF ($r$ =449). During the recovery phase of the sprint, the capacity to reposition the leg quickly is required, potentially mirrored during the “preloading” phase of the CMJ in which athletes creates hip flexion then rapidly extends to generate force. Increased nerve contraction velocity aids rapid and forceful contractions, beneficial to both CMJ and sprint performance (Sleivert, Backus, and Wenger, 1995).

A very strong negative correlation ($p$ <0.01) was found between CMJ height and average GCT ($r$ = -.740). In both the CMJ and maximal velocity sprinting, limited time is available for the production of force. Participants who performed better in the CMJ would likely be able to produce more force in less time, increasing RFD. The ability to produce greater RFD essentially reduces the time needed in contact with the floor, generating an impulse of the same size in a shorter period. Extremely weak and insignificant relationships were found between all absolute and relative IMTP RFD intervals and spatiotemporal sprint characteristics, suggesting that the two entities are weakly related.

### *5.4 The Relationship Between Spatiotemporal Sprint Characteristics and Sprint Performance*

A major strength of this investigation was its specific focus upon spatiotemporal sprint characteristics, helping to interpret the mechanism by which greater running speeds are achieved when force production is increased. Significant relationships ($p$ <0.05) were found between all sprint performance and spatiotemporal characteristics. Average SL shared a very strong significant ($p$ < 0.01) correlation with 30-40m split time ($r$ = -.861) and average velocity ($r$ = .886). Average SF also held major significant relationships with 30-40m split time ($p$ < 0.01, $r$ = -.603) and average velocity ($p$ < 0.05, $r$ = .590). Previously both SL and SF have been suggested as the limiting factor of sprint performance (Mero *et al*., 1981; Mero, Komi, and Gregor, 1992; Bezodis, Salo, and Kerwin, 2008; Mackala 2007; Armstrong, Costill, and Gehlse, 1984) however our study reports a marginally greater relationship with SL. Such discrepancy between literature may be explained by the work of Salo *et al.* (2011), suggesting an individual SL of SF dominance did not inhibit sprint performance. If the sample was generally more SL dependent this may explain the increased correlation.

Large significant correlations ($p$ <0.05) were found between average GCT and sprint performance (30-40m split time $r$ = .627; average velocity $r$ = -.643). Thus suggesting a greater period of ground contact is detrimental to sprint speed as suggested by Weyand *et al.* (2000). It must be noted however that the assessment of GCT was limited by the methodology, using slow motion cameras that gave a large degree of error as explained in the methodology.

### *5.5 Limitations*

Despite following a sound methodological procedure, there were a number of limitations that may have influenced the research findings. Every effort was taken to guarantee up most accuracy, however there is an innate possibility for human error. To ensure continuity, testing took place over two Thursdays in consecutive weeks with participants being told to avoid strenuous activity and the consumption of alcohol in the 24 hours prior to the investigation.

Despite having a sample size that reflected the existing literature (Cronin & Hansen, 2005; Baker & Nance, 1999; Weyand *et al*., 2000) it is hard to draw comparisons between these studies. Firstly, adopting a voluntary sample meant numerous factors were left unaccounted for; sport, playing standard and playing age for example. Cronin and Hansen (2005) used a sample of elite sprinters whilst Baker and Nance (1999) used solely Rugby League players. This increases the specificity of the population and allows the findings to be adopted for future practice. With our sample being of mixed sports, genders and abilities, this limits the validity of our findings and ability to practically apply them in future.

The participants were of mixed ability, yet commonly at the lower end of the necessary resistance training history stated to take part in the study. As sprint performance, the IMTP and CMJ are complex and trainable skills, those with a greater training age would have likely achieved better results in the study. A small training age may reduce the likelihood of truly maximal effort, limited by technical failure. Maximal testing also required subject motivation. Despite every effort to encourage the participants we cannot be sure they performed to the best of their ability. Having such vast contrasts in ability in both CMJ and sprint performance may have created heightened correlations with results lying at either end of the spectrum.

This study adopted both dynamic and isometric methods to assess muscular power, a key strength of the study. However, our findings could be improved by implementing a measure of horizontal power given its importance to sprint speed (Mero *et al.,* 1992; Morin *et al.*, 2012). Similarly, our findings have limited validity for sportspersons as the attainment of maximal velocity is rare in this setting. Most sports are dependent upon accelerative efforts and would require further investigation over a shorter distance.

### *5.6 Practical Implications*

Our study has shown CMJ height is an accurate predictor of sprint performance. Being more affordable, less time consuming and easier to implement in a practical setting when compared to the IMTP. This begins to build support for the CMJ acting as a talent identification tool, helping to highlight sprint potential from VJ performance. However, our study is unable to identify true causation, and for this reason should be implemented with caution. Despite only presenting moderate relationships, it was evident that relative RFD was more successful than absolute RFD for reporting correlations with sprint performance.

Our study begins to suggest that athletes would benefit from increased CMJ performance. This could be achieved through the development of SSC efficiency, using plyometric training to rapidly develop and apply force. The ability to produce greater force in less time is an essential component of sprint performance (Weyand *et al.,* 2000; Hunter, Marshall and McNair*,* 2005) however the importance of CMJ height needs further validation.

### *5.7 Future Recommendations*

To further our knowledge in this area additional study is recommended. To increase the validity of the findings the test could be repeated amongst a more specific population. Identifying specific requirements for gender, sport and playing standard would increase our confidence to practically apply our findings.

If implementing a new study, both horizontal and vertical power should be assessed, helping to identify the greatest predictor of sprint performance and each spatiotemporal sprint characteristic. Furthermore, a training study could be implemented to reinforce the given relationship between muscular power and sprint performance. Aiming to improve VJ height through plyometric training modalities could strengthen the relationship between CMJ height and sprint performance if concurrent improvements were apparent in both.

### *5.8 Conclusion*

Our findings allow a number of conclusions to be drawn. CMJ height appears to be strongly related to sprint speed, acting as a stronger predictor of sprint performance than the IMTP; allowing us to accept hypothesis 1 and null hypothesis 2. Similarly, CMJ height showed significant correlations with all average spatiotemporal sprint characteristics whilst the IMTP was weakly related with these parameters, thus allowing us to accepting hypothesis 3 and null hypothesis 4. The poor relationships shown between the IMTP and sprint performance may be governed by methodological flaws or a lack of dynamic correspondence between the isometric and dynamic sporting action. As suggested previously, the IMTP does not hold a stretch shortening action and may be limited by poor technique, with athletes failing to display truly maximal reflections of their muscular power.

The major limitations of the study have been addressed amongst the discussion (*see 5.5 Limitations*) and future recommendations made (*see 5.7 Future Recommendations*). The problems faced do not seem to have significantly compromised the major findings supporting the existing literature.

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# APPENDECIES

# APPENDIX A

# PARTICIPANT ACTIVITY READINESS QUESTIONAIRE (PAR-Q)

**Name:** **D O B:**

**Address:** **Postcode:**

**Email:** **Mobile:**

# Physical Activity Readiness Questionnaire (PAR-Q)

If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you significantly change your physical activity patterns. If you are over 69 years of age and are not used to being very active, check with your doctor. Common sense is your best guide when answering these questions. Please read carefully and answer each one honestly: check YES or NO.

1. Has your doctor ever said you have a heart condition and that you should only do physical activity recommended by a doctor? Yes ☐ No ☐
2. Do you feel pain in your chest when you do physical activity? Yes ☐ No ☐
3. In the past month, have you had a chest pain when you were not doing physical activity? Yes ☐ No ☐
4. Do you lose you balance because of dizziness or do you ever lose conciousness? Yes ☐ No ☐
5. Do you have a bone or joint problem (for example, back, knee, or hip) that could be made worse by a change in your physical activity? Yes ☐ No ☐
6. Is your doctor currently prescribing medication for your blood pressure or heart condition? Yes ☐ No ☐
7. Do you know of any other reason why you should not do physical activity? Yes ☐ No ☐

**If yes, please comment:** ____________________

**YES to one or more questions:**
You should consult with your doctor to clarify that it is safe for you to become physically active at this current time and in your current state of health.

**NO to all questions:**
It is reasonably safe for you to participate in physical activity, gradually building up from your current ability level. A fitness appraisal can help determine your ability levels.

**I have read, understood and accurately completed this questionnaire. I confirm that I am voluntarily engaging in an acceptable level of exercise, and my participation involves a risk of injury.**

Signature ____________________

Print name ____________________

Date ____________________

**Having answered YES to one of the above, I have sought medical advice and my GP has agreed that I may exercise.**

Signature ____________________

Date ____________________

**Note:** This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the 7 questions.

# APPENDIX B

# PARTICIPANT INFORMATION FORM

**Ned Partridge, Tom Osmond, William Pinnell**
**15/5/336U**

*"The importance of strength, power and utilization of the stretch-shortening cycle in maximal sprint performance"*

# PARTICIPANT INFORMATION FORM

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## Background

**This study will investigate the relationship between maximal sprinting and numerous physical attributes (strength, power and the stretch shortening cycle).**

**The main aims of the study are:**

1) Highlight the most predominant physical component that contributes to the maintenance phase of sprinting.
2) Create training guidance and further knowledge for strength and conditioning coaches looking to develop sprint performance.

*The data collected will be used for three separate undergraduate dissertation studies and potentially given to supporting professionals for greater investigation.*

You have been invited to take part in the study as an undergraduate student of Cardiff Metropolitan University. We have requested your participation as you are of good health, within the given age category and posses sufficient resistance training experience

## What will I have to do?

Following a structured warm up you will be asked to perform three maximal and one submaximal test of performance as seen below:

- **45m sprint test:** Here you will be asked to sprint maximally for 45m between two timing gates that will record the total time. As well as this a component of the sprint shall be video recorded allowing a number of sprint characteristics to be measured. This test shall be repeated three times following suitable rest.
- **Iso Mid-thigh pull test:** During the Iso Mid-thigh pull test you will be required to pull maximally against a fixed bar for a three second duration. Each test will be repeated three times, exclusive of the attempts in the familiarisation period.
- **Depth Jump:** The first jumping test will also require three maximal effort rebound jumps. You will start at an elevated height stood on a box. From here you will be asked to step off and upon making contact with the floor jump again to achieve maximal height. The time spent in contact with the ground and flight time shall be recorded.
- **Sub-Maximal Hopping test:** The second jump test will require participants to "hop" sub maximally for a total of 20 consecutive jumps. A metronome will be used to set a rhythm and provided speed guidance. This test will be conducted twice.

## Are there any risks?

We do not believe there are any substantial risks of undertaking the study. Despite being asked to perform tasks of maximal effort you will be guided by suitably trained individuals – those with predisposing health conditions should make these apparent during the PAR-Q and at the start of each testing session. You may be asked to consult an medical professional before continuing with the project. During the study you may experience emotional/physiological stress due to the nature of the task – every measure will have been taken to avoid such a situation occurring. You will be given the opportunity to withdraw from the study if you feel at all in danger or unwilling to continue.

Despite this we wish to inform you about a number of factors. The research team collecting the data will be all male; if this would cause you to feel at all uncomfortable please refrain from continuing in this application process. The data collected will be published and shared with numerous sports professionals and fellow students – however the results shall not be linked to specific individuals and your identity protected with allotted number codes.

This is a voluntary sample, which means you have complete control over your participation do not feel swayed towards participating due to the interest of your peers or external influences.

### What will happen to the test data?

The values measured and obtained throughout the study will be kept on password locked computers and use participant numbers as codes rather than listing the names – this will allow comparison yet hide the identity of the athlete. The information will be then used for an undergraduate dissertation project.

### What will you gain?

You will be able to gain an understanding of the research process that you will take part in during your final year of study. You will be given your test data upon completion of the study to assess your individual performance. The process will not cost you anything apart from the investment of your time.

### What happens next?

Alongside this information sheet is a written consent form, please complete this in order to register your interest for the study.

The following steps will help ensure your privacy; firstly, all information will be kept securely on password locked computers. Secondly at the end of the process all consent forms will be locked away safely by the university then destroyed after ten years. Finally, all the participants will be given numbers and there data recorded under this code to avoid them being identified.

*To gain further information please contact:*

Ned Partridge

@cardiffmet.ac.uk

Tom Osmond

@cardiffmet.ac.uk

Will Pinnell

@cardiffmet.ac.uk

# APPENDIX C

# PARTICIPANT CONSENT FORM

**Ned Partridge, Tom Osmond, William Pinnell**
**15/5/336U**

*“The importance of strength, power and utilization of the stretch-shortening cycle in maximal sprint performance”*

# PARTICIPANT CONSENT FORM

**Participant Number:**

*By ticking the following boxes I agree…*

1) That I have read and understood the accompanying information sheet. ☐
2) I have had time to understand the information sheet and been given opportunity to answer any questions I may have had. ☐
3) I am aware that the study will incorporate tests of maximal exertion yet suitably trained and knowledgeable individuals will supervise me. ☐ ☐
4) I understand that my participation in the study is voluntary.
5) I am aware that I have the right to withdraw at any time. ☐

___________________________________ __________________

Signature of Participant Date

___________________________________ __________________

Name of Person Taking Consent Date

___________________________________

Signature of Person Taking Consent

# APPENDIX D

# WARM UP PROTOCOL

|  | **Exercise** | **Distance** | **Sets** | **Intensity** |
|---|---|---|---|---|
| 1 | Jog | 200m | 1 | Moderate |
| 2 | Walking Lunge | 10m | 1 | Moderate |
| 3 | Squats | 10m | 1 | Moderate |
| 4 | Spiderman’s | 10m | 1 | Moderate |
| 5 | Inchworms | 10m | 1 | Moderate |
| 6 | High Knees | 10m | 2 | Moderate |
| 7 | Progressive Sprints | 40m | 3 | 60, 70 & 80% of MAX |