Evaluating and developing the key determinants of push-start performance in bobsleigh

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Director of studies: Dr. Jon L. Oliver

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Collaborating establishment: British Bobsleigh

Declaration page

This work is being submitted in fulfilment of the requirements for the degree of Doctor of Philosophy within the field of bobsleigh performance testing.

I certify that this work has not been previously accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree. I further certify that the whole of this work is the result of my individual efforts, except where otherwise stated. All quotations from books and journals have been acknowledged and a bibliography is appended.

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Abstract

It is a common belief in bobsleigh that the push-start is a vital aspect of successful performance. Therefore, British Bobsleigh places a heavy emphasis on the use of field-based performance testing to assist with both athlete monitoring and talent identification. There is a general lack of published academic literature in bobsleigh. Thus, limited evidence exists confirming the importance of the push-start, as well as validating the field-based performance tests used by British Bobsleigh. The aim of this thesis was to validate and develop the core principles and scientific underpinnings of squad monitoring and talent identification specific to 'brake-men'/'brake-women' push-start performance in bobsleigh.

Study 1 examined the relationship between the push-start and finish time across elite bobsleigh competitions for 2-man, 4-man and female event formats, across multiple tracks and over multiple on-ice seasons. The study demonstrated most tracks on the elite bobsleigh circuit to be either push-start dominant or moderately influenced by the push-start (common variance ≥ 10%). Thus, it highlighted the value of evaluating and developing push-start performance in British Bobsleigh athletes.

Studies 2 and 3 investigated the current performance testing practices of British Bobsleigh, used in both talent identification and squad monitoring. Study 2 investigated the predictive validity of the 'evaluation test' used by British Bobsleigh to assess whether the whole test battery, as well as individual tests included within it relate to the bobsleigh push-start. Although this study confirmed the predictive validity of 'evaluation test' total points to assess athletes push-start capabilities (r = -0.86 to -0.94), completion of the entire testing battery proved somewhat unnecessary. This largely manifested from the major finding of this study that confirmed that the roll-bob push test could be used as a reliable (CV = 0.7 to 1.7%) and valid (r = 0.83 to 0.98) predictor of push-start performance. Subsequent attempts to explain push-start performance using only the general performance tests included within the

‘evaluation test’, highlighted the importance of body mass and 30 m sprint time. However, the explained variance in male push-start performance (55 %), highlighted a clear need to examine other performance qualities beyond those in the current British Bobsleigh ‘evaluation test’. Study 3 explored the reliability, discriminative validity and predictive validity of the British Bobsleigh ‘Keiser Squat Test’. The findings of the study confirmed the reliability of the test protocol (CV = 6 to 10 %), as well as reporting very large to near perfect predictive ability for the female push-start (r = -0.86 to -0.96). Despite this, the strength of the prediction was only moderate in male athletes (r = -0.30 to -0.47) and the test could only distinguish between world class performance (WCP) and national development (ND) male athletes at a moderate load. Subsequently, other performance tests outside the current practices of British Bobsleigh but identified from the winter sliding sport, strength and power diagnostic and sprinting literature were explored.

Study 4 investigated the validity of vertical and horizontal jump test metrics, completed under both bilateral and unilateral conditions, to predict push-start performance. The major findings were that horizontally oriented tests (e.g. standing long jump (SLJ)) may represent better push-start predictive ability than vertically oriented tests (e.g. the countermovement jump (CMJ) and ‘Keiser Squat Test’). Also, maximising an athlete’s unilateral facilitation, as well as minimising any between limb asymmetries appears to be beneficial for push-start performance (r = 0.67 to 0.88). Thus, the addition of unilateral SLJ peak horizontal force, bilateral index and asymmetry index to the British Bobsleigh ‘evaluation test’, may help to account for some of the unexplained variance in push-start performance identified in study 2.

Study 5 explored the discriminative validity and predictive validity of sprint force-velocity profiling for the bobsleigh push-start. Also, the study investigated the influence of a 16-week pre-season training phase on bobsleigh athlete’s sprint force-velocity mechanical profiles and associated changes in push-start performance. The sprint force-velocity mechanical variables $P_{\max}$, relative $P_{\max}$, V_0 and V_{opt} were all shown to provide discriminative validity for the bobsleigh push-start. However, of these variables, $P_{\max}$ demonstrated the strongest correlation with push-start performance (r = 0.80). At a group level, the findings of the study detected training induced improvements in push-start performance, sprint speed and P_{max} (absolute & relative), with the largest group-based improvements observed in absolute P_{max}. This was reflected with all athletes making worthwhile gains in P_{max}, however this did not always translate to improvements in push-start performance on an individual level. Thus, there may be other factors important for push-start performance beyond those measured in this study.

To conclude, the push-start has a moderate to large influence on performance at most tracks on the elite bobsleigh circuit. The roll-bob push test provides a reliable and valid measure to quantify the push-start capabilities of bobsleigh athletes. When considering the key underpinning determinants of push-start performance in bobsleigh, this thesis highlighted the importance of body mass, sprinting speed (30 m sprint time), sprinting maximal mechanical power (sprint force-velocity profiling), unilateral horizontal force production (unilateral SLJ) and power production under moderate external loads (‘Keiser Squat Test’). Thus, practitioners working in bobsleigh should consider these key qualities when designing future squad monitoring and talent identification performance testing batteries and designing training programmes.

Acknowledgments

The completion of this PhD thesis has been the most challenging experience I have completed to date and without the guidance, and encouragement from so many people it would have not been possible.

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Next, I would like to show my gratitude to all the staff and athletes at British Bobsleigh, who made this project possible. Particularly, I would like to thank Gary Anderson, Lauren Forrow and Chris Woolley, who have all been essential advisors throughout the project. Also, big thanks must go to the Sport Wales Institute and all its staff for their continual support during completion of this thesis, as well as throughout my professional career.

Finally, and most importantly, thanks go to my Mum and Dad for all their sacrifice and support throughout not only my PhD, but my entire life. Particularly, the many evenings my Mum gave up to proof read chapters of this thesis. She is now an expert in bobsleigh.

I would like to dedicate this thesis to my Nephew’s and Niece, Jake, Logan and Esmé Condliffe.

Conference Presentations from this Thesis

Thesis Embargo

At the beginning of the PhD candidature an embargo was placed on this thesis for a period of five years. This was a result of the potential influence the PhD findings could have on the applied practices of British Bobsleigh and therefore the organisation wanted to protect any possible competitive advantage. This embargo has restricted the candidate's opportunity to disseminate the work within the public domain through journal publications and conference presentations, without the prior approval of British Bobsleigh. Despite this, the candidate still managed to present on several aspects of this thesis as outlined below:

Peer-reviewed abstracts and conference proceedings

Condliffe, R.J. et al. (2016). Importance of the push-start in elite bobsleigh. *Proceedings of the Cardiff Metropolitan University Academic Associate Committee Annual Poster Symposium (poster presentation).* May 2016

Condliffe, R.J. et al. (2017). Validation of a physical performance evaluation battery to predict push-start performance in elite bobsleigh. *Proceedings of the Cardiff Metropolitan University Academic Associate Committee Annual Poster Symposium (poster presentation).* May 2017

Condliffe, R.J. et al. (2018). Physiological profiling in elite bobsleigh. *Proceedings of the 2nd Pan Wales Sport, Health and Exercise Science PhD conference (oral presentation)*. May 2018

Condliffe, R.J. et al. (2018). Sprint force-velocity profiling: ability to predict bobsleigh push-start performance. *Proceedings of the European College of Sport Science (ECSS) conference (oral presentation)*. July 2018.

Condliffe, R.J. et al. (2018). Training induced changes in sprint force-velocity profiles and push-start performance in elite bobsleigh athletes. *Proceedings of the United Kingdom Strength and Conditioning Association (UKSCA) conference (poster presentation)*. August 2018.

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List of Abbreviations

Abbreviation	**Term**
5-RBJ	5-Repeated Bound Jump
A	Acceleration Time Constant
CI	Confidence Interval
CMJ	Countermovement Jump
CV	Coefficient of Variation
DJ	Drop Jump
D_{RF}	Index of Force Application
F_0	Theoretical Maximal Force
F_{aero}	Aerodynamic Drag to Overcome During Sprinting
F_H	Net Horizontal Ground Reaction Force
F_{opt}	Force at Maximal Power
IBSF	International Bobsleigh and Skeleton Federation
ICC	Intraclass Correlation Coefficient
LoA	Limits of Agreement
ND	National Development: Athletes that are part of the British Bobsleigh national development squad.
P_{max}	Theoretical Maximal Power
PPO	Peak Power Output
RF	Effectiveness of Force Application
RFD	Rate of Force Development
RM	Repetition Maximum
SEE	Standard Error of the Estimate
S_{FV}	Slope of the Force Velocity Relationship

SJ	Squat Jump
SLJ	Standing Long Jump
SWC	Smallest Worthwhile Change
TE	Typical Error
TEE	Typical Error of Estimate
USBSF	USA Bobsleigh and Skeleton Federation
V_0	Theoretical Maximal Velocity
V_H	Horizontal Velocity
V_{Hmax}	Maximal Horizontal Velocity
V_{opt}	Velocity at Maximal Power
WCP	World Class Performance: Athletes that are part of the British Bobsleigh world class performance squad.

Chapter 1

Introduction

1.1 Research Context

Historically research with elite athletic populations and sports has been difficult to conduct (Coutts 2016). This is because often only small samples of elite athletes exist within a given sport or discipline and it has been difficult for researchers to access those samples. However, a unique opportunity arose where the candidate was embedded within the British Bobsleigh support staff structure for an entire Olympic Cycle, preparing athletes for the 2018 Winter Olympic Games in Pyeongchang, South Korea. As British Bobsleigh's 'sport scientist', the candidates' role was to validate the core principles and scientific underpinnings of squad monitoring and talent identification specific to 'brake-men'/'brake-women' push-start performance in bobsleigh. The candidate and British Bobsleigh were working in collaboration with the common ambition of increasing the chance of medals at the 2018 Winter Olympic Games. Therefore, the following thesis will document the candidates journey through several applied research projects that aimed to answer applied" performance questions of British Bobsleigh and thus help to facilitate and develop evidence-based practice in the sport.

1.2 Bobsleigh

The sport of bobsleigh was invented in the late 19th century by a group of Englishman holidaying in St Mortiz, Switzerland (BBSA 2019a). Following this, in 1897 the first bobsleigh club was established in the town, which resulted in an evolution of the sport across Europe (IBSF 2019). In 1923, the International Bobsleigh & Skeleton Federation (IBSF) was formed and a year later 4-man bobsleigh became part of the first Winter Olympic programme in Chamonix (Brüggemann et al. 1997; IBSF 2019; IOC 2015). Eight years later in Lake Placid, a 2-man format also became part of the Olympic program (IBSF, 2019).

In its infancy bobsleigh was predominantly a sport enjoyed by adventurous wealthy individuals and training was non-existent (IBSF, 2019). However, by the mid-nineties a fast push-start had been identified as an important performance component, which brought stronger and faster athletes to bobsleigh from other sports such as track and field (IBSF, 2019). In 1952, a total crew and sled mass limit was introduced, which further heighten the importance of having an athletic crew (IBSF, 2019). This increase in athleticism within the sport coincided with technological advancements in the sleds and now in modern-day bobsleigh, nations adopt a year-round approach to the training process and compete using high-tech sleds (IBSF, 2019).

Modern-day bobsleigh includes three event formats; 2-man, 4-man and female (2-women), with nations competing across three different competition circuits at the elite level; World Cup, North Americas Cup and Europa Cup (IOC 2015; IBSF 2018a). Additionally, there is a yearly World Championships, apart from the seasons where Olympic Games take place (IBSF 2018a). On the elite circuit, races take place on 12 different tracks across 8 different countries, with all tracks displaying unique characteristics in terms of start profile (the first 65 m of a race track), gradient, vertical drop, number of corners and track length (IBSF 2018b).

At IBSF competitions, crews compete over either a 2 (World Cup, North Americas Cup & Europa Cup) or 4 (World Championships & Olympic Games) heat format, with final finish positions being based on the crew with the fastest accumulative run time over all the heats (IBSF 2015). There are strict rules on the mass of a crew’s sled, as well as the accumulative mass of the sled and its crew. The sled minimum mass restrictions are set at 170 kg for a 2-man sled, 210 kg for a 4-man sled and 165 kg for a female sled (IBSF 2015). Subsequently, the accumulative mass of the sled and its crew must not exceed 390 kg in 2-man, 630 kg in 4-man and 325 kg in female bobsleigh (IBSF 2015). If a crew is below this maximum accumulative sled and crew mass, they are permitted to add ballast weight to the sled to reach this limit (IBSF 2015).

During a standard bobsleigh run prior to the crew boarding the bobsleigh; they accelerate it from a standing start over around ~40 m within 6 seconds (Godfrey et al. 2007). This aspect of the run is often referred to as the ‘push-start’ and is officially reported by the IBSF during competition as the initial 50 m split time (IBSF 2015; Morlock & Zatsiorsky 1989). Crew’s then board the sled and descend the track as fast as possible via the driver negotiating the corners, while trying to stay on the optimal race line. The sled and its crew then reach the finish line, following which the brakeman must apply the brakes to stop the sled.

1.3 British Bobsleigh

In 1926, the UK governing body for bobsleigh known as British Bobsleigh, was founded in New York (BBSA, 2019b). Seventy-four years later, the governing body then became the British Bobsleigh Association, when it was incorporated in 1980 (BBSA, 2019b). In 2010, it was formally agreed that the British Bobsleigh Association and British Skeleton Association would merge to form the British Bobsleigh and Skeleton Association, to be known as the BBSA (BBSA, 2019b). The merger was completed in 2015 and the BBSA assumed the responsibility as the UK national governing body for bobsleigh and skeleton (BBSA, 2019b). Thus, the organisation would now manage the funding used to support the Bobsleigh and Skeleton performance programmes at international competitions, as well as running memberships for the sports at an amateur and spectator level (BBSA, 2019b).

Since winning a silver medal at the first ever Winter Olympic Games in Chamonix, British Bobsleigh have only won two Olympic Medals since; notably a 2-man gold medal at Innsbruck 1964 and a 4-man Bronze at Nagano 1998 (BBSA, 2019b). However, British Bobsleigh’s 4-man crew finished 5th at the 2014 Sochi Winter Olympic Games, which was later updated to a 3rd place finish by the IBSF following doping violations (IBSF, 2018b). Additionally, between 2007 and the Sochi 2014 Winter Olympic Games, British Bobsleigh achieved 7 top-10 finishes at Olympic or World Championship level across all formats, with one podium finish (gold) in the female 2009 World Championship at Lake Placid, USA. Subsequently, following the Sochi 2014 games, the target for the British Bobsleigh program was to achieve 1 medal at the 2018 Winter Olympic Games in Pyeongchang, in either the 2-man, 4-man or female format.

To support UK medal success at Olympic Games, UK Sport developed a World Class Performance Programme, which began in May 1997 (UK Sport 2019a). Table 1 provides a summary of the funding British Bobsleigh have received from UK Sport's World Class Performance Programme over previous Olympic cycles.

Table 1.1 UK Sport World Class Performance Programme funding received by British Bobsleigh (UK Sport 2019).

Olympic Cycle	Olympic Venue	Funding
1998-2002	Salt Lake City	£ 1,061,489
2002-2006	Torino	£ 1,773,862*
2006-2010	Vancouver	£ 496,000
2010-2014	Sochi	£ 3,304,250
2014-2018	PyeongChang	£ 5,003,476

* includes skeleton

This funding is primarily used to support the podium and podium potential tiers of the British Bobsleigh programme, however to maximise the pool of podium and podium potential athletes, British Bobsleigh operates a wider programme structure (see Figure 1.1).

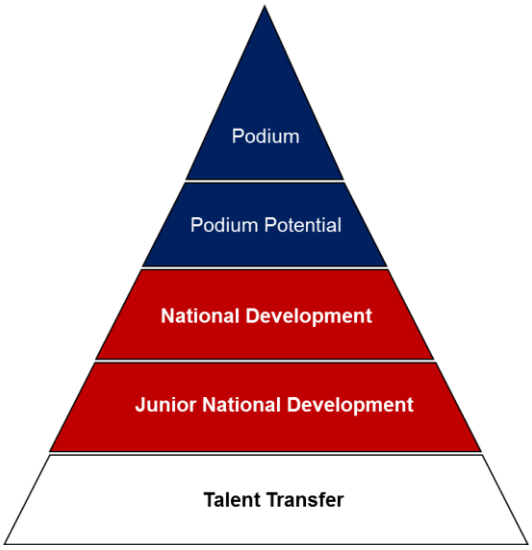

Figure 1.1. British Bobsleigh Programme Structure

The podium tier comprises of athletes with either a top-3 or top-5 World Championship Performance and a realistic chance of a medal at the next Winter Olympic Games (UK Sport 2019b). Whereas, podium potential athletes have a realistic medal chance at future Winter Olympic Games beyond the current cycle (UK Sport 2019b). This tier comprises of athletes with a Top-12 World Championship performance or graduates of the national development (ND) and talent transfer programmes. The podium and podium potential tiers form the British Bobsleigh World Class Performance (WCP) squad and the term WCP athlete will be used to refer to this squad throughout the thesis. The ND tier includes athletes with a significant performance in a second-tier bobsleigh competition (i.e. North Americas Cup or Europa Cup) and the junior ND tier comprises of athletes with the potential to meet either the podium or podium potential standards in junior competitions (athletes aged < 26). Thus, the ND squad is made up of athletes from both the ND and junior ND tiers and the term ND athlete will be used to refer to this squad throughout the thesis. The final tier of the British Bobsleigh programme is talent transfer, which includes athletes who enter the programme from British Bobsleigh's talent scouting work and various talent transfer campaigns. Generally, athletes aged between 18 to 28 with creditable sporting backgrounds in power-based sports (e.g. sprinting, jumping, heptathlon/decathlon, rugby and weightlifting) are attracted to and recruited into the sport.

1.4 Bobsleigh Push-Start Research

There is a lack of published literature in the sport of bobsleigh, however the body of work that does exist is focused across three main areas; equipment (both athlete & sled), sled aerodynamics and the push-start (Forrow 2013). However, it is a common belief across the sport that the push-start is a vital aspect of any successful performance and when considering the entire race field, researchers have reported moderate to very large relationships (r = 0.30 to 0.88) between push-start time and finish time (Brüggemann et al. 1997; Harrison 2017; Morlock & Zatsiorsky 1989; Smith et al. 2006). However, a reduction in this relationship has been detected when the top-15 finishing crews have been considered in isolation (Brüggemann et al. 1997). Therefore, the push-start appears to be a pre-requisite for success in the sport, but is not a key determinant of finish time or rank (Brüggemann et al. 1997). Despite this conclusion, the bobsleigh literature is somewhat limited by a focus on the male formats only (2-man & 4-man), as well as some studies not considering the top half (e.g. top-10 or top-15) of the race field as a distinct sub-group. Additionally, existing research has tended to focus on specific races or tracks in isolation. Given that each track on the elite circuit has unique characteristics, the importance of the push-start is unlikely to be consistent across tracks, nevertheless there is limited information on this (Harrison 2017). This specific race or track focus from the literature has also resulted in much of the work being based on relatively small data sets, compared to the amount of data that is publicly available, with push-start and finish times recorded and published by the IBSF at all major events (IBSF 2018a). Hence, the importance of push-start performance in elite-level bobsleigh needs to be explored in more detail.

1.5 Performance Testing in Bobsleigh

Performance testing has become a fundamental part of many sports annual training and competition plan, as it allows them to identify athlete strengths and weaknesses, evaluate training, predict competition performance, assess the effectiveness of specific interventions, benchmark athletes and assist with talent identification and selection (Bullock et al. 2013; Garvican et al. 2013; Hahn 2013; Rice & Osbourne 2013; Savage & Pyne 2013; Winter, Bromley, et al. 2007). However, for performance testing to be effective and worthwhile it is vital that the tests included are specific, valid, and reliable (Currell & Jeukendrup 2008; Winter, Bromley, et al. 2007). In terms of a measure representing good validity there are three types that can be applied to performance testing including; ecological or face validity, criterion or predictive validity and construct validity (i.e. discriminative ability across athletes of varying standards) (Currell & Jeukendrup 2008). Subsequently, these are all important concepts for practitioners to consider when designing performance testing batteries.

To monitor athlete performance and assist with talent identification, British Bobsleigh uses a field-based performance test battery named the ‘evaluation test’, consisting of six tests and including measures of speed, reactive strength and resisted sprinting on a bobsleigh specific apparatus designed to mimic an actual sled (named the ‘roll-bob push’). The six specific tests are as follows:

- 60 m sprint
- 5-repeated bound jump (5-RBJ)
- Light back roll-bob push
- Light side roll-bob push
- Heavy back roll-bob push
- Heavy side roll-bob push

Points are awarded for performance in each test (maximum of 200) and then a total sum score accumulated across the six tests (maximum of 1200), referred to in bobsleigh as ‘evaluation test’ total points. Although during the 60 m sprint an athletes’ points are allocated based on their 0-60 m sprint time, two additional splits are collected to assist with training monitoring and prescription (0-30 m and 30-60 m). British Bobsleigh coaches believe that ‘evaluation test’ total points score is indicative of an athlete’s push-start capabilities, however the validity of this points score has yet to be empirically examined.

Studies examining the validity of performance testing in bobsleigh, have only considered the speed and reactive strength qualities included by British Bobsleigh (Harrison 2017; Osbeck et al. 1996). Current evidence has confirmed the importance of acceleration speed for the bobsleigh push-start, however Osbeck et al. (1996) have suggested that the removal of the 5-RBJ from performance testing batteries would not be detrimental to its overall validity. Despite the fact this statement was made over 20 years ago, the 5-RBJ has remained in the British Bobsleigh ‘evaluation test’ and has received little additional scrutiny. Nevertheless, the work of Osbeck et al. (1996) is limited by the nature of the sample group involved not truly representing “elite” modern day bobsleigh athletes, because of the research being over 20 years old and the low physical ability of the athletes included; i.e. one athlete was almost two tenths off the national/development bobsleigh athlete standards (Bobsleigh Canada 2015; Godfrey et al. 2007; Harrison 2017). Also, to date, none of the literature has included the roll-bob push test used by British Bobsleigh (Harrison 2017; Osbeck et al. 1996). Hence, more research is needed to confirm or dismiss the validity of the British Bobsleigh ‘evaluation test’ and the individual performance tests included within it.

Outside of the ‘evaluation test’, British Bobsleigh has designed and developed a power-load assessment on the Keiser® AIR300 Squat, named the ‘Keiser Squat Test’. The test involves completing 3 maximal effort repetitions at several different predefined absolute loads and is used in the programme to monitor an athlete’s ability to express power under loaded conditions, in and around training on a more regular basis. Apparatus portability and the already extensive nature of the ‘evaluation test’ has resulted in its exclusion from this testing battery. Nevertheless, the ‘Keiser Squat Test’ was designed to reflect the push-starts requirement to produce high force mainly with the lower limbs against an external load (Deweese et al. 2014a). Thus, it is believed that power production under loaded conditions is a key quality for the bobsleigh push-start. This belief is somewhat substantiated in the skeleton push-start research, where large to near perfect relationships been observed between power output in several different loaded jumps (5kg, barbell, 20 %, 40 %, 50 % & 60 % body mass) and various push-start metrics; push-start velocity ($r = > 0.50$) and push-start time ($r = -0.73$ to -0.92) (Colyer 2015; Sands et al. 2005). Additionally, Colyer (2015) has demonstrated a very large relationship between push-start velocity (15 m) and theoretical maximal power (P_{max})

produced on the Keiser leg press dynamometer (*r* = 0.85). Despite British Bobsleigh's use of the 'Keiser Squat Test' and the value of loaded power assessments for the skeleton push-start highlighted in the literature, little is known about its reliability and/or its validity for bobsleigh athletes. Therefore, research is needed to determine the reliability and validity of the 'Keiser Squat Test'.

Beyond those tests used by British Bobsleigh, there is a range of other field-based performance tests that have been identified and used across both winter sliding sports (bobsleigh & skeleton) and within strength and power diagnostics in other sports. These performance tests have measured several different qualities including; maximal isometric strength (e.g. isometric squat & isometric mid-thigh pull), maximal isokinetic strength, maximal isoinertial strength (e.g. 1 repetition max (RM) back squat, clean or bench press), cyclic power, ballistic power (e.g. squat jump (SJ), CMJ, SLJ, underhand medicine ball throw & underhand shot toss), reactive strength (e.g. drop jump (DJ) & repeated vertical jumps) force-velocity mechanical characteristics (e.g. sprinting & leg press exercise) and resisted sprinting (Bobsleigh Canada 2015; Brown et al. 2017; Bullock et al. 2007; Bullock, Martin, Ross, Rosemond, Jordan, et al. 2008; Bullock, Gulbin, et al. 2009; Chapman et al. 2012; Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Colyer, Stokes, Bilzon, Holdcroft, et al. 2017; Cross et al. 2015; Deweese et al. 2014b; Forrow 2013; Godfrey et al. 2007; Harrison 2017; McGuigan et al. 2013; Mendiguchia et al. 2014; Mendiguchia et al. 2016; Moore et al. 2016; Morin et al. 2012; Mosey 2014; Mosey 2015; Osbeck et al. 1996; Sands et al. 2005; Sanno et al. 2013; Skeleton Canada 2016; USBSF 2015). These tests that are not currently used by British Bobsleigh but are identified within winter sliding sport and the wider literature warrant further consideration.

Of these aforementioned qualities, ballistic power in the form of CMJ height has already been identified as a key determinant of the bobsleigh push-start (Osbeck et al. 1996). Also, CMJ metrics have been repeatedly shown to relate to sprint acceleration performance, across a range of populations from elite sprinters to physical education students (Alemdaroğlu 2012; Cronin & Hansen 2005; Dobbs et al. 2015; Loturco et al. 2015; Maulder & Cronin 2005; Maulder et al. 2006; McFarland et al. 2016; Meylan et al. 2009; Vescovi & McGuigan 2008; Young et al. 2011). In addition to CMJ height the collection of kinetic metrics may provide a more valuable insight (Holm et al. 2008), as shown in the works of Maulder et al. (2006), who demonstrated CMJ force and power (r = -0.70 to -0.79) to be stronger predictors than jump height (r = -0.13) of 10 m block start performance (time taken to cover 10 m) in national level sprinters. Despite this, the CMJ may lack specificity to many athletic movements including bobsleigh, due to its vertical and bilateral force production nature (Maulder & Cronin 2005; Meylan et al. 2009). Hence, unilateral and/or horizontal alternatives maybe more ecologically valid for bobsleigh. This theory is supported by the recent works of Dobbs et al. (2015) and Loturco et al. (2015) who have both demonstrated that SLJ peak force, is a stronger predictor of 30 m sprint performance (time and velocity respectively) than CMJ peak force (SLJ r = -0.62 & 0.62; CMJ r = -0.44 & 0.33 respectively). However, the bobsleigh literature to date has only considered either the CMJ (Osbeck et al. 1996) or SLJ (Harrison 2017) in isolation, with no research incorporating both tests within a single investigation. Therefore, the validity of the CMJ and SLJ tests performed both bilaterally and unilaterally, with additional kinetic analysis warrants further investigation in bobsleigh.

In addition to ballistic power, bobsleigh research has also confirmed the importance of sprint speed for the push-start and traditionally this has been measured by practitioners using various split time distances up to 100 m (Harrison 2017; Osbeck et al. 1996). However, simple split time measurements do not provide practitioners with any insight into which mechanical properties are causing the observed performance (Buchheit et al. 2014). Therefore, an emerging body of literature has used sprint force-velocity profiling to provide more in-depth analysis of an athlete's sprint performance (Brown et al. 2017; Clark et al. 2017; Cross et al. 2015; Mendiguchia et al. 2014; Mendiguchia et al. 2016; Morin et al. 2011; Morin et al. 2012; Moore et al. 2016; Rabita et al. 2015; Samozino et al. 2015). Additionally, recent methodological developments now allow an athletes sprint force-velocity profile to be calculated using simple speed-time or distance-time measurements in the field (Samozino et al. 2015). Subsequently, increasing the ecological validity and practicality of measuring force-velocity mechanical characteristics in the bobsleigh field testing environment. Nevertheless, the only force-velocity profiling conducted to date in winter sliding sports was undertaken on a leg press dynamometer; highlighting P_{max} (r = 0.85) and theoretical maximal velocity (V_0) (r = 0.62) as determinants of skeleton push-start velocity (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017). Therefore, force-velocity profiling needs exploring in more push-start ecologically valid movements such as sprinting.

Once practitioners have identified reliable and valid performance tests for their sport, they can be used on a longitudinal basis to monitor the effectiveness of their training interventions on key qualities for the sport. There is a lack of published research that has conducted longitudinal monitoring on training interventions in elite athletes and how these influence performance (i.e. push-start performance) in the build-up to major competitions (Colyer, Stokes, Bilzon, Holdcroft, et al. 2017). However, a study does exist in elite skeleton which tracks changes in physical performance measures (sprinting, jumping and leg press force-velocity profiles) and push-start performance over an 18 month period, including both pre-season and on-ice training phases (Colyer, Stokes, Bilzon, Holdcroft, et al. 2017). Although the study demonstrated training induced changes in all its physical performance measures as well as push-start performance (Colyer, Stokes, Bilzon, Holdcroft, et al. 2017), it did not include any analysis on an individual level. Similar work has yet to be undertaken in bobsleigh and thus highlights a potential topic for future research.

1.6 Thesis Aim and Objectives

The aim of this thesis is to validate and develop the core principles and scientific underpinnings of squad monitoring and talent identification specific to push-start performance in bobsleigh. Therefore, the specific objectives of the project are:

1. Examine the relationship between the push-start and finish time across elite bobsleigh competitions for the 2-man, 4-man and female event formats, across multiple tracks and over multiple on-ice seasons.
2. Investigate the validity of the 'evaluation test' used by British Bobsleigh to predict push-start performance, as well as assess the individual performance qualities that contribute to the bobsleigh push-start.
3. Explore the reliability, discriminative validity and predictive validity of the British Bobsleigh 'Keiser Squat Test'.
4. Investigate the validity of vertical and horizontal jump test metrics completed under both bilateral and unilateral conditions, to predict push-start performance.
5. Explore the discriminative validity and predictive validity of sprint force-velocity profiling for the bobsleigh push-start.
6. Investigate the influence of a 16-week pre-season training phase on bobsleigh athlete's sprint force-velocity mechanical profiles and associated changes in push-start performance.

Figure 1.1 provides a schematic overview of the chapters included within this PhD thesis and shows the links between chapters to achieve the specific aim and objectives of this applied research project.

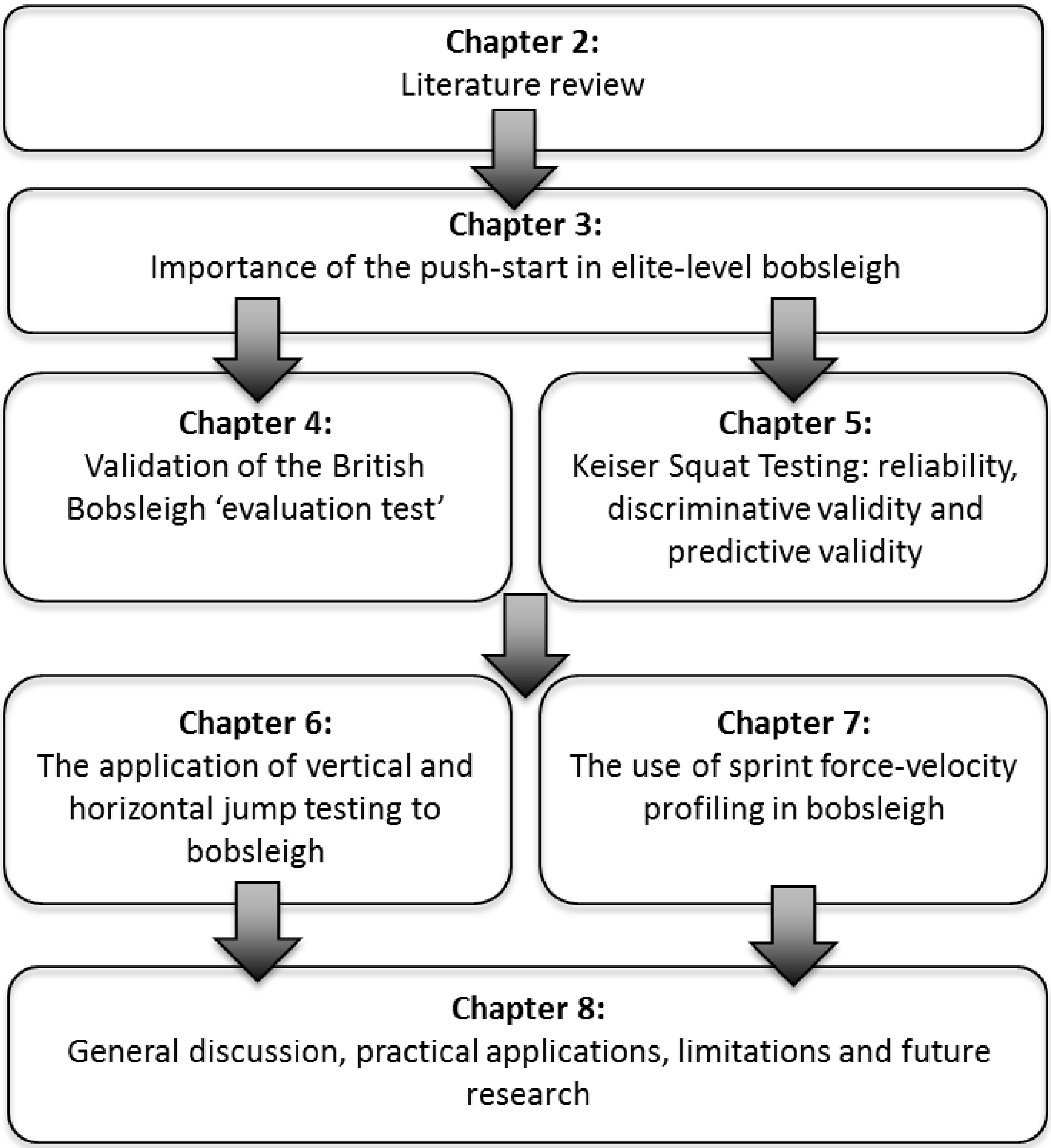

Figure 1.2 A schematic overview of the chapters included in the thesis.

Chapter 2

Literature Review

2.1 Research in Elite Sport

Traditionally it has been difficult to conduct research in elite sports because of limited access to elite athletic populations (Coutts 2016), as well as opposing agenda's between universities and sports . However, in recent years more elite sport studies have emerged for several reasons including; the release of study embargo's, a greater quantity of sport science and medicine practitioners wanting to publish their work, more mutual collaborations between academic institutions and elite sport national governing bodies and journals such as IJSPP providing an avenue for applied research to be published (Coutts 2016).It is important to acknowledge that some sports do great in-house research, without the desire to publish their data.

Ultimately, the goal of university and sport collaborations is to undertake research that translates across to the sports current practices and thus facilitates improvements in the preparation and performance of their athletes (Coutts 2017). Coutts (2017) described this process as "evidence based" or "evidence informed" practice, in which current research, athlete values, and coach expertise are integrated to inform the decision making process around athlete delivery. However, the term "evidence based" practice is often misunderstood and is never truly represented unless practices are underpinned by randomised controlled trials (Swisher 2010). The concept of practice-based evidence provides a better description of research in the elite sport environment, whereby real-world practice is measured, tracked and documented, rather than controlling practice delivery (Swisher 2010). Nevertheless, practice-based evidence or evidence based practice is best achieved when researchers embed themselves in elite sport environments with a specific focus driven by the needs of the sport (Buchheit 2017; Coutts 2016). This focus can often be to answer questions that fast thinking, innovative elite practitioners working at the cold face of athlete preparation do not have the time to undertake, for example assessing measurement error and/or scientifically validating the methods and concepts used by the sport (McCall et al. 2016).

Despite the increased demand for high quality research with elite athletic populations, the nature of the elite sport environment means this type of research is subject to several limitations. Firstly, as highlighted by Coutts (2017) the use of randomised control experimental designs are difficult to undertake with elite athletes, as they often interfere with their normal preparation plans, as well as control groups lacking application to the nature of the elite sport environment. Additionally, elite sport research is often subject to numerous environmental constraints and small athlete population sizes (Coutts 2017). However, despite these limitations, if researchers are able to embed themselves within a specific elite sport they are much better placed to design and implement ecologically valid research studies that answer the “real” performance problems and questions of the sport (Coutts 2017).

A typical approach in research to answer these performance problems, would be to collect data from a sample that is taken from the population of interest (O’Donoghue 2012). This sample data would then be used to generalise any observations or findings back to the population it was drawn from (Field 2013; Hopkins 2000). However, when adopting this approach there is a level of error, known as sampling error, associated with using sample statistics to estimate the probability of a real finding in the given population (O’Donoghue 2012). Nevertheless, if a large enough sample is used, one can infer that it reflects the population of interest and thus this gives greater confidence when generalising the findings to this population (Field 2013; O’Donoghue 2012). To support this process statistical power should be considered and calculations can be used to estimate the sample size required to observe a significant effect in the population from which the sample was drawn (O’Donoghue 2012). However, often this is either not done or not reported in research and thus it is likely that many studies using a sample population are underpowered.

Very little research exists were an entire population has been measured, however due to the small elite athlete population sizes previously identified, measurement of an entire population can be possible within elite sport. Therefore, in these situations the research findings are being generated on the population to which they need to be applied, unlike the sampling approach used in most research. While statistical power may still be an issue when measuring an entire population, it does however guarantee that the findings are valid for the population of interest and contemporary statistical approaches (for example, magnitude-based inferences) can be applied to help combat issues of statistical power.

2.2 Research in Bobsleigh

2.2.1 General Overview

The sport of bobsleigh has been part of the Winter Olympic program since the inclusion of the 4-man event at the first ever games held at Chamonix in 1924 (Brüggemann et al. 1997; IOC 2015). Since then, the sport has developed and now includes three event formats; 2-man, 4-man and female (IOC 2015). Bobsleigh can be characterised as a power dominant event in which crews compete over a 2 or 4 heat format (IBSF 2015; Forrow 2013). Dabnichki and Avital (2006) divided a single heat run into three discrete phases; the push-start, the drive and the finish. However, podium places are awarded based on accumulative run time over all the heats and are often decided by the smallest of margins (Dabnichki & Avital 2006; Forrow 2013). This means crews are required to consistently perform well in each phase of each run to increase the likelihood of success.

In comparison to some other sports, bobsleigh is widely under researched within the academic literature. Although the exact reasons for this are unclear, it could result from either lower participation levels within the sport, or other nations seeking to gain a competitive advantage and in doing so, not wanting their research to be within the public domain (Forrow 2013). Despite this, the current body of bobsleigh literature has focused its attention on three main areas; equipment (both athlete & sled), sled aerodynamics and the push-start (Forrow 2013). However, given that the aim of this thesis is to validate and develop the core principles and scientific underpinnings of squad monitoring and talent identification specific to push-start performance in bobsleigh, the remainder of this review will only consider bobsleigh research that is relevant to the push-start.

2.2.2 Push-Start Performance

The bobsleigh push-start involves a crew of athletes accelerating a sled from a standing start for approximately 40 m within ~ 6 seconds, with the aim of achieving maximal acceleration and speed before loading and descending down the track (Godfrey et al. 2007). As shown in Figure 2.1, the push-start is defined and officially reported by the International Bobsleigh and Skeleton Federation (IBSF) during competition as the initial flying 50 m (15 to 65 m) split time (IBSF 2015; Morlock & Zatsiorsky 1989). It is commonly accepted by coaches and athletes in the sport that the push-start is a vital aspect of any successful performance and anecdotally it is believed that a 0.01 s improvement in push-start time translates to a 0.03 s improvement in finish time (Dabnichki & Avital 2006; Smith et al. 2006). Subsequently, if the British Bobsleigh 4-man crew had improved their push-start time by 0.01 s during each run at the 2014 Winter Olympic Games, this anecdotal belief suggests that they would have won a Medal; they finished in 5th only 0.11 s off a podium place over four runs (IBSF 2018a). Anecdotal beliefs such as the above are of high importance within science, as they often go on to form hypothesis that are proven in future research studies (Irwig et al. 2008). Therefore, given thesmall margins of success or failure in bobsleigh and the hypothetical impact improvements in push-start performance could have, it is vital to scientifically substantiate the anecdotal beliefs within the sport surrounding the importance of this aspect of performance. However, it is apparent from the current literature that only a handful of studies within bobsleigh have examined the importance of the push-start. In fact, when considering bobsleigh in addition to other winter sliding sports such as skeleton collectively, the present author identified less than 10 peer-reviewed research studies (see Table 2.1).

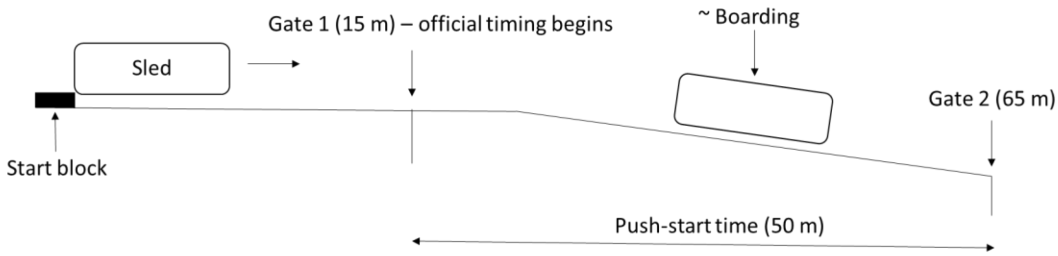

Figure 2.1 A schematic representation of the bobsleigh push-start. Adapted from Bullock, Martin, Ross, Rosemond, Holland, et al. (2008, p.352).

Table 2.1 Studies examining the correlation between push-start time and finish time in elite-level bobsleigh and skeleton races.

Reference	Sport	Sample	Level	Seasons	Tracks	Push-Start Time: Finish Time Correlation Coefficient
Morlock & Zatsiorsky (1989)	Bobsleigh	4-man race	WOG	1987-1988	Calgary	Heat 1 to 4: 0.53 ^{L} to 0.74 ^{VL} Overall: 0.46 ^{m}
Brüggemann et al. (1997)	Bobsleigh	2-man & 4-man race	WOG	1993-1994	Lillehammer	Overall: ~ 0.88 ^{VL} Top 15 2-man: < 0.30 Top 15 4-man: ~ 0.39 ^{m}
Smith et al. (2006)	Bobsleigh	11 2-man crews	USA NT	2004	Lake Placid	0.63 ^{L}
Fedotova & Philipiva (2011)	Bobsleigh	Top 10 2-man & 4-man finishers from 6 & 5 races respectively	WCH WC	2005-2006 2006-2007 2007-2008 2008-2009	St Moritz	N/A
Harrison (2017)	Bobsleigh	Top 20 2-man and 4-man finishers at all races	WC	2014-2015 2015-2016	Altenberg Calgary Igls Königssee La Plagne Lake Placid Park City Sochi St Mortiz	Average: 0.62 ^{L} 2man: 0.30 ^{m} to 0.83 ^{VL} 4man: 0.46 ^{m} to 0.84 ^{VL}
Zanoletti et al. (2006)	Skeleton	24 male & female races	WC NAC EC	2002-2003 2003-2004	N/A	Male: 0.46 ^{m} to 0.49 ^{m} Female: 0.56 ^{L} to 0.67 ^{L}

Reference	Sport	Sample	Level	Seasons	Tracks	Push-Start Time: Finish Time Correlation Coefficient
Bullock, Martin, Ross, Rosemond, Holland et al. (2008)	Skeleton	Top 20 female finishers	WC	2005-2006	Lake Placid Sigulda St. Mortiz	Lake Placid: 0.51 [L] Sigulda: 0.03 St Mortiz: 0.14
Bullock, Hopkins, et al. (2009)	Skeleton	Top 20 finishers from 22 male & 25 female races	WC	2002-2003 2003-2004 2004-2005 2005-2006	Altenberg Calgary Cesana Igls Königssee Lake Placid Lillehammer Park City Sigulda St. Mortiz Winterberg	Male Top 10: -0.14 to 0.44 [m] Female Top 10: -0.09 to 0.57 [m]
Fedotova (2010)	Skeleton	Top 20 male finishers from 16 races	WCH IC WC NAC	2004-2005 2005-2006 2006-2007 2007-2008 2008-2009	Lake Placid Whistler[1]	Lake Placid: n/s to 0.25 Whistler: N/A

Push-start time = 15 m to 65 m split time, finish time = time taken for a crew to complete a single run, WOG = Winter Olympic Games race, WCH = World Championship race, WC = World Cup race, EC = Europa Cup race, NT = national trials, IC = Intercontinental Cup race, NAC = North Americas Cup race, [1] = one race only, [m] = moderate correlation ($r \geq 0.30$), [L] = large correlation = ($r \geq 0.50$), [VL] = very large correlation ($r \geq 0.70$), n/s = reported as not significant. N/A = not available.

2.2.2.1 Bobsleigh

Table 2.1 firstly compares the studies in the literature that have assessed the correlation between push-start time and finish time in bobsleigh. When researchers have considered the entire field of competitors, moderate to very large relationships (see Table 2.1 for correlation thresholds) have been reported between push-start time and finish time (Brüggemann et al. 1997; Morlock & Zatsiorsky 1989; Smith et al. 2006). However, when study sample groups have been reduced to the top 15 race finishers only, the relationship between the two variables has been reduced to either trivial or moderate (Brüggemann et al. 1997). Hence, as concluded by Brüggemann (1997) the present literature suggests that in bobsleigh the push-start is a pre-requisite to success, but may not represent a key criterion in determining finish time or rank. However, much of this early push-start research has focused on either 2-man or 4-man bobsleigh and has only analysed specific tracks or races in isolation.

Harrison (2017) undertook a more comprehensive approach by examining multiple tracks across multiple seasons and demonstrated moderate to very large relationships between push-start and finish time (see Table 2.1). Also, they demonstrated a high degree of variability in the observed correlation coefficients between tracks. However, the research did not acknowledge that they may be reporting inflated correlations by focusing on the top 20 only and not considering the top 10 as a sub group. Additionally, given the race seasons analysed, the author did not include all the tracks on the World Cup circuit and only 36% of the tracks included multiple races, all of which were analysed in isolation. Thus, this restricted their run sample size for each track and makes it less likely the findings are a true reflection of push-start time: finish time relationship at each track.

2.2.2.2 Skeleton

Given the limited volume of literature on the bobsleigh push-start, it is necessary to consider work undertaken in other winter sliding sports with a similar push-start phase, specifically skeleton. Subsequently, in addition to bobsleigh, Table 2.1 also compares current studies within the literature that have assessed the push-start time and finish time relationship in skeleton. Researchers have presented conflicting evidence on the strength of the relationship between the push-start and finish time, with trivial to large correlation coefficients being reported (Bullock, Martin, Ross, Rosemond, Holland, et al. 2008; Bullock, Hopkins, et al. 2009; Fedotova 2010; Zanoletti et al. 2006). Despite these disparities, Zanoletti et al. (2006) have demonstrated faster finishing male and female skeleton athletes to have moderately faster push-start times (ES = 0.76 to 1.01). However, the research group failed to detect a correlation between percentage change in both push-start time and finish time across two heats (Zanoletti et al. 2006). Subsequently, this highlights that there may be other factors contributing to performance other than just changes in push-start performance, for example driver skill.

The lack of agreement between the skeleton push-start studies presented above and in Table 2.1, is likely to be at least partly attributed to the different race tracks analysed. This is supported by both the works of Bullock, Martin, Ross, Rosemond, Holland, et al. (2008) and Bullock, Hopkins, et al. (2009) where the strength of the push-start: finish time relationship has been shown to be track dependent (see Table 2.1). In the latter study, tracks were classified by two coaches and an Olympic medallist into four distinct categories; ‘pure push track’, ‘tracks with a large push component’, ‘tracks with a large drive component’ and ‘pure driving tracks’. However, the relationship of these track classifications with push-start correlations varied dramatically between the top-10 ranked male (r = 0.50; 0.25 to 0.69) and female skeleton athletes (r = 0.03; -0.50 to 0.55) (Bullock, Hopkins, et al. 2009).

On this premise and in conjunction with the fact that the highest common variance reported by Bullock, Hopkins, et al. (2009) for any track was 32%, the subjective track classifications used by the research group should be questioned. There is a need for a more objective, evidence-based method to classify tracks using relevant statistical approaches. Therefore, four new objective categories to classify different winter sliding sport tracks using a statistical approach are proposed by the present author as follows;

- Drive dominant track with a small push-start component (common variance < 10 %);
- Drive dominant track with a moderate push-start component (common variance 10 to 49 %);
- Push-start dominant track with a moderate drive component (common variance 50 to 89 %);
- Push-start dominant track with a small drive component (common variance ≥ 90 %).

Despite the above discussion, the application of skeleton based research across to bobsleigh should be viewed with caution, as although the events take place on the same tracks, the nature of the two sports varies dramatically due to differences in push-start techniques, athlete/crew masses, energetic losses and equipment (Harrison 2017; Zanoletti et al. 2006).

2.2.2.3 Summary

In summary, the volume of literature that has investigated the importance of push-start performance in elite bobsleigh or skeleton is relatively small. Additionally, the application of skeleton based research to bobsleigh should be applied with caution due to distinct between-sport differences. Nevertheless, both bobsleigh and skeleton have suggested the push-start: finish time relationship to be track dependent, as well as a reduction in its magnitude when considering more homogenous sample groups e.g. top 10 to 15 finishers. To date, the bobsleigh literature has tended to focus on the male discipline (2-man and/or 4-man) and specific tracks or events in isolation. Although Harrison (2017) carried out a more comprehensive study into the bobsleigh push-start, the authors did not include all the tracks on the World Cup circuit or consider the importance of the push-start amongst the top half (e.g. top 10) of an elite-level bobsleigh field. Hence, there is a need for a comprehensive study that examines the relationship between the bobsleigh push-start and finish time across all track and formats (e.g. 2-man, 4-man and female) on the elite-level circuit that accounts for different within-race field performance tiers (e.g. top 10 and top 20).

2.3 Performance Testing in Sport Science

Laboratory and field-based performance tests are commonly used in sport in order to predict athlete performance (Osbeck et al. 1996). The works of both Tanner and Gore (2013) and Winter, Jones, et al. (2007) have outlined an extensive collection of performance tests and protocols for use when assessing athletes in a wide variety of sports, ranging from triathlon to sprint kayaking. These performance tests represent a range of different physiological and neuromuscular qualities, for example the vertical jump test would be used to assess neuromuscular power, while the 3km time trial would assess aerobic endurance (Tanner & Gore 2013; Winter, Jones, et al. 2007). Many sports have found that the inclusion of performance testing is of some benefit and testing has become an integrated part of the annual training and competition plan (Garvican et al. 2013; Rice & Osbourne 2013). The inclusion of these tests provide value to sports in terms of identifying an athlete's strengths and weaknesses, evaluating training (for example progression or regression), predicting competition performance, assessing the effectiveness of specific interventions (for example ergonomic aids & warm ups), benchmarking athletes, and talent identification and selection (Bullock et al. 2013; Hahn 2013; Rice & Osbourne 2013; Savage & Pyne 2013; Winter, Bromley, et al. 2007). For laboratory and field-based tests to be effective, it is vital that they are specific, valid, and reproducible (Winter, Bromley, et al. 2007). Therefore, researchers have tried to ascertain which specific performance tests and parameters are of high validity when trying to predict performance in a particular sport (Osbeck et al. 1996). For example, researchers within cycling have identified a number of lab-based performance tests and measures that can help to predict time-trial performance over various distances (Coyle et al. 1991; Davison & Wooles 2007). However, it is important to be aware that there are several other different types of validity beyond criterion validity, these include ecological or face validity and construct or discriminative validity (Currell & Jeukendrup 2008). Ecological validity refers to a test which "measures what it intends to measure" and discriminative validity refers to a test that can discriminate between athletes of different performance levels (Currell & Jeukendrup 2008, p.298). Despite the aforementioned value of lab-based testing, recently coaches have become more interested in moving testing procedures from the lab into the field (Godfrey & Williams 2007), which also reduces the cost implications for national governing bodies. Sports scientists have supported this shift and therefore have begun to focus their attention more and more on the use of field-based testing (Hahn 2013).

2.4 Performance Testing in Bobsleigh

British bobsleigh and the sport of bobsleigh in general places a heavy emphasis on field-based performance tests in order to help inform athlete selection (Osbeck et al. 1996). Table 2.2 and 2.3 summaries what current literature and practice have suggested or utilised with regards to different performance tests when working with male and female bobsleigh athletes; including the SJ, CMJ, SLJ, 5-RBJ**,** repeated vertical jumps, 30 m and 60 m sprints (0 to 15 m, 0 to 30 m, 0 to 45 m, 0 to 60 m, 15 to 45 m & 30 to 60 m), 1 RM power clean, 3 RM back squat, 3 RM 'Keiser Squat Test' (peak power output), isometric mid-thigh pull, modified 6 s and 10 s Wingate tests (peak power output, time to peak power output, peak power output/kg, & work), underhand shot toss, underhand medicine ball throw and light/ heavy roll-bob pushes (Bobsleigh Canada 2015; Deweese et al. 2014b; Forrow 2013; Godfrey et al. 2007; British Bobsleigh 2014a; British Bobsleigh 2014b; USBSF 2015). The tests in question have been employed by researchers and practitioners to assess the use of a warm-up intervention (Forrow 2013), in talent identification and selection processes (Bobsleigh Canada 2015; Deweese et al. 2014b; Godfrey & Williams 2007; British Bobsleigh 2014a; British Bobsleigh 2014b; USBSF 2015), and to profile athletes (Deweese et al. 2014b; Sanno et al. 2013).

It is clear from Tables 2.2 and 2.3 that none of the outlined research or national governing body literature has assessed the predictive validity of any of the performance tests used in bobsleigh. However, in contrast to most sources who only report standards for a single population, some report standards for bobsleigh athletes of different levels (i.e. elite or international and national or development), which provides some support for the discriminative validity of the CMJ, SLJ, 15 m and 30 m sprint, 1 RM power clean and underhand medicine ball throw (see Table 2.2 & 2.3). Therefore, elite bobsleigh athletes appear to sprint faster, jump higher or further and produce more power than sub-elite bobsleigh athletes. Hence, this suggests that tests of speed and power are important for determining potential bobsleigh push-start performance. Nevertheless, it is important to note that none of this work is underpinned by statistical analysis and thus the discriminative validity of these performance tests warrants further investigation.

Table 2.2 A summary of standards and descriptive statistics for male bobsleigh athletes from academic research and national governing bodies.

Performance Test	Reference	Elite or International	National or Development	Junior
Squat Jump	Sanno et al. (2013) •	N/A	-	-
Countermovement Jump	Forrow (2013) • MF	-	-	0.67 m
	Godfrey et al. (2007)	≥ 0.8 m	≥ 0.7 m	-
	Sanno et al. (2013) •	~ 50 cm	-	-
Standing Long Jump	Bobsleigh Canada (2015)	≥ 3.15 m	≥ 2.43 m	-
	USBSF (2015)	2.97 m	-	-
Repeated Vertical Jumps	Deweese et al. (2014b)	N/A	-	-
5-Repeated Bilateral Bound Jump	British Bobsleigh (2014a; 2014b) SB	18.20 m	-	-
15 m Sprint	Bobsleigh Canada (2015)	≤ 2.15 s	≤ 2.40 s	-
	USBSF (2015)	2.18 s	-	-
30 m Sprint	Bobsleigh Canada (2015)	≤ 3.65 s	≤ 3.90 s	-
	Godfrey et al. (2007)	3.80 s	3.90 s	-
	British Bobsleigh (2014a; 2014b) SB	3.42 s	-	-
	USBSF (2015)	3.81 s	-	-
30 m Flying Sprint (30 to 60 m)	British Bobsleigh (2014a; 2014b) SB	2.71 s	-	-
30 m Flying Sprint (15 to 45 m)	USBSF (2015)	3.61 s	-	-
45 m Sprint	USBSF (2015)	5.42 s	-	-
60 m Sprint	British Bobsleigh (2014a; 2014b) SB	6.17 s	-	-
	USBSF (2015)	6.90 s	-	-
1 RM Power Clean	Godfrey et al. (2007)	≥ 120 kg	≥ 110 kg	-

Performance Test	Reference	Elite or International	National or Development	Junior
	USBSF (2015)	110 kg	-	-
3 RM Back Squat	USBSF (2015)	150 kg	-	-
3 RM Keiser Squat Test	-	N/A	-	-
Underhand Medicine Ball Throw	Bobsleigh Canada (2015)	5 kg ≥ 17.50 m	5kg ≥ 11.50 m	-
Underhand Shot Toss	USBSF (2015)	7.3 kg 15.10 m	-	-
Isometric Mid-Thigh Pull	Deweese et al. (2014b)	N/A	-	-
Modified 6 s Wingate	Godfrey et al. (2007)	PPO 1400-1500 W ~15-16 $W.kg^{-1}$ Time to PPO ≤ 2.5 s	-	-
Modified 10 s Wingate	Forrow (2013) • [MF]	-	-	PPO 1181 W PPO/kg 15.76 $W.kg^{-1}$ Time to PPO 3.18 s Work 9282 J
Light Back Roll-bob Push	British Bobsleigh (2014a; 2014b) [SB]	3.72 s	-	-
Light Side Roll-bob Push	British Bobsleigh (2014a; 2014b) [SB]	3.72 s	-	-
Heavy Back Roll-bob Push	British Bobsleigh (2014a; 2014b) [SB]	3.93 s	-	-
Heavy Side Roll-bob Push	British Bobsleigh (2014a; 2014b) [SB]	3.97 s	-	-

Junior = aged 18-26, N/A = not reported, PPO, RM = repetition max, • = descriptive statistics, [MF] = pooled sample of males & females, [SB] = national squad best, RM = repetition max, Light = 20kg of additional mass added to the Roll-bob, Heavy = 45kg (female) or 50kg (male) of additional mass added to the Roll-bob.

Table 2.3 A summary of standards and descriptive statistics for female bobsleigh athletes from academic research and national governing bodies.

Performance Test	Reference	Elite or International	National or Development	Junior
Countermovement Jump	Forrow (2013) • [MF]	-	-	0.67
	Godfrey et al. (2007)	≥ 0.60 m	≥ 0.50 m	-
Standing Long Jump	Bobsleigh Canada (2015)	≥ 2.70 m	≥ 2.30 m	-
	USBSF (2015)	2.62 m	-	-
Repeated Vertical Jumps	Deweese et al. (2014b)	N/A	-	-
5-Repeated Bilateral Bound Jump	British Bobsleigh (2014a; 2014b) [SB]	15.00 m	-	-
15 m Sprint	Bobsleigh Canada (2015)	≤ 2.30 s	≤ 2.50 s	-
	USBSF (2015)	2.33 s	-	-
30 m Sprint	Bobsleigh Canada (2015)	≤ 4.00 s	≤ 4.20 s	-
	Godfrey et al. (2007)	4.15 s	4.25 s	-
	British Bobsleigh (2014a; 2014b)[SB]	3.86 s	-	-
	USBSF (2015)	4.11 s	-	-
30 m Flying Sprint (30 to 60 m)	British Bobsleigh (2014a; 2014b)[SB]	3.00 s	-	-
30 m Flying Sprint (15 to 45 m)	USBSF (2015)	3.66 s	-	-
45 m Sprint	USBSF (2015)	5.92 s	-	-
60 m Sprint	British Bobsleigh (2014a; 2014b)[SB]	6.92 s	-	-
	USBSF (2015)	7.90 s	-	-
1 RM Power Clean	Godfrey et al. (2007)	≥ 80 kg	≥ 70 kg	-
	USBSF (2015)	75 kg	-	-
3 RM Back Squat	USBSF (2015)	80 kg	-	-

Performance Test	Reference	Elite or International	National or Development	Junior
Underhand Medicine Ball Throw	Bobsleigh Canada (2015)	4kg ≥ 14.50 m	4kg ≥ 12.50 m	-
Underhand Shot Toss	USBSF (2015)	5.4kg 11.50 m	-	-
Isometric Mid-Thigh Pull	Deweese et al. (2014b)	N/A	-	-
Modified 6 s Wingate	Godfrey et al. (2007)	PPO 800-900 W PPOkg ~ 12 $W.kg^{-1}$ Time to PPO 3-3.5 s	-	-
Modified 10 s Wingate	Forrow (2013) • [MF]	-	-	PPO 1181 W PPOkg 15.76 $W.kg^{-1}$ Time to PPO 3.18 s Work 9282 J
Light Back Roll-bob Push	British Bobsleigh (2014a; 2014b) [SB]	4.25 s	-	-
Light Side Roll-bob Push	British Bobsleigh (2014a; 2014b) [SB]	4.31 s	-	-
Heavy Back Roll-bob Push	British Bobsleigh (2014a; 2014b) [SB]	4.49 s	-	-
Heavy Side Roll-bob Push	British Bobsleigh (2014a; 2014b) [SB]	4.51 s	-	-

Junior = aged 18-26, N/A = not reported, PPO, RM = repetition max, • = descriptive statistics, [MF] = pooled sample of males & females, [SB] = national squad best, RM = repetition max, Light = 20kg of additional mass added to the Roll-bob, Heavy = 45kg (female) or 50kg (male) of additional mass added to the Roll-bob.

As pictured below in Figures 2.2, 2.3 and 2.4 (BBSA 2018a), the push-start begins with the athletes in a stationary position, from which they are required to accelerate the fixed external load of the sled over approximately 40 m before loading (Godfrey et al. 2007; Osbeck et al. 1996). Similar to that seen in sprinting and running, athletes produce both vertical and horizontal propulsive force unilaterally during the push-start, in order to move the sled from its static start position (McCurdy et al. 2010; Meylan et al. 2009). Comparability between the push-start and sprinting is also evident when considering both from a kinematic perspective. Authors in both bobsleigh and skeleton have highlighted a closer association between the push-start and the sprint acceleration phase, as opposed to the maximal velocity phase (Kivi et al. 2004; Mosey 2014; Smith et al. 2006; Wild et al. 2011). Therefore, the initial phase of the push-start places greater emphasis on concentric and slow stretch-shortening cycle muscle actions (Maulder & Cronin 2005; Wild et al. 2011). However, given the downhill nature of the bobsleigh push-start, it could be suggested that there will be a greater eccentric component to the movement when compared to conventional level ground sprinting (Eston et al. 1995).

Figure 2.2 Start position of the bobsleigh push-start. Available from BBSA (2018a).

Figure 2.3 Acceleration phase of the bobsleigh push-start. Available from BBSA (2018a).

Figure 2.4 Load phase of the bobsleigh push-start. Available from BBSA (2018a).

Based upon the nature of the bobsleigh push-start described above, Table 2.4 provides a comparison between the performance tests outlined within the bobsleigh literature and the key features of the push-start. As can be seen from Table 2.4, there is a lack of tests that have incorporated a unilateral muscle action and/or a horizontal force production component. Additionally, many of the tests have failed to include any form of external loading. Nevertheless, each test in Table 2.4 represents at least one of the qualities thought to be required by athletes during the push-start. The roll-bob push test which involves athletes completing a 40 m push on an indoor athletics track, with a wheeled apparatus designed to mimic an actual bobsleigh, incorporates all the push-start's key features. Therefore, it is somewhat surprising there is a lack of academic literature that has attempted to scientifically validate most of the performance tests used in bobsleigh (see Table 2.4). Where evidence does exist it is limited to two academic sources only; Osbeck et al. (1996) and Harrison (2017). Consequently, it could be suggested that the discriminative and predictive validity of all the tests highlighted in Table 2.2 and 2.3 warrants further investigation, to either confirm or discard their application to bobsleigh research and practice. Furthermore, researchers should attempt to identify and validate other performance tests that include both a unilateral and horizontal force production component.

Table 2.4 A comparison between the key features of the push-start and the performance tests utilised within bobsleigh testing literature.

Performance test	Contraction type			Force component		Requirement to move an external load	Scientific Validation Study	
	Unilateral	Concentric	Eccentric	Vertical	Horizontal		Predictive	Discriminative
Squat Jump	×	✓	×	✓	×	×	×	×
Countermovement Jump	×	✓	✓	✓	×	×	✓[1]	✓[1]
Standing Long Jump	×	✓	✓	✓	✓	×	✓[2]	✓[2]
Repeated Vertical Jumps	×	✓	✓	✓	×	×	×	×
5-repeated Bilateral Bound Jump	×	✓	✓	✓	✓	×	✓[1]	✓[1]
15 m to 60 m Sprints	✓	✓	✓	✓	✓	×	✓[1,2]	✓[1,2]
1 RM Power Clean	×	✓	✓	✓	×	✓	✓[2]	✓[2]
3 RM Back Squat	×	✓	✓	✓	×	✓	✓[2]	✓[2]
3 RM Keiser Squat Test	×	✓	✓	✓	×	✓	×	×
Isometric Mid-Thigh Pull	×	×	×	✓	×	×	×	×
6 s/10 s Wingate Test	✓	✓	×	×	×	✓	~[1]	×
Underhand Shot Toss	×	✓	✓	✓	✓	✓	✓[1,2]	✓[1,2]
Underhand Medicine Ball Throw	×	✓	✓	✓	✓	✓	×	×
Light/ Heavy Roll-bob Push	✓	✓	✓	✓	✓	✓	×	×

Predictive validity = able to predict push-start performance, discriminative validity = able to distinguish between athletes of different performance tiers, RM = repetition max, Light = 20kg of additional mass added to the Roll-bob, Heavy = 45kg (female) or 50kg (male) of additional mass added to the Roll-bob, ~ = modified version of the test, [1] = Osbeck et al. (1996), [2] = Harrison (2017).

2.5 Determinants of the Bobsleigh Push-Start

A review of the academic literature surrounding the use of performance and biomechanical measures as determinants of the bobsleigh push-start, highlighted a paucity of research within the area (Harrison 2017; Kibele & Behm 2005; Lopes & Alouche 2016; Osbeck et al. 1995; Osbeck et al. 1996; Smith et al. 2006). The limited volume of work is focused within three main areas; kinematic variables (Lopes & Alouche 2016; Park et al. 2018; Smith et al. 2006), laboratory-based measures (Kibele & Behm 2005; Osbeck et al. 1995; Osbeck et al. 1996) and field-based performance tests (Kibele & Behm 2005; Osbeck et al. 1996).

2.5.1 Kinematic Variables

Biomechanical research investigating push-start performance has explored several kinematic variables including; stride length, stride frequency, foot contact time, centre of mass horizontal velocity, shoulder angle, elbow angle, trunk angle, hip angle, and knee angle (Lopes & Alouche 2016; Park et al. 2018; Smith et al. 2006). Smith et al. (2006) have demonstrated a large relationship between push-start and horizontal velocity of the centre of mass at step 2 take-off (r = -0.63). The importance of horizontal motion is supported by Park (2018) who concluded that superior push-start athletes were better able to orientate their force in the horizontal direction, via differences in lower limb joint motions at the hip and ankle, resulting in an increase in stride length. Interestingly, Lopes and Alouche (2016) were unable to demonstrate any joint angle differences at the hip and ankle between performance tiers based on finish rank (1^{st} to 5^{th}, 6^{th} to 10^{th} and 11^{th} to 15^{th}) at the 2004 2-man World Championship. However, the quality of this study's analysis is questionable, given that the authors were unable to use retro-reflexive markers, due to data being collected during actual competition (Lopes & Alouche 2016). The current kinematic literature seems to suggest that horizontal velocity and body position are important for the bobsleigh push-start, but more research in this area is needed.

2.5.2 Laboratory-Based Measures

To date, the literature has demonstrated large to near perfect relationships between the bobsleigh push-start and several lab-based tests including; alactic capacity ($r = 0.79$ to 0.90, $p < 0.01$), excess post-exercise oxygen consumption ($r = 0.61$, $p = 0.05$) (Kibele & Behm 2005) and Wingate absolute minimum power output ($r = -0.65$, $p < 0.05$) (Osbeck et al. 1996). However, application of Kibele and Behm (2005) findings to bobsleigh are somewhat limited by their use of a non-elite and non-power trained sample. Additionally, their push-start criterion measure lacks ecological validity as it was performed on a Woodway treadmill. Osbeck et al. (1996) utilised a more ecologically valid push-start performance test on an outdoor artificial simulation track, which mimics the start segment of an on-ice race track and is considered a gold standard marker of an athletes push-start capabilities by coaches in the sport. However, Osbeck et al. (1996) were only able to demonstrate a large relationship with one out of eight of the Wingate variables measured; absolute minimum power output ($r = -0.65$, $p < 0.05$). The research group attributed the lack of large relationships to the homogenous nature of their sample group, given that this part of the analysis only included the top 10 athletes (Osbeck et al. 1996). However, the present author would argue that a more feasible explanation would be the physiological differences between cycling and the push-start. As opposed to cycling, the latter involves an eccentric muscle contraction similar to running (Bijker et al. 2002; Eston et al. 1995), as well as requiring the utilisation of more muscle mass (Millet et al. 2009). Also, this explanation is further supported by previous evidence suggesting that cycling and over ground sprint performance represent different qualities, with a common variance of only 17% (Nesser et al. 1996).

2.5.3 Field-Based Performance Tests

The use of field based testing in bobsleigh was first explored by Osbeck et al. (1996), who demonstrated very large relationships between the USA Bobsled and Skeleton Federation's (USBSF) 6-item test battery and push-start performance (see Table 2.5). All tests included either had large or very large relationships with the push-start, except for the 5-RBJ (Osbeck et al. 1996).

The study's findings surrounding the 5-RBJ differ from that of Kibele and Behm (2005), who observed a very large relationship between the push-start and Margaria step test (see Table 2.5). As highlighted by Seiler et al. (1990) similar to the 5-RBJ, the step test measures an athletes anaerobic power production of the lower body (5-RBJ and Margaria step test common variance ~55 %). A possible explanation for these contrasting observations is the differences in contraction type used during the Margaria step test and 5-RBJ test. Osbeck et al. (1996) use of double legged bounds in the 5-RBJ lacks specificity to the push-start, requiring bilateral force production, as opposed to the unilateral force production requirement of the push-start and Margaria step test (Maulder & Cronin 2005).

Based upon multiple regression analysis, Osbeck et al. (1996) highlighted the 30 m sprint and CMJ tests to be the most valuable when attempting to predict push-start performance. Also, they recommended that the USBSF still include the underhand shot toss, as a means of replicating the requirement of rapidly accelerating an external load in bobsleigh (Osbeck et al. 1996). However, it is important to note here that this recommendation is only a suggestion of the authors and the test in question was not an outcome variable of their multiple regression analysis. Additionally, it could be argued that the load used in the underhand shot toss (7.3 kg), does not fully represent the demand of accelerating a 165 to 210 kg (minimum mass values equating to a minimum of 52.5 kg per athlete) sled from a standing start (IBSF 2015; Osbeck et al. 1996). Given the nature of the test being discussed and its limitations, it would be impossible to expose athletes to a load of this magnitude (≥ 52.5 kg) during the underhand shot toss.

Harrison (2017) questioned the application of Osbeck et al.'s (1996) findings to elite-level bobsleigh, given the low ability of the athletes involved in the study, for example, one athlete included was almost two tenths off the national/development bobsleigh standards reported in the literature (4.07 s & 3.90 s respectively; see Table 2.2). Harrison's (2017) work addressed this limitation by investigating a sample more reflective of elite bobsleigh using data from 2014 and 2015 USBSF preliminary and national push championships. As shown in Table 2.5, a large variability in the correlation coefficients were reported across all the jump (SLJ), speed (15 m, 30 m, 60 m & 30 m flying sprint), strength (1 RM power clean & 3 RM back squat) and power (underhand shot toss) tests included. This variability could be explained by the different competition years and levels (preliminary or national push championships) being analysed. However, from the presented data there appears to be a reduction in the absolute correlation coefficient for each test, when just considering the top 10 athletes. Although determining general conclusions from the study is problematic given the correlation variability, Harrison (2017) acknowledged the importance of sprint speed but determined absolute strength and power measures (e.g. back squat and power clean) to offer greater push-start predictive ability. However, one of the methodological issues associated with the strength and power tests used by Harrison (2017) was that performance was capped; for example the back squat at 200 kg and power clean at 150 kg. Subsequently, several athletes achieved this performance standard across the two tests and thus did not achieve their true 1 or 3 RM.

Table 2.5 Push-start predictive ability of the performancemeasures explored within the bobsleigh literature.

Performance Test	Reference	Correlation Coefficient	
		All Athletes	Top 10 Athletes
Countermovement Jump	Osbeck et al. (1996)	-0.54 to -0.58	-
Standing Long Jump	Harrison (2017)	-0.29 to -0.58	-0.23 to -0.33
5-Repeated Bound Jump	Osbeck et al. (1996)	-0.24 to -0.32	-
15 m Sprint	Harrison (2017)	0.00 to 0.63	-0.39 to 0.33
30 m Sprint	Osbeck et al. (1996)	0.85 to 0.88	-
	Harrison (2017)	0.17 to 0.77	-0.17 to 0.29
30 m Flying Sprint	Harrison (2017)	0.24 to 0.60	-0.76 to 0.24
60 m Sprint	Osbeck et al. (1996)	0.80 to 0.83	-
	Harrison (2017)	0.30 to 0.70	-0.53 to 0.38
100 m Sprint	Osbeck et al. (1996)	0.66 to 0.69	-
1 RM Power Clean	Harrison (2017)	-0.68 to -0.86	-0.09 to -0.60
3 RM Back Squat	Harrison (2017)	-0.52	0.57 to -0.25
Underhand Shot Toss	Osbeck et al. (1996)	-0.59 to -0.67	-
	Harrison (2017)	-0.50 to -0.72	-0.09 to -0.65
Margaria Step Test	Kibele and Behm (2005)	0.77	-
USBSF 3-Item Test Score	Harrison (2017)	-0.38 to -0.67	0.24 to -0.42
USBSF 6-Item Test Score	Osbeck et al. (1996)	-0.81 to -0.83	-
	Harrison (2017)	-0.51 to -0.79	0.34 to -0.37
USBSF 8-Item Test Score	Harrison (2017)	-0.62	-0.23 to -0.42

1RM = one repetition maximum, USBSF = USA bobsleigh and skeleton federation.

2.5.4 Other Winter Sliding Sports

Given the paucity of literature surrounding the determinants of push-start performance in bobsleigh, it is worth considering work from skeleton given that both sports take place on the same tracks and involve a similar push-start phase. However, it is important to highlight that although skeleton also requires athletes to move a fixed external load from a stationary start (i.e. the sled), these loads are remarkably different; skeleton ≤ 33kg and bobsleigh ≥ 170kg (2-man), ≥ 210kg (4-man) or ≥ 165kg (female) (BBSA 2018b; IBSF 2015). Additionally, there are distinct differences in the running mechanics used in the skeleton and bobsleigh push-start phases (crouched & upright respectively; see Figure 2.5).

Figure 2.5 Comparison between the skeleton and bobsleigh push-start phase. Available at BBSA (BBSA 2018a).

As displayed in Table 2.6, a number of different performance tests have been highlighted by national governing bodies and within the academic literature to assess skeleton athletes (Bullock et al. 2007; Bullock, Martin, Ross, Rosemond, Jordan, et al. 2008; Bullock, Gulbin, et al. 2009; Chapman et al. 2012; Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Colyer, Stokes, Bilzon, Holdcroft, et al. 2017; Cook et al. 2013; Godfrey et al. 2007; Mosey 2014; Mosey 2015; Sands et al. 2005; Skeleton Canada 2016). Most of these tests have already been mentioned above within the review of the bobsleigh literature (see section 2.4 & 2.5), apart from the DJ (Bullock, Gulbin, et al. 2009; Chapman et al. 2012; Sands et al. 2005), loaded CMJ (Bullock, Gulbin, et al. 2009; Mosey 2014; Sands et al. 2005), resisted sprints (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Colyer, Stokes, Bilzon, Holdcroft, et al. 2017), Keiser leg press force-velocity curve (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Colyer, Stokes, Bilzon, Holdcroft, et al. 2017) and 20 m weighted sled pulls (Cook et al. 2013).

However, like bobsleigh, only a handful of studies have explored the validity of these performance tests in skeleton (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Sands et al. 2005). The early works of Sands et al. (2005) attempted to validate the predictive ability of the SJ as well as unloaded and loaded (20 %, 40 % & 60 % body mass) CMJs. Very large relationships were reported for all jump tests and loads with 30m push-start performance, across both jump height (r = -0.70 to -0.88, $p < 0.01$) and peak power output (r = -0.73 to -0.83, $p < 0.01$). However, when considering the metric rate of force development only small to large push-start relationships were detected (r = -0.13 to 0.50, $p > 0.01$). Although the work of Sands et al. (2005) provides support for the findings in bobsleigh surrounding the link between CMJ height and the push-start, the findings may be limited, as recent developments in the sport have meant performance has improved considerably (Colyer 2015). Thus, due to its publication date, it may not capture a true reflection of the capabilities of modern day skeleton athletes (Colyer 2015). Additionally, perhaps the more obvious limitation of the work of Sands et al. (2005) is the inclusion of both males and females within the same statistical analysis. Subsequently, this approach has resulted in a heterogeneous sample group, an approach of this nature is likely to inflate the correlation values reported (Meylan et al. 2009).

Colyer, Stokes, Bilzon, Cardinale et al. (2017) took a more comprehensive approach aiming to identify a model of independent performance tests that characterise push-start performance in skeleton. Eight of the performance tests included were shown to represent different qualities, as well as demonstrate at least a large relationship with push-start performance (15 m sprint time, 15 to 30 m resisted sprint time, unloaded CMJ height, 5 kg CMJ height, maximum isometric force, maximum velocity, maximum power, force at maximum power). However, a principle component analysis identified a model explaining 86% of skeleton push-start performance (i.e. velocity at 15 m) which only included 15 m sprint time, unloaded CMJ height and force at maximal power during a leg press exercise. It is important to note that force at maximal power provided a negative contribution to this model and thus highlights the importance of achieving peak power at light loads for the skeleton push-start (Colyer, Stokes, Bilzon, Cardinale, et al. 2017). This suggests that faster skeleton push-starters should display a more velocity dominant profile when considering the force-velocity relationship and power production during leg press exercise (Colyer, Stokes, Bilzon, Cardinale, et al. 2017). Nevertheless, the application of this latter observation across to bobsleigh should be viewed with caution given the much heavier sled load involved in bobsleigh. Similar to Sands et al. (2005), the works' main weakness is that it includes data pooled from both males and females and thus the reported correlation values and explained variances were potentially inflated. Despite this, the study's findings highlight that in addition to 15 m sprint time and CMJ height, force-velocity profiling maybe useful in winter sliding sports. However, given that Colyer, Stokes, Bilzon, Cardinale, et al. (2017) quantified these mechanical profiles on a leg press dynamometer, force-velocity profiling needs exploring in more push-start ecologically valid movements such as sprinting.

Table 2.6 A summary of the performance tests used in academic research and by national governing bodies as indicators of the push-start in skeleton.

Performance Test	Measures	Reference
Squat Jump	Height Peak Force Rate of Force Development Peak Power Output Peak Velocity Mean Velocity	Bullock, Martin, Ross, Rosemond, Jordan, et al. (2008) Chapman et al. (2012) Sands et al. (2005)
Unloaded Countermovement Jump	Height Peak Force Rate of Force Development Peak Power Output Mean Power Relative Power Reactive Strength Index Peak Velocity Mean Velocity	Bullock Martin, Ross, Rosemond, Jordan, et al. (2008) Bullock Gulbin, et al (2009) Chapman et al. (2012) Godfrey et al. (2007) Mosey (2014) Mosey (2015) Sands et al. (2005) Colyer (2015) Colyer, Stokes, Bilzon, Cardinale et al. (2017)
Loaded Countermovement Jump	Absolute (5, 15, 20, 34, 40 & 60 kg) Relative (20%, 40%, 50% & 60% body mass)	Bullock Gulbin, et al. (2009) Mosey (2014) Sands et al. (2005) Colyer (2015) Colyer, Stokes, Bilzon, Cardinale et al. (2017)
Standing Long Jump	Distance	Skeleton Canada (2016)
Drop Jump	Height Peak Force Rate of Force Development Peak Power Output Contact Time Fight Time	Bullock, Gulbin, et al (2009) Chapman et al. (2012) Sands et al. (2005)

Performance Test	Measures	Reference
	Contact Time; Fight Time Ratio	
Sprint	0 to 15 m Time 15 to 30 m Flying Time 0 to 30 m Time 15 to 45 m Flying Time all 5 m Times up to 30 m	Bullock et al. (2007) Bullock Martin, Ross, Rosemond, Jordan, et al. (2008) Bullock, Gulbin, et al (2009) Godfrey et al. (2007) Mosey (2014) Sands et al. (2005) Skeleton Canada (2016) Colyer (2015) Colyer, Stokes, Bilzon, Cardinale et al. (2017)
Resisted sprint (7.5 kg or 10 kg)	0 to 15 m Time 15 to 30 m Flying Time	Colyer (2015) Colyer, Stokes, Bilzon, Cardinale et al. (2017)
1 RM Power Clean	Mass	Godfrey et al. (2007)
1 RM Back Squat	Mass	Mosey (2014), Mosey (2015)
Keiser Leg Press Force-Velocity Curve	Maximum Isometric Force Maximum Velocity Maximum Power Force at Maximum Power Force-Velocity Gradient	Colyer (2015) Colyer, Stokes, Bilzon, Cardinale et al. (2017) Colyer, Stokes, Bilzon, Holdcroft, et al. (2017)
Modified 6s Wingate Test	Peak Power Output Relative Peak Power Output Time to Peak Power Output	Godfrey et al. (2007)
Underhand Medicine Ball Throw	Distance (4 kg & 5 kg)	Skeleton Canada (2016)
Weight Sled Pulls	20 m Time	Cook et al. (2013)

1RM = one repetition maximum.

2.5.5 Summary

A range of performance tests have been identified and used to assess athletes in both bobsleigh and skeleton. However, to date only a handful of performance tests have considered either the unilateral, horizontal force production or external load component of the push-start. Additionally, there is a paucity of literature that has attempted to scientifically examine the discriminative or predictive validity of the various performance tests used. Nevertheless, the pooled evidence from bobsleigh and skeleton has highlighted sprint acceleration (e.g. 15 m & 30 m splits), explosive power (e.g. CMJ), absolute strength/power (e.g. back squat or clean) and force-velocity mechanical characteristics as important qualities for push-start performance. In addition to the lack of work in the area, much of the literature to date is limited by the nature of the sample groups involved, either not truly representing “elite” winter sliding sport athletes or the pooling of data from both male and female athletes. More research is required to substantiate the current literature using a more homogenous sample group, which is truly reflective of modern bobsleigh athletes. Also, further work is required to investigate the application of other performance tests that are being used in winter sliding sports, but their discriminative or predictive validity has yet to be explored.

2.6 Strength and Power Diagnostics

The limited volume of performance testing literature in bobsleigh has emphasised the importance of speed, strength and power within the sport. It is vitally important to consider the wider strength and power diagnostic research when assessing and developing testing batteries within bobsleigh. Given the push-start is a specialised type of sprint, the following section will discuss the different strength and power diagnostic tests outlined within sprint research, the evidence surrounding their link to athletic sprint performance, and any potential applications across to bobsleigh.

McGuigan et al. (2013) have outlined a number of qualities that can be assessed within strength and power diagnostics and these included maximal strength, ballistic power, reactive strength, rate of force development (RFD) and strength endurance. However, strength endurance qualities are only included in diagnostic batteries when the demands of the sport require repeated maximal efforts (Newton & Dugan 2002). Given the bobsleigh push-start is one maximal effort lasting approximately 6 seconds, strength endurance is not included within the review below. Therefore, maximal strength, ballistic power and reactive strength will now be reviewed in turn, with reference to RFD throughout.

2.6.1 Maximal Strength

Maximal strength is defined as the maximal force that can be produced during a given movement and is traditionally measured during either isometric, isokinetic or isoinertial strength assessments (Colyer 2015; McMaster et al. 2014; McGuigan et al. 2013). Subsequently, each of these different approaches for the measurement of maximal strength will now be reviewed.

2.6.1.1 Isometric Strength

Isometric strength testing involves the measurement of maximal force via an athlete completing a maximal voluntary contraction against a fixed external load, with minimal changes in joint angle and thus fascicle length during the effort (Colyer 2015). The isometric squat and isometric mid-thigh pull are two commonly used tests and have gained popularity due to the minimal amounts of familiarisation, skill and time required to implement (McMahon et al. 2018). Also, their application in strength and power diagnostics allows both athlete peak force and RFD to be measured (Wang et al. 2016). Conflicting evidence exists surrounding the link between isometric strength and athletic sprint performance (Anderson et al. 1991; Kukolj et al. 1999; Requena et al. 2009; Thomas et al. 2015; Wang et al. 2016; Wilson et al. 1995). As previously outlined within the literature, the lack of agreement between studies is likely a result of methodological differences (e.g. joint angle and mode of collection), as well as the disparities in the athletic level of subjects involved (Colyer 2015; West et al. 2011). Additionally, isometric strength tests such as the isometric squat and mid-thigh pull lack specificity to sprint running in terms of contraction type and the direction of force application involved. Work within professional rugby has demonstrated a large correlation between sprint acceleration (10 m time) and several isometric mid-thigh pull variables; peak RFD (r = -0.66), force at 100 milliseconds (r = -0.54) and relative force at 100 milliseconds (r = -0.68) (West et al. 2011). Given this link shown in elite athletes, as well as the similarities between isometric strength testing and the bobsleigh push-start in terms of the requirement to express force against an external object (see Table 2.4), the application of isometric strength testing to bobsleigh warrants further investigation.

2.6.1.2 Isokinetic Strength

Isokinetic strength testing measures force or torque of muscle actions at a constant non-zero angular velocity and allows the assessment of both concentric and eccentric strength (Blazevich & Cannavan 2007). Generally, isokinetic tests are undertaken using specialised machines such as the KIM-COM Isokinetic Dynamometer (Blazevich & Cannavan 2007). Given the test’s lack of angular acceleration, critics have questioned its ecological validity for dynamic exercises such as sprint running (Colyer 2015). Also, isokinetic testing is often used more in injury research, requires significant investment and the dynamometer itself has limited portability. Therefore, the collection and use of such measures lacks practical application to the bobsleigh field testing environment.

2.6.1.3 Isoinertial Strength

Isoinertial strength testing requires athletes to move a fixed external load (e.g. Olympic barbell) with a constant acceleration and deceleration phase (Blazevich & Cannavan 2007). The 1 RM back squat, clean and bench press are three of the most commonly used tests to measure an athletes' maximal strength, which has largely manifested from the ease at which the test can be undertaken during training (McMaster et al. 2014; Paul & Nassis 2015). Additionally, Blazevich and Cannavan (2007) have suggested that when compared to both isometric and isokinetic tests, isoinertial testing represents greater ecological validity to many athletic movements, due to its requirement to move a load using a constant inertia. Comparable to sprinting, they both place an emphasis on concentric as well as eccentric muscle contractions (Colyer 2015). Previous literature undertaken in team sports has demonstrated a clear link between the back squat or clean and sprint performance over various distances up to 40 m (Baker & Nance 1999; McBride et al. 2009; Seitz, Trajano, et al. 2014; Wisloff et al. 2004). Also, a recent meta-analysis conducted by Seitz, Reyes et al. (2014) highlighted a positive transfer of increases in squat strength to sprint performance. Despite its clear link to sprint performance, there are several limitations of isoinertial testing to be considered including; its slow speed of muscle contraction at maximal force, its bilateral nature which differs to the unilateral nature of many athletic tasks, and the high level of lifting competency required to perform either the back squat or clean (Colyer 2015; Meylan et al. 2009). Nevertheless, given that past work has shown a clear association with sprint performance, the application of isoinertial strength tests such as the 1 RM back squat to the push-start in bobsleigh warrants attention from future research.

2.6.2 Ballistic Power

Ballistic assessments typically in the form of either jumps or throws require athletes to accelerate their own body mass or a bar through a complete range of motion (McMaster et al. 2014). Traditionally, the SJ and CMJ tests are two of the most commonly used ballistic assessments and both have been repeatedly shown to relate to sprint acceleration performance across a range of different populations (Alemdaroğlu 2012; Cronin & Hansen 2005; Dobbs et al. 2015; Loturco et al. 2015; Maulder & Cronin 2005; Maulder et al. 2006; McFarland et al. 2016; Meylan et al. 2009; Vescovi & McGuigan 2008; Young et al. 2011). The inclusion of both jump assessments within a testing battery can allow practitioners to quantify and assess how well their athletes are able to use the stretch shortening cycle, by calculating various metrics such as the eccentric utilization ratio (McGuigan et al. 2006; McMahon et al. 2018; McMaster et al. 2014). The use of the SJ in conjunction with the CMJ test offers an application to bobsleigh, due to the eccentric utilisation ratio's ability to quantify one of the key features of the push-start, namely the stretch shortening cycle (see Table 2.4). However, previous authors have questioned the specificity of these assessments to human movements such as sprinting, due to their bilateral and vertical nature (Maulder & Cronin 2005; Meylan et al. 2009). Therefore, horizontal and/or unilateral versions of these tests may have greater transfer and sport specific applications (McMaster et al. 2014). Evidence presented in highly trained rugby players and elite sprinters has supported this notion by demonstrating the SLJ (peak and mean force) to be a stronger predictor of sprint performance up to 30 m, than the CMJ (Dobbs et al. 2015; Luturco et al. 2015). However, to date, a similar predictive ability comparison for bilateral and unilateral ballistic assessments has yet to be undertaken on a comparable population to bobsleigh athletes.

In addition to the unloaded conditions referenced above, McGuigan et al. (2013) outlined that ballistic power tests can also be undertaken with additional load. Loaded ballistic assessments such as a barbell CMJ, may represent a more ecological valid test for the bobsleigh push-start, due to the slower movement velocities and higher loads involved, when compared to a conventional unloaded test. Additionally, several authors have reported moderate to very large relationships between the sprint acceleration phase (≤ 30 m) and loaded SJ or CMJ tests (Cronin & Hansen 2005; Hori et al. 2008; Sleivert & Taingahue 2004; Turner et al. 2015). Subsequently, based on all the current evidence presented above, the application of both unloaded and loaded ballistic assessments to the bobsleigh push-start warrants further investigation.

2.6.3 Reactive Strength

Reactive strength qualities characterise an athlete's use of the stretch shortening cycle to rapidly absorb high eccentric force and produce a resulting concentric force to provide propulsion (Douglas et al. 2017; Flanagan et al. 2008). Typically, this physical quality is assessed in the field using a DJ**,** which requires athletes to step from a specific height, land and then produce a vertical jump as high as possible while minimising ground contact time (Flanagan et al. 2008; McGuigan et al. 2013; Pedley et al. 2017). Previous literature in high level track and field athletes as well as rugby players, has observed a moderate to very large relationship between DJ height and both the sprint acceleration and maximal velocity phases (Barr & Nolte 2011; Bissas & Havenetidis 2008; Hennessy & Kilty 2001; Kale et al. 2009). Additionally, elite track and field athletes have shown large to very large differences across several DJ metrics when compared to either sub-elite or non-sprint trained athletes; including jump height, take-off velocity, contact time, reactive strength index, knee angle and leg stiffness (Coh & Mackala 2013; Douglas et al. 2017). This relationship between the DJ and sprint performance is likely to be a result of several reasons such as movement similarities, both requiring high amounts of lower muscular power and both including the contribution of the stretch shortening cycle (Cronin & Hansen 2005; Kale et al. 2009). Additionally, the DJ is considered a pure form of the stretch shortening cycle muscle action, as it involves the pre-activation of the muscles before impacting the ground (Komi 2000). Therefore, when compared to the SJ or CMJ, the DJ is a closer reflection of the lower limb muscle actions involved in sprinting. Given that the DJ assesses fast stretch shortening cycle performance its importance for sprint performance is likely to increase as velocity increases i.e. moving closer towards the maximal velocity phase (Cronin & Hansen 2005). As a result of the clear links highlighted above, as well as the fact during the push-start bobsleigh athletes are required to use both the slow and fast stretch shortening cycle (Smith et al. 2006), the use of reactive strength assessments such as the DJ within bobsleigh field testing should be explored.

2.7 Sprint Profiling

Sprinting speed is considered a key determinant of performance across many sports (McMahon et al. 2018). Sprint performance can be divided into four phases; 1) first step quickness, 2) the acceleration phase, 3) the maximum or constant velocity phase and 4) the deceleration phase and traditionally it has been measured using various split time distances up to 100 m (Cronin & Hansen 2005; Jiménez-Reyes et al. 2018). Practitioners in bobsleigh, as well as many other sports have utilised these measurements to monitor both training adaptation and inform training prescription. However, simple split time measurements do not provide practitioners with any insight into which mechanical properties are contributing to the observed performance (Buchheit et al. 2014). Subsequently, a more recent body of literature has emerged in which researchers have utilised sprint force-velocity mechanical profiling to provide more in-depth analysis of an athlete's sprint performance (Brown et al. 2017; Clark et al. 2017; Cross et al. 2015; Mendiguchia et al. 2014; Mendiguchia et al. 2016; Morin et al. 2011; Morin et al. 2012; Moore et al. 2016; Rabita et al. 2015; Samozino et al. 2015).

2.7.1 Sprint Force-Velocity Mechanical Profiling

A recent commentary by Morin and Samozino (2016) provided a review of the key mechanical variables underpinning sprint performance. The work emphasised the importance of theoretical maximal force (F_0) for the sprint acceleration phase i.e. sprint distances up to 30 m. Subsequently, factors such as maximal running velocity and the index of force application (D_{RF}) (the ratio between the decrease in force production as speed increases) have been identified as more important variables for longer sprint distances up to 60 m and 100 m (Morin et al. 2012; Morin & Samozino 2016). In Morin and Samozino's (2016) case study example, they provided the force-velocity mechanical profiles of two athletes with similar 20 m sprint times and F_0 values (see Figure 2.6). However, as displayed in Figure 2.6, despite these similarities the athletes displayed different force-velocity and D_{RF} profiles. For example, player C has a higher sprinting F_0 than player D and thus has a greater capacity to produce force in a sprint, particularly at the start. Whereas, player D has a higher V_0 and thus a greater sprinting velocity capability. Given the varying importance of the force-velocity mechanical variables depending on sprint distance, as well as the profile differences observed between athletes with similar sprint times (see Figure 2.6), it is not known whether sprint speed or its mechanical determinants are most important for push-start performance. Therefore, this is a topic that warrants attention from future research.

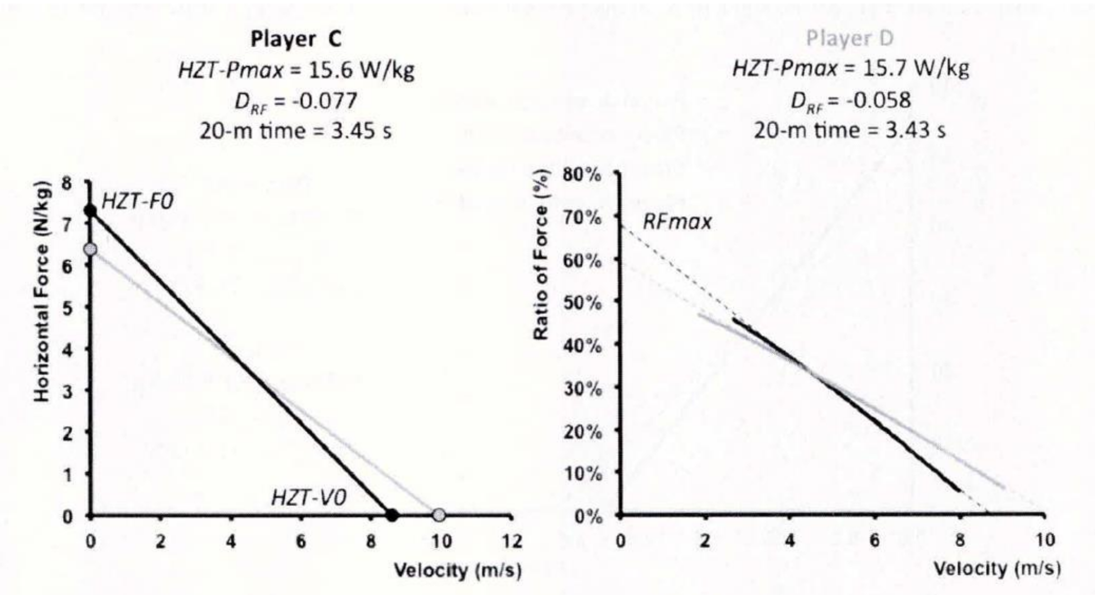

Figure 2.6 Force-velocity mechanical profiles of two elite rugby union players with similar 20 m sprint times. Abbreviations: HZT-P_{max} = maximal horizontal power, D_{RF} = the ratio between the decrease in force production as speed increases, HZT-F0 = maximal horizontal force, HZT-V0 = maximal running velocity, RF_{max} = maximal ratio of force (Morin & Samozino 2016, p.270).

Several methodologies have been presented in the literature which have allowed researchers and practitioners to quantify force-velocity mechanical characteristics during sprint running, these include treadmill ergometry, instrumented treadmills and integrated track force plates using either a single or multiple trial approach (Cross et al. 2016). For a full review of these methodologies please refer to the works of Cross et al. (2016). All of these approaches referred to above lack application to the bobsleigh field testing environment, for example, instrumented treadmills do not replicate normal over ground sprinting and integrated track force plates are expensive and inaccessible for many practitioners (Morin & Samozino 2016; Samozino et al. 2015). Subsequently, as a result of these limitations, Samozino et al. (2015) developed and validated a macroscopic approach which allows athlete sprint force-velocity profiles to be calculated using simple speed-time or distance-time measurements. The increased usability and ecological validity of this methodology has resulted in several authors adopting this approach to assist with rehabilitation interventions (Mendiguchia et al. 2014; Mendiguchia et al. 2016), better understand the mechanical determinants of specific sporting movements (Clark et al. 2017; Cross et al. 2015), monitor training adaptation (Morin et al. 2017) and to assess the association between various mechanical sprint variables and NFL draft selection (Delaney et al. 2018). Despite the link between force-velocity mechanical characteristics and sprint performance, the application of sprint force-velocity mechanical profiling to bobsleigh has yet to be explored.

2.8 Resisted Sprinting

Traditionally, resisted sprinting has been used by strength and conditioning practitioners as a training methodology to enhance their athletes' speed and acceleration qualities (Harrison & Bourke 2009). The approach involves athletes completing several maximal sprint efforts with an additional load in the form of either a sled, vest or parachute or by performing the sprint on a hill or sand dune (Harrison & Bourke 2009; Petrakos et al. 2016). A recent systematic review by Petrakos et al. (2016) highlighted that most studies on resisted sled sprint training have suggested it to be an effective training method to improve sprint acceleration performance in strength-trained individuals. Evidence has shown it to be reliable and demonstrate a large to very large (r = 0.64 to 0.88) relationship with 20 m sprint performance (Cross et al. 2017; Martínez-Valencia et al. 2014). Therefore, given the push-start is a distinct form of resisted sprinting, its application to bobsleigh warrants further investigation.

The resisted sprint training referred to above involves the pulling of a sled, whereas in bobsleigh the sled is pushed. In the sport, the roll-bob training and testing apparatus exists, which is a wheeled apparatus that can be pushed on an athletics track and is designed to mimic an actual bobsleigh. Although the roll-bob represents high ecological validity for bobsleigh, little is known about its reliability, discriminative validity and predictive validity. Therefore, highlighting a potential avenue for future research.

2.9 Monitoring Training Adaptation

Once practitioners have identified reliable and valid performance tests for their sport, they can be used on a longitudinal basis to monitor the effectiveness of their training interventions on key qualities for the sport. There is a lack of research that has conducted longitudinal monitoring on training interventions in bobsleigh athletes and how these influence performance (i.e. push-start and sprint performance) in the build-up to major competitions. Twelve to eighteen month longitudinal training monitoring studies do exist in both elite international rugby and elite skeleton (Barr et al. 2014; Colyer, Stokes, Bilzon, Holdcroft, et al. 2017). The latter work in elite skeleton tracked the development of leg press force-velocity profiles and push-start performance, including both pre-season and on-ice training phases (Colyer, Stokes, Bilzon, Holdcroft, et al. 2017). Colyer, Stokes, Bilzon, Holdcroft et al. (2017) demonstrated that training induced improvements in V_0 appear to be beneficial for push-start performance. Also, an increase in sport specific training, coupled with a reduction in resistance training load can facilitate beneficial shifts in the V_0 component of an athlete's leg press force-velocity profile. Despite this, work of a similar nature has yet to be undertaken in bobsleigh and thus highlights a potential topic for future research.

2.10 Performance Testing at British Bobsleigh

Like other nations, British Bobsleigh uses a performance testing battery (named the 'evaluation test') to assist with both talent identification and national squad monitoring at three to four specific timepoints throughout the pre-season. The 'evaluation test' includes the following six tests;

- 60 m sprint
- 5-RBJ
- Four x 40 m roll-bob pushes completed with different weighted sleds and named as follows;
    - Light back roll-bob push
    - Light side roll-bob push
    - Heavy back roll-bob push
    - Heavy side roll-bob push

Like the athletic events heptathlon and decathlon, points are awarded for performance in each test (maximum of 200 per test) and then these points are added together to create a total sum score (potential maximum total of 1200), referred to in bobsleigh as 'evaluation test' total points (see Table 2.7).

Table 2.7. Performances required of male and female athletes to score 200 points on the individual tests included within the British Bobsleigh 'evaluation test'.

Test Parameter	Male	Female
60 m Sprint (s)	5.95	6.75
5-RBJ (m)	20.00	17.00
Light Back Roll-bob Push (s)	3.30	4.00
Light Side Roll-bob Push (s)	3.30	4.00
Heavy Back Roll-bob Push (s)	3.50	4.30
Heavy Side Roll-bob Push (s)	3.50	4.30

Light roll-bob push = roll-bob push with an additional load of 20kg, heavy roll-bob push = roll-bob push with an additional load of 50kg (males) or 45kg (females) & 5-RBJ = 5 repeated-bound jump.

Although during the 60 m sprint an athletes' points are allocated based on their 0-60 m sprint time, two additional splits are collected to assist with training monitoring and prescription (0 to 30 m and 30 to 60 m). British Bobsleigh coaches believe that 'evaluation test' total points score is indicative of an athlete's push-start capabilities, as each of the included tests represent a different quality that is believed to be important for the push-start. However, the validity of this points score has yet to be empirically examined. Additionally, studies examining the validity of performance testing in bobsleigh, have only considered the speed and reactive strength qualities included by British Bobsleigh (Harrison 2017; Osbeck et al. 1996). As previously discussed (see section 2.5), literature has confirmed the importance of sprint acceleration (i.e. ≤ 30 m sprint) for the bobsleigh push-start (Harrison 2017; Osbeck et al. 1996). Evidence presented by Osbeck et al. (1996) has questioned the inclusion of the 5-RBJ in bobsleigh performance testing batteries, but their work is somewhat limited by the low ability of the athletes involved (Harrison 2017). Despite this, the 5-RBJ has remained in the British Bobsleigh 'evaluation test' and has received little additional scrutiny. To date, no scientific literature has investigated the reliability, discriminative validity or predictive validity of the roll-bob push for bobsleigh push-start performance, even though this test contributes 800 out of the 1200 available 'evaluation test' points. Also, during the 'evaluation test' athletes complete four roll-bob pushes with either a light or heavy additional load, but it is not known if either load is more representative of the push-start. Based on the present literature there is a need to validate the 'evaluation test' currently used by British Bobsleigh.

In addition to the 'evaluation test', British Bobsleigh also uses a power-load assessment on the Keiser® AIR300 Squat (named the 'Keiser Squat Test'), to monitor their athletes on a more regular basis and assess their ability to express power under loaded conditions. The 'Keiser Squat Test' requires athletes to complete three maximal effort repetitions at several different predefined absolute loads, with the attainment of a direct power measurement at each load (see Figure 2.7). However, apparatus portability and the already extensive nature of the 'evaluation test' has resulted in its exclusion from this testing battery. Additionally, despite the 'Keiser Squat Test' replicating the requirement in bobsleigh to move a fixed external load (see Table 2.4), no previous literature has sort to confirm the reliability and/or validity of the test in bobsleigh. Nevertheless, the use of a loaded power assessment is supported by evidence presented in skeleton that has reported large to near perfect relationships between power output in several different loaded jumps (5 kg, barbell, 20 %, 40 %, 50 % and 60 % body mass) and various push-start metrics; push-start velocity (r = > 0.50) and push-start time (r = -0.73 to -0.92) (Colyer 2015; Sands et al. 2005). Also, the work of Colyer (2015) has demonstrated a very large relationship between push-start velocity (15 m) and P_{max} produced on the Keiser leg press dynamometer (r = 0.85). Thus, future research should aim to scientifically validate the 'Keiser Squat Test' used by British Bobsleigh.

Figure 2.7 An athlete completing the British Bobsleigh 'Keiser Squat Test'. Available at BBSA (2018a).

In summary, based on the current practice and the available literature presented above for winter sliding sports (see section 2.5), more research is required to validate the performance testing practices utilised at British Bobsleigh. Additionally, there is a range of other performance tests outside the current practice of British Bobsleigh used in winter sliding sports (see Section 2.5), strength and power diagnostic (see Section 2.6) and sprinting literature (see Section 2.7), which warrant further investigation to assess their application to bobsleigh. Figure 2.8 provides a conceptual framework of the current performance testing practice at British Bobsleigh and the proposed additional tests that warrant attention from this thesis.

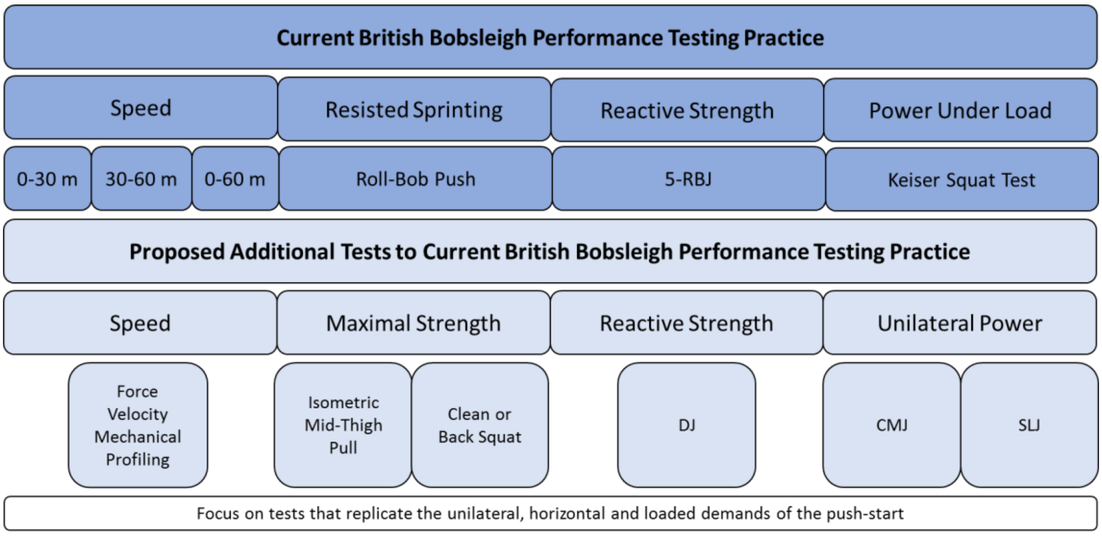

Figure 2.8 Current performance testing practice at British Bobsleigh and proposed additional tests that warrant attention from future research. 5-RBJ = 5-repeated bound jump, DJ = Drop Jump, CMJ = Countermovement Jump, SLJ = Standing Long Jump.

2.11 General Summary

Traditionally, research in elite sport has been difficult to conduct. Embedding researchers within this environment can lead to ecologically valid research projects that tackle applied performance problems (Coutts 2017). In comparison to many other sports, bobsleigh is widely under researched, in particular the importance of the push-start in elite-level bobsleigh has received little attention. Despite this, the existing literature suggests that the importance of the push-start is track dependent and that this phase of the run is a pre-requisite for successful performance in bobsleigh. However, there is still a need for a single comprehensive study examining the importance of the push-start phase across all tracks and formats on the elite circuit.

British Bobsleigh place a heavy emphasis on field-based performance testing to assist with talent identification, selection, profiling, and to assess the effectiveness of interventions. However, because of the limited work within bobsleigh the evidence surrounding the current practices of British Bobsleigh is somewhat limited and based largely on coach intuition, anecdotal evidence and experience per se. Additionally, based upon the review of the bobsleigh, skeleton, strength and power diagnostic and sprinting literature there are several other performance tests outside of the present British Bobsleigh practice which warrant investigation. Therefore, using Figure 2.8 as a framework, this thesis should look to substantiate and develop British Bobsleigh's current performance testing practices.

Chapter 3

STUDY 1: Importance of the Push-Start in Elite-Level Bobsleigh

3.1 Introduction

3.1.1 Preface

Bobsleigh performance is defined by a crew's combined finish time over two to four heats and researchers have suggested it to be influenced by a number of factors including the sled, environmental conditions, starting order and the capabilities of the driver and the crew (Brüggemann et al. 1997; Morlock & Zatsiorsky 1989). Dabnichki and Avital (2006) have characterised a single bobsleigh run into three distinct phases; the push-start, the drive and the finish. However, it is commonly accepted by many coaches and athletes in the sport that the push-start has a fundamental bearing on performance (Smith et al. 2006). In fact, it is an anecdotal belief that a 0.01 s improvement in the push-start can translate to a 0.03 s improvement at the bottom of the track (Dabnichki & Avital 2006). Despite these cultural beliefs in bobsleigh, limited research has sort to scientifically validate the importance of push-start performance in modern day elite level bobsleigh. Hence, further work is needed to establish how important the push-start is in elite level bobsleigh.

3.1.2 Push-Start Performance Literature

Despite the push-start being viewed as a vital aspect of performance, there is a lack of literature attempting to provide scientific support for this across both bobsleigh (Brüggemann et al. 1997; Fedotova & Pilipiva 2011; Harrison 2017; Smith et al. 2006) and skeleton (Bullock, Martin, Ross, Rosemond, Holland, et al. 2008; Bullock, Hopkins, et al. 2009; Fedotova 2010; Zanoletti et al. 2006). Additionally the application of any skeleton based research across to bobsleigh should interpreted with caution, due to between-sport variances such as crew masses, equipment and energetic losses (Harrison 2017; Zanoletti et al. 2006). Subsequently, research in bobsleigh has demonstrated moderate to very large relationships between push-start time and finish time (Brüggemann et al. 1997; Harrison 2017; Morlock & Zatsiorsky 1989; Smith et al. 2006). However, when research has only considered the top 15 crews, a marked reduction in the push-start time andfinish time relationship has been detected, for example in the works of Brüggemann et al. (1997) at Lillehammer (*r* = ~ 0.88 to < ~ 0.39).

With the exception of Harrison (2017), a main weakness of all the studies referred to above is that they have only considered one race venue in isolation, limiting their findings to a specific track and creating difficulties when making comparisons between studies. In addition to this, much of the work has only considered a single event in one season, therefore the observed relationships are more likely to be influenced by environmental factors (e.g. weather), in comparison to if researchers had included multiple races. The more recent work of Fedotova and Pilipiva (2011) and Harrison (2017) have included race data from four and two seasons respectively. However, like much of the works above, Fedotova and Pilipiva (2011) focused solely on St. Moritz. Also, although Harrison (2017) did analyse 9 different tracks, only 4 of these actually included multiple races and the research group did not analyse the top 10 crews in isolation. Finally, the global bobsleigh push-start performance literature to date has tended to focus on the male event formats (2-man & 4-man) rather than female (i.e. 2-women crew).

Despite the need for caution when applying the skeleton literature to bobsleigh, it is still an important body of evidence to consider, given that all skeleton studies have included multiple race tracks within a single study (Bullock, Martin, Ross, Rosemond, Holland, et al. 2008; Bullock, Hopkins, et al. 2009; Fedotova 2010; Zanoletti et al. 2006). To date, the current evidence is conflicting as trivial to large push-start:finish time relationships have been reported across the skeleton literature (Bullock, Martin, Ross, Rosemond, Holland, et al. 2008; Bullock, Hopkins, et al. 2009; Fedotova 2010; Zanoletti et al. 2006). However, the large correlation coefficient variance reported is likely to be attributed to the different tracks being analysed and thus the push start: finish time relationship can be considered track dependent. Bullock, Hopkins, et al. (2009) acknowledged this concept prior to their analyses by classifying tracks into four distinct categories; pure push track, tracks with a large push component, tracks with a large drive component and pure driving tracks (see Table 3.1). Pure push tracks are less technically difficult than pure driving tracks and therefore, theoretically a fast push-start at a pure push track will translate into a fast finish time, with driver ability having a reduced influence (Bullock, Hopkins, et al. 2009).

Table 3.1 Elite skeleton track classifications outlined in the works of Bullock, Hopkins, et al. (2009).

Track category	Race Tracks
Pure push track	Igls & Winterberg
Track with a large push component	Königssee, Calgary, Lake Placid & Park City
Track with a large drive component	St. Mortiz & Lillehammer
Pure driving track	Sigulda, Altenberg & Torino

However, in Bullock, Hopkins, et al.'s (2009) work tracks were categorised prior to analysis based on coach and athlete perception of each track's technical difficulty, as opposed to using objective criteria based on the outcome of research. As previously outlined in the literature review (see Chapter 2.2.2.2), the present author would question the track categories highlighted above because of the magnitude of previously reported push-start: finish time correlations in winter sliding sports (Bullock, Martin, Ross, Rosemond, Holland, et al. 2008; Bullock, Hopkins, et al. 2009; Brüggemann et al. 1997; Fedotova 2010; Harrison 2017; Morlock & Zatsiorsky 1989; Smith et al. 2006; Zanoletti et al. 2006). The categories of "pure push track" or "pure drive track" are indicative of the push-start or drive potentially having no influence on performance, which will never be the case. Hence, the following modifications to Bullock, Hopkins, et al. (2009) track classifications were proposed in Chapter 2.2.2.2; 1) drive dominant track with a small push-start component; 2) drive dominant track with a moderate push-start component; 3) push-start dominant track with a moderate drive component; 4) push-start dominant track with a small drive component.

3.1.3 Rationale

The current volume of literature examining the relationship between the bobsleigh push-start and finish time is relatively small, coupled with a lack of agreement between authors. The wide variety in track venues utilised across the literature makes comparisons between studies problematic and the drawing of a general conclusion challenging. However, the strength of the push-start: finish time relationship appears to be track dependent and reduces in magnitude when considering a more homogenous sample group (i.e. top 10 crews only). The research to date has tended to focus solely on the male event formats (e.g. 2-man and 4-man) rather than also incorporating the female (e.g. 2-women) bobsleigh format. As well as this, few studies have focused beyond a single event/venue and thus have not considered data from multiple seasons or have not considered the influence of specific performance tiers within the race field on the observed relationship. The current skeleton research faces similar limitations to that identified for the bobsleigh literature, as well as the fact that its application to bobsleigh is inappropriate. To date, a single comprehensive study that examines the relationship between push-start and finish time in bobsleigh across all tracks and formats (e.g. 2-man, 4-man & female) on the elite circuit, accounting for different within-race field performance tiers, has yet to be undertaken.

3.1.4 Aim

The aim of this study is to examine the relationship between the push-start and finish time across elite bobsleigh competitions for the 2-man, 4-man and female event formats, across multiple tracks and over multiple on-ice seasons.

3.2 Methods

3.2.1 Subjects

All heats from the 2-man, 4-man and female (1 format i.e. 2-women crew) formats at major elite bobsleigh competitions (World Cup, World Championship & Olympic Games) that took place during the 2012-2013, 2013-2014 and 2014-2015 seasons were included in this study. However, if a crew either failed to finish a heat or were disqualified at any point during a competition, all their heat runs from the given competition were excluded from the analysis. Therefore, a total of n = 3930 heat runs from 28 2-man, 28 4-man and 27 female (2-women) bobsleigh competitions across 11 different venues were included in the present investigation (see Table 3.2). For 91% of the track venues this included multiple races across multiple seasons. Further information on each track venue can be found in Table 3.3. Ethics approval for the project was gained from Cardiff Metropolitan University's School of Sport ethics committee.

Table 3.2 Major elite bobsleigh competition calendar from the 2012-2013, 2013-2014 and 2014-2015 racing seasons.

Season	2012/2013	2013/2014	2014/2015
World Cup 1	Lake Placid	Calgary	Lake Placid
World Cup 2	Park City	Park City [W]	Calgary
World Cup 3	Whistler	Lake Placid [2M]	Altenberg
World Cup 4	Winterberg	Winterberg [4M]	Königssee
World Cup 5	La Plagne	St. Moritz	St. Moritz
World Cup 6	Altenberg	Igls	La Plagne
World Cup 7	Königssee	Königssee	Igls
World Cup 8	Igls	-	Sochi
World Cup 9	Sochi	-	-
World Championship	St. Moritz	-	Winterberg
Olympic Games	-	Sochi	-

[W] = Double women's race weekend (i.e. two races), [2M] = Double 2-man race weekend (i.e. two races), [4M] = Double 4-man race weekend (i.e. two races).

Table 3.3 Individual track venue characteristics.

Track Venue	Country	Length (m)	Start Altitude (m)	Finish Altitude (m)	Maximum Gradient (%)	Average Gradient (%)	Vertical Drop (m%)	Number of Curves
Igls	Austria	1207	1124	1006	18	9.0	124	14
Königssee	Germany	1251	730	630	N/A	9.0	120	16
Winterberg	Germany	1330	760	665	15	9.0	110	15
Park City	USA	1335	2232	2128	15	8.0	104	15
Altenberg	Germany	1413	785	660	15	8.7	122	17
Whistler	Canada	1450	935	802	20	9	148	16
Lake Placid	USA	1455	N/A	N/A	20	9	128	20
Calgary	Canada	1494	1251	1130	15	8	121	19
Sochi	Russia	1500	836	704	22	20	124	17
La Plagne	France	1507	1684	1559	14	8	124	19
St. Moritz	Switzerland	1722	1852	1738	15	8	130	19

Information obtained from IBSF (2018b) and adapted from Harrison (2017). N/A = not reported.

3.2.2 Data Acquisition

For the present study, data was retrieved from the IBSF's online bobsleigh race result database, which is freely available on their website (IBSF 2018a). This consists of six split times for each heat (including push-start time & finish time), as the IBSF specifies the number of time intervals the race organiser is required to officially report (IBSF 2015; Morlock & Zatsiorsky 1989). The first reported 50 m split time (15 m to 65 m) corresponds to a crew's push-start time, with the remaining five being evenly spread down the rest of the track and concluding with finish time (Bullock, Hopkins, et al. 2009; IBSF 2015; Morlock & Zatsiorsky 1989; Zanoletti et al. 2006). All split times were directly imported into Microsoft Excel via the 'Get Data from Web' feature and organised into a pre-determined format ready for further analysis (Microsoft, USA).

3.2.3 Statistical Analysis

All data is reported as mean (± SD) values and all statistical analysis was undertaken using IBM SPSS statistics (Version 24, SPSS, Chicago, USA). Following the removal of any extreme outliers, normality was confirmed for both push-start time and finish time at all tracks for all formats using either the Shapiro-Wilk (< 50 runs) or Kolmogorov-Smirnov (> 50 runs) normality tests ($p > 0.05$ or skewness & kurtosis between – 2 & + 2). Crews were then split into two distinct sub-groups (top 10 crews & crews finishing outside the top 10) and independent t-tests were used to identify any significant differences between groups. To determine the magnitude of the between sub-group differences, Cohen's effect sizes were calculated using Eq. [3.1] and interpreted using the following thresholds; < 0.20 trivial, ≥ 0.20-0.59 small, ≥ 0.60-1.19 moderate, ≥ 1.20-1.99 large, ≥ 2.00 very large and ≥ 4.00 extremely large (Hopkins 2002; Hopkins et al. 2009).

Cohen's effect size = sub group 1 mean – sub group 2 mean / pooled standard deviation from sub group 1 and sub group 2 [3.1; O'Donoghue (2012)]

Pearson's correlation coefficients were determined for both the entire race field and top 10 crews only, to assess the relationships between push-start time and finish time at each individual venue across the three different bobsleigh formats. The magnitude of these correlation coefficients were interpreted using Hopkins (2002) guidelines; < 0.10 trivial, ≥ 0.10-0.29 small, ≥ 0.30-0.49 moderate, ≥ 0.50-0.69 large, ≥ 0.70-0.89 very large and ≥ 0.90 near perfect. Confidence intervals (CI) (± 90%) were then applied to each of the individual correlation coefficients, to determine if there were any relationship differences when analysis included top 10 crews only. Where there was no overlap in the entire field and top 10 correlation CI's at a given track, the difference was deemed to be "real". Finally, to objectively classify the importance of the push-start at each track for each format, common variances were calculated and categorised for each using the following; < 10% drive dominant track with a small push-start component; 10-49% drive dominant track with a moderate push-start component; 50-89% push-start dominant track with a moderate drive component; ≥ 90% push-start dominant track with a small drive component (see Chapter 2.2.2.2). An alpha value of $p < 0.05$ was set as statistically significant for all analysis.

Following the classification of all the tracks into the categories outlined above, the theoretical influence of changes in push-start time (i.e. 0.01 s improvement) on finish time were determined at all tracks across all formats. To assist with interpretation, typical error of estimate (TEE) were then applied to the theoretical changes in finish time.

3.3 Results

3.3.1 Individual Track Analysis

Table 3.4, 3.5 and 3.6 provide a summary by track of the mean (± SD) push-start and finish times for the entire race field and subgroups, across all bobsleigh formats (2-man, 4-man & female) during Major Championship and World Cup races over three consecutive seasons (2012-2015). Also, presented are any between sub group differences ($p < 0.05$), along with effect sizes for both push-start time and finish time. Moderate to very large differences were detected between top 10 crews and crews finishing outside the top 10 for all tracks and formats, except for push-start time in women's bobsleigh at Calgary (ES = < 0.60).

Moderate to very large relationships ($p < 0.05$) were observed between the push-start and finish time across the different formats and tracks on the elite bobsleigh circuit (2-man r = 0.37 to 0.78; 4-man r = 0.43 to 0.78; female r = 0.34 to 0.80). Figure 3.1 compares the common variances between the push-start and finish time across all tracks for 2-man (a), 4-man (b) and female bobsleigh (c). It can be seen from the Figure that for 2-man and 4-man bobsleigh, four tracks were deemed to be push-start dominant with a moderate drive component and for both formats this included Altenberg and St. Moritz. However, in the female format only Igls and Altenberg were deemed to be push-start dominant tracks with a moderate drive component. Consequently, the remaining 23 out of the 33 analyse tracks and formats were deemed to be drive dominant with a moderate push-start component.

When considering the top 10 crews only, a reduction in the push-start: finish time common variance was observed across all formats for each track, except for the 2-man at Königssee and 4-man at Winterberg. However, when confidence intervals (90 %) were applied to the original correlation coefficients, 16 of the 31 track/format combination changes did not overlap and thus were deemed to be different (see Table 3.7). As shown in Figure 3.1, 18 of the track/format combinations were still deemed to be either push-start dominant or moderately influenced by the push-start (n = 1 & 17 respectively).

Table 3.4 Mean (± SD) by track 2-man push-start times and finish times for the entire field and crew sub-groups across all major championship and World Cup races over three seasons (2012-2013, 2013-2014 & 2014-2015).

	Top 10 Crews		Crews Outside the Top 10		Crew Sub-Group Differences		Entire Field	
Track	Push-Start (s)	Finish Time (s)	Push-Start (s)	Finish Time (s)	Push-Start Effect Size	Finish Time Effect Size	Push-Start (s)	Finish Time (s)
Igls	5.12 (± 0.07)	52.37 (± 0.37)	5.25* (± 0.09)	52.96* (± 0.51)	1.57 L	1.34 L	5.20 (± 0.10)	52.71 (± 0.54)
Königssee	4.92 (± 0.06)	50.55 (± 0.55)	5.02* (± 0.09)	51.22* (± 0.71)	1.35 L	1.07 m	4.98 (± 0.09)	51.00 (± 1.12)
Winterberg	5.19 (± 0.06)	56.21 (± 0.46)	5.31* (± 0.08)	56.81* (± 0.52)	1.81 L	1.21 L	5.26 (± 0.10)	56.58 (± 0.58)
Park City	4.90 (± 0.05)	48.37 (± 0.42)	4.98* (± 0.08)	48.86* (± 0.49)	1.17 m	1.08 m	4.94 (± 0.08)	48.64 (± 0.52)
Altenberg	5.32 (± 0.12)	57.28 (± 0.52)	5.46* (± 0.13)	58.02* (± 0.73)	1.13 L	1.19 L	5.39 (± 0.14)	57.65 (± 0.73)
Whistler	4.83 (± 0.05)	52.90 (± 0.22)	4.92* (± 0.08)	53.64* (± 0.54)	1.46 L	1.93 L	4.88 (± 0.09)	53.31 (± 0.57)
Lake Placid	5.17 (± 0.07)	55.82 (± 0.37)	5.28* (± 0.09)	56.44* (± 0.41)	1.37 L	1.57 L	5.23 (± 0.10)	56.16 (± 0.50)
Calgary	5.15 (± 0.05)	54.89 (± 0.19)	5.24* (± 0.08)	55.43* (± 0.27)	1.48 L	2.31 VL	5.20 (± 0.08)	55.16 (± 0.36)
Sochi	4.89 (± 0.06)	56.76 (± 0.37)	4.97* (± 0.07)	57.51* (± 0.48)	1.26 L	1.78 L	4.94 (± 0.08)	57.19 (± 0.57)

	Top 10 Crews		Crews Outside the Top 10		Crew Sub-Group Differences		Entire Field	
Track	Push-Start (s)	Finish Time (s)	Push-Start (s)	Finish Time (s)	Push-Start Effect Size	Finish Time Effect Size	Push-Start (s)	Finish Time (s)
La Plagne	5.96 (± 0.08)	60.16 (± 0.75)	6.09* (± 0.10)	60.72* (± 0.75)	1.43 ^{L}	0.75 ^{m}	6.03 (± 0.12)	60.49 (± 0.80)
St. Moritz	5.11 (± 0.07)	66.36 (± 0.48)	5.25* (± 0.10)	67.22* (± 0.58)	1.48 ^{L}	1.55 ^{L}	5.20 (± 0.11)	66.89 (± 0.68)

* = statistical difference compared to top 10 crew finishers ($p < 0.05$), ^{m} = moderate difference between top 10 crews and crews outside the top 10 (effect size ≥ 0.60), ^{L} = Large difference between top 10 crews and crews outside the top 10 (effect size ≥ 1.20), ^{VL} = Very large difference between top 10 crews and crews outside the top 10 (effect size ≥ 2.00).

Table 3.5 Mean (± SD) by track 4-man push-start times and finish times for the entire field and crew sub-groups across all major championship and World Cup races over three seasons (2012-2013, 2013-2014 & 2014-2015).

	Top 10 Crews		Crews Outside the Top 10		Crew Sub-Group Differences		Entire Field	
Track	Push-Start (s)	Finish Time (s)	Push-Start (s)	Finish Time (s)	Push-Start Effect Size	Finish Time Effect Size	Push-Start (s)	Finish Time (s)
Igls	5.05 (± 0.05)	51.46 (± 0.34)	5.15* (± 0.07)	51.93* (± 0.42)	1.70 [L]	1.21 [L]	5.11 (± 0.08)	51.72 (± 0.45)
Königssee	4.86 (± 0.05)	49.27 (± 0.23)	4.97* (± 0.09)	49.86* (± 0.34)	1.69 [L]	2.06 [VL]	4.92 (± 0.09)	49.60 (± 0.42)
Winterberg	5.10 (± 0.05)	54.73 (± 0.70)	5.21* (± 0.10)	55.26* (± 0.76)	1.65 [L]	0.73 [m]	5.16 (± 0.10)	55.04 (± 0.78)
Park City	4.83 (± 0.04)	47.95 (± 0.42)	4.93* (± 0.07)	48.32* (± 0.56)	1.72 [L]	0.76 [m]	4.89 (± 0.08)	48.16 (± 0.53)
Altenberg	5.25 (± 0.11)	55.25 (± 0.87)	5.39* (± 0.13)	56.00* (± 1.06)	1.20 [L]	0.78 [m]	5.31 (± 0.13)	55.55 (± 1.01)
Whistler	4.81 (± 0.04)	51.99 (± 0.23)	4.96* (± 0.10)	52.90* (± 0.50)	2.21 [VL]	2.45 [VL]	4.88 (± 0.11)	52.43 (± 0.60)
Lake Placid	5.07 (± 0.05)	55.19 (± 0.33)	5.17* (± 0.08)	55.78* (± 0.36)	1.71 [L]	1.71 [L]	5.12 (± 0.08)	55.46 (± 0.45)
Calgary	5.06 (± 0.04)	54.26 (± 0.24)	5.16* (± 0.06)	54.63* (± 0.29)	1.33 [L]	1.40 [L]	5.12 (± 0.06)	54.43 (± 0.32)
Sochi	4.83 (± 0.05)	55.61 (± 0.49)	4.93* (± 0.07)	56.26* (± 0.56)	1.63 [L]	1.25 [L]	4.89 (± 0.08)	55.98 (± 0.62)

Track	Top 10 Crews		Crews Outside the Top 10		Crew Sub-Group Differences		Entire Field	
	Push-Start (s)	Finish Time (s)	Push-Start (s)	Finish Time (s)	Push-Start Effect Size	Finish Time Effect Size	Push-Start (s)	Finish Time (s)
La Plagne	5.89 (± 0.08)	59.00 (± 0.43)	6.03* (± 0.13)	59.65* (± 0.38)	1.36 [L]	1.61 [L]	5.97 (± 0.13)	59.36 (± 0.51)
St. Moritz	5.04 (± 0.05)	65.26 (± 0.34)	5.16* (± 0.11)	65.99* (± 0.57)	1.44 [L]	1.60 [L]	5.11 (± 0.11)	65.71 (± 0.61)

* = statistical difference compared to top 10 crews (p < 0.05), [m] = moderate difference between top 10 crews and crews outside the top 10 (effect size ≥ 0.60), [L] = Large difference between top 10 crews and crews outside the top 10 (effect size ≥ 1.20), [VL] = Very large difference between top 10 crews and crews outside the top 10 (effect size ≥ 2.00).

Table 3.6 Mean (± SD) by track female push-start times and finish times for the entire field and crew sub-groups across all major championship and World Cup races over three seasons (2012-2013, 2013-2014 & 2014-2015).

	Top 10 Crews		Crews Outside the Top 10		Crew Sub-Group Differences		Entire Field	
Track	Push-Start (s)	Finish Time (s)	Push-Start (s)	Finish Time (s)	Push-Start Effect Size	Finish Time Effect Size	Push-Start (s)	Finish Time (s)
Igls	5.62 (± 0.11)	53.93 (± 0.55)	5.78* (± 0.12)	54.71* (± 0.56)	1.41 ^{L}	1.39 ^{L}	5.69 (± 0.14)	54.29 (± 0.38)
Königssee	5.32 (± 0.08)	51.79 (± 0.54)	5.42* (± 0.08)	52.48* (± 0.38)	1.21 ^{L}	1.48 ^{L}	5.36 (± 0.10)	52.05 (± 0.59)
Winterberg	5.66 (± 0.10)	57.27 (± 0.42)	5.77* (± 0.09)	58.02* (± 0.61)	1.20 ^{L}	1.45 ^{L}	5.71 (± 0.11)	57.62 (± 0.63)
Park City	5.31 (± 0.09)	49.54 (± 0.43)	5.43* (± 0.11)	50.12* (± 0.57)	1.22 ^{L}	1.17 ^{m}	5.37 (± 0.12)	49.81 (± 0.58)
Altenberg	5.90 (± 0.13)	58.50 (± 0.60)	6.09* (± 0.17)	59.46* (± 0.87)	1.25 ^{L}	1.31 ^{L}	5.94 (± 0.16)	58.71 (± 0.77)
Whistler	5.28 (± 0.09)	54.95 (± 0.35)	5.36* (± 0.09)	55.67* (± 0.33)	0.89 ^{m}	2.08 ^{VL}	5.30 (± 0.10)	55.21) (± 0.48)
Lake Placid	5.66 (± 0.11)	57.38 (± 0.46)	5.77* (± 0.09)	58.05* (± 0.46)	1.02 ^{m}	1.44 ^{L}	5.70 (± 0.12)	57.62 (± 0.56)
Calgary	5.67 (± 0.11)	56.74 (± 0.49)	5.71 (± 0.05)	57.31* (± 0.34)	0.45	1.39 ^{L}	5.68 (± 0.10)	56.88 (± 0.52)
Sochi	5.31 (± 0.09)	58.33 (± 0.49)	5.41* (± 0.11)	59.18* (± 0.68)	1.02 ^{m}	1.46 ^{L}	5.35 (± 0.11)	58.68 (± 0.71)

	Top 10 Crews		Crews Outside the Top 10		Crew Sub-Group Differences		Entire Field	
Track	Push-Start (s)	Finish Time (s)	Push-Start (s)	Finish Time (s)	Push-Start Effect Size	Finish Time Effect Size	Push-Start (s)	Finish Time (s)
La Plagne	6.60 (± 0.12)	61.72 (± 0.45)	6.73* (± 0.09)	62.59* (± 0.55)	1.29 ^{L}	1.75 ^{L}	6.65 (± 0.13)	62.09 (± 0.65)
St. Moritz	5.58 (± 0.09)	68.13 (± 0.52)	5.70* (± 0.09)	68.95* (± 0.70)	1.33 ^{L}	1.35 ^{L}	5.64 (± 0.11)	68.53 (± 0.74)

* = statistical difference compared to top 10 crews ($p < 0.05$), ^{m} = moderate difference between top 10 crews and crews outside the Top 10 (effect size ≥ 0.60), ^{L} = Large difference between top 10 crews and crews outside the top 10 finishers (effect size ≥ 1.20), ^{VL} = Very large difference between top 10 crews and crews outside the top 10 (effect size ≥ 2.00).

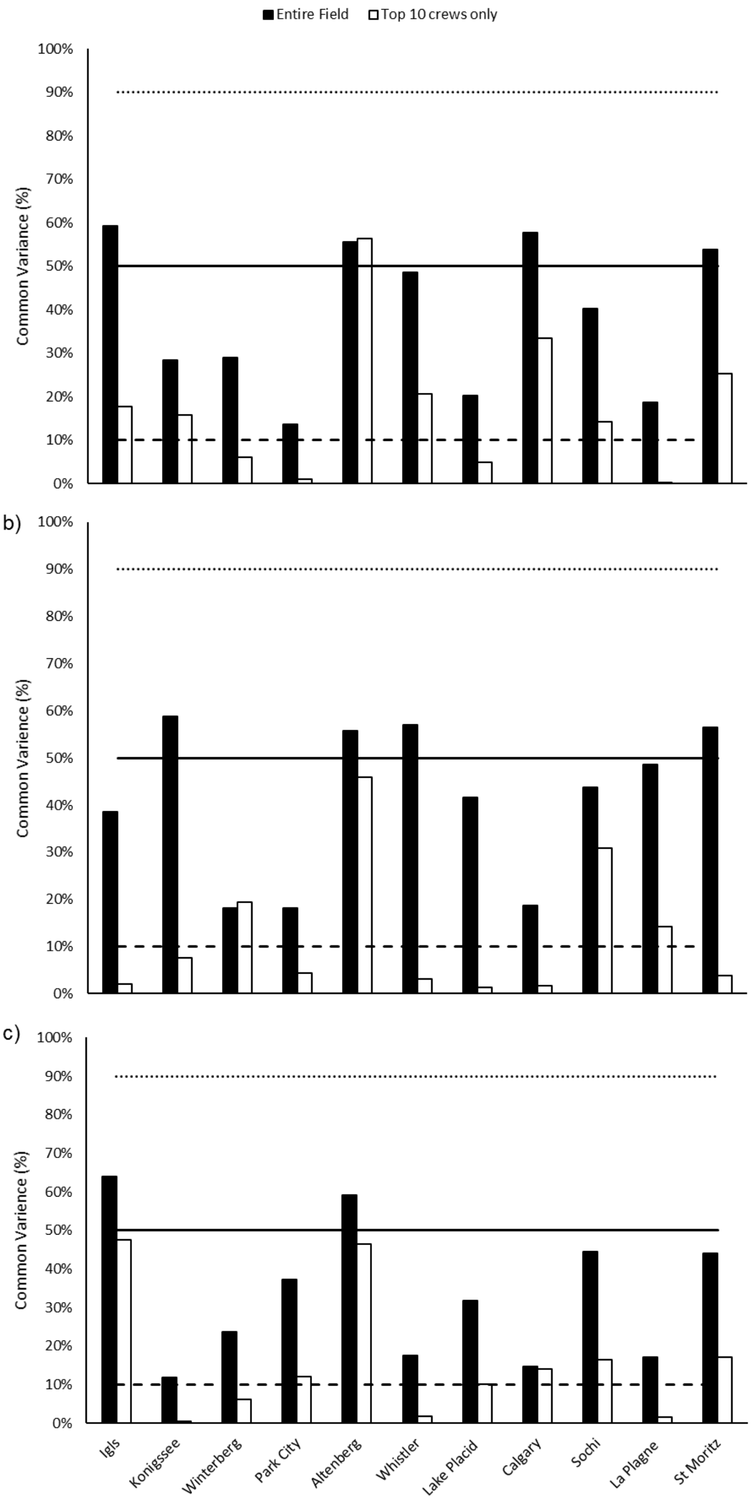

Figure 3.1 Common variance between push-start time and finish time across all Major Championship and World Cup venues between 2012-2015 for all race formats (a = 2-man, b = 4-man, c = female). Below dashed line = drive dominant track with a small push-start component, between dashed and solid line = drive dominant track with a moderate push-start component, between solid and dotted line = push-start dominant track with a moderate drive component, above dotted line = push-start dominant track with a small drive component.

Table 3.7 "Real" differences in correlation coefficients between the entire field and top 10 crew analysis for all tracks and formats.

Track	2-man	4-man	Female
Igls	✓	✓	-
Königssee	-	✓	-
Winterberg	✓	-	-
Park City	-	✓	✓
Altenberg	-	-	-
Whistler	-	✓	-
Lake Placid	✓	✓	-
Calgary	-	-	-
Sochi	✓	-	✓
La Plagne	✓	✓	-
St. Moritz	✓	✓	✓

* ✓ = real difference in correlation coefficient between entire field and top 10 crew only analysis (i.e. real difference = no overlap in correlation coefficient confidence intervals (± 90 %).

3.3.2 Theoretical Influence of Push-Start Time Improvements

Table 3.8 (entire race field) and 3.9 (top 10 crews) displays the theoretical improvements in finish time if a crew improved their push-start time by 0.01 s, using the linear regression models for each format and each track.

Table 3.8 Theoretical influence of a 0.01 s improvement in push-start time on finish time (± TEE) for each format and each track, using the linear regression models from the entire race field.

Track	2-man (s)	4-man (s)	Female (s)
Igls	0.038 ± 0.003	0.035 ± 0.004	0.039 ± 0.004
Königssee	0.041 ± 0.006	0.035 ± 0.003	0.021 ± 0.006
Winterberg	0.033 ± 0.005	0.034 ± 0.007	0.028 ± 0.006
Park City	0.024 ± 0.005	0.030 ± 0.005	0.030 ± 0.005
Altenberg	0.038 ± 0.005	0.057 ± 0.007	0.037 ± 0.005
Whistler	0.046 ± 0.004	0.042 ± 0.004	0.021 ± 0.005
Lake Placid	0.023 ± 0.005	0.035 ± 0.004	0.032 ± 0.004
Calgary	0.034 ± 0.002	0.023 ± 0.003	0.019 ± 0.005
Sochi	0.046 ± 0.004	0.051 ± 0.005	0.044 ± 0.005
La Plagne	0.030 ± 0.007	0.027 ± 0.004	0.022 ± 0.006
St. Moritz	0.044 ± 0.005	0.043 ± 0.004	0.046 ± 0.006

Table 3.9 Theoretical influence of a 0.01 s improvement in push-start time on finish time (± TEE) for each format and each track, using the linear regression models from the top 10 crews.

Track	2-man (s)	4-man (s)	Female (s)
Igls	0.022 ± 0.003	0.009 ± 0.003	0.035 ± 0.004
Königssee	0.038 ± 0.005	0.014 ± 0.002	0.004 ± 0.006
Winterberg	0.009 ± 0.005	0.063 ± 0.006	0.010 ± 0.004
Park City	0.007 ± 0.004	+ 0.024 ± 0.004	0.017 ± 0.004
Altenberg	0.032 ± 0.004	0.055 ± 0.006	0.031 ± 0.005
Whistler	0.021 ± 0.002	+ 0.010 ± 0.002	+ 0.005 ± 0.004
Lake Placid	+ 0.012 ± 0.004	0.008 ± 0.003	0.019 ± 0.004
Calgary	0.021 ± 0.002	0.007 ± 0.002	0.016 ± 0.005
Sochi	0.022 ± 0.003	0.059 ± 0.004	0.022 ± 0.005
La Plagne	0.001 ± 0.008	0.020 ± 0.004	0.005 ± 0.005
St. Moritz	0.036 ± 0.004	0.013 ± 0.003	0.024 ± 0.005

+ = a theoretical increase in finish time.

When considering the entire race field, Altenberg was the only track on the elite circuit to be considered push-start dominant across all race formats. Additionally, when analysing just the top 10 crews, no “real” correlation coefficient changes (90 % CI) were detected for either 2-man (r = 0.75, CI 0.64 to 0.82; Top 10 r = 0.74, CI 0.61 to 0.85), 4-man (r = 0.75, CI 0.64 to 0.82; Top 10 r = 0.68, CI 0.50 to 0.80) or female bobsleigh (r = 0.77, CI 0.65 to 0.85; Top 10 r = 0.68, CI 0.51 to 0.80). Figure 3.2 displays the results obtained from the push-start: finish time linear regression analysis for both the entire field (a) and top 10 crews (b) at Altenberg. Based on Table 3.8 and Figure 3.2a, when considering the entire race field, the presented linear regression predicts that if a crew was to improve their push-start time by 0.01 s this could translate into a 0.037 s to 0.057 s improvement in finish time, depending on the race format (TEE = 0.005 to 0.007). Likewise, when analysis only includes the top 10 crews, Table 3.9 and Figure 3.2b suggests that a 0.01 s improvement in the push-start could result in a 0.031 s (2-man), 0.055 s (4-man) or 0.031 s (female) improvement in finish time.

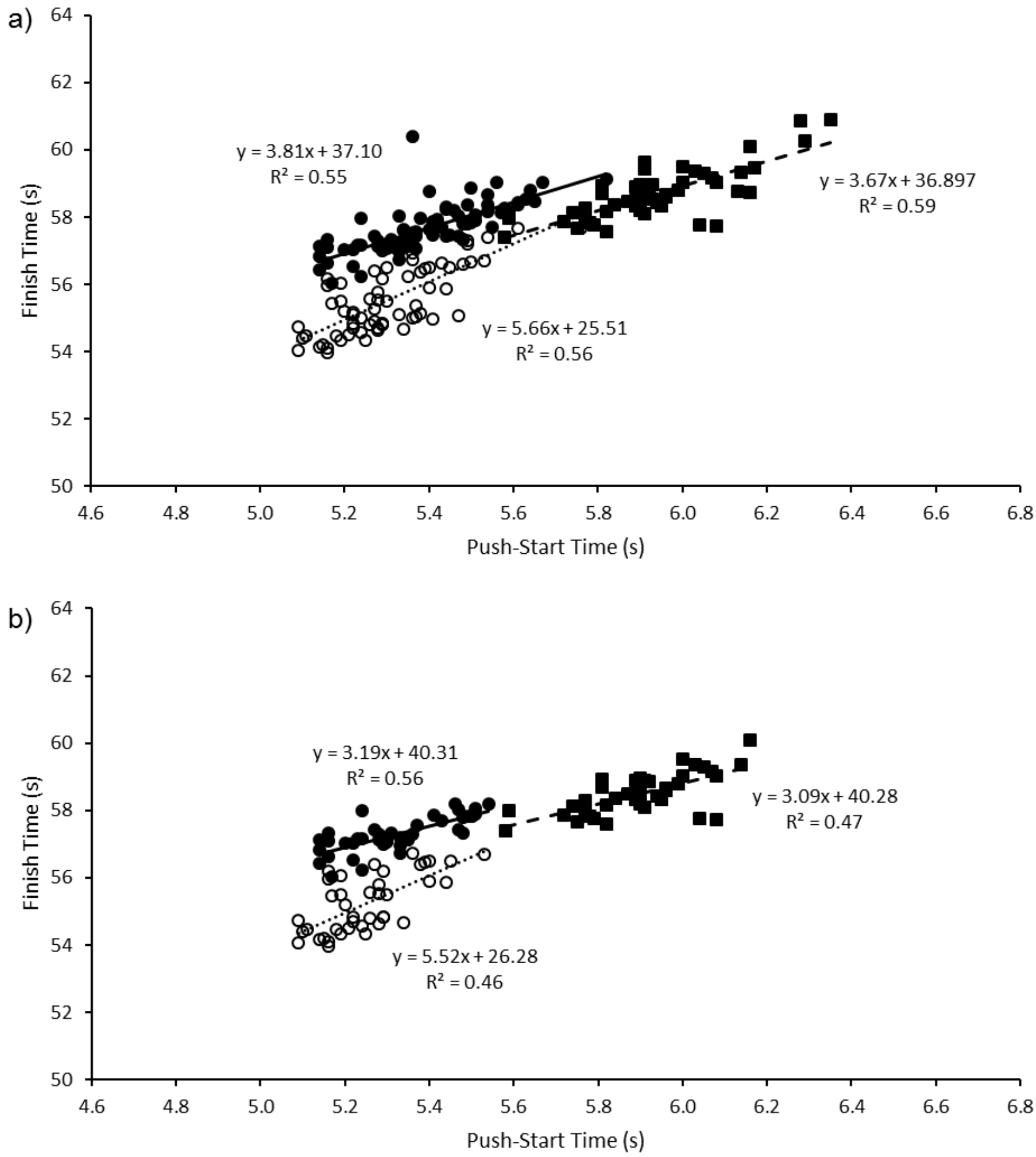

Figure 3.2 Relationship between push-start time (s) and finish time for both the entire field (a) and top 10 crew only (b) at Altenberg. Black circles and solid line = 2-man, white circles and dotted line = 4-man and black squares and dashed line = female.

3.4 Discussion

3.4.1 Key Findings

Push-start performance was shown to have a moderate to very large relationship with finish time and thus its relative importance is track dependent. While few tracks were characterised as being push-start dominant, most tracks and formats were moderately influenced by the push-start. When considering the top 10 crews only, in most cases moderate to large push-start and finish time differences were detected with the rest of the race field. Also, a "real" reduction in the push-start: finish time correlation coefficient was observed across 16 of the track/format combinations, when analysis included the top 10 crews only. However, more than half of the tracks/formats were still moderately influenced by the push-start or deemed to be push-start dominant. Finally, a 0.01 s improvement in push-start time could translate in to a 0.019 to 0.057 s improvement in finish time, depending on race format (i.e. 2-man, 4-man or female) and the specific track. However, the magnitude of this finish time improvement was shown to be reduced amongst the top 10 crews across most tracks.

3.4.2 Push-Start Performance

The mean values presented in Tables 3.4, 3.5 and 3.6 demonstrate clear differences in both push-start time and finish time across the different race tracks on the elite bobsleigh circuit, varying by as much as 21 to 23 % and 31 to 32 % respectively from one track to another. This highlights the need to consider each race track individually, as collating the data into one analysis will have a large influence on the observed outcome. In line with previous observations in bobsleigh, the strength of the push-start: finish time relationship (moderate to very large) varied across the different tracks for each format (Brüggemann et al. 1997; Fedotova & Pilipiva 2011; Harrison 2017; Morlock & Zatsiorsky 1989; Smith et al. 2006). This inconsistency in relationship strength between tracks could be attributed to variances in the technical difficulty of each track, which as highlighted by Bullock, Hopkins, et al. (2009) is a result of factors such as track gradient, curve nature and ice cut (see Table 3.3). Thus, the present study suggests that the importance of the push-start is track dependent for all three formats.

While few tracks were classified as push-start dominant, most of the tracks and formats were moderately influenced by the push-start. These initial observations should be viewed with caution, as moderate to large differences were observed in push-start and finish time between crews finishing in and outside of the top 10, except for the female push-start at Calgary. Subsequently, a reduced push-start: finish time relationship was detected for approximately half of the tracks and formats when analysis included top 10 crews only. These findings further substantiate earlier conclusions in the literature that a fast push-start time is a prerequisite for successful performance in bobsleigh, however at the top end of elite races it represents less importance when determining final race ranking (Brüggemann et al. 1997). Nevertheless, it is important to acknowledge that even when just considering the top 10 crews, more than half of the tracks/format combinations (18 out of 33) were still shown to be moderately influenced by the push-start or push-start dominant. These findings discussed so far suggest that the push-start is an important aspect of performance in elite-level bobsleigh, however other factors (for example, the quality of the drive phase) may have a moderate to large influence on performance, contributing up to 88 % depending on the track when considering the entire race field.

3.4.3 Theoretical Influence of Push-Start Time Improvements

Given that ultimately the goal in bobsleigh is to improve finish time, based on the linear regression models presented above, a 0.01 s push-start improvement could translate to a 0.023 to 0.046 s (2-man), 0.023 to 0.057 s (4-man) or 0.019 to 0.056 s (female) improvement in finish time, depending on the specific track (see Table 3.8). For example, these theoretical improvements could be practically significant, as they suggest that if the British Bobsleigh 4-man crew competing at the 2014 Sochi Winter Olympic Games had improved their push-start time by 0.01 s on each run, they would have improved their overall finish time by 0.204 s and won a bronze medal instead of their 5th place finish (IBSF 2018a). These findings, while preliminary provide some support for the belief of coaches and athletes in bobsleigh surrounding the transfer of push-start improvements into changes in finish time (i.e. 0.01 s improvement at the top, results in a 0.03 s improvement at the bottom). However, it appears that the magnitude of these changes is track specific and a standard push-start: finish time transfer improvement value cannot be applied across all tracks. Additionally, when analysis only included the top 10 crews, the magnitude of the theoretical finish time improvement reduced in most cases (see Table 3.8 and 3.9). This finding provides further support for the fact that at the top end of elite bobsleigh races, the push-start represents less importance when determining final race ranking.

Of all the tracks included in this study, Altenberg was the only venue to be categorised as push-start dominant across 2-man, 4-man and female bobsleigh (see Figure 3.1). Also, no "real" correlation coefficient magnitude changes were detected when analysis only included the top 10 crews. At Altenberg, the regression model suggests that a 0.01 s push-start improvement could translate into a 0.037 to 0.055 s improvement in finish time (see Figure 3.2). In contrast to most tracks, the magnitude of these theoretical improvements is consistent for the entire field and the top 10 crew analysis, with the latter suggesting that finish time improvements could range from 0.031 to 0.055 s. Given the small TEE reported above (≤ 0.007), it could be speculated that these finish time changes are meaningful, because of the small margins between crews in elite-level races. For example, at the most recent 4-man Altenberg World Cup the top 3 crews were separated by just 0.12 s over two heats (IBSF 2018a). Nevertheless, these speculations should be interpreted with caution due to the fact that previous skeleton literature has failed to detect a correlation between percentage change in both push-start time and finish time across two heats (Zanoletti et al. 2006).

3.4.4 Limitations

The main limitation of this study is the fact it was unable to account for changes in environmental conditions between different heats, races and venues, for example ice temperature. This was beyond the scope of the present investigation, as the IBSF do not report environmental condition data on its online result database (IBSF 2018a). Nevertheless, the current dataset did include races from multiple seasons for 91 % of tracks analysed, which would help to minimise the influence of any extreme weather conditions. Secondly, critics could highlight the fact that the current investigation only included push-start time and thus did not consider the influence of any velocity measurements, which are arguably more reflective of the entire push-start phase (e.g. sled acceleration and loading). However, the method used to determine push-start velocity varies from track to track (Harrison 2017), making between-track comparisons for this metric problematic and thus should be avoided.

3.4.5 Practical Applications

The results of this study indicate that there are varying demands at the different tracks on the elite bobsleigh circuit for each format. However, the findings indicate that for all formats at most tracks the push-start can be considered to have a moderate or large influence on finish time. Nevertheless, at the top end of elite races (e.g. Top 10), a fast push-start time represents less importance when determining overall race ranking and thus it should be considered a pre-requisite for successful performance at this level. At tracks deemed to be push-start dominant (e.g. Altenberg) a 0.01 s improvement at the top of the track could translate into finish time improvements of up to 0.055 s, albeit format dependent. Therefore, the push-start should be identified as a target area for performance enhancement in the sport. However, practitioners should not ignore the influence of other factors such as driver skill, as they still have a large bearing on finish time and race outcome in bobsleigh. In the build-up to a major championship when planning the focus of training, practitioners should consider the specific demands of the track venue and how influential the push-start is on overall performance.

3.4.6 Conclusions

In agreement with the aim of this study, the author examined the relationship between the push-start and finish time across elite bobsleigh competitions for the 2-man, 4-man and female event formats, across multiple tracks and over multiple on-ice seasons. The present investigation established the following key outcomes:

1. The importance of push-start performance in elite bobsleigh across all formats is track dependent.
2. More than half of the format/track combinations on the elite bobsleigh circuit are moderately influenced by the push-start or push-start dominant, even when considering the top 10 crews only.
3. A 0.01 s improvement in push-start time could translate to a finish time improvement between 0.019 to 0.057 s, depending on race format and track. However, in most cases the magnitude of this improvement is reduced amongst the top 10 crews.

Chapter 4

STUDY 2: Validation of the British Bobsleigh 'Evaluation Test'

4.1 Introduction

4.1.1 Preface

Chapter 3 of this thesis has confirmed the importance of the push-start in elite bobsleigh by identifying most tracks on the elite circuit to either be push-start dominant or moderately influenced by the push-start. Hence, it is important to identify factors that contribute to predict push-start performance. British Bobsleigh use a field-based testing battery, named the 'evaluation test' to aid talent identification as well as for athlete monitoring and selection. It is used based on the belief of coaches that a high-test score is related to a fast push-start. The 'evaluation test' battery includes a 60m sprint, a 5-RBJ and four x 40 m roll-bob pushes completed with different weighted sleds. Despite this, no scientific evidence has attempted to validate the British Bobsleigh 'evaluation test' as a means of predicting push-start performance. Hence, further research is required to explore the predictive validity of the testing approach used by British Bobsleigh.

4.1.2 Field-based Performance Testing in Bobsleigh

Despite the publicised use of field based performance testing in bobsleigh, not only by the British team, but other nations such as America and Canada (4 and 1 medal/s respectively at the 2014 Winter Olympic Games) (Bobsleigh Canada 2015; British Bobsleigh 2014a; Harrison 2017; IBSF 2018a; Osbeck et al. 1996; USBSF 2015), it is very surprising that only a handful of scientific papers have looked to explore the ability of various performance tests to predict the push-start in both bobsleigh and skeleton (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Harrison 2017; Osbeck et al. 1996; Sands et al. 2005). As previously highlighted in Chapter 2, the application of skeleton based research across to bobsleigh should be viewed with caution, due to differences in sled load and push-start running mechanics (skeleton ≤ 33kg and crouched;

bobsleigh ≥ 160kg and upright respectively) (BBSA 2018b; IBSF 2015). Therefore, this chapter will now only summarise the bobsleigh literature, for a full review of performance testing in skeleton refer to literature review section 2.5.4.

To the authors knowledge only two studies have attempted to validate the use of field-based performance tests as a means of predicting bobsleigh push-start performance (Harrison 2017; Osbeck et al. 1996). Both the works of Harrison (2017) and Osbeck et al. (1996) have assessed slight variations of a 6-item field-based test battery utilised by the USBSF;

- SLJ, underhand shot toss and 15 m, 30 m, 45 m sprint time and 30 m flying sprint time (Harrison 2017).
- 5-RBJ, underhand shot toss, vertical jump and 30 m, 60 m and 100 m sprint time (Osbeck et al. 1996).

The evidence presented has supported the use of the USBSF 6-item test battery by demonstrating large to very large relationships between overall test score and the push-start (r = -0.51 to -0.83). Additional multiple regression analysis by Osbeck et al. (1996) highlighted 30 m sprint time (r = 0.85 to 0.88) and CMJ performance (r = -0.54 to -0.58) as the most valuable tools for predicting performance. In fact the research group concluded their work by suggesting that the removal of the 5-RBJ, 60 m sprint and 100 m sprint tests would not negatively impact the USBSF's battery validity (Osbeck et al. 1996). Harrison (2017) also acknowledged the importance of sprint speed for the push-start, but in fact due to additional analysis using the back squat and power clean, the work determined these absolute strength and power measures to offer greater push-start predictive ability. Subsequently, the current bobsleigh literature has identified sprint acceleration, explosive power and absolute strength/power as important qualities for the bobsleigh push-start (Harrison 2017; Osbeck et al. 1996).

For a full review on the limitations of the work mentioned above refer to literature review section 2.5.3. One major criticism of the literature to date is that it is very specific to the testing approaches utilised by the USBSF and thus generalisation of these findings across to the British Bobsleigh 'evaluation test' is somewhat problematic. This is largely a result of the ‘evaluation test’ including 4 x roll-bob pushes, which constitutes two-thirds of the testing battery. A roll-bob is a 42kg framed apparatus on wheels designed to mimic an actual bobsleigh (British Bobsleigh 2014b). To the authors knowledge, there is no scientific literature that has attempted to validate the roll-bob push used by British Bobsleigh as a means of predicting push-start performance.

4.1.3 Rationale

The limited existing evidence suggests that the use of field-based performance test batteries maybe useful when trying to predict an athletes push-start capabilities (Harrison 2017; Osbeck et al. 1996). However, the research to date has focused solely on the 6-item test battery utilised by the USBSF. Therefore, the predictive validity of the ‘evaluation test’ used by British Bobsleigh for talent identification, monitoring and selection purposes has yet to be explored. Establishing this test battery’s validity is important given that it does not include an identical set of tests to that used by the USBSF. For example, the British Bobsleigh battery does not include the CMJ, which was identified by Osbeck et al. (1996) as one of the most valuable tests to use when attempting to predict push-start performance. Also, little is known about how well the roll-bob push relates to the push-start, which is of interest given it constitutes two-thirds of the British Bobsleigh ‘evaluation test’.

4.1.4 Aims

The aim of this study was to investigate the validity of the ‘evaluation test’ used by British Bobsleigh to predict push-start performance, as well as assess the individual performance qualities that contribute to the bobsleigh push-start.

4.2 Method

4.2.1 Athletes

Data was collected from 61 (36 male & 25 female) bobsleigh athletes who attended British Bobsleigh's autumn selection trials in 2012, 2013 or 2014. All athletes were part of either British Bobsleigh's WCP or ND squad (see Chapter 1.3). A sample size of 61 was considered sufficient and is almost 3-fold larger than that used in the works of Osbeck et al. (1996). The mean (±SD) body masses of the athletes were; males 92.6 ± 11.8 kg and females 69.2 ± 8.5 kg. Cardiff Metropolitan University's School of Sport ethics committee granted the project ethics approval. Retrospective written informed consent for use of the data was provided by the Performance Director of British Bobsleigh.

4.2.2 Experimental Design Overview

All selection testing took place in either August or September of the given year and was hosted at the outdoor push-track and indoor athletics track facilities located at the British Bobsleigh National Training Centre. Athletes were required to attend two testing sessions scheduled on consecutive weekends. In session one, athletes completed the British Bobsleigh 'evaluation test' and in session two they undertook push-testing on the outdoor push-track (see Methods 4.2.4). The latter is considered by British Bobsleigh coaches as the gold standard measure of an athlete's push-start ability, given that the test and track have been designed to replicate the start demands and profile of an actual on-ice bobsleigh run (Osbeck et al. 1996). In terms of familiarisation, all athletes had previously completed at least one full 'evaluation test' and one training session on the outdoor push-track. Prior to the beginning of testing and data collection, all athletes had a one hour warm up period in which to complete their own individualised warm up plan. Athletes were told to ensure by the end of this period they were physically ready to achieve maximal performance during testing. Prior to the warm up in session one, body mass was measured using digital scales (SECA-Model 770, Vogel & Halke, Hamburg, Germany). Athletes were given no formal pre-test instructions to follow; however, they were all aware that they had to arrive at the sessions in optimal physical condition to maximise their chances of gaining funding and selection for the coming season (for example, staying well hydrated & avoiding strenuous exercise 24 hours prior to testing). Throughout the testing sessions, British Bobsleigh support staff and other athletes provided all athletes with verbal encouragement.

4.2.3 British Bobsleigh 'Evaluation Test'

The 'evaluation test' measures three different aspects of athletic performance (sprinting, pushing & jumping) and consists of a 60 m sprint, four x 40 m roll-bob pushes and a 5-RBJ (British Bobsleigh 2014b; British Bobsleigh 2014a). Similar to the USA's 6-item battery, each individual test score is assigned a points value (Osbeck et al. 1996), in this instance up to a maximum of 200, with each single point equating to 0.01 s or 0.05 m in sprints/pushes and jumps respectively. Table 4.1 highlights the performances required of both male and female athletes to achieve the maximum of 200 points on any of the individual tests. To determine each athlete's 'evaluation test' total points, scores from each of the six tests are added together (maximum of 1200), therefore the roll-bob push tests account for two-thirds (4 out of 6 tests) of an athlete's points score. During the 2014 selection process British Bobsleigh set a minimum criterion score of 800 (males) and 850 (females) points to be considered for UK Sport funding.

Table 4.1 Performances required of male and female athletes to score 200 points on the individual tests included within the British Bobsleigh 'evaluation test'.

Test Parameter	Male	Female
60 m Sprint (s)	5.95	6.75
Light Back Roll-bob Push (s)	3.30	4.00
Light Side Roll-bob Push (s)	3.30	4.00
Heavy Back Roll-bob Push (s)	3.50	4.30
Heavy Side Roll-bob Push (s)	3.50	4.30
5-RBJ (m)	20.00	17.00

Light roll-bob push = roll-bob push with an additional load of 20kg, heavy roll-bob push = roll-bob push with an additional load of 50kg (males) or 45kg (females) & 5-RBJ = 5 repeated-bound jump.

4.2.3.1 60 m sprint

Athletes were given a one meter start box in which their front foot had to be placed and the initial movement had to be forward otherwise the attempt was discounted (British Bobsleigh 2014b). Each athlete completed two sprint trials and a minimum recovery period of five minutes was allocated between attempts. Timing gates (Brower Timing System, Brower, Draper, Utah) were used to measure each participants 0 to 60 m split time, with the best attempt of the two being used to allocate their point's score for the sprint (see Table 4.1). Although points were allocated based upon an athlete's 0 to 60 m split time, timing gates were also placed at 30 m (to assist the coaches with training monitoring and prescription), which allowed the collection of two additional split times; 0 to 30 m and 30 to 60 m (flying sprint time). Subsequently, these two times have been included in the analysis. Several studies using either elite skeleton or experienced track and field athletes have confirmed reliability for sprint time measurements up to 60 m (intraclass correlation coefficient (ICC) = 0.94 to 0.99) (Fletcher & Anness 2007; Kistler et al. 2010; Sands et al. 2005).

4.2.3.2 Roll-Bob Push Test

All athletes completed four pushes over 40 m, with a minimum recovery period of five minutes between each attempt. Pushes were completed on the indoor athletics track and athletes were required to self-steer the roll-bob, as there is no guide to keep the apparatus straight. Each individual roll-bob push was taken using a different set-up of the apparatus; pushes were either taken from the back or side handle and with a light (20 kg for both males & females) or heavy (50 kg for males & 45 kg for females) additional load. Therefore, the four roll-bob pushes were named as follows; light back roll-bob push, light side roll-bob push, heavy back roll-bob push, heavy side roll-bob push. The handle that each athlete pushed from first (back or side) was dictated by the running order (alphabetical) as the roll-bob set ups were alternated to maximise the efficiency of the testing session. However, all light pushes were completed prior to any heavy push attempts. Each athlete's time was measured using timing gates (Brower Timing System, Brower, Draper, Utah) placed at 10 m and 40 m, with this split (10 to 40 m) being used to allocate an individual's points for each of the roll-bob tests (see Table 4.1). To the authors knowledge, the roll-bob push test is a novel test, and its reliability has yet to be determined by British Bobsleigh or within the academic literature. Therefore, the author undertook a pilot study to assess the reliability of each separate roll-bob push test across three separate trials (see Methods 4.2.5 & Results 4.3.1).

4.2.3.3 5-Repeated Bound Jump

Athletes completed 5 successive plyometric bounds from a wood block start using a two-footed contact technique. Jump distance was measured using a tape measure (SECA-Model 201, Vogel & Halke, Hamburg, Germany) and was taken from the end of the starting block to the heel mark made in the sand by the athlete on completion of the fifth hop. In agreement with Osbeck et al. (1996), athletes were encouraged to ensure the time between hops was as short as possible in order to maximise performance. Each athlete was allowed a maximum of 5 attempts and they were given a 5-minute recovery period between jumps. The jump attempt where the greatest distance was achieved was recorded and this used to allocate an individual's points score (see Table 4.1). To the authors' knowledge the reliability of the 5-RBJ has not been determined on athletes within a sport comparable to bobsleigh. However, a number of studies have assessed the jump's reliability utilising either experienced or elite athletes, reporting intraclass correlation coefficients between 0.91 to 0.94 (Chamari et al. 2008; Slattery et al. 2006).

4.2.4 Push-Start Testing

Push-start testing took place on the purpose-built outdoor push-track at the British Bobsleigh National Training Centre. As outlined in the works of Osbeck et al. (1996), the track facility (~65 m long) comprises of a wheeled bobsled apparatus which is fixed to the course via a metal rail. The final section of the track includes a steep incline to assist in the process of slowing and stopping the sled (Osbeck et al. 1996). The push-start procedure used during British Bobsleigh's selection trials was in accordance with that described by Osbeck et al. (1996) and took place as follows; firstly, an individual push attempt commenced with the athlete in a braced position with their feet placed on the wood start block. They were then given a clear verbal command of "go", on which they push the sled as fast as possible down the push-track before boarding it at ~40 m. A cut off marker was placed at 50 m, at which the athlete must be in the sled or the attempt was discounted and thus not recorded. Push-start time was measured over a 40 m section (15 m to 55 m) of the track using an electronic timing system (developed in house by Sheffield Hallam University, UK) installed within the walls of the push-track. Male and female athletes (tested on separate days of the push testing weekend; males on Saturday & females on Sunday) were required to complete six and four pushes respectively, with a minimum recovery period of 10 minutes between each individual push attempt (British Bobsleigh 2014c). Unlike the female athletes who took all four pushes from the brake-women handle, males were required to take two pushes from each test handle (left, right & brake-men). However, to make gender comparisons easier and to maximise the study's' sample size, only the push from the brake-men handle where each athlete achieved their fastest 15 m to 55 m split time was taken forward for analysis.

4.2.5 Roll-bob Push Test Reliability (Pilot Study)

The reliability of each roll-bob push test was assessed using data collected from three of British Bobsleigh's 2014 squad testing events; May (baseline), July (mid-preseason) and September (selection). Data from 12 (6 male & 6 female) national-level bobsleigh athletes was used in the study. The mean characteristics of the sample groups were as follows; males age 23 ± 3 years and body mass 95.4 ± 7.4 kg and females age 22 ± 4 years and body mass 71.3 ± 3.5 kg. Pushes were completed as part of British Bobsleigh's 'evaluation test' and this took place in the format outlined above (see Methods 4.2.3.2).

4.2.6 Statistical Analysis

All data is presented as mean (±SD) values and all statistical analysis was completed using IBM SPSS statistics (Version 20, SPSS, Chicago, USA). Although British Bobsleigh uses raw data (not transformed) when interpreting scores, normality of all variables collected during the study was assessed using the Shapiro-Wilk Normality Test and confirmed for both male and female athletes ($p > 0.05$ or Skewness < 2).

In order to determine reliability, raw data was log-transformed in a previously developed and formatted spreadsheet to allow typical error (TE), ICC and coefficient of variation (CV) values to be calculated (Hopkins 2000). In line with suggestions from the literature, the following ICC and CV reliability thresholds were set; ICC > 0.75 & CV ≤ 10% = acceptable reliability and ICC > 0.90 = high reliability (Atkinson & Nevill 1998; Stålbom et al. 2007). Also, Cohen's effect sizes (for thresholds see below) were calculated to determine the magnitude of any between trial differences and a paired sample t-test was undertaken to assess if any of these differences were statistically significant.

Independent t-tests were used to determine any statistical differences between the male and female sample groups on the push-start, as well as all the variables measured during the 'evaluation test'. The magnitude of any between-sex differences were assessed using Cohen's effect sizes and these were interpreted using the following thresholds; < 0.20 trivial, ≥ 0.20-0.59 small, ≥ 0.60-1.19 moderate, ≥ 1.20-1.99 large, ≥ 2.00 very large and ≥ 4.00 extremely large (Hopkins 2002; Hopkins et al. 2009).

Linear regression and Pearson's correlation coefficients were determined between push-start times on the outdoor track and individual tests included within the 'evaluation test', along with the accumulative scores. Also, an inter-correlation analysis was undertaken to assess the relationships between the general performance tests (body mass, sprinting & jumping) within the 'evaluation test', as well as the various roll-bob push tests. The strength of any correlations observed were classified based upon previously suggested coefficient threshold values outlined within the literature; < 0.10 = trivial, 0.10-0.29 = small, 0.30-0.49 = moderate, 0.50-0.69 = large, 0.70-0.89 = very large and ≥ 0.9 = near perfect (Hopkins 2002). Finally, a stepwise multiple regression analysis was completed for the push-start using the general performance test results (body mass, 30m sprint, 30m flying sprint, 60m sprint & 5-RBJ). 95 % limits of agreement (LoA) were calculated as the group mean difference between actual and predicted time multiplied by 1.96 of the mean difference standard deviation.

An alpha value of $p < 0.05$ was set as statistically significant for all analysis.

4.3 Results

4.3.1 Roll-Bob Push Test Reliability (Pilot Study)

Tables 4.2 and 4.3 displays the mean (±SD) times for all four of the roll-bob push tests (measured using three separate trials), along with the between trial ICC, TE and CV values for both male (a) and female (b) athletes. Although in several cases differences were detected between trials ($p < 0.05$), these were all small to moderate in magnitude (ES = 0.53 to 1.17). All roll-bob push tests were deemed to represent acceptable reliability for male and female athletes, with CV values < 10%. Also, in 14 out of 16 cases the ICC values were ≥ 0.70.

Table 4.2 Mean (±SD) times for all roll-bob push tests and between trial ICC, TE and CV values for male athletes (n = 6).

Roll-bob Push Test	Mean (± SD)			Trial 1 to 2			Trial 2 to 3		
	Trial 1	Trial 2	Trial 3	ICC	TE	CV (%)	ICC	TE	CV (%)
Light Back Roll-Bob Push (s)	4.03 (± 0.10)	3.98 (± 0.07)	4.00 (± 0.10)	0.49	1.28	1.7	0.75	0.78	1.4
Light Side Roll-bob Push (s)	4.10 (± 0.11)	4.05 (± 0.07)	4.05 (± 0.08)	0.76	0.76	1.4	0.56	1.13	1.5
Heavy Back Roll-bob Push (s)	4.24 (± 0.17)	4.22 (± 0.09)	4.25 (± 0.14)	0.83	0.63	1.7	0.85	0.59	1.5
Heavy Side Roll-bob Push (s)	4.40 (± 0.12)	4.29* (± 0.09)	4.25 (± 0.13)	0.87	0.56	1.2	0.83	0.63	1.4

* = Difference compared to previous trial ($p < 0.05$), ICC = intraclass correlation coefficients, TE = typical error & CV = coefficient of variation.

Table 4.3 Mean (±SD) times for all roll-bob push tests and between trial ICC, TE and CV values for female athletes (n = 6).

Roll-bob Push Test	Mean (± SD)			Trial 1 to 2			Trial 2 to 3		
	Trial 1	Trial 2	Trial 3	ICC	TE	CV (%)	ICC	TE	CV (%)
Light Back Roll-Bob Push (s)	4.66 (± 0.14)	4.53* (± 0.14)	4.60 (± 0.12)	0.98	0.25	0.7	0.93	0.42	1.1
Light Side Roll-bob Push (s)	4.77 (± 0.11)	4.63* (± 0.13)	4.70 (± 0.14)	0.91	0.48	1.1	0.93	0.41	1.1
Heavy Back Roll-bob Push (s)	4.91 (± 0.16)	4.83* (± 0.13)	4.91* (± 0.15)	0.99	0.25	0.7	0.95	0.37	1.0
Heavy Side Roll-bob Push (s)	5.08 (± 0.12)	4.94* (± 0.14)	4.97 (± 0.17)	0.89	0.52	1.2	0.93	0.41	1.2

* = Difference compared to previous trial ($p < 0.05$), ICC = intraclass correlation coefficients, TE = typical error & CV = coefficient of variation.

4.3.2 'Evaluation Test'

The mean (±SD) results for the 'evaluation test' and push-start test for both males and females are presented below (see Table 4.4). Of those athletes included within the study, 8 males and 7 females achieved the minimum 'evaluation test' points score to be considered for UK Sport funding (800 & 850 respectively). In contrast to all other variables presented in Table 4.4, not all athletes performed a push-start, consequently the sample sizes of athletes who completed this test were n = 25 males and 10 females. A very large difference ($p < 0.05$ & ES ≥ 2.0) was observed between males and females across all variables, except for 'evaluation test' total points.

Table 4.4 Mean (±SD) results for the 'evaluation test' and the push-start test for both male (n = 35) and female (n = 25) athletes.

Test Parameter	Male	Female
Body Mass (kg)	92.6 (±11.8)	69.2* ^{VL} (±8.5)
30 m Sprint (s)	3.79 (±0.15)	4.12* ^{VL} (±0.14)
30 m Flying Sprint (s)	3.10 (±0.17)	3.46* ^{VL} (±0.19)
60 m Sprint (s)	6.89 (±0.32)	7.58* ^{VL} (±0.33)
5-RBJ (m)	15.76 (±1.33)	13.00* ^{VL} (±1.02)
Light Back Roll-bob Push (s)	4.07 (±0.23)	4.65* ^{VL} (±0.18)
Light Side Roll-bob Push(s)	4.10 (±0.21)	4.70* ^{VL} (±0.18)
Heavy Back Roll-bob Push (s)	4.30 (±0.25)	4.95* ^{VL} (±0.22)
Heavy Side Roll-bob Push (s)	4.33 (±0.24)	4.98* ^{VL} (±0.22)
'Evaluation Test' Total Points	701 (±139)	769 (±120)
Push-Start Time (s)	4.60 (±0.17) ^{25}	4.95* ^{VL} (±0.15) ^{10}

*= Difference from male sample group ($p < 0.05$), ^{VL} = very large from male sample group (effect size ≥ 2.0), ^{25} = 25 athlete sample only & ^{10} = 10 athlete sample only.

As shown in Figure 4.1, a negative correlation (p < 0.05) was observed between 'evaluation test' total points and push-start performances for both males (r = -0.97) and females (r = -0.94). Consequently, 93% (male) and 89% (female) of the variance in the push-start could be explained by an athlete's 'evaluation test' total points. From Figure 4.1, four males performed considerably worse (< 450 points and represented by black squares) than the rest of the male sample group (> 600 points) and could be causing an inflated correlation coefficient value. Subsequently, when they were removed from the analysis the resultant r value reduced to -0.86 (p < 0.05; 74% common variance). For the remainder of the study the male sample group who scored > 600 points on the 'evaluation test' will be referred to as sub-group 1 (n = 21).

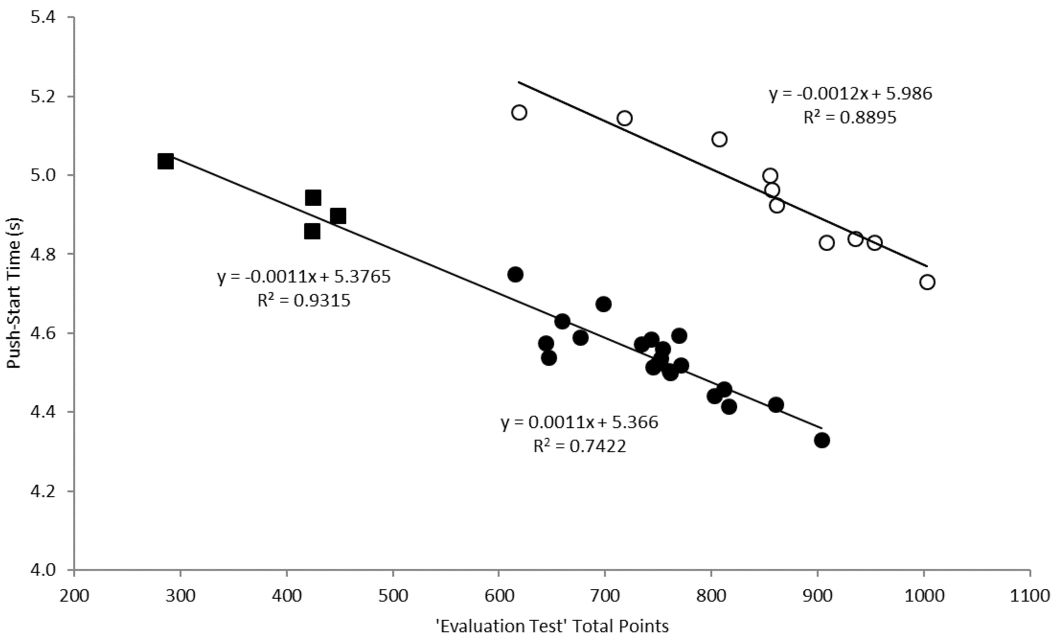

Figure 4.1 Relationships between 'evaluation test' total points and push-start time (s) for both male (black circles and squares) and female athletes (white circles).

Relationships (r values) between the different roll-bob push tests and the criterion push-start performance measure for male athletes ranged from 0.94 to 0.96 and from 0.89 to 0.98 for female athletes. Although, all correlations were significant at the $p = 0.05$ level, the strongest positive correlation was observed for the heavy back roll-bob push for both sexes (see Figure 4.2). In line with Figure 4.1, the four male athletes excluded from sub-group 1 were also considerably slower on the roll-bob push test (> 4.62 s and represented by black squares). Subsequently, analysis of sub-group 1 (all male athletes scoring > 600 points) revealed correlation r values ranging from 0.83 to 0.85 ($p > 0.05$).

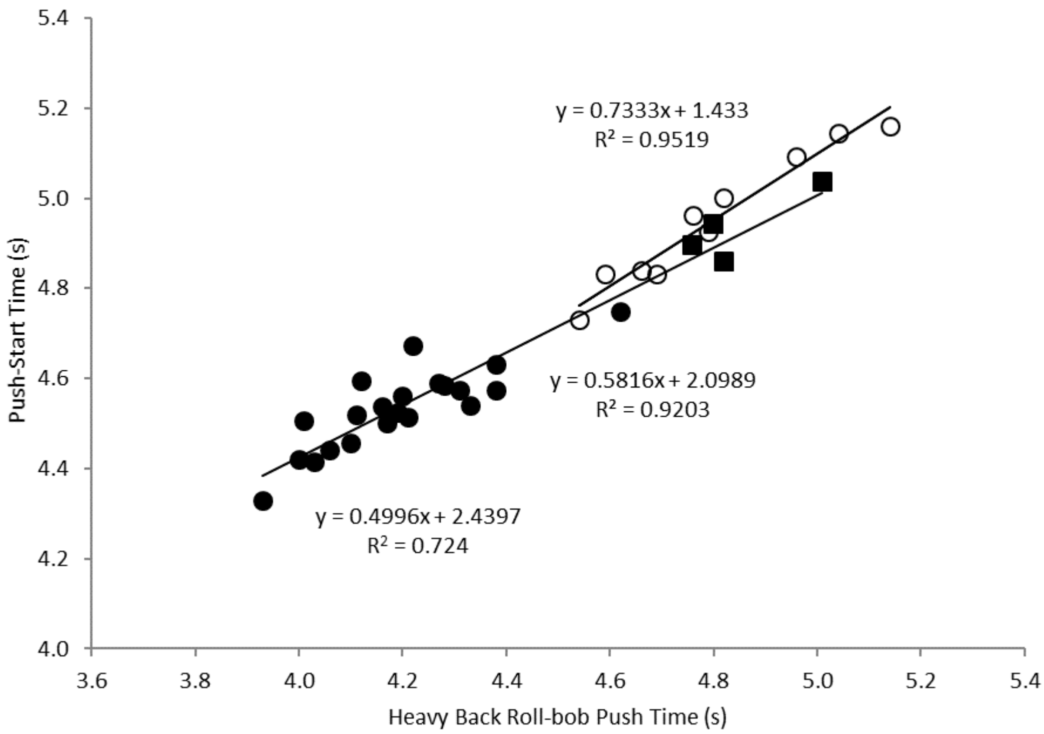

Figure 4.2 Relationship between push-start time (s) and heavy back roll-bob push time (s) for both male (black circles and squares) and female (white circles) athletes.

The relationships for the general performance tests against both the push-start and heavy back roll-bob push tests are summarised in Table 4.5. The strengths of these correlations highlighted in the table are generally quite similar between the push-start and heavy back roll-bob push tests and between males and females, with the majority also demonstrating correlations at the $p < 0.05$ level. The only exception was body mass for females, which was not correlated ($p < 0.05$) to either the push-start or the heavy back roll-bob push. However, when similar analysis was conducted on male sub-group 1, it revealed only body mass and the 5-RBJ to be correlated ($p < 0.05$) to the push-start and heavy back roll-bob push (see Table 4.5).

Table 4.5 Pearson correlation coefficients (*r* values) between the push-start or heavy back roll-bob push and the general performance tests for males (n = 25), (males in sub-group 1 (n =21)) and females (n = 10).

Test Parameter	Push-Start		Heavy Back Roll-bob Push	
	Male	Female	Male	Female
Body Mass (kg)	-0.69* (-0.50*)	0.06	-0.62* (-0.48*)	0.18
30m Sprint (s)	0.78* (0.30)	0.84*	0.67* (0.21)	0.89*
30m Flying Sprint (s)	0.74* (0.28)	0.76*	0.68* (0.14)	0.83*
60m Sprint (s)	0.76* (0.30)	0.80*	0.69* (0.17)	0.87*
5-RBJ (m)	-0.82* (-0.47*)	-0.78*	-0.75* (-0.46*)	-0.77*

* $p < 0.05$.

4.3.3 Inter-correlation Analysis

Table 4.6 considers the relationships between all the general performance tests included within the ‘evaluation test’. It is apparent from this table that near perfect relationships ($p < 0.05$) were observed between the various sprint split times for males, sub-group 1 males and females with common variance vales ranging from 82 to 96 %, 86 to 97 % and 88 to 98 % respectively. Relationships ($p < 0.05$) were also observed between the 5-RBJ and various sprint split times for both sexes, however the same was not the case for sub-group 1 as no relationships ($p > 0.05$) were detected. Interestingly, in contrast to that reported above, the shared variances between sprints and jumping were much lower where relationships were identified ($p < 0.05$); coefficient of determination values for males ranging from 40 to 54 % and 49 to 56 % for females. Further correlation analysis of the roll-bob push tests included within the ‘evaluation test’ revealed relationships ($p < 0.05$) between all push types and weights for male (r = 0.95 to 0.98), sub-group 1 male (r = 0.89 to 0.94) and female (r = 0.93 to 0.99) athletes.

Table 4.6 Inter-correlation matrix (r values) between sprint split times and the 5-repeated bound jump (5-RBJ) for male, male sub-group 1 (in brackets) and female athletes.

Test Parameter		30 m Sprint	30 m Flying Sprint	60 m Sprint	5-RBJ
30 m Sprint (s)	M	1			
	F	1			
30 m Flying Sprint (s)	M	0.91* (0.93*)	1		
	F	0.95*	1		
60 m Sprint (s)	M	0.97* (0.98*)	0.98* (0.99*)	1	
	F	0.98*	0.99*	1	
5-RBJ (m)	M	-0.73* (-0.16)	-0.63* (-0.10)	-0.70* (-0.13)	1
	F	-0.75*	-0.70*	-0.73*	1

*$p < 0.05$, M = males, F = females.

4.3.4 Multiple Regression Analysis

A summary of the the results obtained from the stepwise multiple regression analysis for the push-start, which only included the general performance tests (body mass, 30 m sprint, 30 m flying sprint, 60 m sprint & 5-RBJ) are displayed below (see Table 4.7, Table 4.8 and Table 4.9).

Table 4.7 Multiple regression result summary for male athletes.

Model	Variable Entered	R	R^2	Adjusted R^2	Standard Error of the Estimate
1	5-RBJ (m)	0.82	0.67	0.65	0.10
2	30 m Sprint (s)	0.87	0.76	0.74	0.09
3	Body Mass (kg)	0.95	0.91	0.89	0.06

Table 4.8 Multiple regression result summary for male sub group 1 athletes.

Model	Variable Entered	R	R^2	Adjusted R^2	Standard Error of the Estimate
1	Body Mass (kg)	0.50	0.25	0.21	0.08
2	30 m Sprint (s)	0.77	0.60	0.55	0.06

Table 4.9 Multiple regression result summary for female athletes.

Model	Variable Entered	R	R^2	Adjusted R^2	Standard Error of the Estimate
1	30 m Sprint (s)	0.84	0.70	0.66	0.09
2	Body Mass (kg)	0.96	0.92	0.90	0.05

The data displayed above can be used to generate the following equations to predict push-start performance for male, male sub-group 1 and female athletes (see Table 4.7, 4.8 and 4.9 respectively). Where BM = body mass (kg), 30S = 30 m sprint time (s), 30F = 30 m flying sprint time (s), 60S = 60 m sprint time (s) and 5-RBJ = 5-repeated bound jump (m).

- Male Push-Start (s) = 3.316 – (0.031 x 5RBJ) + (0.604 x 30S) – (0.006 x BM)
- Male Sub-group 1 Push-Start (s) = 2.871 – (0.006 x BM) + (0.607 x 30S)
- Female Push-Start (s) = 1.878 + (1.225 x 30S) – (0.028 x BM)

The models for males and females accounted for 89% (standard error of the estimate (SEE) = 0.06) and 90% (SEE = 0.04) of the variability in push-start performance respectively. In contrast, the model developed for male sub-group 1 was only able to account for 55% (SEE = 0.06) of the variability in performance.

Figures 4.3a to 4.3c displays comparisons for male, female and male sub-group 1 athletes between actual and predicted push-start performance, along with both 95 % limits of agreement (LoA) and mean difference values.

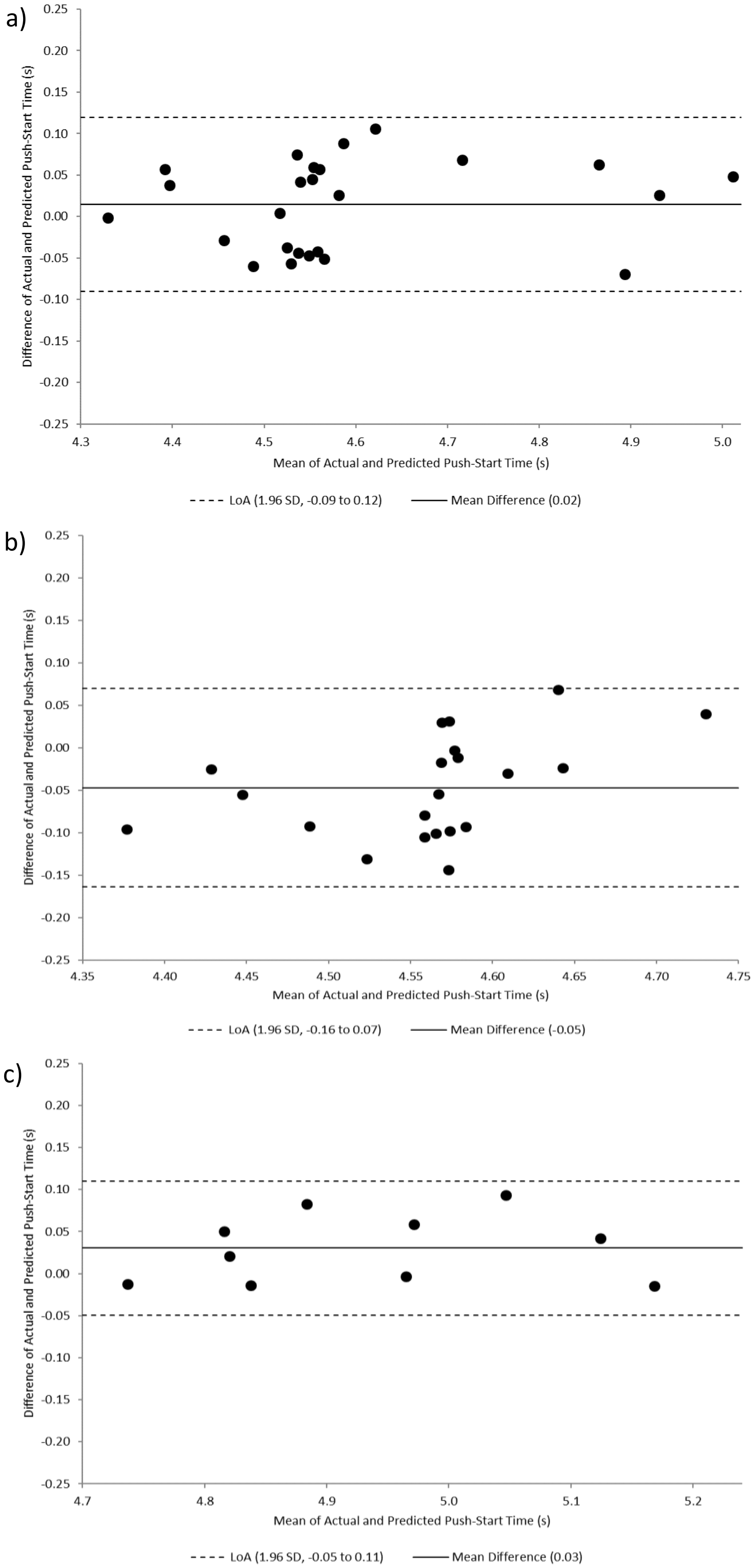

Figure 4.3 Actual v's predicted (from body mass, sprint time and jump performance) push-start times for male (a), sub-group 1 male (b) and female (c) athletes.

4.4 Discussion

4.4.1 Key Findings

The initial pilot work undertaken as part of this study confirmed the reliability of all roll-bob push tests used by British Bobsleigh. Following which, the main study detected very large between-sex differences for both push-start performance, as well as all the tests included within the 'evaluation test', but not total points. 'Evaluation test' total points were shown to demonstrate a very large to near perfect relationship with push-start performance for both sexes. Additionally, similar very large to near perfect correlations were detected between the push-start and all the different roll-bob push tests (r^2 change ≤ 10 %). Hence, the push-start: 'evaluation test' relationship appears to be largely a result of the strength of the correlations observed between the push-start and the roll-bob push test. Subsequently, attempts to explain push-start performance using only the general performance tests included within the British Bobsleigh 'evaluation test', highlighted body mass and 30 m sprint time as important qualities for both sexes. However, there is still a large aspect of push-start performance that is not fully understood amongst male bobsleigh athletes. Hence, more research is required on the determinants of the bobsleigh push-start.

4.4.2 Roll-Bob Push Test Reliability

One main finding of this study is that analysis for both sexes showed all roll-bob push tests to be reliable. The CV values presented above (0.7 to 1.7 %) are all below the 10% threshold outlined in the literature and in most cases the observed ICC values are equal to or in excess of the acceptable reliability threshold (Atkinson & Nevill 1998; Stålbom et al. 2007). Additionally, the observed roll-bob push test CV values are in line with that reported by a range of sprint performance studies (0.9 to ≤ 3 %) (Duthie et al. 2006; Kolsky et al. 2010; Meylan et al. 2009; Moir et al. 2004). Based on these results it can be suggested that the roll-bob push test offers an acceptable level of reliability when testing and monitoring bobsleigh athletes. However, it is important to bear in mind that this finding is specific to the sample studied and when using this test with other groups (for example, talent transfer athletes), caution must be applied. The reliability of the roll-bob push test across a range of sample groups requires further investigation.

4.4.3 Sex Comparisons

As expected, the male athletes in the present study outperformed their female counterparts across most of the measured variables, as well as being heavier ($p < 0.05$). To the author's knowledge, to date, only one study within the literature has presented a body mass comparison between male and female bobsleigh athletes, in which similar between-sex differences were detected (Zanoletti et al. 2006). These observed between-sex differences may partly be due to the disparities in optimal athlete body mass between male and female bobsleigh (90 to 110 kg and 70 to 80 kg respectively). These optimal athlete body masses exist as a result of male and female bobsleigh crews attempting to maximise momentum within the constraints of different minimum sled (i.e. without a crew) and maximal loaded sled (i.e. with a crew) weight limits (Deweese et al. 2014a; IBSF 2015).

In terms of performance tests (e.g. sprinting and jumping), between-sex differences in bobsleigh athletes have yet to be determined, therefore the wider winter sliding sport literature was considered. Similar if not larger between-sex sprint performance differences have been observed for skeleton athletes (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Sands et al. 2005). None of these studies included any horizontal jump tests, thus no meaningful comparisons could be made for this metric. Nevertheless, the observed between-sex differences in both sprint and jump performance in the present study could be in part attributed to the neuromuscular, biomechanical and body composition differences between males and females (Karastergiou et al. 2012; Vescovi & McGuigan 2008). There was one variable where the male sample group did not perform better (namely, 'evaluation test' total points) and in fact on average females achieved a higher score, but this difference was not significant ($p > 0.05$). The explanation for this are that males and females are awarded points on different scales (see Table 4.1), as well as the fact that British Bobsleigh sets female athletes a higher criterion score (850 as opposed to 800 points) to be considered for UK Sport funding (British Bobsleigh 2014a).

4.4.4 'Evaluation Test'

Initial analysis and graphical representation of the results (see Figures 4.1 and 4.2), revealed that the correlation values for male athletes may have become inflated as a result of a heterogeneous sample (Meylan et al. 2009). Given that British Bobsleigh's 'evaluation test' aims to identify talented athletes, it is more important to examine predictive ability amongst a smaller, more homogenous cohort of their best athletes as opposed to across a wider spectrum of athletes. Subsequently, when the four-weakest performing male athletes were removed ('evaluation test' total points < 450 and heavy back roll-bob push time > 4.62s), all relationships for the push-start and heavy back roll-bob push were reduced (see Results 4.3.2). Given the information presented above, the rest of the discussion will now focus on the data that excluded the four male athletes who scored < 450 'evaluation test' points. Any further mention of the male sample refers to sub-group 1 (see Results 4.3.2).

Perhaps the most important finding of this study was the large to near perfect correlations between 'evaluation test' total points and push-start performance for both males and females. These findings provide support for the anecdotal belief of British Bobsleigh coaches that 'evaluation test' total points score is indicative of an athlete's push-start capabilities. Also, they agree with previous bobsleigh literature which has shown a large to very large relationship between the push-start and points scored on the USBSF field testing battery (Harrison 2017; Osbeck et al. 1996). However, this comparison should be viewed with caution, as unlike the present investigation the USBSF's testing battery does not include any roll-bob push tests.

This study's findings relating to the 6 tests used in the 'evaluation test' (60m sprint, 5-RBJ and 4 x roll-bob pushes) revealed that the very large to near perfect correlations observed between total points and the push-start, were a result of the roll-bob push tests contributing to two-thirds of 'evaluation test' points, as well as each roll-bob test demonstrating at least a very large relationship with the push-start. Unfortunately, given the novelty of the roll-bob push test and lack of bobsleigh-specific literature, to the author's knowledge there are no studies that exist to allow any meaningful comparisons to be made. When considering each roll-bob push test in isolation the heavy back roll-bob push was shown to provide similar push-start predictive ability as 'evaluation test' total points (*r* = 0.85 to 0.98 and -0.86 to -0.98 respectively). Therefore, it could be suggested that there is little benefit of including any other tests beyond the heavy back roll-bob push, as the other five items of the 'evaluation test' are providing no additional insight to predicting the push-start. Consequently, in terms of talent identification, British Bobsleigh getting athletes to complete a heavy back roll-bob push will provide a strong predictor of their push-start ability. Similarly, this approach could be used to monitor training and assess the effectiveness of specific interventions.

4.4.5 General Performance Tests

The fact that the roll-bob push alone is sufficient to predict an athlete's push-start, highlights the need to examine the other general performance tests. This would help to develop a greater understanding of the push-start, as well as assisting with the design of a specific testing battery when access to a roll-bob is limited (Osbeck et al. 1996). In line with that reported by Osbeck et al. (1996), the results of this study showed a moderate relationship between the 5-RBJ and the push-start for male athletes. However, when considering the female sample group, the magnitude of the observed correlation increased to very large. Thus, on this basis it appears the 5-RBJ offers greater push-start predictive ability for female as opposed to male bobsleigh athletes. However, this suggestion should be viewed with caution given the disparity in sex sample sizes used in the present investigation.

In agreement with previous research, all sprint split times were shown to be inter-correlated (Loturco et al. 2015)**,** as well as displaying a very large relationship to the push-start and heavy back roll-bob push for female athletes. These results suggest that all sprint split times are measuring the same characteristic, thus supporting the notion that British Bobsleigh only awards 'evaluation test' points based on the 0 to 60 m sprint split time. However, given that the strongest relationship detected for females was 0 to 30 m sprint time, it could be argued that points should be awarded based upon this shorter split, although, it is important to bear in mind that all correlations were very similar. Further support for this idea is provided by the push-start multiple regression analysis presented in the results, as well as in the work of Osbeck et al. (1996), which have both shown 30 m sprint time to be a predictor of push-start performance. This is likely to be related to a 30 m sprint requiring a rapid acceleration movement similar to the push-start (Osbeck et al. 1996). When considering the male sample group only small to moderate push-start relationships were detected for the various sprint split times. This observation differs from the very large push-start: sprint time relationships presented by Osbeck et al. (1996), but are in agreement with some of the observations of Harrison (2017). The reasons for the conflicting results between the current study and previous work in male athletes are unclear, however it could be speculated that variations in the physical ability of the different study sample groups, might be having some influence on the magnitude of the reported correlations. Osbeck et al.'s (1996) sample group may not truly reflect modern day bobsleigh athletes and thus their data is difficult to generalise and compare with other studies in the sport (Harrison 2017). However, it is important to reiterate that both this study and the works of Osbeck et al. (1996) highlight 30 m sprint time as a determinant of push-start performance in their multiple regression analysis.

In addition to the above, the multiple regression analysis also showed body mass to be a vital aspect of bobsleigh performance for both sexes. Heavier athlete body masses are advantageous in the sport, as it allows a crew to reach the maximal loaded sled weight limit, maximising their sleds potential momentum, without having to add additional external load to the sled. Given this and the fact that Osbeck et al. (1996) identified an alternative variable (CMJ performance), that was not measured in the present investigation, the current body of literature emphasises that body mass, sprint time and CMJ performance all represent unique qualities important for the bobsleigh push-start. However, to date, no study has included all three of these variables simultaneously in the same investigation. Thus, further research is required to substantiate these suggestions.

4.4.6 Practical Applications of the Multiple Regression Equations

When interpreting the application of the multiple regression equations to a practical setting, it is important to consider the amount of performance accounted for. In terms of the female sample group the regression equation could predict 90 % of performance, suggesting that this model may provide bobsleigh practitioners with an alternative approach to predict performance when either the roll-bobs are unavailable, or they are subject to time constraints during testing. This suggestion is further supported by the fact that on average predicted push-start times using the regression equation were within 1 % of actual push-start performance during testing.

In contrast, the regression model for male athletes was only able to predict 55 % of push-start performance. This observed between sex difference could be partly explained by the present investigation using a smaller, more heterogeneous group of female athletes when compared to their male counterparts. This is consistent with the fact that a greater range in female push-start times was observed. Nevertheless, these results highlight that there is still a lot of unexplained contributors to bobsleigh push-start performance in males.

The use of body mass and the 30 m sprint to predict the push-start gave a 95 % LoA of 0.12 s and 0.08 s for male and female athletes respectively, thus coaches working within bobsleigh need to decide whether this provides an adequate level of accuracy. Given the time margins that separate successful and unsuccessful bobsleigh performance over four runs (IBSF 2018a), and the fact that changes in push-start time at push dominant tracks could affect finish time by three to five-fold (see Chapter 3), it could be suggested that greater accuracy is required. However, knowing that body mass and 30 m sprint performance are key qualities for the push-start, is still useful for general training prescription and monitoring.

An implication of the regression equations is that they may allow practitioners to predict how various interventions (to improve 30 m sprint time and increase body mass) may impact on push-start performance for both genders. Previous literature has reported that on average over a 24 week pre-season skeleton athletes can improve their 30 m sprint time by ~ 0.07 s (Colyer, Stokes, Bilzon, Cardinale, et al. 2017). Subsequently, based upon the equation generated in this study, it could be suggested that a pre-season training intervention may reduce push-start performance by 0.04 s in male athletes. In contrast, if a similar change in 30 m time was observed for a female bobsleigh athlete, it could potentially reduce push-start time by 0.09 s.

With regards to body mass, Reimers (2008) highlighted that the addition of 350 extra kcals to an athlete's daily diet (consisting of the adequate macronutrients and in conjunction with resistance training) can elicit a weekly gain in lean mass of ~0.5 kg. Consequently, it could be suggested that gaining 2 kg of lean body mass over a month period is a realistic goal and if a bobsleigh athlete was able to achieve this while maintaining their current 30 m sprint time, it could potentially reduce their push-start by 0.012 s (male) or 0.056 s (female). However, it is important to note that in bobsleigh an increase in mass is not necessarily performance advantageous for all athletes, as it can affect a crews ability to meet the maximum sled weight limit (with crew), due to the minimum sled weight (without crew) rule (IBSF 2015).

The predictions above highlight that a female bobsleigh athlete transferring the same absolute gain in either size or sprinting speed, will see a much greater push-start time improvement than a male counterpart. This contrast in performance gain is largely a result of these two measures accounting for a greater proportion of the variance in female push-start performance; 90 % as opposed to 55 %. Thus, in a practical setting it may be easier for practitioners to impact on female bobsleigh performance, however a note of caution is due here as this may change with a more homogenous population. In addition to this, the results again emphasise the large amount of currently unexplained performance in the male push-start. This highlights the need to identify other performance tests that provide high value when trying to predict the push-start in male bobsleigh athletes, providing scope and rationale for further studies to be undertaken in this area.

Based on Chapter 3, the reduction in the push-start predicted above (0.012 s to 0.09 s) could be suggested to relate to an improvement in finish time at a push-start dominant track in the range of 0.036 to 0.45 seconds. Given that at the 2014 Winter Olympic Games British Bobsleigh were only 0.11 s off a podium position over four heats (IBSF 2018a), the potential improvement in push-start offered by specific interventions (e.g. pre-season sprint training or lean weight gain) could be practically significant. Nevertheless, it is important to bear in mind that these are only assumptions based upon the equations generated from the multiple regression analysis within the present investigation. Therefore, future work should be undertaken to investigate the impact of specific interventions aimed to improve bobsleigh athlete sprint performances and/or body mass and evaluate the magnitude of any associated changes in push-start performance.

4.4.7 Hypothesised Explanations

A possible explanation for the reported correlations between the push-start and roll-bob tests could be attributed to the fact that both movements are very similar requiring athletes to possess high levels of speed, strength and power. These qualities have been highlighted by Godfrey et al. (2007) and Osbeck et al. (1996) as vital characteristics of the ‘ideal’ bobsleigh athlete. Both movements require athlete’s to rapidly accelerate a fixed load from a standing start, as well as being designed with the intention to closely replicate pushing an actual bobsled on ice (British Bobsleigh 2014b; Osbeck et al. 1996). In terms of the movement specifics, both are measured over a comparable distance (30 and 40 m respectively) and begin with athletes on a wood start block in the braced position (British Bobsleigh 2014b; Osbeck et al. 1996).

Although the mechanisms behind the moderate to very large correlation between the 5-RBJ and the push-start are unclear, it may partly be explained by both movements being of a similar nature. Firstly, in line with sprint running both the 5-RBJ and push-start involve a combination of both vertical and horizontal ground reaction force, predominately relying on the latter (Maulder et al. 2006; Maulder & Cronin 2005; Meylan et al. 2009). Secondly, the repeated aspect of the jump test requires force application of a cyclic nature which as outlined by Maulder and Cronin (2005) is similar to the majority of locomotion. Horizontal jumps similar to the 5-RBJ have been frequently used within the literature and are accepted as indirect tests to measure power of the leg extensors (Meylan et al. 2009). Comparably, like the sprint start, the push-start demands the leg musculature to generate large amounts of force (Harland & Steeke 1997; Maulder et al. 2006). Therefore, the reliance both movements place on the strength of the lower extremities offers a possible explanation for the observed correlation in the present study. Finally, as outlined by Nesser et al. (1996) the nature of the lower extremities role requires the muscle groups utilised to perform contractions of high velocity incorporating a stretch shortening cycle, again similar to that seen in either a sprint or push-start. Despite the moderate to very large relationships between the push-start and the 5-RBJ, as well as their similarities in nature, it is important to remind the reader that the 5-RBJ was not included in the male (sub-group 1) or female multiple regression models presented in the results (see Results 4.3.4). Thus, the 5-RBJ test does not provide any additional push-start predictive value beyond body mass and sprint time.

The observed correlations between sprint performance and the push-start for female athletes in the present study could be explained by a range of similar mechanisms underpinning performance. Firstly, given the duration of the activities (< 6 seconds), both the magnitude of and time to achieve peak velocity have been identified by previous authors as key factors in performance (Forrow 2013; Ross et al. 2001). Given this duration, both are heavily reliant on the anaerobic energy system and thus initially utilise Adenosine Triphosphate (i.e. ATP) as a major energy source to facilitate the generation of maximal power output (Forrow 2013). Secondly, as outlined by Forrow (2013) the sprint and push-start both utilise similar muscle groups of the lower body; Gluteal, Quadriceps and Hamstrings. Finally, the activation of fast twitch type II fibres is evident in both and their key characteristics contribute towards the development of a high force production at a fast contraction speed (Hunter & Harris 2008; McArdle et al. 2010).

4.4.8 Limitations

A limitation of the current study is the small number of male and female bobsleigh athletes used. However, the recruitment of a larger female sample group was not possible, as the investigation had access to the entire population of British bobsleigh athletes (i.e. the national program). Also, some critics could question that the use of a heterogeneous male sample group may have caused inflated correlation values to be reported (Meylan et al. 2009). Nevertheless, the author attempted to address this issue by reanalysing the male dataset once four lower performing male athletes (< 450 ‘evaluation test’ points) had been removed, leading to the formation of a more homogenous male sample group (male sub-group 1).

4.4.9 Practical Applications

The results of this study indicate that points scored on the ‘evaluation test’ is a valid predictor of on-land bobsleigh push-start performance, however, a single heavy back roll-bob push in isolation was shown to be just as effective as the whole test battery. Additionally, evidence suggests that the roll-bob push test is reliable for both sexes, therefore, when a roll-bob is available this should be the test of choice for both talent identification and squad monitoring. The focus on physical qualities contributing to the push-start, particularly the 30 m sprint and body mass may be of use when practitioners are attempting to predict performance and evaluate training. Although, it is important to note that there is still a considerable amount of unexplained variance in push-start performance amongst male bobsleigh athletes, which warrants further investigation.

4.4.10 Conclusions

In agreement with the aim of this study, the author investigated the validity of the 'evaluation test' used by British Bobsleigh to predict push-start performance, as well as assessed the individual performance qualities that contribute to the bobsleigh push-start. The present investigation established the following key outcomes:

1. The British Bobsleigh ‘evaluation test’ is a valid predictor of an athletes’ push-start ability.
2. The validity of the ‘evaluation test’ is largely a result of the strength of the correlations observed between the roll-bob push tests and the push-start.
3. Attempts to explain push-start performance using only body mass, sprint time and jump performance, highlighted body mass and 30m sprint time as key qualities for the bobsleigh push-start. However, there is still a large aspect of performance that is not fully understood amongst male bobsleigh athletes.

Chapter 5

STUDY 3: ‘Keiser Squat Testing’: Reliability, Discriminative Validity and Predictive Validity.

5.1 Introduction

5.1.1 Preface

Attempts to explain the qualities underpinning push-start performance in chapter 4 using the general performance tests included within the British Bobsleigh ‘evaluation test’, highlighted a large aspect of the push-start that is still not fully understood, particularly in male bobsleigh athletes. However, to date, the ‘evaluation test’ has yet to consider any measurements of power under loaded conditions. Given that during the push-start athletes are required to produce high force against an external load to accelerate a sled (Deweese et al. 2014a), it could be argued that power measurements under loaded as opposed to unloaded conditions may be more specific to the push-start, as a result of the slower movement velocities and higher loads involved. This is supported by several studies in elite skeleton who have reported a link between loaded power assessments and the push-start (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Sands et al. 2005). Hence, it could be suggested that the addition of a loaded power-based measure to the British Bobsleigh ‘evaluation test’, may help account for some of the unexplained push-start performance variance highlighted in chapter 4 of this thesis.

5.1.2 Loaded Power Assessments

Mosey et al. (2014) have suggested a loaded CMJ profile to be a suitable test when attempting to directly quantify loaded power based qualities related to the skeleton push-start. These suggestions are somewhat supported by work in the literature that has observed large to near perfect relationships (r = -0.73 to -0.92; r = > 0.50 respectively) between power output in several different loaded jumps (5 kg, barbell, 20 %, 40 %, 50 % & 60 % body mass) and push-start time or velocity metrics (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Sands et al. 2005). Also, recent work has examined an alternative power test on a Keiser leg press dynamometer using pneumatic resistance and demonstrated large to very large correlations between push-start velocity (15 m) and various mechanical variables including; P_{max} (r = 0.85) and V_0 (r = 0.62) (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017). Conclusions of the regression analysis identified force at maximal power (F_{opt}) to be an independent predictor of push-start performance. However, F_{opt} did in fact provide a negative contribution to the push-start model and thus highlighted the importance of achieving peak power at light loads for the skeleton push-start (Colyer, Stokes, Bilzon, Cardinale, et al. 2017). The application of this latter observation across to bobsleigh should be viewed with caution given the much heavier sled load involved in bobsleigh. At this point, it is important to acknowledge that the direct comparisons made between the skeleton studies highlighted above should be interpreted with caution, given the disparity in the type of resistance used for loading (e.g. free weight v's pneumatic). Additionally, the body of skeleton work is somewhat limited by the heterogenous nature of the sample groups involved, with results combined for both male and female athletes (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Sands et al. 2005). Despite this work on the skeleton push-start, no literature to date has examined the validity of loaded power assessments for the bobsleigh push-start.

5.1.3 British Bobsleigh

Given the link highlighted above between loaded power assessments and the skeleton push-start, British Bobsleigh have developed their own power-load assessment on the Keiser® AIR300 Squat (named the 'Keiser Squat Test'), to evaluate their athlete's ability to express power under loaded conditions. In comparison to conventional barbell testing, the Keiser® AIR300 Squat reduces the impact of inertia and momentum, by replacing traditional weighted resistance with pneumatic resistance (Colyer 2015). The protocol itself involves athletes completing 3 maximal effort repetitions at several different predefined absolute loads, with the attainment of a direct power measurement at each load. To date, the 'Keiser Squat Test' has been excluded from the 'evaluation test' due to the already extensive nature of the 'evaluation test' protocol, however it is still used by British Bobsleigh to monitor their athletes on a more regular basis and assess their ability to express power under loaded conditions. Study two highlighted the possibility of reducing the number of tests included within the ‘evaluation test’, together with the need to identify other physical qualities that contribute to the push-start (see Chapter 4). Thus, providing a rationale to scientifically explore the use of the ‘Keiser Squat Test’ in bobsleigh. Given the novelty of the testing protocol in question and the fact that the current Keiser Squat literature is limited to fatigue and post activation potentiation studies (Golas et al. 2016; Owen et al. 2015), no evidence exists confirming its reliability or validity for push-start performance in bobsleigh.

5.1.4 Rationale

There is still a large aspect of the bobsleigh push-start that is not fully accounted for by the general performance tests included within the British Bobsleigh ‘evaluation test’. However, the test battery has yet to consider any power measurements examined under loaded conditions. Previous research has demonstrated a link between loaded power assessments and start performance in skeleton. Nevertheless, there is a paucity of work that has explored if this link is still present in a more homogenous athletic group and transfers across to the bobsleigh push-start. Despite not being included within the ‘evaluation test’, tests of this nature are used by British Bobsleigh (e.g. ‘Keiser Squat Test’), however, the reliability and validity of the protocol in question in bobsleigh has yet to be empirically investigated.

5.1.5 Aim and Hypothesis

The aim of this study is to explore the reliability, discriminative validity and predictive validity of the British Bobsleigh ‘Keiser Squat Test’.

5.2 Methods

5.2.1 Athletes

Twenty-One British bobsleigh athletes (8 maleND, 6 male WCP & 7 females consisting of 6 ND push athletes and 1 WCP pilot) took part in this study. This sample represents 60 % of the total British bobsleigh athlete population. The mean age, body mass and height of the athletes involved in the study are displayed in Table 5.1. Cardiff Metropolitan University's School of Sport ethics committee granted the project ethics approval and British Bobsleigh's performance director provided consent to use the data for this work.

Table 5.1 Mean (range) descriptive statistics for the study sample group.

Characteristic	Male WCP (n = 6)	Male ND (n = 8)	Female (n = 7)
Age (years)	27 (23 to 33)	26 (20 to 31)	21 (17 to 25)
Body Mass (kg)	99.1 (90.0 to 107.5)	98.5 (87.6 to 111.6)	72.9 (66.0 to 80.6)
Height (cm)	185 (180 to 191)	185 (176 to 193)	167 (163 to 173)

5.2.2 Experimental Design Overview

All Keiser Squat testing took place at the British Bobsleigh National Training Centre (University of Bath, UK), between June and July 2016, during summer training preparations for the 2016/2017 on-ice season. All athletes took part in one testing session; however, 6 athletes completed an additional session as part of a reliability pilot study (see Methods 5.2.4). Athlete descriptive data was determined using previously collected data from squad baseline 'evaluation testing' (May 2016). Prior to the warm up of each 'Keiser Squat Test' session, athlete body mass was measured using digital scales (SECA-Model 770, Vogel & Halke, Hamburg, Germany). Following which, athletes were given 20-minutes to undertake their own individual warm up routines. Athletes then completed the full 'Keiser Squat Test' in accordance with the British Bobsleigh protocol (see Methods 5.2.3), which involved completing 3 reps to produce maximal power at six predetermined loads. All athletes were deemed to be technically proficient with the apparatus used in the 'Keiser Squat Test' , given they use the Keiser® AIR300 Squat as part of their strength and conditioning training programmes. Throughout testing, all athletes were provided with verbal encouragement from both British Bobsleigh support staff and other athletes taking part.

In addition to the ‘Keiser Squat Test’, 13 of the males (8 ND & 5 WCP) and 5 of the female athletes also undertook the British Bobsleigh ‘evaluation test’ within a ± 16-day period at one of British Bobsleigh’s training camp facilities. These ‘evaluation tests’ were completed in accordance with the protocol outlined in chapter 4 (see Section 4.2.3). The results from this testing were used to allow the relationships between performance in the ‘Keiser Squat Test’ and general performance tests (30 m sprint, 30 m flying sprint, 60 m sprint & 5-RBJ) as well as push-start performance to be explored. The heavy back roll-bob push was selected as a push-start criterion measure, given its very large correlation (r = 0.85) with the push-start (see Chapter 4).

5.2.3 ‘Keiser Squat Test’

The ‘Keiser Squat Test’ was undertaken on the Keiser® AIR300 Squat (Keiser, Fresno, CA, USA), which is a pneumatically powered machine used for power testing and training. The system uses algorithms to display power output on the machine interface using force (via air pressure change) and velocity (via a position transducer) metrics measured from the air cylinder piston (Keiser 2017; Sayers & Gibson 2012). Prior to actual data collection, all athletes completed two warm up sets at loads of 100 kg (females) and 100 kg & 120 kg (males). After which, athletes completed 3 maximal explosive repetitions at 6 different loads, increasing by 20 kg each set; females 100 kg, 120 kg, 140 kg, 160 kg, 180 kg & 200 kg and males 140 kg, 160 kg, 180 kg, 200 kg, 220 kg & 240 kg. Athletes started the first repetition from a half squat position (knee angle ~ 90-degrees), with the machine pads placed on the shoulders. They then initiated the movement by driving into a fully extended upright position, as fast as possible (Owen et al. 2015). This full extension was then followed by two continuous explosive repetitions; where the athlete returned to the half squat position and then completed a full extension. In accordance with Owen et al. (2015), the highest peak power output (PPO) observed over the three repetitions for each load was recorded and used in all further analysis. These values were then imported into Microsoft Excel (Microsoft, USA) where relative (expressed against body mass), as well as overall test PPO were determined. Overall test PPO was defined as the highest PPO achieved by a given athlete across the 6 predefined test loads.

5.2.4 'Keiser Squat Test' Peak Power Output Reliability (Pilot Study)

The reliability of PPO produced in the 'Keiser Squat Test' at loads from 140 kg to 240 kg was assessed using data collected from n = 6 male ND bobsleigh athletes on two separate occasions; 21 to 33 days apart. The mean characteristics of the sample group were; age 24 (17 to 31) years, body mass 96.0 (87.2 to 110.2) kg and height 184 (176 to 193) cm.

5.2.5 Statistical Analysis

All data is displayed as means (including range) and statistical analysis was completed using both Microsoft Excel (Microsoft, USA) and IBM SPSS statistics (Version 23, SPSS, Chicago, USA). Normality of all 'Keiser Squat Test' PPO values and 'evaluation test' scores used in this study were determined using the Shapiro-Wilk Normality test and normality was confirmed for all variables ($p > 0.05$ or skewness & kurtosis – 2.0 to + 2.0).

Reliability analysis was undertaken using the spreadsheet developed and formatted by Hopkins (2000), where raw values were log-transformed to calculate TE, ICC and CV values for each 'Keiser Squat Test' load. In line with the analysis in chapter 4 and suggestions from the literature (Atkinson & Nevill 1998; Stålbom et al. 2007), the following ICC and CV reliability thresholds were set; ICC > 0.75 & CV ≤ 10% (acceptable reliability) and ICC > 0.90 (high reliability). Additionally, Cohen's effect sizes (thresholds below) were calculated to determine the magnitude of any between trial differences and a paired sample t-test was undertaken to assess if any of these differences were statistically significant.

In the main study, Cohen's effect sizes were calculated to assess the magnitude of absolute and relative PPO differences between the three sample groups using the following thresholds; < 0.20 trivial, ≥ 0.20-0.59 small, ≥ 0.60-1.19 moderate, ≥ 1.20-1.99 large, ≥ 2.00 very large and ≥ 4.00 extremely large (Hopkins 2002; Hopkins et al. 2009). A one-way ANOVA with a LSD post-hoc test was used to determine any differences between the sample groups for PPO at 140 kg, 160 kg, 180 kg and 200 kg as well as overall test PPO. An independent t-test was used to detect any main effect differences in PPO between WCP and ND male athletes at test loads of 220 kg and 240 kg. Finally, for each sample group, PPO differences between each incrementing load was assessed via a repeated measures ANOVA.

Pearson's correlation coefficients were determined to assess any relationships between 'Keiser Squat Test' PPO (absolute & relative) and roll-bob push performance, as well as the general performance tests included in the British Bobsleigh 'evaluation test'. Additionally, inter-correlation analyses were undertaken with absolute and relative PPO across all loads included in the 'Keiser Squat Test'. Correlation coefficient thresholds were set in accordance with the suggestions of Hopkins (2002) and were as follows; < 0.10 trivial, ≥ 0.10-0.29 small, ≥ 0.30-0.49 moderate, ≥ 0.50-0.69 large, ≥ 0.70-0.89 very large and ≥ 0.90 near perfect. As exploratory research with a small sample of homogenous athlete's, for all the analysis described above an alpha value of $p < 0.10$ was set as statistically significant.

5.3 Results

5.3.1 ‘Keiser Squat Test’ Peak Power Output Reliability (Pilot Study)

Table 5.2 displays the mean (range) PPO values on the ‘Keiser Squat Test’ from 140 kg to 240 kg (measured using 2 separate trials), along with the between trial effect size, ICC, TE and CV values. Although performance was higher in trial 2 at all loads, between trial differences were all trivial or small and not different (*p* > 0.10).

Table 5.2 Mean (range) peak power outputs on the Keiser Squat Test from 140 kg to 240 kg and between trial ICC, TE and CV values.

‘Keiser Squat Test’	Mean (range)		Reliability			
	Trial 1	Trial 2	ES	ICC	TE	CV (%)
140 kg (W)	2899 (2263-3394)	3004 (2569-3224)	0.29	0.72	0.83	8.9
160 kg (W)	3156 (2382-3720)	3341 (2741-3795)	0.41	0.77	0.74	9.1
180 kg (W)	3362 (2522-3982)	3533 (3049-3791)	0.42	0.57	1.10	10.4
200 kg (W)	3519 (2853-4139)	3708 (2971-4158)	0.41	0.88	0.53	6.4
220 kg (W) (n = 5)	3737 (2944-4243)	3899 (3507-4269)	0.39	0.93	0.53	5.7
240 kg (W) (n = 5)	3745 (2884-4174)	3875 (3438-4161)	0.28	0.91	0.60	6.4

ES = Cohen’s effect size, ICC = intraclass correlation coefficients, TE = typical error, CV = coefficient of variation & W = Watts.

5.3.2 'Keiser Squat Test'

Table 5.3 reports the mean (range) absolute and relative PPO values achieved during the 'Keiser Squat Test' by WCP male, ND male and female athletes in the British Bobsleigh squad. As can be seen in Table 5.3, a large difference was detected between WCP and ND male athletes for absolute PPO at 140kg (ES = 1.24, $p < 0.10$). However, no differences were observed between the groups across any of the remaining absolute loads, any of the loads expressed relative to body mass, overall absolute PPO or overall relative PPO ($p > 0.10$).

When compared to the female squad, extremely large differences in absolute overall PPO and absolute PPO across all loads were detected for both WCP (ES = 4.83 to 5.82, $p < 0.10$) and ND male athletes (ES = 5.52 to 6.27, $p < 0.10$). Similar differences were observed when these PPO values were expressed relative to body mass, however the strength of these differences ranged from large to very large (WCP ES = 1.84 to 2.39, $p < 0.10$ & ND ES = 1.44 to 2.29, $p < 0.10$).

Although within group PPO increased for each incrementing test load except for male ND PPO at 240 kg (absolute & relative) and female PPO at 200 kg (absolute & relative), results of the repeated measures ANOVA analysis for each group, highlighted only several of the PPO increases to be significant at the $p = 0.10$ level for ND male and female athletes (see Table 5.3). No differences were detected amongst the WCP male sample group ($p > 0.10$).

Table 5.3 Group mean (range) absolute and relative peak power output values (PPO) for WCP male, ND male and female British Bobsleigh squad athletes from the ‘Keiser Squat Test’.

	Absolute PPO			Relative PPO		
Load	WCP Male (n = 6)	ND Male (n = 8)	Female (n = 7)	WCP Male (n = 6)	ND Male (n = 8)	Female (n = 7)
100 kg	-	-	1612 W (1133-1977)	-	-	22.31 W.kg^{-1} (14.89-28.76)
120 kg	-	-	1770 W (1431-2076)	-	-	24.46 W.kg^{-1} + (18.51-30.41)
140 kg	3293 W (3033-3580)	3060 W * (2805-3224)	1875 W *"+ (1516-2172)	33.34 W.kg^{-1} (29.71-36.74)	31.21 W.kg^{-1} (26.90-36.51)	25.89 W.kg^{-1} *"+ (19.92-31.45)
160 kg	3563 W (3151-4007)	3414 W + (3167-3795)	2009 W *" (1738-2410)	36.08 W.kg^{-1}+ (32.79-40.64)	34.85 W.kg^{-1} + (28.38-40.57)	27.78 W.kg^{-1} *" (21.33-36.52)
180 kg	3770 W (3242-4295)	3582 W + (3292-3791)	2032 W *" 6 (1600-2435)	38.14 W.kg^{-1} (34.64-43.56)	36.56 W.kg^{-1} + (30.67-42.85)	28.53 W.kg^{-1} *" 6 (21.02-36.89)
200 kg	3844 W (3534-4372)	3763 W + (3414-4158)	1958 W *" 6 (1595-2341)	39.00 W.kg^{-1} (33.00-45.34)	38.40 W.kg^{-1} + (32.80-45.24)	27.47 W.kg^{-1} *" 6 (21.10-34.59)

Load	Absolute PPO			Relative PPO		
	WCP Male (n = 6)	ND Male (n = 8)	Female (n = 7)	WCP Male (n = 6)	ND Male (n = 8)	Female (n = 7)
220 kg	3900 W (3461-4573)	3811 W (3483-4269)	-	39.53 $W.kg^{-1}$ (32.20-46.38)	38.91 $W.kg^{-1}$ (33.21-48.73)	-
240 kg	4038 W (3648-4740)	3798 W (3438-4161)	-	40.89 $W.kg^{-1}$ (36.33-48.07)	38.74 $W.kg^{-1}$ (33.37-46.04)	-
PPO	4058 W (3681-4740)	3883 W (3575-4269)	2088 W *" (1757-2435)	41.09 $W.kg^{-1}$ (36.67-48.07)	39.65 $W.kg^{-1}$ (33.37-48.73)	29.29 $W.kg^{-1}$ *" (21.33-36.89)

W = Watts, W/kg = Watts per kg, [6] = only 6 female athletes, * = difference compared to WCP male ($p < 0.10$). " = difference compared to ND male ($p < 0.10$) & $^{+}$ = difference compared to preceding Keiser Squat Test load ($p < 0.10$).

As shown in Figure 5.1, a negative near perfect correlation was observed between 'Keiser Squat Test' PPO at 160 kg and the roll-bob push for female athletes (r = -0.96, p < 0.10). Similar very large to near perfect relationships were detected for the roll-bob push across the remaining 'Keiser Squat Test' loads, for overall PPO and when all values were expressed relative to body mass (r = -0.87 to -0.96, p < 0.10). Despite the homogenous nature of the female sample group, on average 'Keiser Squat Test' PPO differed by ~700 W (~ 40 %) from the best to worst athlete (see Table 5.3 and Figure 5.1). Hence, based on the presented results that equated to a difference of 0.50 s (~ 10%) on the roll-bob push.

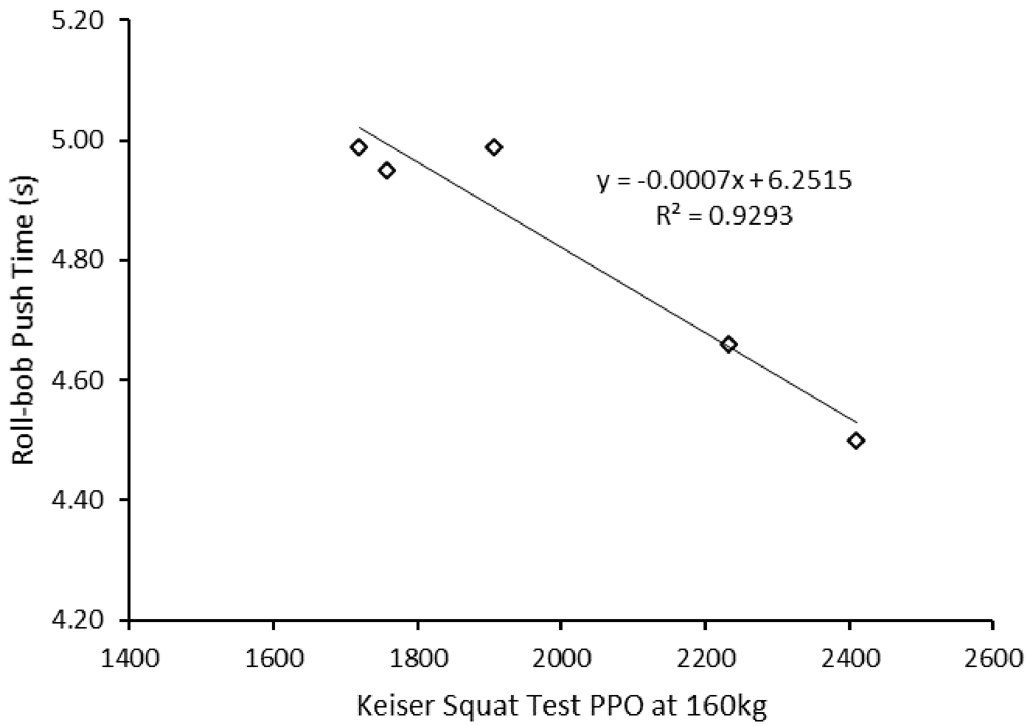

Figure 5.1 Relationship between Keiser Squat Test peak power output (PPO) at 160 kg and roll-bob push time (s) for female athletes.

The results of the correlation analysis between the 'Keiser Squat Test' and the British Bobsleigh 'evaluation test' for male WCP and ND athletes are outlined in Table 5.4. A moderate relationship was observed between the roll-bob push (group mean 4.06 s; range 4.00 to 4.14 s) and 'Keiser Squat Test' absolute PPO at loads of 160 kg, 180 kg, 220 kg and 240 kg (r = -0.30 to -0.47). However, when PPO was expressed relative to body mass, only trivial to small correlations with roll-bob push performance were detected for all loads and overall PPO (r = 0.05 to -0.23).

As shown in Table 5.4, across all the general performance tests, the strongest correlation was observed between the 5-RBJ (group mean 16.67 m; range 15.68 to 17.47 m) and relative PPO at 200 kg (r = 0.69, $p < 0.10$). However, large positive correlations for the 5-RBJ were also detected for relative PPO at 160 kg, 180 kg, as well as overall relative PPO (r = 0.58 to 0.60, $p < 0.10$). The remaining loads expressed relative to body mass were shown to display a moderate relationship with the roll-bob push and apart from PPO at 140 kg were all statistically significant (see Table 5.4). The same was not the case for absolute PPO and the 5-RBJ, as moderate relationships were only observed at 200 kg (r = 0.46, $p > 0.10$) and overall PPO (r = 0.35, $p > 0.10$).

Moderate negative correlations were observed for both 30 m and 60 m sprint time (group mean 3.78 s; range 3.61 to 3.91 s & group mean 6.81 s; range 6.55 to 6.97 s respectively), with absolute PPO at loads of 140kg, 160kg and 180kg (r = -0.34 to -0.39). However, the remaining loads and overall PPO, only displayed a small correlation with 30 m and 60 m sprint times (r = -0.18 to -0.28). Similar findings were observed for the relationships between 30 m flying sprint time (group mean 3.03 s; range 2.84 to 3.16 s) and all the Keiser loads, which were all small in magnitude (r = -0.12 to -0.27). In terms of relative PPO and sprint performance, a similar pattern to absolute values was seen, except for the additional moderate relationships detected at 180 kg (30 m flying sprint r = -0.30), 200 kg (30 m sprint r = -0.31) and 240 kg (30 m sprint r = -0.33 & 60 m sprint r = -0.30) with the various sprint parameters.

Due to the small sample sizes, none of the correlations highlighted for either the roll-bob push or sprint performance were significant, apart from the 5RBJ ($p < 0.10$).

Further inter-correlation analysis of absolute and relative PPO achieved in all the ‘Keiser Squat Test’ loads as well as overall test PPO, revealed both very large and near perfect correlations ($p < 0.10$) between all the various loads; with common variance ranging from 61 to 96 %.

Table 5.4 Pearson correlation coefficients (r values) between ‘Keiser Squat Test’ absolute or relative peak power output (PPO) at all loads, as well as overall absolute or relative PPO and the ‘evaluation test’ for male WCP and ND athletes (n = 13).

Test	Roll-bob Push (s)		30m Sprint (s)		30m Flying Sprint (s)		60m Sprint (s)		5-RBJ (m)	
Load	W	W/kg	W	W/kg	W	W/kg	W	W/kg	W	W/kg
140 kg	-0.21	-0.03	-0.39 ^{m}	-0.42 ^{m}	-0.27	-0.29	-0.37 ^{m}	-0.41 ^{m}	0.05	0.45 ^{m}
160 kg	-0.47 ^{m}	-0.23	-0.33 ^{m}	-0.35 ^{m}	-0.27	-0.28	-0.34 ^{m}	-0.36 ^{m}	0.29	0.58 ^{L*}
180 kg	-0.35 ^{m}	-0.17	-0.34 ^{m}	-0.38 ^{m}	-0.27	-0.30 ^{m}	-0.35 ^{m}	-0.39 ^{m}	0.26	0.59 ^{L*}
200 kg	-0.08	0.05	-0.28	-0.31 ^{m}	-0.12	-0.18	-0.23	-0.27	0.46 ^{m}	0.69 ^{L*}
220 kg	-0.30 ^{m}	-0.12	-0.18	-0.23	-0.19	-0.23	-0.22	-0.27	0.18	0.49 ^{m*}
240 kg	-0.36 ^{m}	-0.20	-0.27	-0.33 ^{m}	-0.14	-0.20	-0.23	-0.30 ^{m}	0.18	0.49 ^{m*}
Peak	-0.21	-0.05	-0.21	-0.25	-0.14	-0.18	-0.20	-0.25	0.35 ^{m}	0.60 ^{L*}

W = Watts, W/kg = Watt per kg, 5-RBJ = 5 repeated bound jump, ^{m} = moderate correlation (r = 0.30 to 0.49), ^{L} = large correlation (*r* = 0.50 to 0.69), * = $p < 0.10$.

5.4 Discussion

5.4.1 Key Findings

The British Bobsleigh ‘Keiser Squat Test’ was deemed to be reliable amongst male ND bobsleigh athletes, however it was unable to distinguish between male athletes of different performance levels (i.e. WCP and ND), except at a moderate load (i.e. 140 kg). ‘Keiser Squat Test’ PPO was shown to be a very large to near perfect predictor of push-start performance in a small sample of female athletes, with the strongest relationship observed at a load of 160 kg. In male bobsleigh athletes, several of the test loads were shown to moderately relate to push-start performance (160 kg, 180 kg, 220 kg, and 240 kg), as well as all test loads representing a unique quality when compared to the general performance tests included within the British Bobsleigh ‘evaluation test’. Thus, the addition of the ‘Keiser Squat Test’ to the British Bobsleigh ‘evaluation test’ may help to account for some of the unexplained variance in push-start performance identified in Chapter 4.

5.4.2 ‘Keiser Squat Test’ Reliability (Pilot Study)

The results of the reliability pilot study analysis showed ‘Keiser Squat Test’ PPO at all loads to be within the thresholds previously outlined in the literature (CV 5.7 to 9.1 % and ICC 0.75 to 0.96), apart from PPO at 180 kg, which was just outside the CV and ICC thresholds of ≤ 10% and ≥ 0.75 respectively (Atkinson & Nevill 1998; Stålbom et al. 2007). Hence, it can be suggested that the ‘Keiser Squat Test’ protocol used by British Bobsleigh is sufficiently reliable to be used in the testing and monitoring of bobsleigh athletes, although more testing with a larger sample size would help to confirm this. Despite this, an increase was observed in the mean values from trial 1 to 2 across all test loads, however these differences were either trivial or small in magnitude and thus it was deemed there was no systemic bias or learning effect. Although this study showed the ‘Keiser Squat Test’ to be reliable in bobsleigh athletes who have experience in the testing procedures, caution should be taken when testing talent transfer athletes, given their lack of exposure to the testing apparatus and protocol. Preferably, an athlete should undertake several familiarisation sessions before performing the ‘Keiser Squat Test’.

5.4.3 British Bobsleigh 'Keiser Squat Test'

To the author's knowledge this is the first study to report normative PPO values for British Bobsleigh athletes. The presented male WCP and ND absolute PPO's well exceed the best score observed in elite male soccer players, in a four-repetition version of the test at 120 kg (range 1782 to 2022 W) (Owen et al. 2015). The absolute PPO differences observed between bobsleigh athletes and soccer players is of no surprise to the author and could be attributed to the contrasting backgrounds of the athletes in question (e.g. strength and power versus team sport respectively). Although on average bobsleigh athletes did also outperform their soccer counterparts when PPO's were expressed in their relative form, there appears to be some cross over between the best and worst performances (mean ~ 24.7 W/kg and range ~ 19.0 to 32.4 W/kg) (Owen et al. 2015). Thus, much of the difference in absolute PPO between these populations could be attributed to body size.

Despite the relatively homogenous nature of the athlete sample groups included in this study, a large between-athlete range relative to the group mean was detected across 'Keiser Squat Test' loads for WCP (17 to 36 %), ND (14 to 40 %) and female (32 to 62 %) bobsleigh athletes. Thus, highlighting the expression of power under load as a potential limiting factor for the poorer performing athletes in each performance tier. However, it is important to consider the discriminative and predictive validity of 'Keiser Squat Test' PPO, before identifying this as a target area for individualised athlete training interventions.

In line with the observations for sprint and jump performance in Chapter 4, the male athletes (both WCP and ND) outperformed the female group across Keiser loads from 140 kg to 200 kg and overall PPO, both in absolute and relative terms ($p < 0.10$). The contrast in PPO between males and females on the 'Keiser Squat Test' could in part be explained by both body mass and neuromuscular differences between the sexes (Vescovi & McGuigan 2008). It is important to note that this study only used body mass as a means of relatively scaling athletes PPO. Hence, this approach does not consider any anthropometric measures such as body composition or muscle cross sectional area. Only using body mass will disadvantage females, as a result of their higher fat mass compared to males (Karastergiou et al. 2012). Thus, the use of fat-free mass may be a more appropriate relative scaling option, to achieve true between sex comparisons.

A difference was only detected between WCP and ND athletes for absolute PPO on the 'Keiser Squat Test' at a load of 140 kg ($p < 0.10$). Also, of all the absolute values, PPO at 160 kg displayed the strongest correlation with push-start performance in the male sample group. Hence, like the findings in skeleton, it could be suggested that PPO produced at lower loads maybe more important for push-start performance (Colyer, Stokes, Bilzon, Cardinale, et al. 2017). These lower loads used in the 'Keiser Squat Test' (i.e. 140 and 160 kg), represent a relatively moderate load in the context of those examined in this study (59 to 67 % of the highest 'Keiser Squat Test' load), which coincides with the push-start and/or the roll-bob pushes requirement to produce high forces against a moderate external load (i.e. 85 to 140 kg). Hence, offering a possible explanation for moderate loads detecting a difference between performance tiers (i.e. WCP and ND) and representing the strongest push-start predictive value. However, it is important to acknowledge that moderate push-start performance correlations were also observed for absolute PPO at 180 kg, 220 kg and 240 kg. The confidence intervals between these test loads will overlap, due to the small sample of male bobsleigh athletes used in this study. More testing with a larger sample size is required to confirm the importance of power production at a moderate load for the bobsleigh push-start.

Despite these moderate correlations for male bobsleigh athletes between push-start performance and PPO across several of the 'Keiser Squat Test' loads, when expressed in their relative form only trivial to small relationships were detected. The collective absolute and relative PPO findings of this study conflict the large to near perfect correlations reported in the literature for loaded power measurements and the skeleton push-start (Colyer 2015; Sands et al. 2005). These discrepancies may in part be attributed to the disparity in testing apparatus and methodologies used. However, it seems more likely that the current literature has reported inflated correlations, as a result of pooling data for males and females (Meylan et al. 2009). Therefore, the present results suggest that for push-start performance absolute as opposed to relative power is more important. Additional support for this is that the least powerful male always produces a higher absolute PPO than the most powerful female and this is not the case for relative PPO. These findings partly confirm those presented in study 2 of this thesis (see Chapter 4), which identified body mass as a predictor of the push-start. Collectively these both reflect the advantage of body size when moving an external load. However, it is important to acknowledge that an optimal athlete body mass exists in bobsleigh (i.e. male approx. 90 to 110 kg and female 70 to 80 kg), due to minimum sled (i.e. without crew) and maximal loaded sled (i.e. with crew) weight restrictions (Deweese et al. 2014a; IBSF 2015). Thus, a gain in body mass may not be performance advantageous for all athletes.

Unlike for the male sample group, very large to near perfect correlations were detected for female athletes between roll-bob push performances and PPO at all ‘Keiser Squat Test’ loads in both absolute and relative terms, as well as overall absolute and relative PPO. However, the sample of female athletes included in this study is small (even relative to the male sample group) and it is apparent from Figure 5.1 that the results are quite dispersed. This offers a possible explanation for the differences in correlation strengths observed between sexes. Subsequently, the female results need to be interpreted with caution. Despite this, based on the linear regression equation presented in Figure 5.1, increasing ‘Keiser Squat Test’ PPO by 140 W could reduce push-start time by 0.10 s. In turn, this improvement could translate into a reduction in finish time of up to 0.37 s, at push-start dominant race tracks (see Chapter 3). However, more research is required to confirm the ‘Keiser Squat Test’: push-start performance relationship in female athletes, as well as explore the transfer between improvements in ‘Keiser Squat Test’ PPO and improvements in push-start performance.

Based on the interpretations thus far, there is sufficient evidence to suggest that the addition of ‘Keiser Squat Test’ absolute PPO to the British Bobsleigh ‘evaluation test’, may help to account for some of the unexplained variance in the push-start highlighted in Chapter 4. This is further supported by the correlations for each test load (loads moderately correlated to the roll-bob push only) with sprint performance (shared variance 2 to 12 %) and the 5-RBJ (shared variance 3 to 8 %), with the shared variances all indicating that 'Keiser Squat Test' PPO is measuring a unique quality, when compared to the general performance tests already included within the British Bobsleigh 'evaluation test'. Additionally, there would be no need to include all 'Keiser Squat Test' loads, given the very large to near perfect intercorrelations observed between absolute PPO at all loads. Based on the results of this study in conjunction with the findings of Chapter 4, these data suggest the use of the following measurements when attempting to quantify athletes push-start capabilities; body mass, sprint performance, and Keiser Squat Test PPO.

5.4.4 Limitations

One limitation of the present study is the paucity of female athletes who took part and thus the findings for this athlete group should be interpreted with caution. However, the recruitment of a larger female sample group in bobsleigh is not feasible, given the limited pool of only 10 athletes within the current British Bobsleigh population. Secondly, this study only used body mass as a method of determining athletes relative PPO performances. Other relative scaling approaches exist including the use of fat free mass or muscle cross sectional area, however the addition of such measurements to a national squad testing day that includes up to 30 athletes may be unrealistic. Finally, it could be argued that higher loads should have been tested, given that for several athletes a drop off in PPO was not observed with increasing load. However, it is apparent from the results that the strongest correlation with the roll-bob push was observed at the second lightest load tested; 160kg.

5.4.5 Practical Applications

The findings of the pilot study confirm the reliability of the British Bobsleigh 'Keiser Squat Test' protocol in ND athletes, hence it can be used as a method to monitor and evaluate PPO qualities of bobsleigh athletes across different loads. 'Keiser Squat Test' absolute and relative PPO is a valid predictor of push-start performance in female bobsleigh athletes. However, for male bobsleigh athletes it appears that 'Keiser Squat Test' absolute PPO at moderate loads provides the greatest discriminative (i.e. 140 kg) and predictive (i.e. 160 kg) validity for push-start performance. Also, absolute PPO is an independent quality when compared to sprint performance, with both qualities explaining a similar amount of the variance in push-start performance. Taking this into consideration as well as earlier findings in this thesis, it is recommended that Keiser Squat Test absolute PPO is added to the British Bobsleigh 'evaluation test', as it may help to account for some of the unexplained variance observed in male push-start performance (see Chapter 4). These recommendations highlight the importance of body mass, sprint acceleration (30 m sprint) and power production under a moderate load ('Keiser Squat Test' PPO) as important qualities for bobsleigh push-start performance.

5.4.6 Conclusions

In line with the initial aim of this study, the author explored the reliability, discriminative validity and predictive validity of the British Bobsleigh 'Keiser Squat Test'. The present investigation established the following key outcomes:

1. The British Bobsleigh 'Keiser Squat Test' protocol is reliable in ND bobsleigh athletes.
2. 'Keiser Squat Test' absolute and relative PPO has almost perfect push-start predictive value for female bobsleigh athletes.
3. For male bobsleigh athletes, 'Keiser Squat Test' absolute PPO is a moderate predictor of push-start performance and PPO at a moderate load (i.e. 140 kg) can distinguish between WCP and ND male bobsleigh athletes.
4. All 'Keiser Squat Test' loads represent the same quality and test PPO is an independent quality when compared to the general performance tests in the British Bobsleigh 'evaluation test'.
5. It is recommended that 'Keiser Squat Test' PPO is added to the British Bobsleigh 'evaluation test', as it could help to account for some of the currently unexplained variance in the qualities that determine push-start performance.

Chapter 6

STUDY 4: The Application of Vertical and Horizontal Jump Testing to Bobsleigh

6.1 Introduction

6.1.1 Preface

Based on the current performance testing practices of British Bobsleigh, previous work in this thesis has highlighted body mass, sprint acceleration (30 m) and power production under loaded conditions, as important measures when determining the key qualities underpinning an athlete's push-start performance. However, beyond the tests utilised by the British team, a large selection of other strength and power based tests exist, allowing practitioners to quantify and evaluate the qualities of their athletes (McGuigan et al. 2013). For instance, ballistic (e.g. SJ & CMJ), reactive (e.g. DJ) and isoinertial (e.g. 1RM back squat) strength tests have been utilised when attempting to explain qualities amongst elite sprinters and professional rugby league players (Baker & Nance 1999; Coh & Mackala 2013; Luturco et al. 2015). However, it is important that the tests selected measure qualities that are related to the performance demands of the given sport (McGuigan et al. 2013). To improve the understanding of bobsleigh performance, there is a need to determine if any other strength and power tests relate to the push-start, and if so whether they help to account for some of the unexplained performance variance identified in chapter 4.

6.1.2 Jump Testing

One of the most commonly used lower body power tests within strength and power diagnostics is the CMJ, which has been repeatedly shown to relate to sprint acceleration performance, across a range of populations from elite sprinters to physical education students (Alemdaroğlu 2012; Cronin & Hansen 2005; Dobbs et al. 2015; Loturco et al. 2015; Maulder & Cronin 2005; Maulder et al. 2006; McFarland et al. 2016; Meylan et al. 2009; Vescovi & McGuigan

2008; Young et al. 2011). It could be speculated that the known relationship between a CMJ and sprinting has provided the rationale for the use of a CMJ across a body of research in bobsleigh (Forrow 2013; Godfrey et al. 2007; Osbeck et al. 1996; Sanno et al. 2013). However, to date, the research surrounding the relationship between CMJ and push-start performance in winter sliding sports is limited to a handful of studies (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Osbeck et al. 1996; Sands et al. 2005). The available research indicates that CMJ height could be a valuable predictor of push-start performance in both bobsleigh and skeleton (r = -0.58 to -0.92). Although this provides support for the use of the CMJ, as highlighted by Holm et al. (2008), height alone does not explain which underlying characteristics of the jump relate most closely to performance. Hence, further kinetic analysis into the CMJ may provide a more valuable insight (Holm et al. 2008). This is supported by the works of Maulder et al. (2006), who demonstrated CMJ force and power (r = -0.70 to -0.79) to be stronger predictors than jump height (r = -0.13) of 10m block start performance in national level sprinters. Both Colyer et al. (2015) and Sands et al. (2005) included similar CMJ kinetic analysis when examining skeleton athletes, however both findings are somewhat limited by the heterogeneous nature of the sample groups; both studies pooled results for males and females.

Meylan et al. (2009) have questioned the ecological validity of vertical jump assessments, arguing that human movements such as sprinting, also include horizontal force production, which is not measured during this type of jump assessment. This theory is supported by the recent works of Dobbs et al. (2015) and Loturco et al. (2015) who have both demonstrated that SLJ peak force, is a stronger predictor of 30 m sprint performance (time and velocity respectively) than CMJ peak force (SLJ r = -0.62 and 0.62; CMJ r = -0.44 and 0.33 respectively). The push-start in bobsleigh is similar to sprinting in that athletes are primarily trying to achieve horizontal propulsion (McCurdy et al. 2010), thus USA and Canadian bobsleigh have documented their use of the SLJ when testing their talent identification and elite squad athletes (Bobsleigh Canada 2015; USBSF 2015). Given its use across bobsleigh, it is somewhat surprising that only one study exists examining its relationship with the push-start, reporting small to large correlations for SLJ distance (*r* = -0.23 to -0.56) (Harrison 2017). However, the work in question only measured jump distance and did not include any kinetic analysis.

Based on previous literature the CMJ or SLJ could add to the understanding of the push-start. However, both are typically completed bilaterally. As highlighted by Maulder and Cronin (2005), this lacks specificity to many movements (including bobsleigh), where unilateral force production is required. Maulder and Cronin (2005) argued that undertaking the aforementioned jumps unilaterally may better represent the power requirements of movement. Additionally, unilateral kinetics can be used to help inform specific training interventions to address force asymmetries. For example, Brown et al. (2017) used a targeted unilateral hip extension intervention to reduce horizontal force asymmetries and improve sprint performance. As well as impacting on athletic performance, Brown et al. (2017) highlighted that force asymmetries can potentially increase injury risk. Additional support for this is provided in a one year study which demonstrated elite sprinters who sustained an injury, displayed strength deficiencies in the injured limb (Sugiura et al. 2008). To date, no unilateral jump kinetic research has been undertaken within bobsleigh. Thus, highlighting a topic of interest for this thesis, given that unilateral jump kinetic measurements may better represent the power requirements of bobsleigh, as well as their potential to inform training interventions.

The unilateral force demands of the push-start could be suggested to cause the development of a bilateral force deficit in bobsleigh athletes, a phenomenon where force production from one bilateral task is smaller than the total force from two unilateral tasks (Bračič et al. 2010; Nijem & Galpin 2014). Bračič et al. (2010) have provided evidence to support the existence of the bilateral force deficit in elite sprinters, highlighting a negative association between the bilateral force deficit and the total impluse of force on the blocks (*r* = -0.55), as well as rear leg peak force production (*r* = -0.63) during sprint starts (e.g. a greater bilateral force deficit was related to higher total impluse of force and rear leg peak force production). Despite this work, the research surrounding the link between the bilateral force deficit and athletic performance is still limited and warrants further investigation (Skarabot et al. 2016). This highlights a potential area to explore within bobsleigh. Like the observations in sprinting above (Bračič et al. 2010), in theory, given the bobsleigh push-start is a unilateral based movement, it would be advantageous for athletes to be stronger unilaterally i.e. display a larger bilateral force deficit. Given this suggestion, from this point on the author will replace the term ‘bilateral force deficit’ with ‘unilateral force facilitation’.

6.1.3 Rationale

Previous work within this thesis highlighted a clear need to explore additional qualities that contribute to push-start performance. It is evident from the current body of literature that research surrounding the determinants of the push-start is scarce, not only in bobsleigh but other winter sliding sports such as skeleton. Nevertheless, the limited work in the area, in conjunction with the strength and power diagnostic and sprint performance literature, has highlighted several tests and approaches that warrant further investigation. These areas include examination of CMJ and SLJ tests performed both bilaterally and unilaterally, with the addition of kinetic analysis during these jump assessments. Finally, the presence of any unilateral force asymmetries as well as the unilateral force facilitation and their links with push-start performance has yet to be explored within the sport.

6.1.4 Aim

The aim of this study is to investigate the validity of vertical and horizontal jump test metrics completed under both bilateral and unilateral conditions, to predict push-start performance.

6.2 Method

6.2.1 Athletes

Six male bobsleigh athletes, who were all part of the British Bobsleigh ND squad took part in this study. This sample represents 66% of the British Bobsleigh ND squad. On average, the athletes had been part of the programme for 4 years (range 3 to 5 years) and in the previous season had all competed in either multiple World Cup or Europa Cup races. The sample's mean (range) characteristics are as follows; age 26 (20 to 31) years, mass 97.3 (91.9 to 103.2) kg and height 184 (176 to 190) cm. Cardiff Metropolitan University's School of Sport ethics committee granted the project ethics approval. Consent for use of the data presented below was provided by British Bobsleigh's Performance Director.

6.2.2 Experimental Design Overview

All testing took place in July 2016, as part of British Bobsleigh's pre-season preparations for the 2016/2017 on-ice racing season. Athletes were required to take part in two testing sessions (jump testing and the British Bobsleigh 'evaluation test') separated by 3 days and scheduled within one of the ND squad camps (see Table 6.1). On day three of the camp, athletes undertook jump testing in the high-performance gym facility located at the British Bobsleigh National Training Centre (see Methods 6.2.3). On the final day of the camp, athletes were required to take part in the British Bobsleigh 'evaluation test', at the National Indoor Athletics Centre located at Cardiff Metropolitan University, Wales. The 'evaluation test' was completed in accordance with the procedure outlined in chapter 4 (see Chapter 4.2.3). The results from this latter testing were used to explore the relationship between jumping and push-start performance. The heavy back roll-bob push was selected as the criterion measure to assess an athlete's push-start capabilities, given its very large relationship (r = 0.85) with the push-start detected earlier in the thesis (see Chapter 4).

Table 6.1 British Bobsleigh pre-season camp schedule for national development squad athletes.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
Morning	Technical Pushing	Pushing	Jump Testing S&C	Pushing	Technical Pushing	Rest
Afternoon	S&C	Injury Prevention	Rest	S&C	Recovery	'Evaluation Test'

6.2.3 Jump Testing

Prior to testing, all athletes were given 20 minutes to complete their own individualised warm up plans, which consisted of a selection of the following; foam rolling, mobility exercises, cycling and jumping/bounding. Athletes were instructed to ensure by the end of this 20-minute period they were physically ready to achieve maximal performance during the jump testing. This was then followed by a 10-minute jump familiarisation session, including up to two submaximal reps of each jump test. The warm up protocol outlined above was chosen over a standardised approach, as it is reflective of the 'evaluation test' protocol currently implemented by British Bobsleigh (see Chapter 4.2.2). After familiarisation, all athletes completed two trials of each jump test in the following order:

1. Bilateral CMJ: Trial 1
2. Unilateral CMJ (left and then right): Trial 1
3. Bilateral CMJ: Trial 2
4. Unilateral CMJ (left and then right): Trial 2
5. Bilateral SLJ: Trial 1
6. Unilateral SLJ (left and then right): Trial 1
7. Bilateral SLJ: Trial 2
8. Unilateral SLJ (left and then right): Trial 2

Throughout jump testing, left and right jump attempts were completed consecutively within the same trial, approximately 20 seconds apart. A minimum of 3 minutes recovery was given between each of the eight jump trials included within testing. Unfortunately, one athlete had to withdraw because of an on-going injury issue following the second unilateral CMJ trial, therefore only five athletes completed the SLJ included in the testing session.

The reliability of both the CMJ and SLJ tests used in this work have been demonstrated in previous research (ICC = 0.71 to 0.95; CV = 2.1 to 9.9 %) amongst elite AFL athletes, highly trained rugby players and team sport athletes (Cormack et al. 2008; Dobbs et al. 2015; Meylan et al. 2010).

6.2.3.1 Bilateral and Unilateral Countermovement Jump

For both the bilateral and unilateral CMJ, athletes started from a fully erect upright position (knee at full extension) and were instructed to sink to a self-selected depth, then instantly attempt to jump as high as possible (Maulder et al. 2006). Hands were required to remain on hips throughout the jumps and athletes were encouraged to land on two feet for both the bilateral and unilateral attempts to minimise any injury risk. In accordance with Maulder and Cronin (2005), for all vertical jumps athletes were instructed to take off and land on the same spot, with the knees and ankles in an extended position.

6.2.3.2 Bilateral and Unilateral Standing Long Jump

From the same start position as the CMJ, athletes were instructed to sink to a self-selected depth before instantly attempting to jump as far as possible (Dobbs et al. 2015; Meylan et al. 2010). To minimise injury risk, athletes were not required to stick the landing and were encouraged to use a double legged landing strategy. Swinging of the arms were permitted throughout all bilateral and unilateral SLJ tests.

For all jumps (CMJ or SLJ and bilateral or unilateral), if any athlete deviated away from the required technique, the trial in question was discarded and repeated until the correct technique was achieved.

6.2.3.3 Data Collection and Analysis

Jumps were performed on a portable force plate (AMTI, Massachusetts, USA) sampling at 1000 Hz, with all data acquisition and analysis undertaken via AccuPower 2.0. The software was set to trigger data collection at a F_z < 20 Hz, following which a 2nd order Butterworth low-pass filter, with a cut off frequency of 20 Hz was applied to filter the raw force data (AMTI 2014). AccuPower then automatically calculated the following variables of interest using the equations outlined below (AMTI 2014):

- CMJ Height (cm): Derived from projectile motion equations, see Eq. [6.1] and represents the maximum vertical displacement of the centre of mass following take-off.

$$JH = V^2 / 2*G \qquad [6.1]$$

Where JH = jump height, V = vertical velocity of centre of mass at take-off, G = gravity.

- CMJ Peak Force (N): Maximal instantaneous ground reaction force applied in the vertical direction, by the athlete during the jump cycle.
- CMJ Peak Power (W): Derived using Eq. [6.2] and represents the maximum positive power value observed during the jump cycle.

$$P = F^r \; x \; V^r \qquad [6.2]$$

Where P = peak power, F^r = resultant force, V^r = resultant centre of mass velocity.

- SLJ Jump Distance (cm): Derived using multiple equations (developed by AMTI (2014)) using take off velocity, flight time and landing angle. The distance represents the maximal horizontal displacement of the centre of mass following take-off. A similar approach has been used by Meylan et al. (2012).
- SLJ Peak Horizontal Force (N): Maximal instantaneous ground reaction force applied in the horizontal direction by the athlete during the jump cycle.
- SLJ Peak Horizontal Power (W): Derived using Eq. [6.2] and represents the maximum positive power value observed during the jump cycle in the horizontal direction.

The above outputs from the AccuPower software were then exported to Microsoft Excel (Microsoft, USA), where normalised values (expressed against body mass) were calculated for all variables, except jump height and distance. The CMJ and SLJ attempts where the greatest absolute peak force was achieved were used in all further analysis. In line with previous research, the leg that achieved the better performance in the unilateral jump attempts was defined as the dominant leg (Focke et al. 2016; Kobayashi et al. 2013; Stephens et al. 2007). However, in the present study, this was determined using absolute peak force, as opposed to jump height.

As in the works of Meylan et al. (2010) and Newton et al. (2006), asymmetry index values were determined using Eq. [6.3]. The resultant indexes were then all converted to positive values for further statistical analysis and interpretation. An asymmetry index threshold of > 10% was set to indicate the presence of a between limb asymmetry (Meylan et al. 2010).

Asymmetry index (%) = [(Dominant leg – Non-Dominant Leg) / Dominant Leg)] x 100 [6.3]

Bilateral index values were calculated for all variables in accordance with the equation outlined by Howard and Enoka (1991) see Eq. [6.4], which replicates aspects of the approaches taken by Bračič et al. (2010) and Pain (2014). A bilateral index > 0 % indicates a bilateral facilitation and a bilateral index < 0 % indicates a unilateral facilitation (which previous literature has classified as a bilateral deficit).

Bilateral Index (%) = [100 x (bilateral leg measure/ (dominant leg measure + none-dominant leg measure))] – 100 [6.4]

6.2.4 Statistical Analysis

Data is reported as mean (range) values and all statistical analysis was undertaken using IBM SPSS statistics (Version 23, SPSS, Chicago, USA). Normality of all bilateral and unilateral CMJ and SLJ variables (jump height/distance, force and power) as well as 'evaluation test' scores used during the study were assessed using the Shapiro-Wilk Normality Test. Following the removal of any extreme outliers, normality was confirmed for all variables ($p < 0.05$ or Skewness between – 2.0 to + 2.0). Cohen's effect sizes were calculated to determine the magnitude of differences between dominant and non-dominant leg jump performance for all variables and were classified based on the following thresholds; < 0.20 trivial, ≥ 0.20-0.59 small, ≥ 0.60-1.19 moderate, ≥ 1.20-1.99 large, ≥ 2.00 very large (Hopkins 2002). Pearson's correlation coefficients were determined between the roll-bob push and all the CMJ and SLJ parameters. Additionally, an inter-correlation analysis was run using 30 m sprint time, as well as the jump test parameters that demonstrated at least a large relationship with the roll-bob push. Finally, a correlation analysis was undertaken to determine the relationships between asymmetry index as well as bilateral index values and roll-bob push performance. Correlation strengths were classified using the guidelines outlined by Hopkins (2002); <0.10 = trivial, 0.10-0.29 = small, 0.30-0.49 = moderate, 0.50-0.69 = large, 0.70-0.89 = very large and ≥ 0.9 = near perfect. As the current study involved exploratory research with a small sample of homogenous bobsleigh athletes, an alpha value of $p < 0.10$ was set as statistically significant for all analysis.

6.3 Results

6.3.1 'Evaluation Test' and Jump Testing

The mean and range results for the British Bobsleigh 'evaluation test' are presented below (see Table 6.2). Of those athletes included within the study, 4 out of 6 achieved British Bobsleigh's minimum funding consideration points target of 800, with all finishing in the Top 6 when ranked against the remainder of the ND squad.

Table 6.2 Group mean (range) results for the British Bobsleigh 'evaluation test'.

Parameter	Mean (range)
'Evaluation test' (n = 6)	
30m Sprint (s)	3.82 (3.71-3.91)
Flying 30m Sprint (30-60 m) (s)	3.03 (2.92-3.15)
60m Sprint (s)	6.85 (6.63-6.96)
5-RBJ (m)	17.00 (15.78-17.47)
Light back roll-bob push (10-40 m) (s)	3.89 (3.80-3.99)
Light side roll-bob push (10-40 m (s)	3.92 (3.85-3.97)
Heavy back roll-bob push (10-40 m) (s)	4.07 (4.00-4.14)
Heavy side roll-bob push (10-40 m) (s)	4.12 (4.02-4.20)
Total Points	811 (779-865)

Table 6.3 and Table 6.4 displays the mean and range values for the CMJ and SLJ tests, under both bilateral and unilateral conditions. Asymmetry index and bilateral index values are also presented alongside the data. A large range in values were observed across all kinetic measures for both jump tests, even when considered relative to the mean group values (CMJ bilateral 14 to 42 %, CMJ unilateral 13 to 52 %, SLJ bilateral 21 to 31 % & SLJ unilateral 28 to 55 %).

Table 6.3 Group mean (range) values for countermovement jump kinetic measures (n = 6).

Parameters	Bilateral	Dominant Leg	Non-Dominant Leg	Asymmetry Index	Bilateral Index
Jump Height (cm)	40.0 (37.1-43.9)	17.2 (13.5-21.8)	18.6 (13.2-22.9)	18.9% (5.8 to 34.3%)	13.1% (3.6 to 34.8%)
Peak Force (N)	2502 (2168-3225)	1991 (1845-2240)	1926 (1832-2121)	3.1% (0.1% to 5.3%)	-36.3% (-26.0 to -41.4%)
Relative Peak Force (N)	25.6 (21.8-30.8)	20.4 (18.6-22.3)	19.7 (18.5-21.2)	3.1% (0.1% to 5.3%)	-36.3% (-26.0 to -41.4%)
Peak Power (W)	5812 (5334-6288)	3355 (3077-3685)	3446 (2927-3884)	7.7% (3.8% to 15.1%)	-14.4% (-6.6 to -20.6%)
Relative Peak Power ($W.kg^{-1}$)	59.5 (53.7-62.1)	34.4 (31.1-37.9)	35.4 (29.4-39.8)	7.7% (3.8% to 15.1%)	-14.4% (-6.6 to -20.6%)

cm = centimetres, N = newtons, W = watts, kg = kilograms.

Table 6.4 Group mean (range) values for standing long jump kinetic measures (n = 5).

Parameters	Bilateral	Dominant Leg	Non-Dominant Leg	Asymmetry Index	Bilateral Index
Jump Distance (cm)	308 (261-346)	245 (203-296)	245 (204-294)	1.8% (0.2% to 4.0%)	-36.9% (-31.6 to -42.5%)
Peak Horizontal Force (N)	1104 (948-1286)	766 (685-903)	698 ^{m} (605-881)	8.9% (2.5% to 20.0%)	-24.1% (-15.9 to -31.7%)
Relative Peak Horizontal Force ($N.kg^{-1}$)	11.36 (9.68-13.06)	7.9 (6.5-9.2)	7.2 ^{m} (5.8-8.9)	8.9% (2.5% to 20.0%)	-24.1% (-15.9 to -31.7%)
Peak Horizontal Power (W)	3066 (2707-3362)	1855 (1438-2206)	1685 (1282-2151)	9.0% (1.2% to 21.0%)	-12.1% (3.7 to -22.3%)
Relative Peak Horizontal Power (W)	31.58 (26.90-34.72)	19.1 (13.7-22.7)	17.4 (12.2-21.8)	9.0% (1.2% to 21.0%)	-12.1% (3.7 to -22.3%)

cm = centimetres, N = newtons, W = watts, kg = kilograms, ^{m} = moderate difference from dominant leg (effect size > 0.60).

The relationships for all jump measures with the roll-bob push are summarised in Table 6.5. A large negative correlation was observed between the roll-bob push and non-dominant leg SLJ peak force (see Figure 6.1). Large negative relationships were also detected for the roll-bob push and SLJ relative peak horizontal force (r = -0.56, p > 0.10), as well as peak horizontal power (r = -0.55, p > 0.10). Finally, unilateral SLJ distance was shown to have a large positive correlation with the roll-bob push (r = 0.53 and 0.54, p > 0.10), however, the positive direction of these relationships suggests that a longer jump distance is indicative of slower roll-bob push times.

Table 6.5 Pearson correlation coefficients (r values) between the roll-bob push and kinetic measures from both the bilateral or unilateral countermovement jump and the unilateral or bilateral standing long jump.

Parameters	Bilateral	Dominant	Non-Dominant
Countermovement Jump (n = 6)			
Jump Height (cm)	0.42	0.08	0.36
Peak Force (N)	0.22	0.15	0.03
Relative Peak Force (N/kg)	0.27	0.22	0.09
Peak Power (W)	-0.12	-0.02	0.15
Relative Peak Power (W/kg)	-0.11	0.03	0.17
Standing Long Jump (n = 5)			
Jump Distance (cm)	0.32	0.53 [L]	0.54 [L]
Peak Horizontal Force (N)	0.03	-0.15	-0.61 [L]
Relative Peak Horizontal Force (N/kg)	0.06	-0.16	-0.56 [L]
Peak Horizontal Power (W)	0.25	-0.12	-0.55 [L]
Relative Peak Horizontal Power (W/kg)	0.24	-0.08	-0.48

* [L] = large correlation (r = ≥ 0.50), cm = centimetres, N = newtons, W = watts, kg = kilograms.

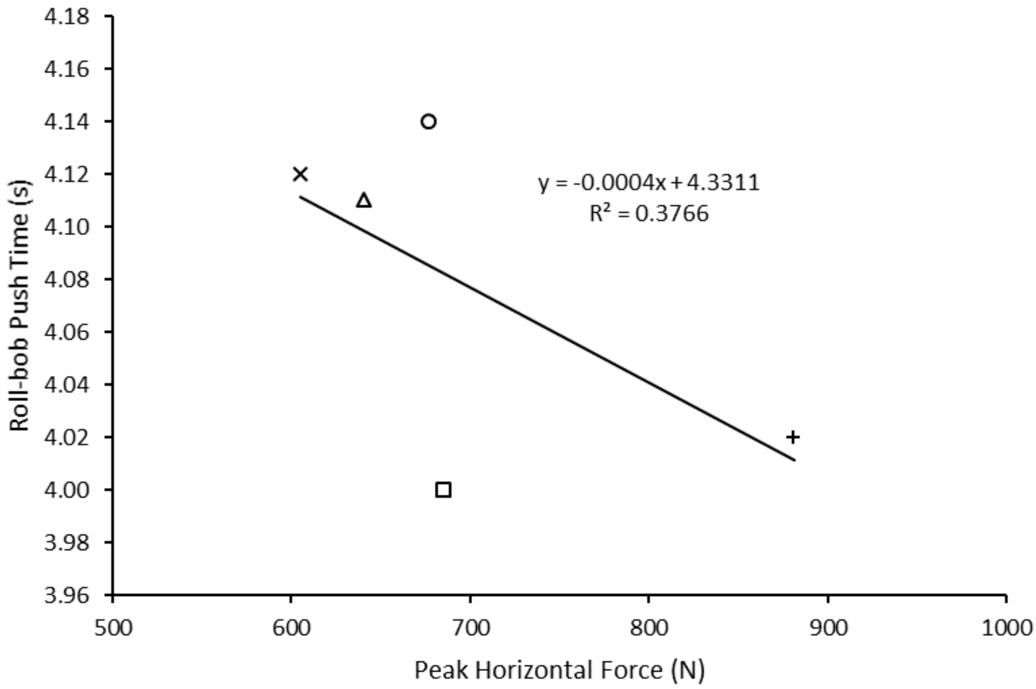

Figure 6.1 Relationship between standing long jump peak horizontal force (N) and roll-bob push time (s).

Inter-correlation analysis between the 30 m sprint and jump parameters that demonstrated at least a large correlation ($r \geq 0.50$) with the roll-bob push, are displayed in Table 6.6. The analysis revealed both very large and near perfect correlations ($p < 0.10$) when jump performance metrics were considered in isolation, with a common variance of 88 to 92 %. However, when sprint and jump performances were compared to one another, only moderate to large relationships were detected, with a common variance < 33 %.

Table 6.6 Inter-correlation matrix (r values) for the 30 m sprint and standing long jump parameters that demonstrated at least a large (r = ≥ 0.50) correlation with roll-bob push performance.

Parameter	Non-Dominant SLJ Peak Horizontal Force	Non-Dominant SLJ Relative Peak Horizontal Force	Non-Dominant SLJ Peak Horizontal Power	30m Sprint
Peak Horizontal Force (N)	1			
Relative Peak Horizontal Force ($N.kg^{-1}$)	0.94 ^{NP*}	1		
Peak Horizontal Power (W)	0.95 ^{NP*}	0.96 ^{NP*}	1	
30m Sprint (s)	0.55 ^{L}	0.57 ^{L}	0.49 ^{m}	1

^{m} = moderate correlation (*r* = 0.30 to 0.49), ^{L} = large correlation (*r* = 0.50 to 0.69), ^{VL} = very large correlation (*r* = 0.70 to 0.89), ^{NP} = near perfect correlation (*r* = ≥ 0.90), * = $p < 0.10$.

6.3.2 Asymmetry Index

As can be seen from the range data in Table 6.3 and 6.4, a CMJ and SLJ limb asymmetry (asymmetry index > 10 %) exists for some but not all athletes in the sample group. Four out of the six athletes who took part in this study displayed a limb asymmetry for CMJ height (13 to 34 %), however only two of these athletes also displayed an asymmetry for absolute/relative CMJ peak force and peak power (10 and 15 %). Contrastingly, no athletes displayed a SLJ asymmetry when considering the parameter jump distance. However, the presence of a limb asymmetry was apparent for two athletes when examining peak horizontal force and peak horizontal power (11 to 21 %). Interestingly, only one of these athletes displayed any form of limb asymmetry for the CMJ test, namely for jump height.

A very large positive correlation ($p < 0.10$) was detected between SLJ peak horizontal force asymmetry index and roll-bob push time (see Figure 6.2). Similar asymmetry index and roll-bob push relationships were observed for SLJ relative peak horizontal force, peak horizontal power and relative peak horizontal power ($r = 0.87$ to 0.88, $p < 0.10$). Finally, a large positive relationship was detected for roll-bob push time when compared to SLJ distance asymmetry index ($r = 0.50$, $p > 0.10$). In contrast, only small to moderate correlations were seen between the push-start criterion measure and asymmetry index values for all CMJ parameters ($r = 0.13$ to 0.49, $p > 0.10$).

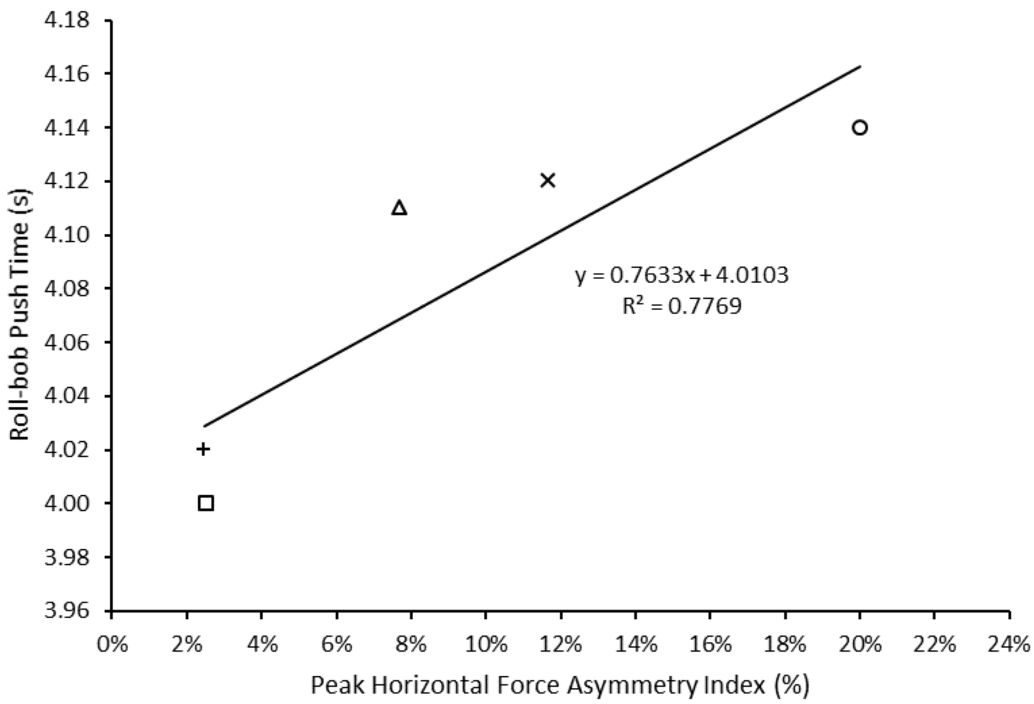

Figure 6.2 Relationship between standing long jump peak horizontal force asymmetry index (%) and roll-bob push time (s).

6.3.3 Unilateral Facilitation

Small differences were detected for all variables, when comparing dominant and non-dominant leg CMJ performance (ES = 0.33 to 0.51, see Table 6.3). For jump height, this translated into bilateral facilitation for all athletes, with bilateral index values ranging from 3.6 to 34.8 %. Contrastingly, all athletes displayed a unilateral facilitation for absolute and relative CMJ peak force, as well as absolute and relative peak power (bilateral indexes ranging from -15.9 to -31.7 % and -6.6 to -20.6 % respectively).

Moderate differences were observed between dominant and non-dominant leg SLJ horizontal peak force, when expressed in both its absolute and relative form (ES = 0.66 and 0.63 respectively). Apart from one athlete's peak horizontal absolute and relative power bilateral index (3.7 %; bilateral facilitation), all athletes displayed a unilateral facilitation across all variables; jump distance (-31.6 to -42.4 %), peak horizontal force (-15.9 to -31.7 %) and peak horizontal power (3.7 to -22.3 %).

It is apparent from Figures 6.3 and 6.4 that bilateral index values for SLJ peak horizontal force and power, were largely or very largely related to the roll-bob push (r = 0.67, p > 0.10 and r = 0.71 p > 0.10 respectively). Hence, this indicates those with a faster roll-bob push have a greater unilateral facilitation for these variables. Contrastingly, for SLJ distance and all CMJ variables (height, peak force & peak power), bilateral index values were only small to moderately related to the roll-bob push (r = -0.11 to -0.48, p > 0.10).

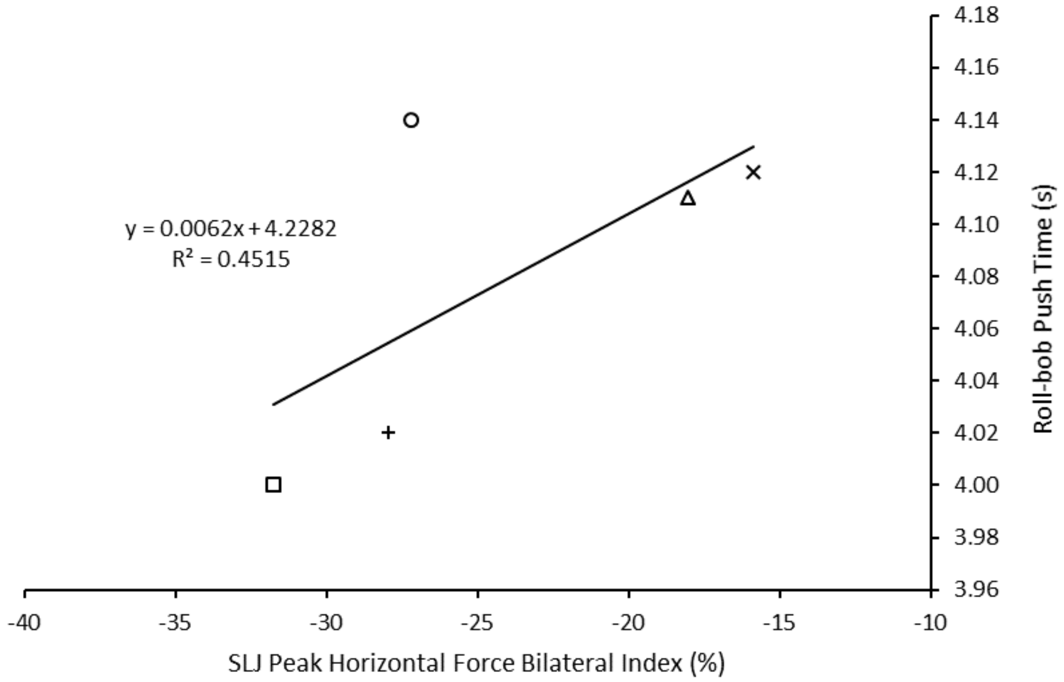

Figure 6.3 Relationship between standing long jump peak horizontal force bilateral index (%) and roll-bob push time (s).

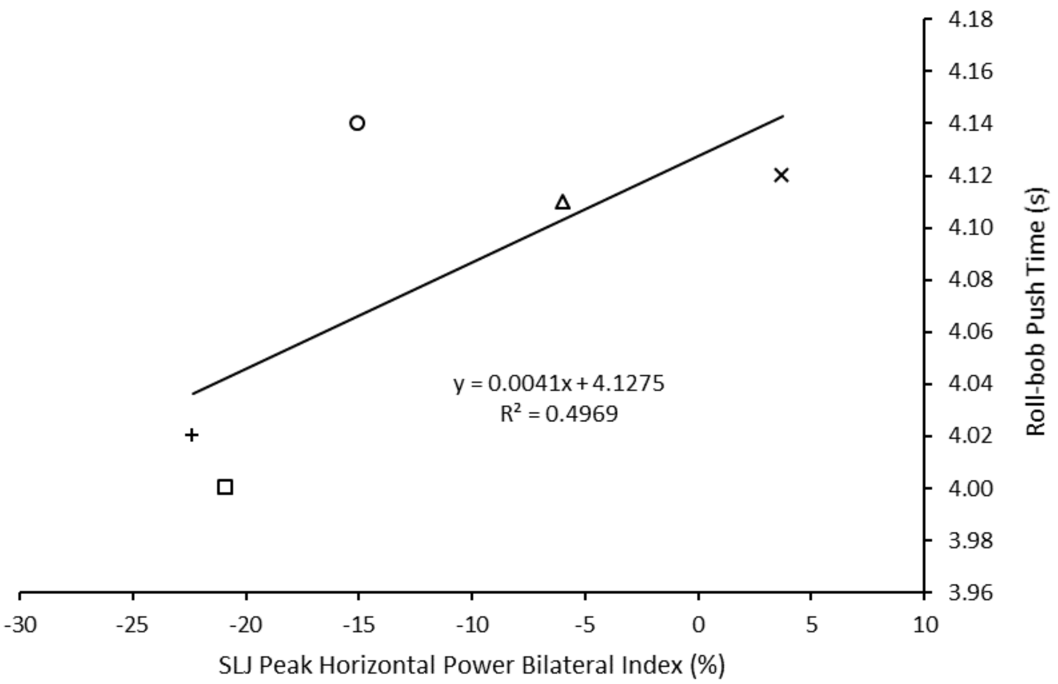

Figure 6.4 Relationship between standing long jump peak horizontal power bilateral index (%) and roll-bob push time (s).

6.4 Discussion

6.4.1 Key Findings

Although this is a small homogenous sample of athletes the normative data indicates a large range in values across all CMJ and SLJ measures, even when considered relative to the group mean (CMJ 13 to 52 % & SLJ 21 to 55 %). The results demonstrated large negative correlations between roll-bob performance and unilateral non-dominant leg SLJ peak horizontal force, relative peak horizontal force and peak horizontal power. Hence, a greater SLJ force or power was related to a quicker push-start time. This was not the case when examining either the bilateral jump condition or the CMJ under both unilateral or bilateral conditions, as no large relationships with the roll-bob push were detected. The present study also demonstrated some athletes exhibited a between limb asymmetry, however it appears that these asymmetries are both movement and parameter specific. Finally, this investigation detected the existence of a unilateral force and power facilitation in male bobsleigh athletes. When examining the relationship for roll-bob performance, large to very large correlations were observed for both SLJ force and power asymmetry index and bilateral index values. Considered collectively, the evidence from this study identifies the unilateral SLJ as a potential means to explain some of the unaccounted variance in push-start performance highlighted in chapter 4. Also, the SLJ can highlight differences in individual athlete profiles and may help to inform targeted, individualise training by identifying those athletes with asymmetries and/or poor unilateral facilitations. It is possible to hypothesise that increasing an athlete’s unilateral facilitation while minimising any between limb asymmetries, will have a beneficial impact when trying to improve their push-start performance.

6.4.2 Athlete Benchmarking

The ‘evaluation test’ results displayed above highlight the elite nature of the sample group, given that all athletes matched the World Cup or Americas Cup brakeman sprint time standards outlined by USA bobsleigh (USBSF 2015). Additionally, the range of 5-RBJ and roll-bob push performances in this study exceeded the mean values presented in study 2 of this thesis (see Chapter 4).

A possible explanation for this latter observation is the improved physical standard of athletes involved within the British programme in the intervening two years, because of the programme's goal of achieving medal success at the 2018 Pyeongchang Winter Olympic Games.

To the authors knowledge, the existence of vertical and horizontal jump performance standards for bobsleigh athletes is limited. Hence, this is one of the only studies within the literature, to provide a comprehensive characterisation of the CMJ and SLJ kinetics of a homogenous sample of male bobsleigh athletes. The bilateral CMJ heights reported are in close proximity to those stated for skeleton and bobsleigh athletes in the literature (Sands et al. 2005; Sanno et al. 2013), as well as the SLJ distances being in line with the performance standards outlined by other rival nations (Bobsleigh Canada 2015; USBSF 2015). Additionally, the absolute and relative CMJ peak force values observed in the present investigation are similar to those reported for elite sprinters (Habibi et al. 2010; Loturco et al. 2015) and skeleton athletes (Sands et al. 2005).

Despite these similarities, the CMJ heights reported in this study fail to match those for bobsleigh athletes examined by Forrow (2013) and Osbeck et al. (1996) (mean heights of 67 cm and 79 cm respectively). However, these discrepancies come from experimental differences in measurement protocols between studies, for example Osbeck et al. (1996) used a Vertec apparatus to measure CMJ height. Similar disparities have been displayed when comparing the relative CMJ peak power values in this study to those reported for elite skeleton and sprint athletes, where higher values have been observed in all cases with the exception of Sands et al. (2005) (Colyer 2015; Habibi et al. 2010; Maulder et al. 2006). Given that the athletes involved in these studies all come from either a sprinting or skeleton background (as opposed to bobsleigh), it could be speculated that training history and/or sporting background has played a part in these observed differences. Additionally, it is important to note the large variation in body masses between the present study (91.9 to 103.2 kg) and the literature in question (61.4 to 84.0 kg), as this will have some influence when peak power values are presented in their normalised form, favouring smaller individuals.

The peak SLJ horizontal force values achieved by the athletes in this study are inconsistent with those reported by Loturco et al. (2015) (1104 N and 1899 N respectively). Given the comparable SLJ distances between studies, this observation could suggest that elite sprinters are better able to produce force horizontally, when compared to their bobsleigh counterparts. Hence, it could be speculated that this disparity in SLJ horizontal force might explain the faster acceleration phase velocities observed for Loturco et al. (2015) athletes (30m velocity, 8.67 m/s compared to 7.85 m/s). This hypothesis is based on the similarities between the SLJ test and the sprint acceleration phase, which include the emphasis they both place on horizontal ground reaction force, their requirement to direct leg extension force horizontally and their high concentric component (Wild et al. 2011).

Despite the small, homogenous nature of the present study's sample, the CMJ and SLJ results indicate a large range in values across all measures, when considered relative to the group mean value (14 to 55 %). The large magnitude of these ranges is further highlighted when compared to the range in values observed for roll-bob push performances (3.1 to 4.9 %) and the general performance tests (4.8 to 9.9 %), included in the British Bobsleigh 'evaluation test'. From a talent identification perspective, these findings could make it problematic to set adequate minimum performance thresholds that must be achieved by athletes seeking to gain a place on the programme. Although this begins to question both the CMJ and SLJ tests application to this form of testing, it is also important to consider how well these tests and its accompanying metrics relate to push-start performance. In fact, if any of the CMJ and SLJ parameters are demonstrated to be large predictors of push-start performance, the large range in values observed in the present study becomes less problematic. Instead it identifies a potential limiting factor for the poorer performing athletes, resulting in a large scope for improvement and a focus for targeted, individualised training interventions.

6.4.3 Predicting Push-Start Capabilities

The current study failed to detect any large correlations between any CMJ kinetic measures and roll-bob push performance. These findings are somewhat surprising and conflict the large to near perfect negative correlations reported by previous work for bilateral CMJ kinetics and the push-start (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Osbeck et al. 1996; Sands et al. 2005). However, these comparisons should be interpreted with caution, given the heterogenous nature of several of the sample groups within the previous literature (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017; Sands et al. 2005). This finding coupled with the large range in CMJ performances discussed above, questions the use of the CMJ for performance monitoring and talent identification testing in bobsleigh. Although the CMJ does not appear to relate to push-start performance, the present author acknowledges that the test could still be used by practitioners within bobsleigh for other purposes, such as monitoring neuromuscular status and fatigue (Claudino et al. 2017; Cormack 2008).

The lack of large relationships observed between the CMJ and push-start criterion in the current study, could in part be explained by the fact the CMJ measures force production capabilities in the vertical plane, with little consideration of force produced horizontally (Meylan et al. 2009). This differs from the push-start where force production is required in both the vertical and horizontal planes. These results further corroborate the ideas of Dobbs et al. (2015) that vertical jump kinetic measurements lack ecological validity when attempting to predict sporting performance. Hence, Dobbs et al. (2015) went onto argue that practitioners should include horizontal measures when attempting to quantify the physical qualities of athletes.

To the authors knowledge, this is the first study within winter sliding sports to consider the validity of SLJ kinetic variables to predict the push-start. No large correlations were detected between the roll-bob push and any of the bilateral SLJ kinetic parameters. This result could be explained by the fact that the jump test in question does not replicate the unilateral propulsive force requirements of the push-start. Hence, unilateral SLJ’s may provide better prognostic value than their bilateral counterparts to predict functional sport movements, such as the push-start (Dobbs et al. 2015; Meylan et al. 2009).

A large relationship was observed between unilateral SLJ distance and the roll-bob push. However, the positive direction of this relationship is not advantageous to push-start performance and suggests that a greater jump distance translates to a slower roll-bob push time. Interestingly, large correlations were observed between the roll-bob push and non-dominant leg SLJ peak horizontal force (r = -0.61), relative peak horizontal force (r = -0.56) and horizontal peak power (r = -0.55). These findings agree with those obtained by Dobbs et al. (2015) for peak force and sprint performance over 10 m, 20 m and 30 m (r = -0.51 to -0.55) and also support the ideas of Holms et al. (2008), that the addition of kinetic measurements to jump testing may provide better prognostic value.

Based on the interpretations thus far, it appears that unilateral SLJ kinetic measurements are better predictors of push-start performance, when compared to both bilateral and vertical alternatives. Hence, it could be hypothesised that the addition of the unilateral SLJ and its associated metrics to the British Bobsleigh 'evaluation test', may help to account for some of the unexplained variance in push-start performance outlined in Chapter 4. The inclusion of such measurements is further supported by the unilateral SLJ tests correlation with 30 m sprint performance (r^2 < 33 %), with the shared variance indicating they represent different qualities. Additionally, there would be no need to include both force and power metrics as well as absolute and relative values for the unilateral SLJ, given the near perfect correlations observed between peak horizontal force, relative peak horizontal force and peak horizontal power (r^2 = 88 to 92 %).

6.4.4 Asymmetry Index

Initial interpretation of the CMJ and SLJ mean asymmetry index values using a threshold of 10 % (Meylan et al. 2010), suggests the presence of a between limb asymmetry for only one metric, CMJ height (18.9 %). However, closer inspection of the index ranges and analysis on an individual level, revealed athletes displayed limb asymmetries across the following metrics; CMJ height (n = 4), CMJ absolute/relative peak power (n = 2), SLJ absolute/relative peak force and power (n = 2). No individual athlete asymmetries were identified across any of the other CMJ and SLJ kinetic measurements collected in this study. Hence, from these findings we can infer that some CMJ and SLJ parameters are more sensitive than others to limb asymmetries when using a 10% threshold. In addition to this, those athletes who were found to have a CMJ peak power asymmetry, did not present a SLJ peak force or power asymmetry and vice versa. This provides support for suggestions in the literature that limb asymmetries are movement specific and are influenced by the force application direction of the test (Maulder & Cronin 2005; Meylan et al. 2010).

Very large relationships were detected between SLJ absolute/relative peak force and peak power asymmetry index values and the roll-bob push. However, similar large correlations were not detected when comparing the roll-bob push to asymmetry indexes observed in the CMJ. This combination of findings, in conjunction with the SLJ tests' specificity to the push-start in terms of force application, could lead to suggestions that practitioners should place greater emphasis on asymmetries identified in the horizontal plane. Thus, it could be speculated that interventions prescribed to address SLJ force and power asymmetries (for example athlete ᵒ, see Figure 6.2), may not only reduce injury risk but improve global push-start performance; however, more research is required to substantiate this hypothesis.

6.4.5 Unilateral Facilitation

The presence of a unilateral facilitation for CMJ peak force (-36.2 %), is in agreement with Bračič et al. (2010), who also reported a unilateral facilitation in elite sprinters (-33.2 %). However, in contrast to this work, no evidence of a unilateral facilitation for CMJ height was detected and in fact a bilateral facilitation was observed. A note of caution is due here given that critics have questioned the value of bilateral indexes determined from jump height, given that it is affected by the method used to define height; for example either standing height or height at take-off (Bobbert et al. 2006; Skarabot et al. 2016). To the authors' knowledge, the existing elite athlete research has yet to explore the presence of a unilateral force facilitation in horizontal ballistic movements (e.g. SLJ), hence this is the first study of this nature within the literature. Comparable to the CMJ, the presence of a unilateral facilitation was detected across all SLJ kinetic measurements (-12.1 to -35.9 %).

Skarabot et al. (2016) summarised a number of mechanisms that have been suggested in the literature as possible causes of a unilateral facilitation including; psychological, task specificity, physiological and neurophysiological factors. Although determining the exact mechanisms responsible for the unilateral facilitation detected in bobsleigh athletes is beyond the scope of the present investigation, it could be suggested that neural drive may play a role (Nijem & Galpin 2014; Skarabot et al. 2016). Theoretically, this hypothesis relies on the assumption that there is sufficient difference in neural drive between unilateral and bilateral tasks to cause a performance reduction in the latter (Nijem & Galpin 2014). This theory is supported by the fact that previous research has demonstrated surface electromyography to be higher in unilateral as opposed to bilateral contractions (Gabriel et al. 2006). However, as highlighted in a review by Nijem and Galpin (2014), the current literature lacks a consensus on muscle activation differences between unilateral and bilateral tasks, especially when a unilateral force facilitation is evident.

Much of the current unilateral facilitation literature has failed to explore the phenomenon's relationship with athletic performance (Skarabot et al. 2016). Hence, this study adds to the paucity of research in this area. The large to very large correlations detected between the roll-bob push and SLJ horizontal force (r = 0.67) and power (r = 0.71) bilateral index values, suggest those who displayed greater unilateral facilitation were faster on the roll-bob push (for example, athlete □ & + in Figure 6.3). These findings are in line with previous literature, which has shown greater unilateral facilitation to relate to higher rear leg peak block force production during sprint starts (Bračič et al. 2010). A possible explanation for the relationship between unilateral facilitation and roll-bob push performance might be due to the unilateral force production requirements of the roll-bob push (i.e. the ability of some athletes to better produce unilateral force).

6.4.6 Targeted Training Prescription

Based on the results reported above, the inclusion of the SLJ test and its associated metrics as part of British Bobsleigh's performance testing practices, could be of value to inform training prescription. For example, the two fastest push-start athletes in this study (athlete □ and +), both presented a low SLJ force asymmetry (see Figure 6.2), alongside a high unilateral force facilitation (see Figures 6.3 and 6.4). Despite these similarities, the two athletes produced very different unilateral SLJ peak horizontal force values (see Figure 6.1). Thus, these observations suggest that athlete □ training should focus on developing unilateral horizontal force. In another case example, Athlete ○ displayed a similar SLJ peak force output on the non-dominant leg as athlete □ (see Figure 6.1), as well as a good SLJ unilateral force facilitation (see Figures 6.3 and 6.4). Nevertheless, athlete ○ displayed a very poor horizontal asymmetry and thus training should prioritise reducing this asymmetry and strengthening his weaker limb.

6.4.7 Limitations

One weakness of the current study is the limited number of bobsleigh athletes included, however this has resulted from the project being undertaken in the high-performance environment. The athletes were drawn from a total population of n = 9 athletes in the ND squad and 'evaluation test' scores showed that the six best athletes within the ND squad took part in the research. Hence, the recruitment of a larger athlete sample size while maintaining its homogenous nature is unrealistic in a niche sport, such as bobsleigh. Another weakness of this work is that no direct measure of the push-start was used when attempting to explore the relationships between jump tests and parameters used, with an athlete's push-start capabilities. Nevertheless, the push-start criterion measure selected in this study (heavy back roll-bob push), has been designed to mimic the push-start and a very large relationship between the two was demonstrated in Chapter 4 of this thesis (r = 0.85). Finally, the present study's approach included a lack of kinematic jump data. However, the 3D motion analysis systems considered gold standard to collect such data (e.g. Vicon), requires significant financial cost to acquire, has limited portability, and involves time intensive data collection and analysis procedures (Ortiz et al. 2016), which rendered their usage impractical for the British Bobsleigh performance programme.

6.4.8 Practical Applications

The results displayed above provide bobsleigh practitioners with CMJ and SLJ performance standards for a homogenous group of male bobsleigh athletes. However, the present evidence questions the application of the CMJ and bilateral SLJ to performance monitoring and talent identification testing in the sport. This is a result of the large range in values observed across both tests for all kinetic measures, as well as the lack of large relationships detected with push-start performance. Nevertheless, the findings do indicate some association between unilateral SLJ kinetic measures and the push-start. This result in conjunction with the SLJ kinetic measures being shown to represent similar qualities (r^2 > 50%), means it can be speculated that the inclusion of unilateral SLJ force to the current performance testing practices of British Bobsleigh maybe of value.

Additionally, from a training perspective these findings could suggest that unilateral dynamic exercises in the horizontal plane might have greater transfer to the push-start, when compared to bilateral and/or vertical alternatives. Also, the SLJ test may help to inform targeted, individualised training as it can be used to demonstrate differences in individual athlete profiles, by identifying those with asymmetries and or a poor unilateral facilitation. The relationships presented above between the push-start and SLJ horizontal force/power asymmetry index, as well as bilateral index values, provide the indirect rationale for the inclusion of unilateral exercises (e.g. single leg hip thrust, single leg back extension and single leg banded broad jump) into bobsleigh training programmes, as training of this nature has been proposed and demonstrated in the literature to increase the expression of unilateral facilitation and reduce between limb asymmetries (Botton et al. 2016; Brown et al. 2017; Gonzalo-Skok et al. 2017; Nijem & Galpin 2014; Skarabot et al. 2016). Based on the above its possible that the inclusion of unilateral training could result in an improvement in an athlete's push-start performance, due to an increase in their unilateral facilitation and/or a reduction in between limb asymmetry. However, this suggestion must be interpreted with caution, as it assumes cause and effect relationships exist. Providing scientific proof for this hypothesis is an important issue for future training studies in the area to address.

6.4.9 Conclusions

Aligning to the initial aim of the study, the author investigated the validity of vertical and horizontal jump test metrics completed under both bilateral and unilateral conditions, to predict push-start performance. The present investigation established the following key outcomes:

1. Unilateral SLJ kinetic metrics (i.e. force and power) appear to be better predictors of push-start performance in bobsleigh when compared to bilateral and/or vertical alternatives. Also, SLJ kinetic metrics represent a unique quality when compared to sprint performance. Thus, the addition of the unilateral SLJ to the British Bobsleigh 'evaluation test' or monitoring practices could help to account for some of the currently unexplained variance in push-start performance.
2. Maximising an athlete's unilateral facilitation, as well as minimising any between limb asymmetries appears to be beneficial for push-start performance. Thus, to facilitate improvements in the push-start, training interventions could target these specific parameters through the inclusion of unilateral strength exercises.

Chapter 7

STUDY 5: The Use of Sprint Force-Velocity Profiling in Bobsleigh

7.1 Introduction

7.1.1 Preface

Previous work in this thesis has established body mass, sprint performance, power expression under load and unilateral horizontal force production as key determinants of bobsleigh push-start performance. However, thus far these constructs have been measured in isolation and with a lack of kinetic measurements (e.g. force and power) collected during ecologically valid sprint-based assessments. An athletes ability to produce horizontal force and power during sprinting, are captured by the linear force-velocity and polynomial power-velocity relationships (Morin et al. 2012; Samozino et al. 2015), with past research demonstrating various parameters from the subsequent force-velocity mechanical profile to be linked to sprint performance (Cross et al. 2015; Morin et al. 2011; Morin et al. 2012; Rabita et al. 2015). Additionally, when attempting to maximise performance, authors have suggested that an athlete's force-velocity profile can be optimised independently of their power capabilities (Samozino et al. 2012; Samozino et al. 2015). As shown for ballistic performance, this optimal profile is neither force or velocity dominant, but an optimal combination of the two (Samozino et al. 2012). As illustrated by Morin and Samozino (2016), it is feasible that athletes with similar sprint times and power capabilities can display opposite force-velocity profiles and thus understanding an individual's profile can help inform training practice. The addition of sprint force-velocity profiling to the British Bobsleigh 'evaluation test', could provide a better understanding of which mechanical determinants are more closely related to the push-start and help tailor training programmes to develop specific mechanical sprint qualities (Rabita et al. 2015; Samozino et al. 2015).

7.1.2 Sprint Force-Velocity Profiling

Force-velocity profiling during sprinting identifies the maximal capacity of the neuromuscular system and is summarised through the following variables; theoretical maximal force (F_0), theoretical maximal velocity (V_0) and the product of the these two variables theoretical maximal power (P_{max}) (Cross et al. 2015; Samozino et al. 2015). To date, there has been limited research of force-velocity profiling during sprints in winter sliding sports. The works of Colyer et al. (2017) used a Keiser A450 horizontal leg-press dynamometer to determine force-velocity profiles amongst skeleton athletes and highlighted P_{max} as a strong determinant of start performance. Additionally, Colyer et al. (2017) concluded V_0 to be more important for the skeleton start than F_0, as a result of its larger correlation with sled velocity (r = 0.62 and 0.39 respectively). These findings were supported by a follow-up study in which elite skeleton athletes were shown to exhibit a more velocity dominant force-velocity curve, than their talent squad counterparts (Colyer, Stokes, Bilzon, Holdcroft, et al. 2017). Although the Keiser A420 is capable of quantifying neuromuscular adaptation, it lacks specificity to the movement and co-ordination patterns required from athletes during the push-start. Hence, the collection and analysis of force-velocity profiles during sprint running may provide a more valuable insight (Colyer, Stokes, Bilzon, Holdcroft, et al. 2017).

Traditionally, previous studies have utilised either a non-motorised treadmill or integrated track force plate to quantify force-velocity profiles during sprint running (Brown et al. 2017; Morin et al. 2011; Morin et al. 2012; Rabita et al. 2015). However, both approaches are somewhat limited when applied to the bobsleigh field testing environment. The main limitation of a non-motorised treadmill is that it lacks ecological validity, as it does not replicate normal over ground running, due to the involvement of a waist attachment and an increased friction from the treadmill belt (Samozino et al. 2015). Although the use of an integrated track force plate would represent greater ecological validity compared to the non-motorised treadmill, the approach is impractical in bobsleigh given it requires access to multiple interlinked force plates, which are expensive and often inaccessible (Morin & Samozino 2016; Samozino et al. 2015). To resolve these issues for practitioners, Samozino et al. (2015)

developed and validated a simple method to quantify athlete sprint force-velocity profiles using only anthropometric and speed-time (radar gun) or distance-time (timing gates) measurements.

Several elite rugby studies have adopted this approach and demonstrated the importance of a force dominant profile for acceleration performance, with faster backs displaying a higher P_{max} , F_0 and F_{opt} than slower backs (Cross et al. 2015). Also, Dr Isabel Moore (Personal Communication, 2016) has observed very large to near perfect correlations for maximal sprint velocity with mean power output (r = 0.91), mean horizontal force (r = 0.71) and index of force application (r = 0.90) in elite rugby. The index of force application represents the decrease in horizontal force, as velocity increases i.e. the linear slope of the force-velocity profile (Morin et al. 2011). A note of caution is due here when interpreting these studies from a bobsleigh practitioner perspective, as both are investigating sprint as opposed to push-start performance. Hence, the strong relationships reported in this situation would be expected given the calculated (e.g. force and power) and criterion metrics (e.g. sprint time or velocity) are determined from the same sprint effort. The literature to date has yet to utilise this approach with bobsleigh athletes or investigate whether sprint-based force-velocity mechanical variables are key determinants of bobsleigh push-start performance. Given that previous literature has shown skeleton athletes to display a more velocity-based profile and faster rugby players to exhibit a more force-based profile, it could be speculated that bobsleigh athletes may sit somewhere between the two and have more power-based profiles across all regions of the force-velocity curve, because of having to move a heavier load than skeleton athletes. Therefore, F_0 and V_0 may represent equal importance for the bobsleigh push-start and thus sprinting P_{max} maybe an important determinant of performance.

From a practical perspective, sprint force-velocity profiling provides practitioners with a simple tool to monitor training-induced individual responses in P_{max} and its mechanical determinants (i.e. F_0 and V_0) on a long-term basis (Jiménez-Reyes et al. 2018). Subsequently, it could help further understand whether individual improvements in force-velocity mechanical qualities translate to improvements in push-start performance. The use of this approach within winter sliding sports is limited. Nevertheless, the aforementioned works of Colyer, Stokes, Bilzon, Holdcroft et al. (2017) demonstrated training-induced shifts towards more velocity dominant leg press force-velocity profiles, to relate to improvements in push-start performance metrics. However, the authors only presented the group mean responses and did not consider any training induced adaptations on an individual level. It is important to interpret the variability in individual responses not only to determine the "real" existence of a "cause and effect" relationship between variables, but particularly in elite sport for practitioners examining performance changes in the inherently small sample groups of the elite sport environment. Thus, helping to understand the effectiveness of training programs for each athlete at enhancing global performance (i.e. the push-start).

7.1.3 Rationale

The current winter sliding sport literature has demonstrated a link between force-velocity mechanical variables and the skeleton start. Also, training-induced shifts towards more velocity dominant profiles have been shown to relate to improvements in push-start performance. However, the nature of the force-velocity profiling approach used in previous work lacks specificity to the co-ordination and movement patterns involved in the bobsleigh push-start. Recent research developments have allowed force-velocity profiles to be quantified during sprinting using a simple radar or split time method, and authors have utilised such an approach to demonstrate links between force-velocity mechanical variables and sprint performance. However, this method has yet to be explored as a means of quantifying the key determinants that underpin the push-start in bobsleigh. Additionally, the monitoring of training-induced changes in sprint force-velocity profiles can help to further understand whether any mechanical quality changes on an individual level, translate across to improvements in bobsleigh push-start performance.

7.1.4 Aims

The aims of this study are two-fold; 1) explore the discriminative validity and predictive validity of sprint force-velocity profiling for the bobsleigh push-start, 2) Investigate the influence of a 16-week pre-season training phase on bobsleigh athlete’s sprint force-velocity mechanical profiles and associated changes in push-start performance.

7.2 Methods

7.2.1 Athletes

Fourteen male bobsleigh athletes took part in this study. All athletes were part of either the WCP or ND squad within the British Bobsleigh programme (n = 8 and n = 6 respectively). This sample represents 50% of the total WCP and ND male bobsleigh athlete population in the country. In the subsequent season, all WCP athletes included in this study were selected to compete on the World Cup circuit, with four going on to represent their country at the major championships. The sample's characteristics are presented below in Table 7.1.

Table 7.1 Mean and range descriptive characteristics for the study sample group.

Characteristic	WCP (n = 8)	ND (n = 6)
Age (years)	28 (24 to 34)	26 (21 to 32)
Body Mass (kg)	98.8 (89.1 to 113.7)	98.5 (90.3 to 107.3)
Height (cm)	184 (175 to 193)	186 (176 to 193)
Years in the programme	4 (2 to 7)	4 (3 to 5)

7.2.2 Experimental Design Overview

Conducted in two parts, this study used a cross-sectional experimental design to determine and compare sprint force-velocity variables amongst WCP and ND bobsleigh athletes, as well as determining the relationship of these variables with the push-start (Part A). A longitudinal experimental design was then used to examine how sprint force-velocity mechanical variables changed over a 16-week pre-season training phase in WCP athletes (Part B). All testing took place as part of British Bobsleigh's pre-season preparations for the 2016/2017 on-ice racing season.

7.2.2.1 Part A

During part A, WCP and ND athletes were required to complete the British Bobsleigh 'evaluation test' in accordance with the protocol outlined in chapter 4 (see Chapter 4.2.3), at the National Indoor Athletics Centre located at the Cardiff Metropolitan University, Wales. In addition to the normal protocol, during the 60 m sprint assessment each athlete's sprint force-velocity mechanical profile was modelled via a recently validated simple split time method (see Methods 7.2.3) (Samozino et al. 2015). To explore the relationships for push-start performance, with both the 'evaluation test' performances and athlete sprint force-velocity mechanical profiles, 11 athletes also took part in push-start testing completed in accordance with the British Bobsleigh protocol (see Methods 7.2.4). Push-start testing was scheduled as part of British Bobsleigh's selection testing weekend and thus took place 27 days after the 'evaluation test' and sprint force-velocity mechanical profiling testing session.

7.2.2.2 Part B

British Bobsleigh 'evaluation test' profiles and force-velocity mechanical characteristics were monitored for 6 WCP athletes over a 16-week pre-season training phase outlined in Figure 7.1. All testing protocols were completed in accordance with the procedures outlined in part A (see Methods 7.2.2.1). The sample's mean (range) characteristics are as follows; age 29 (26 to 34) years, mass 101.6 (89.1 to 113.7) kg and height 185 (177 to 193) cm. The pre-season phase was periodised into 3 blocks using a conjugated approach, allowing for periods of overreach followed by recovery with a primary emphasis for each block (Plisk & Stone 2003; Turner 2011). The 16-week pre-season phase included an initial 5-week conditioning emphasis block, followed by a 4-week strength emphasis block and a 5-week speed emphasis block, as well as two 2-week intensive push-start training camps (see Figure 7.1). Athletes were given 48-hours rest prior to the pre- and post-training phase testing sessions. Table 7.2 provides an overview of the typical exercises, loads and repetition schemes used across the three-training blocks. Mechanical loading was increased from the conditioning to strength block and then the number of weekly speed sessions was increased in the speed block. Within this general training structure each athlete followed an individualised plan, however their programme was not individualised based on their sprint force-velocity profile but rather their overall ‘evaluation test’ profile in conjunction with the coach’s professional judgement. Hence, the athletes were not being specifically trained to target certain mechanical qualities in their sprint force-velocity profile. The heavy back roll-bob push was used as a criterion marker of push-start performance over the pre-season training phase because of its very large (r = 0.85) relationship with the push-start (see Chapter 4).

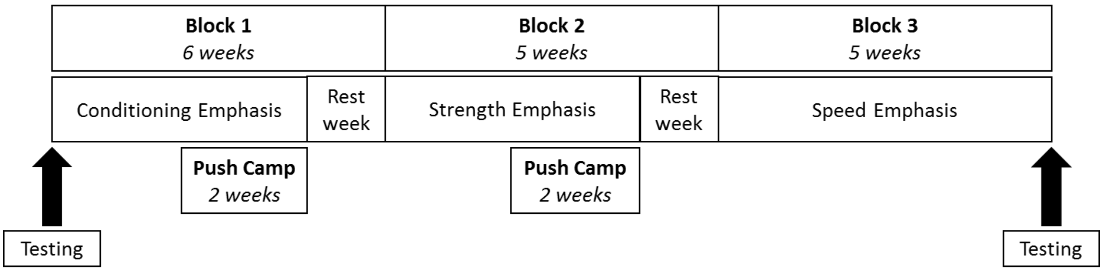

Figure 7.1 A schematic representation of the 16-week pre-season training phase completed by WCP athletes.

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Table 7.2 Example exercises, loads and rep schemes used across the pre-season training blocks.

Training Block	Session	Exercise Examples	Load	Rep Schemes	Frequency
1	Power	Squat Clean Power Clean Jerks	65 to 85 % 1 RM	3 x 2-4	1
	Strength	Deadlift Squat Bench Press	65 to 80 % 1 RM	6 x 6-10	2
	Speed	Drive-outs Sled drags Uphill sprints	10 to 30 m	4-6 x 1	2
2	Power	Block Clean Hang Clean Squat Thrust & Jerk	70 to 90 % 1 RM	5-6 x 2-4	1
	Strength	Anderson Squat Step Up Viking Press	65 to 90 % 1 RM	3-5 x 4-6	2
	Speed	Drive-outs & cruise Build-ups	20 to 60 m	3-7 x 1-3	2

Training Block	Session	Exercise Examples	Load	Rep Schemes	Frequency
3	Power	Power Clean Dead Pull Keiser Squat	80 to 95 % 1 RM	5-6 x 2-3	1
	Strength	Banded Squat Deadlift Reverse Lunge	50 to 90 % 1 RM	4-5 x 2-4	2
	Speed	Build-ups Sprints	45 to 60 m	1-3 x 2-3	3

* RM = repetition max.

7.2.3 Force-Velocity Profiling

During the 60-m sprint assessment completed as part of the British Bobsleigh 'evaluation test', additional split times were measured via photoelectric timing gates (Smartspeed, Fusion Sport, Brisbane, Australia) placed at 0 m, 5 m, 10 m, 15 m, 20 m and 25 m. The author deemed split times up to 25 m to be sufficient for sprint force-velocity profiling in bobsleigh athletes, as a result of evidence in the literature suggesting a comparable population of elite rugby players are in their maximal velocity phase by 21 m (Barr et al. 2013). Additionally, exploratory analysis using the dataset from part A confirmed all athletes were at ≥ 95% maximal velocity by 25 m. In part A, each athlete was filmed over the initial phase of the sprint using high speed video at 240 Hz (iPad Pro, Apple Inc., California, USA) to determine the time difference between their onset of force production (first meaningful movement) and the triggering of the first timing gate via their largest body segment (Samozino et al. 2015). An athlete's onset of force production was defined by the present author as the point at which the leading knee passed over the front toe. Any trials where the onset of force production could not be accurately determined using this approach were removed from the analysis. The time difference defined as the offset value, was then applied to each athlete's raw split times to remove any possible bias and to account for the fact that athletes are not at zero velocity when the first gate is broken (Samozino et al. 2015). The applied offset value was 0.406 s. This average athlete offset value determined during part A of the study was applied to the datasets collected in part B.

7.2.3.1 Mechanical Variable Computation

Five sprint split times up to 25 m were used to determine force-velocity mechanical variables via a publicly available spreadsheet (Morin & Samozino 2017), using the macroscopic inverse dynamic approach outlined by Samozino et al. (2015). However, during part B pre-intervention testing, data from the gate placed at 5 m was unavailable for some athletes and thus it was removed for all athletes from this dataset. Ambient conditions, athlete anthropometric measurements (mass and height) and corrected sprint times (raw split time + offset value) were used to model the horizontal velocity (V_H) time (t) curve (Eq. [7.1]).

$V_H(t) = V_{Hmax}$ x $(1 – e^{t}/_{A})$ [7.1; Samozino et al. (2015)]

Where V_{Hmax} is maximal horizontal velocity and $_{A}$ is the acceleration time constant.

Following which Eq. [7.2] was used to calculate the body’s centre of mass acceleration (a(t)):

$a(t) = (V_{Hmax} / _{A})$ x $e^{-t}/_{A}$ [7.2; Samozino et al. (2015)]

Net horizontal ground reaction force (F_H) was then modelled over time using Eq. [7.3]:

$F_H(t) = m$ x $a(t) + F_{aero}(t)$ [7.3; Samozino et al. (2015)]

Where m is the athlete’s body mass (kg) and $F_{aero}(t)$ is the aerodynamic drag to overcome during sprinting, which is a function of wind velocity, aerodynamic friction constant, estimated athlete frontal area and drag coefficient (Samozino et al. 2015).

For each athlete’s fastest 60 m sprint, their force-velocity relationship was extrapolated to determine the following variables; F_0, V_0 and the slope of the force-velocity relationship (S_{FV}) (see Figure 7.2). P_{max} was determined using the previously validated model outlined in Eq. [7.4].

$P_{max} = F_0$ x $V_0 / 4$ [7.4; Samozino et al. (2015)]

Velocity at P_{max} (V_{opt}) was calculated using Eq. 7.5 and represents the velocity at the point of peak power production (see Figure 7.2).

$V_{opt} = V_0 / 2$ [7.5; Morin & Samozino (2017)]

Relative F_0 and relative P_{max} were determined as a product of each athlete's absolute values for these variables, divided by their body mass. Finally, each athlete's D_{RF} was computed as the resulting slope of the effectiveness of force application (*RF)*-velocity relationship, with *RF* calculated throughout the sprint using Eq. [7.6] (Morin & Samozino 2016).

RF (%) = $F_H / [\sqrt{F_H^2 + ((m*g)^2)}]$ [7.6; Samozino et al. (2015)]

Where F_H is horizontal ground reaction force, m is body mass (kg) and g is gravity (9.81 m/s^2).

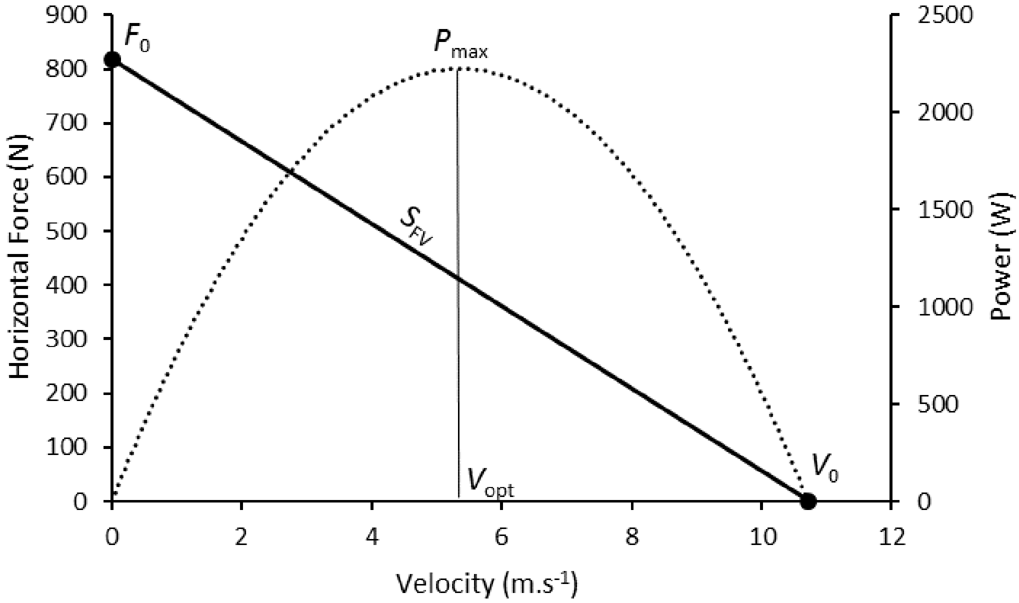

Figure 7.2 A graphical representation of an example bobsleigh athlete force-velocity mechanical profile and its associated variables. Pmax = maximal power output, F_0 = theoretical maximal horizontal force, V_0 = theoretical maximal velocity, V_{opt} = velocity at maximal power output and S_{FV} = slope of the force velocity relationship. Adapted from Cross et al. (2015, p.696).

7.2.4 Push-Start Testing

Push-start testing took place at the purpose-built outdoor push-track located at the British Bobsleigh National Training Centre. All athletes undertook 4 maximal pushes, with a minimum of 10 minutes rest between each push. As part of the British Bobsleigh selection protocol, athletes were required to take at least one push from each of the three handles (left, right and brakeman handle). However, to allow comparison to earlier work in this thesis and previous literature, only data collected from the brakemen handle was used in this study. Brakeman handle pushes were measured over a 50 m section of the track (15 m to 65 m) using an electronic timing system (developed in house by Sheffield Hallam University, UK) installed within the perimeter wall of the push track. If any athlete failed to load the sled before a cut off marker placed at 50 m, the push attempt was discounted. The push from the brakeman handle where each athlete achieved their fastest 15 m to 65 m split time (defined as push-start time) was taken forward and used in all analysis.

7.2.5 'Evaluation Test' and Force-Velocity Profile Reliability

The reliability of both the 'evaluation test' and force-velocity mechanical variables have been confirmed by earlier work in this thesis (see Chapter 4), exploratory analysis (see Appendix 2), and by Samozino et al. (2015), using bobsleigh athletes and high-level sprinters respectively (see Table 7.3).

Table 7.3 'Evaluation test' and force-velocity mechanical variable reliability from this thesis and previous literature.

Parameter	CV (%)	
	Chapter 4 and Appendix B	Samozino et al. (2015)
Evaluation Test'		
Body Mass (kg)	1.2 %	-
30m sprint (s)	0.8 %	-
Flying 30m Sprint (s)	1.4 %	-
60m Sprint (s)	1.0 %	-
5-RBJ (m)	2.1 %	-
Roll-bob Push (s)	1.6 %	-
Force-Velocity Mechanical Variables		
F_0 (N)	-	2.9 %
V_0 ($m.s^{-1}$)	-	1.1 %
P_{max} (W)	-	1.9 %
S_{FV}	-	4.0 %
D_{RF} (%)	-	4.0 %

7.2.6 Statistical Analysis

Group data is reported as mean (range) values and all statistical analysis was completed using IBM SPSS statistics (Version 23, SPSS, Chicago, USA). The normality of all the data used in this study was checked using the Shapiro-Wilk Normality test and confirmed for all variables ($p > 0.05$). Independent t-tests were used to detect any significant differences between WCP and ND athletes for the 'evaluation test', force-velocity profiling results and push-start testing. To determine the magnitude of differences between the WCP and ND athletes, Cohen's effects sizes were determined and interpreted using the following thresholds; < 0.20 trivial, ≥ 0.20-0.59 small, ≥ 0.60-1.19 moderate, ≥ 1.20-1.99 large, ≥ 2.00 very large and ≥ 4.00 extremely large (Hopkins 2002; Hopkins et al. 2009). Pearson's correlation coefficients were calculated to assess the push-start performance relationships to both the 'evaluation test' and the sprint force-velocity mechanical variables. The magnitude of these correlation coefficients were interpreted using the guidelines of Hopkins (2002); < 0.10 trivial, ≥ 0.10-0.29 small, ≥ 0.30-0.49 moderate, ≥ 0.50-0.69 large, ≥ 0.70-0.89 very large and ≥ 0.90 near perfect.

It is important to note that prior to the training phase analysis (Part B), the 'evaluation test' and force-velocity mechanical variables that did not display at least a moderate relationship with the push-start were removed. For the group analysis, paired sample t-tests were used to determine any changes in the 'evaluation test' performances and sprint force-velocity mechanical variables over the 16-week pre-season training phase. Cohen's effects sizes were then calculated to assess the magnitude of any of these changes using the above thresholds.

Given the exploratory nature of the present research and the small sample of homogenous bobsleigh athletes involved, an alpha value of $p < 0.10$ was set as statistically significant for all analysis.

In addition to the above analysis, individual athlete percentage changes for each variable over the 16-week phase were determined. To account for typical error, a ± 1 CV was then applied to the individual percentage change scores, thus providing a confidence interval for the observed change in each variable for each athlete (Pyne 2003). Subsequently, to identify “real” performance changes, athlete percentage change scores including confidence intervals were compared to the smallest worthwhile change (SWC), set at ± 0.3 of the CV (Hopkins 2004; Samozino et al. 2015). Although a SWC of 0.3 CV is low, it has been shown to be meaningful as an improvement of this magnitude would provide a competitive advantage for elite sprint athletes (Hopkins 2004). Any performance changes ≥ 1.0 CV and ≥ 2.0 CV were considered moderate and large in magnitude respectively. Finally, performance changes were classified by applying Batterham and Hopkins (2006) 3-level scale of magnitudes and a frequency count was used to determine the number of athletes with either positive, negative, trivial or unclear changes. These performance change descriptors were defined as outlined in Figure 7.3 (Batterham & Hopkins 2006).

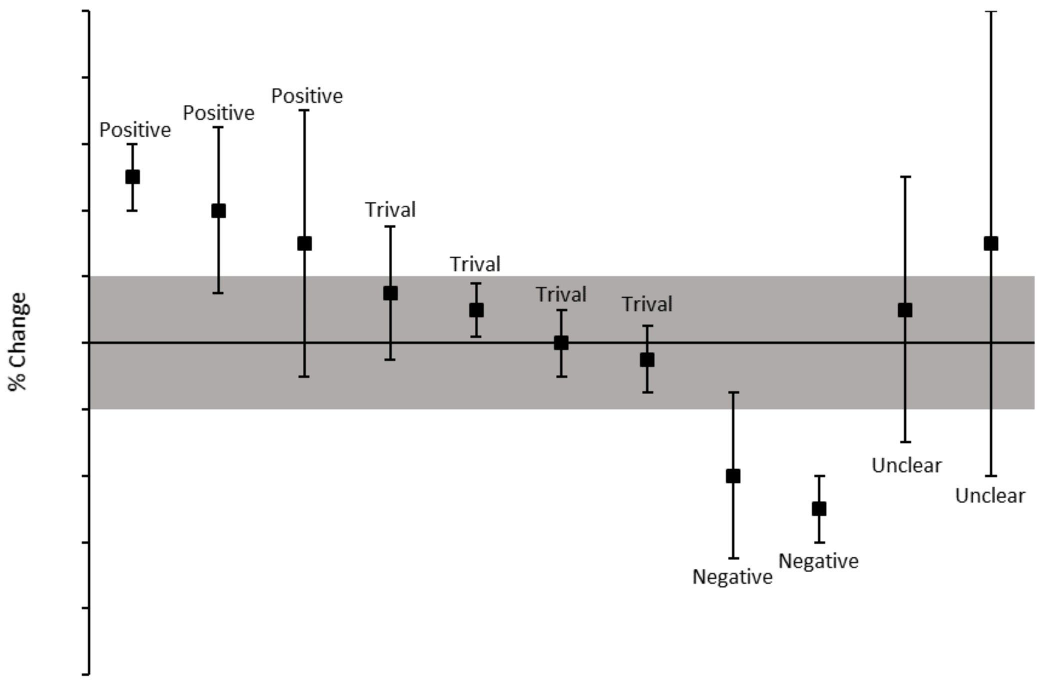

Figure 7.3 A schematic representation of the 3-level scale of magnitudes used to classify individual performance changes over the 16-week pre-season training phase. Adapted from Batterham and Hopkins (2006, p.53).

7.3 Results

7.3.1 World Class Performance and National Development Squad Performances

Table 7.4 displays the mean (range) ‘evaluation test’ results, force-velocity mechanical variables and push-start testing performances for WCP and ND squad athletes. Despite the homogenous nature of both the WCP and ND athletes in terms of push-start performance (2 to 3 % range when compared to the group means), a large between-athlete range relative to the group mean was detected across the force-velocity mechanical variables; F_0 (26 to 29 %), relative F_0 (26 to 31 %), V_0 (15 to 17%), P_{max} (13 to 22 %), relative P_{max} (18 to 23 %) and V_{opt} (15 to 17 %).

Large to very large differences were observed between WCP and ND athletes for all the general performance tests included within the ‘evaluation test’ (ES = 1.76 to 2.46; $p < 0.10$), apart from the 5-RBJ (ES = 0.01; $p > 0.10$). Likewise, a very large between-group difference was detected for push-start performance (ES = 2.20; $p < 0.10$). When comparing the WCP and ND athletes force-velocity mechanical profiles, large differences were observed for V_0, V_{opt}, P_{max} and relative P_{max} (ES = 1.43 to 1.82; $p < 0.10$). However, no differences were detected for any of the remaining force-velocity mechanical variables (ES < 1.20; $p > 0.10$).

Table 7.4 Group mean (range) for WCP and ND British Bobsleigh squad athletes for the 'evaluation test', sprint force-velocity profiling variables and push-start testing.

Parameter	WCP (n = 8)	ND (n = 6)
'Evaluation Test'		
Sprint Performance		
30m Sprint (s)	3.61 (3.45 to 3.75) *	3.83 (3.70 to 3.88)
30m Flying Sprint (s)	2.88 (2.69 to 3.08) *	3.06 (2.91 to 3.15)
60m Sprint (s)	6.48 (6.14 to 6.83) *	6.89 (6.61 to 7.01)
5-RBJ (m)	16.82 (15.61 to 18.29)	16.81 (15.55 to 17.49) [4]
Roll-bob Push (s)	3.99 (3.88 to 4.06) *	4.11 (4.05 to 4.19) [4]
Points	884 (816 to 982) *	783 (747 to 813) [4]
Force-Velocity Profiling		
F_0 (N)	825 (755 to 966)	797 (665 to 894)
Relative F_0 (N.kg^{-1})	8.40 (7.16 to 9.78)	8.10 (6.56 to 8.66)
V_0 (m.s^{-1})	11.33 (10.72 to 12.43) *	10.47 (9.78 to 11.61)
P_{max} (W)	2331 (2145 to 2665) *	2076 (1924 to 2186)
Relative P_{max} (W.kg^{-1})	23.75 (20.96 to 26.32) *	21.12 (19.04 to 22.88)
S_{FV}	-0.74 (-0.61 to -0.91)	-0.78 (-0.57 to -0.85)
V_{opt} (m.s^{-1})	5.66 (5.36 to 6.22) *	5.23 (4.89 to 5.80)
D_{RF} (%)	-6.72% (-5.57 to -8.15%)	-7.13% (-5.19 to -7.84%)
Push-Start Testing		
Push-Start Time (15-65m)	5.21 (5.14 to 5.29) * [6]	5.34 (5.30 to 5.40) [5]

[6] = Data included from 6 athletes only, [5] = Data included from 5 athletes only, [4] = Data included 4 athletes only, * = Difference compared to ND athletes (p < 0.10).

7.3.2 Push-Start Performance

The results of the correlation analysis for push-start performance, with both the general performance tests included in the 'evaluation test' and sprint force-velocity profile mechanical variables are summarised in Table 7.5. As shown in Table 7.5 and Figure 7.4, the strongest relationship (p < 0.10) with push-start performance was with sprinting P_{max}. Additionally, large correlations (p < 0.10) were observed for the push-start with both relative P_{max} and F_0. Finally, large relationships (p < 0.10) were shown for 30 m sprint time (see Figure 7.5) and 60 m sprint time with the push-start. No other significant and/or large push-start performance correlations were observed for any of the other force-velocity mechanical variables or general performance evaluation tests (r < 0.50 &/or p > 0.10).

Table 7.5 Pearson correlation coefficients (r values) for the push-start with both 'evaluation test' and sprint force-velocity mechanical variables (n = 11).

Parameter	*r* value
Performance Evaluation	
Body Mass (kg)	-0.25
Sprint Performance	
30m Sprint (s)	0.69* L
30m Flying Sprint (s)	0.42 m
60m Sprint (s)	0.59* L
5-RBJ (m)	-0.14
Force-Velocity Profiling	
F_0 (N)	-0.58* L
Relative F_0 ($N.kg^{-1}$)	-0.37 m
V_0 ($m.s^{-1}$)	-0.37 m
P_{max} (W)	-0.80* VL
Relative P_{max} ($W.kg^{-1}$)	-0.55* L
S_{FV}	0.13
V_{opt} ($m.s^{-1}$)	-0.38 m
D_{RF} (%)	0.08

* = p < 0.10.

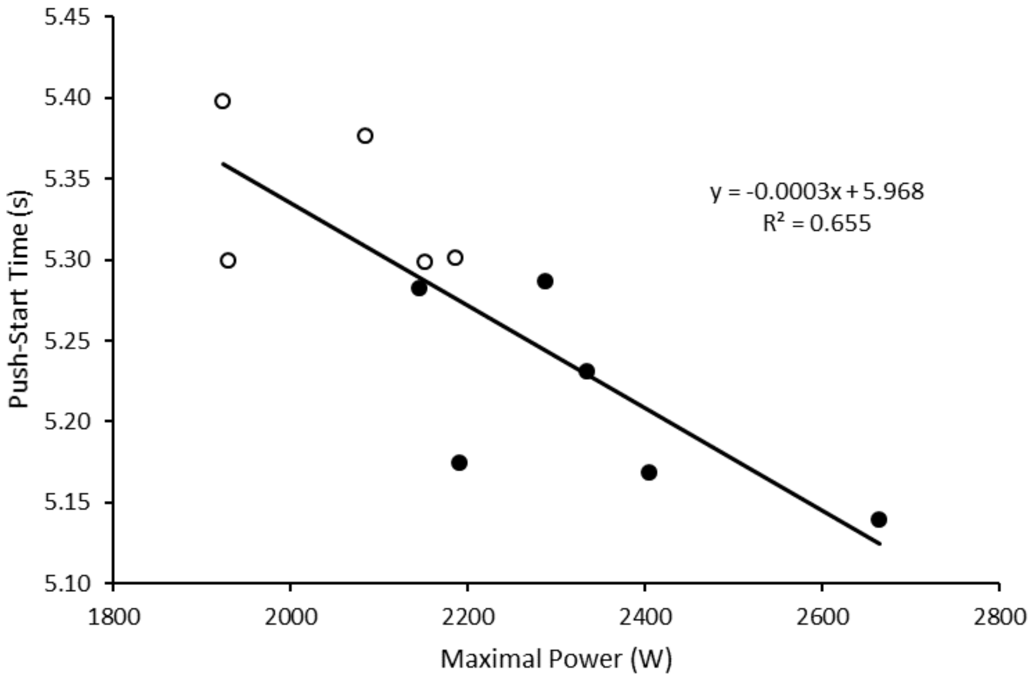

Figure 7.4 Relationship between Pmax (W) and push start time (s). Filled dot = WCP athlete.

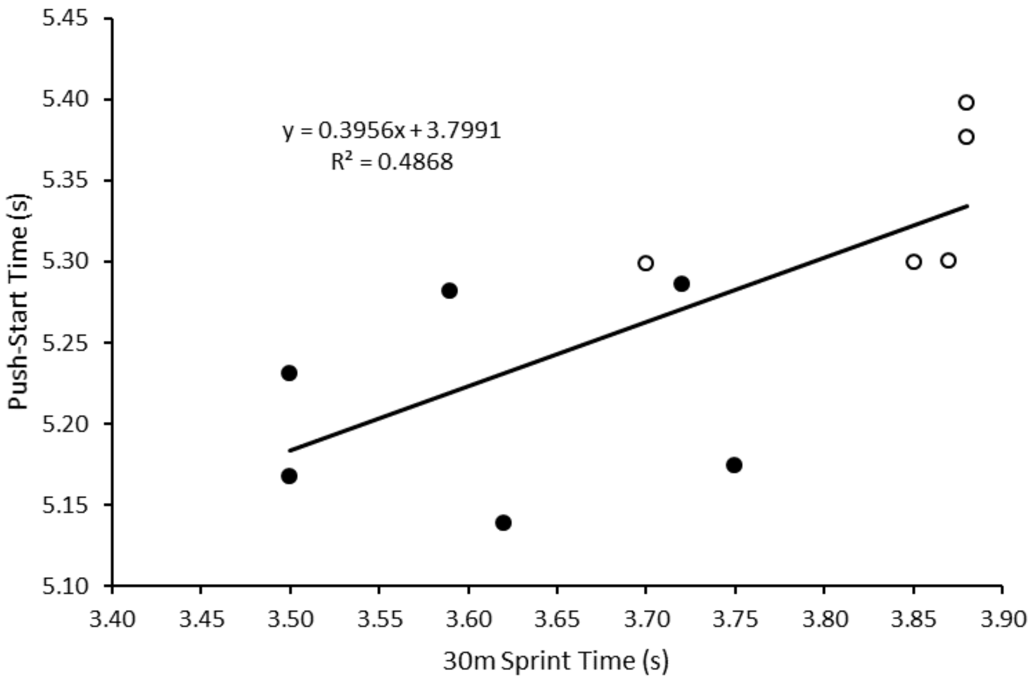

Figure 7.5 Relationship between 30 m sprint time (s) and push start time (s). Filled dot = WCP athlete.

Based on Figure 7.4, the presented linear regression predicts that if an athlete was to increase their sprinting P_{max} by ~ 5% (i.e. 100 W), this could translate to an improvement in their push-start time of ~ 0.6% (i.e. 0.03 s). Likewise, to achieve similar improvements in push-start time, the results of a separate linear regression analysis suggest that an athlete would have to reduce their 30 m sprint time by ~ 2% (i.e. 0.075 s) (see Figure 7.5).

Figure 7.6 shows the sprint force-velocity mechanical profiles of two ND athletes with the same push-start time (5.30 s), as well as similar sprint times over 60 m (30 m 3.87 s & 3.85 s; 30 m flying 3.14 s & 3.15 s; & 60 m 7.01 s & 7.00 s respectively). However, it is apparent from the Figure that they have quite different mechanical profiles, with athlete A (solid line) displaying a more force dominant profile than athlete B (dashed line), because of a higher F_0 but a lower V_0.

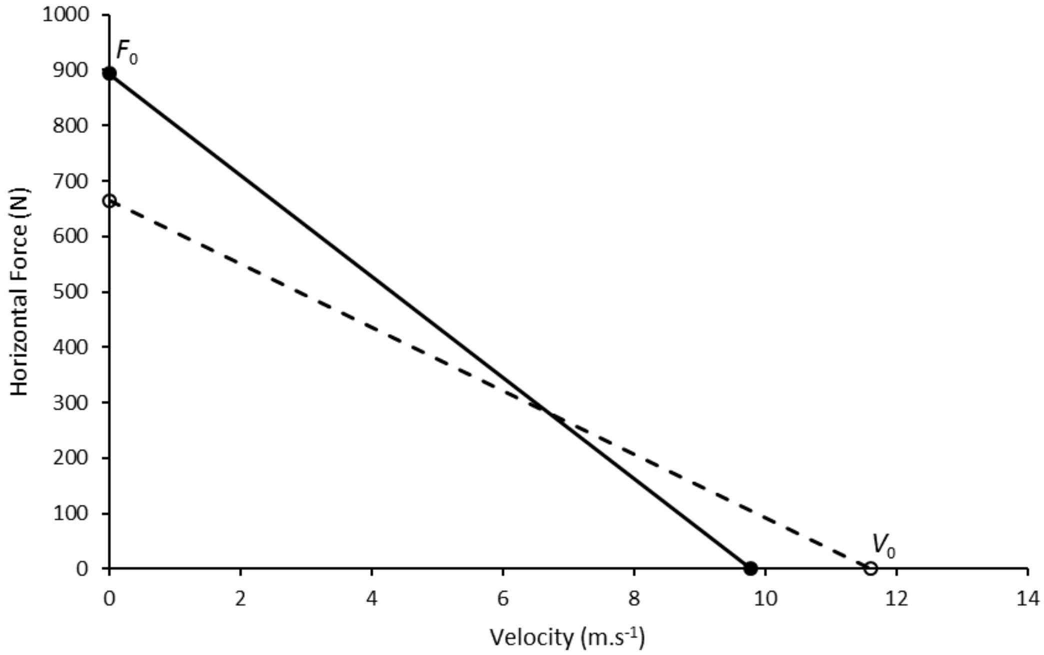

Figure 7.6 Sprint force-velocity mechanical profiles of two ND bobsleigh athletes with the same push-start and near identical sprint times.

7.3.3 Pre-Season Training Block Responses

Table 7.6 displays the mean (range) pre-and-post training phase 'evaluation test' results, and sprint force-velocity mechanical variables, alongside group mean changes (± 95% CI), effect sizes and individual athlete responses. Moderate differences were observed in pre-to-post roll-bob push performances, P_{max} and relative P_{max} (ES = 0.61 to 1.06; $p < 0.10$). Also, V_0 and V_{opt} were shown to moderately increase over the 16-week training phase (ES = 0.74; $p > 0.10$). As shown in Table 7.6, pre-to-post training phase changes for all other variables were either trivial to small in magnitude or non-significant (ES < 0.60 or $p > 0.10$).

Table 7.6 considers the individual athlete responses to the 16-week training phase, as well as Figures 7.7 and 7.8 displaying these responses for selected 'evaluation test' parameters and sprint mechanical variables respectively (see Appendix 3 for Figures of all variables). It is apparent that at least half of the athletes had positive responses in sprint and jump performance (n = 3 to 4), with only one athlete having either a negative response in 60 m sprint performance or the 5-RBJ.

Clear individual changes were observed in the sprint force-velocity mechanical variables V_0 and P_{max} (see Figure 7.8b and 7.8c), with 5/6 and 6/6 athletes having positive improvements above the SWC in V_0 and P_{max} respectively. In fact, the athletes with positive improvements all displayed a change that was deemed to be either moderate (≥ 1 x CV %) or large in magnitude (≥ 2 x CV %). Contrastingly, a more mixed training response in F_0, S_{FV} and D_{RF} was detected, with 3 athletes having a positive improvement and 1 to 2 athletes having a negative response to the 16-week training phase (see Table 7.6 & Figure 7.8a). Finally, in terms of push-start performance a positive change was observed for 4/6 of the athletes over the training phase (see Figure 7.7a). However, as would be expected the small to moderate magnitude of these individual positive changes, was typically lower than that observed for the other variables, such as sprint performance and sprinting P_{max} (see Figures 7.7 & 7.8).

Table 7.6 Changes in 'evaluation test' and sprint force-velocity variables over the 16-week training phase.

Parameter	Testing		Pre-to-Post Training Changes		Individual Responses
	Pre (range)	Post (range)	Absolute Change (± 95% CI)	Effect Size	Positive/Trivial/Negative (unclear)
30m sprint (s)	3.68 (3.46 to 3.84)	3.63* (3.45 to 3.75)	-0.05 (± 0.19)	0.38	3 – 0 – 0 (3)
60m Sprint (s)	6.63 (6.22 to 7.02)	6.51* (6.14 to 6.83)	-0.12 (± 0.14)	0.46	4 – 0 – 1 (1)
Roll-bob Push (s)	4.05 (4.00 to 4.10)	3.99* (3.88 to 4.06)	-0.06 (± 0.05)	1.06 ^{m}	4 – 0 – 0 (2)
F_0 (N)	796 (728 to 947)	822 (755 to 966)	26 (± 46)	0.35	3 – 0 – 2 (1)
Relative F_0 ($N.kg^{-1}$)	7.93 (7.26 to 8.65)	8.12 (7.16 to 8.94)	0.19 (±0.51)	0.31	3 – 0 – 2 (1)
V_0 ($m.s^{-1}$)	11.00 (10.25 to 11.82)	11.46 (10.72 to 12.43)	0.46 (± 0.61)	0.74 ^{m}	5 – 0 – 1 (0)
P_{max} (W)	2188 (1949 to 2585)	2350* (2192 to 2665)	162 (± 110)	0.83 ^{m}	6 – 0 – 0 (0)
Relative P_{max} ($W.kg^{-1}$)	21.83 (19.22 to 25.49)	23.27* (20.96 to 26.21)	1.44 (± 1.60)	0.61 ^{m}	4 – 0 – 0 (2)
V_{opt} ($m.s^{-1}$)	5.50 (5.12 to 5.91)	5.73 (5.36 to 6.22)	0.23 (± 0.30)	0.74 ^{m}	5 – 0 – 1 (0)

* = statistical difference from pre-training phase testing ($p < 0.10$), ^{m} = moderate difference from pre-training phase testing (effect size ≥ 0.60). CI = confidence interval (± 95%).

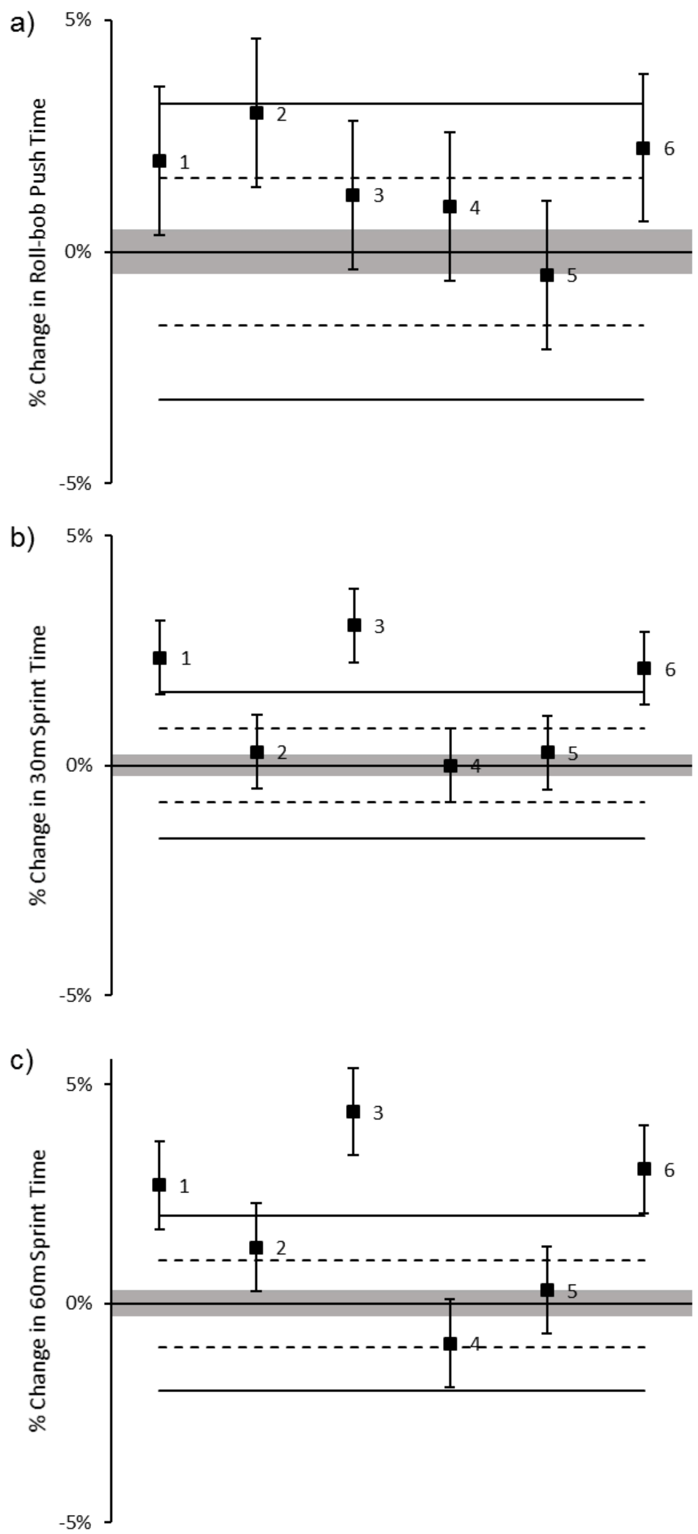

Figure 7.7 Individual athlete percentage changes (%) in selected 'evaluation test' parameters (a= Roll-bob Push, b = 30m Sprint & c = 60m Sprint) over the pre-season training phase. Smallest worthwhile change (CV % x 0.3) = grey shaded area, moderate change (CV % x 1) = black dashed line and large change (2 x CV %) = black solid line.

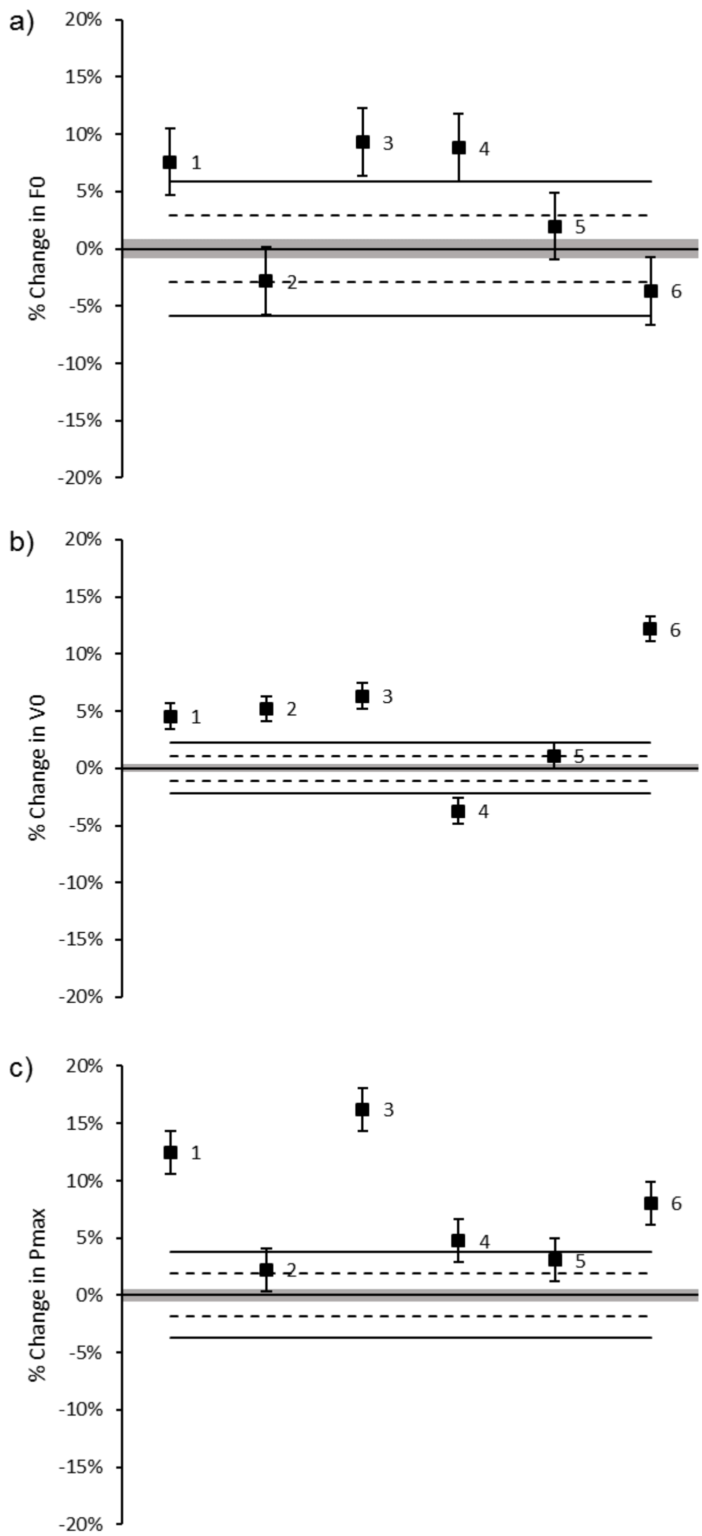

Figure 7.8 Individual athlete percentage changes (%) in selected sprint force-velocity mechanical variables (a = F0, b = V0 & c = Pmax) over the pre-season training phase. Smallest worthwhile change (0.3 x CV %) = grey shaded area, moderate change (1 x CV %) = black dashed line and large change (2 x CV %) = black solid line.

7.4 Discussion

7.4.1 Key Findings

Bobsleigh athletes in the WCP squad had faster push-start times and were faster sprinters over 60 m, with higher V_0 and greater P_{max} outputs than ND athletes. The WCP athletes appear to exhibit a more velocity dominant sprinting profile. Also, the normative data presented highlighted limited overlap between the lower and upper limits in the WCP and ND athletes for both speed and absolute sprinting power; which may provide some tentative guidelines for benchmarking. Finally, speed and absolute maximal power during sprinting demonstrated the strongest relationships with push-start performance. Hence, the push-start appears to be more reliant on velocity and absolute power production rather than relative power or force. Sprinting maximal force did show a reasonable relationship with the push-start; however, it could not differentiate between performance levels and thus was deemed less important. Considered collectively, the evidence suggests that sprint speed and P_{max} should be considered as important determinants of bobsleigh push-start performance. The addition of sprint force-velocity profiling to the British Bobsleigh 'evaluation test' could help distinguish between different athlete performance levels, as well as assisting with identifying the mechanical strengths and weaknesses of different athletes.

At a group level, the British Bobsleigh pre-season phase demonstrated training induced improvements in push-start performance, sprint speed and P_{max} (absolute and relative). Of the qualities measured in this study the largest group-based improvements were observed in absolute P_{max}. This was reflected with all athletes making worthwhile gains in P_{max}, however this did not always translate to an improvement in push-start performance on an individual level. Thus, highlighting that there may be other factors important for push-start performance than those measured in this study, for example technical ability. Nonetheless, more research is required to fully understand the nature of the sprinting maximal power: push-start relationship.

7.4.2 Profiling

7.4.2.1 'Evaluation Test'

Sprint performance demonstrated a moderate to large relationship with the push-start, as well as being able to differentiate between WCP and ND bobsleigh athletes. Of the sprint measures collected in this study, the strongest correlation was observed for time to 30 m. Additionally, it is apparent from the range in scores and data presented in Figure 7.4 that there was not much overlap in 30 m sprint time between WCP and ND athletes, with the latter also generally displaying slower push-start times. Collectively these findings make it possible to propose 30 m sprint performance thresholds for a WCP bobsleigh athlete. Based on Figure 7.5, athletes achieving 30 m sprint times > 3.75 s would be deemed as ND and thus 3.75 s creates a minimum requirement benchmark for a WCP bobsleigh athlete. However, it is important to note that this does not indicate that if athletes hit 3.75 s they automatically become WCP, as shown in this study by one ND athlete (see Figure 7.5). Thus, a cut off at 3.65 s may reflect a more definitive benchmark, with athletes who achieve faster 30 m sprint times than this very likely to be of WCP standard. These thresholds must be interpreted with caution due to the small sample of both WCP and ND athletes included in this study. In summary, the 30 m sprint findings from this study support that observed in Chapter 4, where it was highlighted as an important quality for push-start performance.

In contrast to the above, both body mass and the 5-RBJ only displayed a small push-start performance relationship. Also, the 5-RBJ did not distinguish between WCP and ND level athletes. The body mass findings of this study conflict that presented in Chapter 4 and this disparity could be attributed to an increased homogenous nature of the athlete sample in the present study. Also, as previously described there is the existence of an optimal body mass range (i.e. approx. 90 to 110 kg) in bobsleigh, as a result of crews attempting to maximise momentum within the constraint of minimum sled (i.e. without a crew) and maximal loaded sled (i.e. with a crew) weight limits (Deweese et al. 2014a; IBSF 2015). All but one athlete (+ 3 %) in the present study's sample group were within this optimal weight range.

7.4.2.2 Sprint Force-Velocity Mechanical Profiling

To the author's knowledge, this is one of the first studies within the academic literature to characterise sprint force-velocity profiles amongst a group of male bobsleigh athletes and thus comparisons can only be made with data from other sports. Moderate to extremely large sprint P_{max} differences were observed between the WCP squad and those reported for elite rugby players across three different codes; union (ES = 2.18 to 2.22), league (ES = 2.11 to 4.42) and 7's (ES = 0.62) (Cross et al. 2015; Dr Isabel Moore, Personal Communication, 2016). When compared to the rugby players presented in the works of Cross et al. (2015) and Dr Isabel Moore (Personal Communication, 2016), the present cohort of bobsleigh athletes recorded higher V_0 (ES = 3.91 to 4.58), but similar or lower F_0 values (ES = 0.08 to 1.61). It could be conceivable to speculate that WCP and ND bobsleigh athletes exhibit more velocity dominant sprint profiles, when compared to their rugby counterparts. It is likely that this could be attributed to the differences in the demands of the sports, as rugby involves a greater volume of high force-oriented work. Also, a disparity in the training history of the athlete cohorts being compared may offer another possible explanation.

Of all the sprint force-velocity mechanical variables, absolute P_{max} was shown to be the strongest predictor of push start performance. Additionally, this variable could differentiate between WCP and ND bobsleigh athletes, who also display different push-start and sprinting capabilities (see Table 7.4). These results mirror the observations of Cross et al. (2015) where faster elite rugby union and league backs exhibited higher sprinting P_{max} values. Also, they support the recent works in skeleton that have suggested the importance of P_{max} as a key determinant of push-start performance (Colyer 2015; Colyer, Stokes, Bilzon, Cardinale, et al. 2017). However, this skeleton based research was conducted on a leg press dynamometer and to the author's knowledge the present study is the first to confirm this relationship using sprinting.

Like the observations above for sprint performance, Figure 7.4 highlights a lack of overlap between the best ND and worst WCP athlete in terms of sprinting P_{max}. Hence, two distinct groups are apparent and in line with the performance tiers of the British Bobsleigh programme. Given this observation and in conjunction with the variable's very large relationship with the push-start, it can be suggested that sprinting P_{max} could be a useful variable when creating the benchmarking standards for a WCP bobsleigh athlete. Like the above for sprint performance and based upon the data presented in Figure 7.4, the present author suggests that an athlete who achieves a sprinting P_{max} value < 2100 W would be deemed ND and thus 2100 W creates a minimum requirement benchmark for a WCP bobsleigh athlete. However, if an athlete achieved this minimum threshold it does not make this athlete become WCP and thus a more definitive WCP benchmark could be set at 2200 W. However, given the small sample size of this study, these thresholds should be used with caution and warrant validation with a greater number of athletes.

When expressed in its relative form, a reduction from very large to large was observed in the push start: P_{max} relationship. It can therefore be assumed that absolute as opposed to relative P_{max} is more important for bobsleigh. However, it should be acknowledged that the confidence intervals for these variables may overlap, because of the small sample of bobsleigh athletes used in this study. Nevertheless, these findings could lead to the suggestion that for bobsleigh it is somewhat important to be heavier, as well as faster to generate more power and thus help accelerate the sled during the push-start.

Practically, the data from part A suggests that in order to enhance an athletes push-start capability an emphasis should be placed on increasing their P_{max} during sprinting, which as highlighted by Morin and Samozino (2016), can be achieved by improving its key determinants F_0 and V_0. Of these two key determinants, F_0 displayed the stronger relationship with the push-start, however it was unable to differentiate between WCP and ND athletes, whereas V_0 was. These results corroborate the findings of Colyer et al. (2017) who showed elite skeleton athletes to display higher V_0 but similar F_0 values, when compared to the talent squad. Thus far, it could be speculated that having a more velocity dominant mechanical sprint profile maybe more important for push-start performance. However, the force component should not be overlooked given its large push-start performance relationship, as well as the fact that mechanical power is a construct of both velocity and force output

(Morin et al. 2012). It could be suggested that an individual optimal sprint force-velocity profile may exist in order to maximise push-start performance, as shown in previous literature for jump performance (Samozino et al. 2012). However, further research is required to substantiate this theory.

Although sprint performance split times were moderately to largely related to the push-start, the evidence indicates that sprinting P_{max} has a greater push-start predictive ability. Therefore, it could be suggested that the addition of sprint force-velocity profiling to the British Bobsleigh 'evaluation test' may add additional value beyond the current split time measurements. Also, the collection of this additional information will allow practitioners within bobsleigh to understand what fundamental physical and technical qualities are allowing their athletes to achieve certain sprint performances (Jiménez-Reyes et al. 2018; Morin & Samozino 2016). Essentially, bobsleigh practitioners can use the force-velocity mechanical profile standards presented above, in conjunction with the large within-group discrepancies observed for WCP and ND athletes to compare their athletes. Identifying what underlying sprint based mechanical qualities make their athletes fast and what areas can be developed to enhance their performance, via targeted individualised training interventions (Morin & Samozino 2016).

Figure 7.6 provides a practical example of the value of using sprint force-velocity profiling in the field, by illustrating profiles of two ND bobsleigh athletes with similar push-start and sprint times over 60 m. On the basic premise that the two athletes have very similar push-start capabilities and sprint times, it would be highly likely that they were given a similar training programme. However, based on their individual sprint mechanical profiles presented in Figure 7.6 and as suggested by Morin and Samozino (2016) this would probably result in suboptimal adaptations. Athlete A has a higher F_0 than athlete B and in fact sits towards the top end of the WCP standard bracket for this variable. However, athlete A has a much lower V_0, which sits towards the bottom end of the ND performance bracket. Therefore, based on this analysis the present author would suggest that athlete A's training should prioritise developing the V_0 component of his sprinting mechanical profile, whereas Athlete B should prioritise F_0.

7.4.3 Pre-Season Training Phase Responses

Distinct group changes were observed in the 'evaluation test' and sprint force-velocity mechanical profiles over the 16-week pre-season training phase (see Table 7.6). The moderate positive group shifts detected in both sprint P_{max}, and V_0 over the pre-season training phase, contradict those observed by Colyer et al. (2017) for elite skeleton athletes. This disparity in results is likely to be attributed to the difference in training programmes implemented during the pre-season training phase, as well as being influenced by the different approaches used to model the force-velocity mechanical profile. A possible explanation for this clear group level improvement in sprint P_{max} and V_0 in this study, could be the emphasis placed on speed during the final phase of the pre-season block, with the volume of weekly speed sessions increased from 2 to 3 (see Figure 7.1 and Table 7.2). This supports the idea of training specificity to improve certain mechanical components of an athlete's force-velocity profile (Jiménez-Reyes et al. 2017). Nevertheless, it is important to highlight that on an individual level, athlete 4 increased their $P_{\max}$ via what appeared to be an improvement in his F_0 only, as opposed to the other athlete's displaying improvements in V_0 or both $P_{\max}$ determinants (i.e. F_0 and V_0) simultaneously. Therefore, except for athlete 4 it is possible to speculate that the P_{max} increases observed in this study are a result of the athletes increasing the V_0 component of their sprint mechanical profiles. Although the exact explanation for the individual response from athlete 4 is unclear, it may be due to the heavy emphasis placed on strength over the first two pre-season training blocks. Additionally, this finding highlights the individual training responsiveness to the same programme.

Of the variables included in this study that demonstrated either a large or very large push-start relationship, significant group changes were detected for both sprinting speed and $P_{\max}$, however only the latter variable change reached a moderate magnitude. An increase in $P_{\max}$ of 0.6 % or 14 W equates to the SWC in this variable for WCP bobsleigh athletes. However, given that ultimately the goal is to improve push-start performance, based on the push-start: $P_{\max}$ relationship (see Figure 7.4), an improvement in $P_{\max}$ of ~ 100 W would be necessary to transfer to a SWC in push-start performance. In fact, this study demonstrated an observed group change in sprinting P_{max} above the SWC at 160 W and because of its relationship with the push-start, a group gain in performance of 0.049 s could be expected. Interestingly, the actual observed improvement in push-start performance at a group level was 0.06 s. Subsequently, although preliminary, these findings begin to suggest the presence of training transfer between the variables and a potential cause and effect relationship. When considering the individual training responses (see Figure 7.6a and 7.7c), all athletes displayed either moderate or large positive changes in sprint P_{max} and for four of the athletes their change was > 100 W. As expected these observed improvements only translated into smaller but still worthwhile changes in push-start performance. However, athlete 3 who had the largest positive shift in P_{max} (326 W), had the smallest shift in push-start performance amongst the four athletes where a clear positive change was detected. In fact, athlete 3 demonstrated large improvements in all other variables measured in this study, except the 5-RBJ, S_{FV} and D_{RF} (see Figure 7.6, 7.7 and Appendix 3). However, based on earlier findings we do not expect any of these variables (i.e. 5-RBJ, S_{FV} and D_{RF}) to have much of an effect on the push-start, because of the trivial to small relationships reported. Athlete 2 is also of interest, given that they demonstrated the smallest improvement in sprinting P_{max}, but had the largest positive changes in push-start performance amongst the WCP group.

Considered collectively, based on the findings above, it could be suggested that there are other important factors apart from those included in this study that influence push-start performance, for example push-start technique. This highlights the potential danger of relying on correlation-based analysis to form the basis of training programmes. As a result of part A, at a group level the training responses followed the pattern we would expect; sprinting P_{max} improved, speed improved and push-start performance improved. However, this was not necessarily reflected in the pattern of individual changes observed. Hence, the existence of a cause and effect relationship at an individual level is less clear and requires further investigation.

7.4.4 Limitations

One major drawback of the timing gate approach used to quantify athlete sprint force-velocity profiles in the present study, is that it does not consider any inter-step differences (Cross et al. 2016; Samozino et al. 2015). However, the collection of inter-step information in the field requires an extremely rare and expensive integrated track force plate (Samozino et al. 2015), rendering the approach impractical for the British Bobsleigh performance programme. Secondly, critics could highlight the fact that the present author did not measure sprint force-velocity mechanical profiles at the end of each training block. However, the collection of such information was not practically possible given that in each instance, the WCP squad were abroad on intensive push camps. Finally, a limitation of part B of this study is that there was no recognised “taper” week/s leading into testing. Therefore, it could be argued that those athletes who did not respond may have still been carrying some residual fatigue from the previous training block and that they may have shown improvements with a taper. Nevertheless, all athletes were given 48 hours rest prior to testing, to minimise the effect of fatigue on the observed outcomes. Also, tapering strategies are highly individualised, thus it would have been challenging to identify and co-ordinate optimal tapering strategies for the WCP athlete group used in this part of the study.

7.4.5 Practical Applications

The data presented above provides bobsleigh practitioners with normative ‘evaluation test’ and sprint force-velocity mechanical variables for both WCP and ND male bobsleigh athletes. The links shown for push-start performance with both speed and power output during sprinting, as well as both variables distinguishing ability and lack of overlap between different performance levels, suggest they could be used when benchmarking the performance standards of WCP athletes. Additionally, it highlights the need to focus an aspect of training on both sprinting speed and power when looking to enhance athletes push-start capabilities. For the latter, this could involve the inclusion of individualised heavy sled sprints between 69 % to 96 % body weight to induce a ~ 50 % reduction in maximal velocity, in theory providing a sufficient stimulus to operate at P_{max} and develop this physical quality (Cross et al. 2017). However, the effectiveness of this specific intervention at improving P_{max} is still unclear, particularly in elite-level athletes (Cross et al. 2018). Further research is required.

From a general training perspective, the findings of part A suggest that the inclusion of force-velocity profiling as part of the sprint assessment in the British Bobsleigh ‘evaluation test’, could be of value by assisting to profile the mechanical strengths and weaknesses of athletes within both the WCP and ND programmes. Subsequently, individualised training interventions could be prescribed based on each athlete’s relative mechanical strengths or weaknesses, via the inclusion of exercises targeted towards optimising either their force (e.g. heavy sled pushes) or velocity (e.g. free sprinting over 50-80 m, assisted sprinting and sleds with a light load approx. 10 % body mass) mechanical component (Jiménez-Reyes et al. 2018; Morin et al. 2017).

At a group level, it is evident that the current British Bobsleigh pre-season training programme facilitates beneficial improvements in push-start performance. Although it is difficult to determine the exact mechanisms for this improvement, these changes coincided with improvements in sprint performance over 60 m, particularly the sprinting mechanical variables P_{max} and V_0. On an individual level the performance improvement crossover between the push-start and various sprinting variables is less clear. Subsequently practitioners should consider other variables beyond those measured in this study (for example, push-start technique), when attempting to program training focusing on improving push-start performance. Individual athlete sprint force-velocity mechanical profiles can be used to assess the effectiveness of training interventions but should only be one of the tools in the bobsleigh practitioners testing box.

7.4.6 Conclusions

In agreement with the aims of this study, the discriminative validity and predictive validity of sprint force-velocity profiling for the bobsleigh push-start were explored. Also, the work investigated the influence of a 16-week pre-season training phase on bobsleigh athlete's sprint force-velocity mechanical profiles and associated changes in push-start performance. The present investigation established the following key outcomes:

1. Force-velocity profiling via a simple sprint distance-time measurement approach should be added to the British Bobsleigh 'evaluation test', as it can help distinguish between different performance levels and identify mechanical strengths and weaknesses of WCP and ND programme athletes.
2. Sprinting speed and mechanical power can distinguish between performance levels and both demonstrated a relationship of reasonable strength with push-start performance. Therefore, they should be considered key determinants of push-start performance in bobsleigh.
3. The current British Bobsleigh pre-season training programme has a clear beneficial influence on sprinting maximal mechanical power, however the translation of this performance gain into a cause and effect on push-start performance at an individual level is less clear.

Chapter 8

General Discussion, Practical Applications, Limitations and Future Research

8.1 General Discussion

This thesis aimed to validate and develop the core principles and scientific underpinnings of squad monitoring and talent identification specific to push-start performance in bobsleigh. Although evidence does exist around the validity of different performance tests for bobsleigh push-start performance (Harrison 2017; Osbeck et al. 1996), this research is the first to examine and develop the current performance testing practices of British Bobsleigh. The introduction outlined six objectives that were developed to achieve the overarching aim of this thesis (see Chapter 1.6), thus each of these objectives will now be reviewed in turn.

Objective 1: Examine the relationship between the push-start and finish time across elite bobsleigh competitions for the 2-man, 4-man and female event formats, across multiple tracks and over multiple on-ice seasons.

The push-start has long been considered a key determinant of performance in bobsleigh by many athletes and coaches and some evidence does exist confirming this belief (Brüggemann et al. 1997; Harrison 2017; Morlock & Zatsiorsky 1989; Smith et al. 2006). However, to date, the literature has tended to focus on the male formats (2-man and 4-man), specific races or tracks in isolation or not considered any within race field sub-groups (e.g. top-10 or top-15). Therefore, *study 1* examined the relationship between the push-start and finish time across all elite bobsleigh competitions for the 2-man, 4-man and female event formats, over three consecutive on-ice seasons between 2012 and 2015. This was one of the first studies to undertake this type of analysis on a large data set; the analysis included 3930 runs compared to a maximum of approximately 1280 runs in previous studies. Also, except for the new 2018 Winter Olympic track in Pyeongchang, the work included all race tracks on the elite bobsleigh circuit. Finally, this study is the first that has sort to empirically examine the belief in bobsleigh that a 0.01 s improvement in the push-start can translate to a 0.03 s improvement in finish time. The findings revealed the importance of the push-start across all formats to be track dependent, with most tracks on the elite circuit being classified as push-start dominant or moderately influenced by the push-start, and in most cases, this remained the same when considering the top-10 crews only. Additionally, the data suggested that a 0.01 s push-start improvement could translate to a 0.019 to 0.057 s improvement in finish time, depending on the specific track and race format. However, when analysis only included the top 10 crews, the magnitude of this theoretical finish time improvement reduced in most cases. Despite this, data from the most push-start dominant track Altenberg, suggested that depending on format, a 0.01 s improvement in push-start time could translate to an improvement in finish time of between 0.031 to 0.055 s, even when considering the top 10 crews only. Consequently, the study not only confirmed the value of evaluating and developing push-start performance in British Bobsleigh athletes but was also one of the first studies to determine the variability in the importance of the push-start across different tracks and formats in elite-level bobsleigh.

Objective 2: Investigate the validity of the 'evaluation test' used by British Bobsleigh to predict push-start performance, as well as assess the individual performance qualities that contribute to the bobsleigh push-start.

British Bobsleigh use the 'evaluation test' to assist with both talent identification and national squad monitoring, however the test battery had not previously been validated against bobsleigh push-start performance. Hence, *Study 2* investigated the predictive validity of the 'evaluation test' used by British Bobsleigh to assess whether the whole test battery, as well as individual tests included within it relate to the bobsleigh push-start. The 'evaluation test' measures three different aspects of athletic performance (sprinting, pushing and jumping) and consists of a 60 m sprint, four x 40 m roll-bob pushes and a 5-RBJ. Points are awarded for performance in each test (up to a maximal of 200) and then a total sum score accumulated across the six tests (maximum of 1200), referred to in bobsleigh as 'evaluation test' total points. The findings of the study detected a very large and near perfect relationship between 'evaluation test' total points and push-start performance for male and female athletes (*r* = -0.86 and -0.94 respectively), thus confirming the predictive validity of total points scored on the British Bobsleigh 'evaluation test' for the bobsleigh push-start. However, the predictive validity of 'evaluation test' total points was largely a result of two thirds of these points coming from the roll-bob push tests and the very large to near perfect push-start performance relationships detected for both sexes (*r* = 0.83 to 0.98). Additionally, given the novelty of the roll-bob push test used by British Bobsleigh, to the authors knowledge, this is the first study to confirm its reliability for the testing and monitoring of bobsleigh athletes (CV = 0.7 to 1.7 %). Given the strength of the relationships between the push-start and roll-bob push tests, an attempt was made to explain push-start performance using only body mass, sprint and jump performance. Subsequently, the analysis highlighted body mass and 30 m sprint time as key qualities for the push-start and collectively these could explain 55 % and 90 % of the push-start performance variance amongst male and female bobsleigh athletes respectively. To summarise, although 'evaluation test' total points is a valid approach to assess athletes push-start capabilities, completion of the entire testing battery proved somewhat unnecessary. This study was the first to confirm that the roll-bob push test could be used as a reliable and valid predictor of push-start performance. This novel finding is useful as testing with the roll-bob apparatus is more practical and accessible than push-start testing on an outdoor simulation track. Additionally, the results showed a clear need to examine other qualities beyond those in the current British Bobsleigh 'evaluation test' that could contribute to push-start performance.

Objective 3: Explore the reliability, discriminative validity and predictive validity of the British Bobsleigh 'Keiser Squat Test'.

To monitor their athlete's ability to express power under load, British Bobsleigh uses the 'Keiser Squat Test', however very little is known about either its reliability or validity. *Study 3* confirmed the British Bobsleigh 'Keiser Squat Test' protocol to be reliable for the testing and monitoring of bobsleigh athletes (CV = 6 to 10 %). Although the 'Keiser Squat Test' could discriminate between male and female athletes, it was unable to distinguish between male WCP and male ND athletes, except for absolute PPO at 140 kg. In terms of predictive validity, absolute and relative PPO attained from the 'Keiser Squat Test' demonstrated a very large to near perfect relationship with the push-start for females (r = -0.87 to -0.96), however only a moderate relationship was observed for the male group across several of the absolute test loads (r = -0.30 to -0.47). The study found the different 'Keiser Squat Test' loads to all represent the same physical quality, as the inter-correlation analysis undertaken reported at least a very large relationship between each test load ($r \geq 0.78$). Finally, PPO at any absolute load was shown to be an independent quality when compared to either body mass or sprint performance, as measures from these tests shared low common variances (2 to 12 %). In conclusion, the 'Keiser Squat Test' is sufficiently reliable for athlete monitoring in bobsleigh and may help predict push-start performance in female athletes. However, the strength of the prediction is only moderate in male athletes and apart from at a moderate load (i.e. 140 kg), the 'Keiser Squat Test' was unable to discriminate between male athletes in the WCP and ND programmes. Thus, more research was needed to identify other tests and qualities that are important for push-start performance.

Objective 4: Investigate the validity of vertical and horizontal jump test metrics completed under both bilateral and unilateral conditions, to predict push-start performance.

An extensive review of the current winter sliding sport (e.g. bobsleigh & skeleton), strength and power diagnostic and sprinting literature identified several other performance tests not currently used by British Bobsleigh that warranted further investigation (see Figure 8.1). Therefore, *Study 4* investigated the push-start predictive validity of vertical and horizontal jump metrics completed under both bilateral and unilateral conditions. To the authors knowledge, this is the first study in bobsleigh to compare the predictive validity of jump assessments completed vertically and horizontally as well as bilaterally and unilaterally. The main finding of this study was that SLJ unilateral force and power were stronger predictors of push-start performance (r = -0.48 to -0.61) than either the bilateral version of the test (r = 0.03 to 0.24) or the CMJ completed bilaterally or unilaterally (r = 0.27 to -0.12). Additionally, maximising an athletes' horizontal unilateral facilitation while minimising any between limb asymmetries for force and power metrics, appears to be beneficial for push-start performance (unilateral facilitation $r = 0.67$ to 0.71 and asymmetry index $r = 0.87$ to 0.88). For those unilateral SLJ metrics that demonstrated a large relationship with the push-start (peak horizontal force, relative peak horizontal force and peak horizontal power), all were shown to represent similar physical qualities because of high shared variances (CV = 88 to 92 %). Also, the SLJ test showed differences in individual athlete profiles and thus can help to identify those athletes with asymmetries and or a poor unilateral facilitation, forming the basis for targeted, individualised training interventions. Although these findings confirmed the predictive ability of the unilateral SLJ, the small sample size ($n = 6$) used in the study meant that the discriminative validity of all the tests included could not be examined. Despite this, the predictive ability of the unilateral SLJ indicated that horizontally oriented tests may represent better push-start predictive ability than vertically oriented tests (e.g. the CMJ and 'Keiser Squat Test'). Thus, the addition of unilateral SLJ peak horizontal force, bilateral index and asymmetry index to the British Bobsleigh 'evaluation test' or monitoring practices, may help to account for some of the unexplained variance (approximately 45 %) in male push-start performance highlighted in study 2.

Objective 5: Explore the discriminative validity and predictive validity of sprint force-velocity profiling for the bobsleigh push-start.

Study 5 explored the discriminative validity and predictive validity of sprint force-velocity profiling for bobsleigh. To date, this is the first study in winter sliding sports to examine force-velocity profiling in sprinting, which is a more ecologically valid movement for the bobsleigh push-start. All British Bobsleigh's standard sprint split times, as well as the sprinting mechanical variables P_{max}, relative P_{max}, V_0 and V_{opt} were all shown to distinguish between male WCP and ND squad athletes, thus confirming their discriminative validity for the bobsleigh push-start. More specifically, 30 m sprint time and P_{max} appeared to demonstrate the highest discriminative validity, due to limited overlap in the WCP and ND athlete range scores. This was then reflected in the push-start predictive validity analysis, with 30 m sprint time and sprinting P_{max} providing the strongest correlations with push-start performance ($r = 0.69$

and -0.80 respectively). This analysis helped to estimate the transference of sprint time and P_{max} improvements to changes in push-start performance (2 %, 5 % and 0.6 % respectively). Finally, the sprint force-velocity profiling undertaken as part of this study confirmed that athletes with similar sprint and push-start times can display opposite force-velocity mechanical profiles. Thus, it can help to identify the mechanical strengths and weaknesses of bobsleigh athletes. In summary, sprint acceleration (30 m split time) and sprinting P_{max} represent both discriminative and predictive validity for the bobsleigh push-start and thus should be considered key determinants of performance in the sport. Subsequently, sprint force-velocity profiling could be added to the British Bobsleigh 'evaluation test'.

Objective 6: Investigate the influence of a 16-week pre-season training phase on bobsleigh athlete's sprint force-velocity mechanical profiles and associated changes in push-start performance.

Despite previous work in this thesis highlighting sprint acceleration performance (i.e. 30 m sprint time) and sprinting P_{max} as important determinants for bobsleigh push-start performance, little is known about how training induced changes in these variables influence global performance (i.e. push-start performance) in the build up to major competitions. Also, in general, there is a lack of research that has undertaken longitudinal monitoring to track training adaptations in elite-level athletes. Thus, *Study 5* also aimed to investigate the influence of a 16-week pre-season training phase on bobsleigh athlete's sprint force-velocity mechanical profiles and associated changes in push-start performance. At a group level, the findings of this study demonstrated training induced improvements in push-start performance, sprint speed and P_{max} (absolute and relative). Nevertheless, of these qualities the largest group-based improvements were observed in absolute P_{max}. This was reflected with all athletes making worthwhile gains in P_{max}, however this did not always translate to an improvement in push-start performance on an individual level. Subsequently, this highlights that there may be other factors important for push-start performance than those measured in this study, for example technical ability. Therefore, more research is required to fully understand the determinants of bobsleigh push-start performance.

8.2 Overall Summary

To conclude, the bobsleigh push-start has a moderate to large influence on performance at most tracks on the elite bobsleigh circuit. Additionally, 0.01 s improvements in push-start performance at push-start dominant tracks, could translate to finish time improvements of up to 0.055 s. Therefore, this thesis aimed to validate the current performance testing approaches of British Bobsleigh and develop its practice based upon available literature from winter sliding sports, strength/power diagnostics and sprinting. Figure 8.1 first proposed and outlined in the literature review (see Chapter 2.10), provided a framework to shape the direction of the specific research projects included in this thesis. Subsequently, the roll-bob push provides a reliable test with high ecological and predictive validity when quantifying the push-start capabilities of bobsleigh athletes. In terms of the key underpinning determinants of the push-start, the thesis identified the importance of body mass, sprinting speed (30 m sprint time), sprinting maximal mechanical power (sprint force-velocity profiling), unilateral horizontal force production (unilateral SLJ) and power production under moderate external loads ('Keiser Squat Test'). Thus, practitioners in bobsleigh should consider these key qualities when designing future performance testing batteries and designing training programmes.

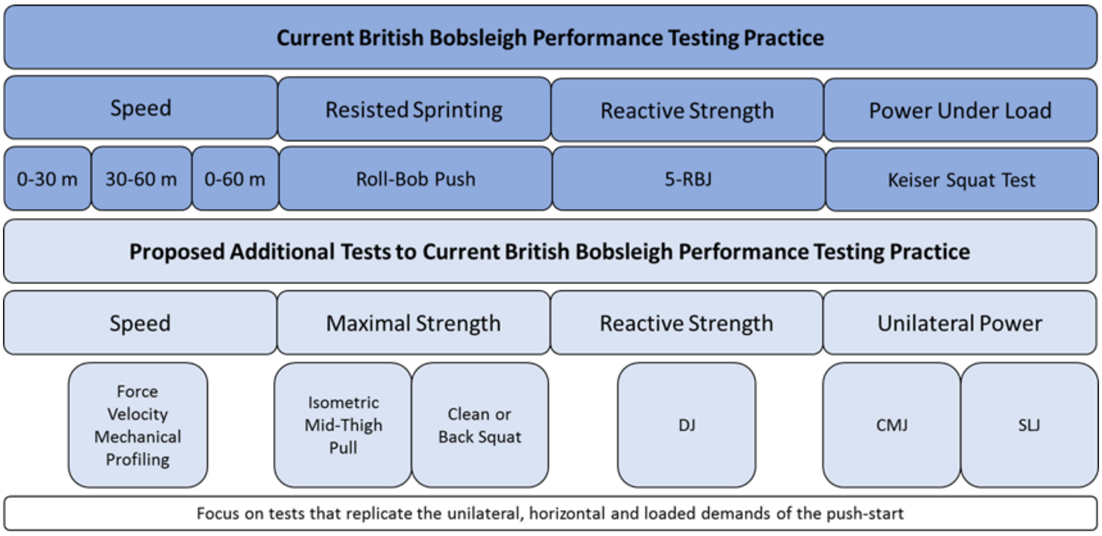

Figure 8.1 Current performance testing practice at British Bobsleigh and proposed additional tests that warrant attention from future research. 5-RBJ = 5-repeated bound jump, DJ = Drop Jump, SJ = Squat Jump, CMJ = Countermovement Jump, SLJ = Standing Long Jump.

8.3 Practical Applications

The thesis has explored the importance of push-start performance in elite-level bobsleigh, followed by investigating the use of performance testing in the sport, as a means of squad monitoring and talent identification specific to push-start performance. Study 1 confirmed the importance of the push-start in elite-level bobsleigh. Study 2 validated the 'evaluation test' currently used by British Bobsleigh. Finally, studies 3, 4 and 5 identified and explored several other performance tests that British Bobsleigh could add to its 'evaluation test' protocol. Thus, despite the small sample sizes, the data presented starts to provide benchmarking standards across a range of tests that reflect different qualities that have been shown to be of some importance for the bobsleigh push-start (see Table 8.1). Subsequently, this provides practitioners at British Bobsleigh with useful data against which to assess their current and future athletes.

Table 8.1 Benchmarking standards for bobsleigh athletes formulated as part of this thesis.

Parameter	Minimum WCP Benchmark	Definitive WCP Benchmark
30 m sprint time (s)	≤ 3.75	≤ 3.65
Sprinting P_{max} (W)	≥ 2100	≥ 2200

In addition to the above, because of the findings of each specific research project undertaken as part of this thesis, the author proposes the following practical applications:

Study 1: Importance of the push-start in elite-level bobsleigh

1. The push-start should be identified as a target area for performance enhancement in elite-level bobsleigh.

2. Practitioners should not ignore the influence of other factors beyond the push-start (i.e. driver skill), as they still have a large influence on finish time and thus the outcome of races. Therefore, in the build up to a major championship when planning the focus of training, practitioners should consider the specific demands of the track venue and how influential the push-start is on overall performance.

Study 2: Validation of the British Bobsleigh 'evaluation test'

1. British Bobsleigh 'evaluation test' total points can be used as a valid indicator of an athletes' push-start capabilities, but it may not be necessary to use all tests or the points-based system.

2. The roll-bob push is a reliable and valid test for squad monitoring and talent identification specific to the bobsleigh push-start and is just as effective in predicting performance as the entire British Bobsleigh 'evaluation test'.

3. Body mass and sprint acceleration performance (i.e. 30 m sprint time) should be considered as key qualities underpinning push-start performance.

Study 3: 'Keiser Squat Testing': reliability, discriminative validity and predictive validity

1. The 'Keiser Squat Test' protocol used by British Bobsleigh is reliable and thus can be used to monitor athlete power production qualities under loaded conditions.

2. All ‘Keiser Squat Test’ loads represent the same physical quality and therefore it is not necessary to include all test loads when athletes are undertaking the test.

3. ‘Keiser Squat Test’ PPO across all loads is a valid predictor of push-start performance in female bobsleigh. However, only absolute PPO at a moderate load represented discriminative (i.e. 140 kg) and predictive (i.e. 160 kg) validity for male push-start performance. Additionally, ‘Keiser Squat Test’ absolute PPO represents a unique quality compared to both body mass and sprint performance. Therefore, it may be a useful addition to the British Bobsleigh ‘evaluation test’.

Study 4: The application of vertical and horizontal jump testing to bobsleigh

1. Unilateral SLJ force should be added to British Bobsleigh’s ‘evaluation test’ or monitoring practices due to its large association with the bobsleigh push-start.

2. From a training perspective, bobsleigh strength and conditioning programmes should incorporate unilateral dynamic exercises in the horizontal plane, as they may provide greater transfer when compared to bilateral and/or vertical alternatives. Also, inclusion of exercises of this nature may help to increase athletes’ expression of unilateral facilitation and reduce any between limb asymmetries, which both appear to be beneficial for push-start performance.

Study 5: The use of sprint force-velocity profiling in bobsleigh

1. The use of sprint force-velocity profiling in bobsleigh may help to identify an athlete’s mechanical strengths and weaknesses, and thus help inform the prescription of individualised training interventions.

2. Both sprinting speed and power should be included within future bobsleigh performance testing batteries, as they represent high discriminative and predictive validity for the push-start.

3. Practitioners in bobsleigh should focus an aspect of training on both sprinting speed and power, when trying to enhance the push-start capabilities of their athletes. However, because the transfer between the push-start and sprint speed/power is still somewhat unclear, they should also consider other factors beyond those measured during performance testing when programming training, for example push-start technical ability.

To conclude, the present thesis used Figure 8.1 as a framework to shape the direction of the specific research projects undertaken as part of this thesis. Based upon the practical recommendations developed because of these individual studies, Figure 8.2 provides an updated schematic representation of the current performance testing practices used by British Bobsleigh, proposed modifications to practice and the performance tests that still require attention from future research. The proposed tests outlined for future practice are colour coded based on the strength of the evidence supporting these tests presented in this thesis. ‘Blue shading’ represents strong evidence and rationale supporting the use of the test, whereas ‘light blue shading’ represents moderate evidence and rationale supporting the use of the test. In addition to the test being reliable, strong evidence for a given test represents at least two of the following; high ecological validity, discriminative validity between different performance groups or at least large predictive validity. On the other hand, moderate evidence represents a test that only has discriminative or predictive validity for the bobsleigh push-start and/or the findings surrounding the test are based on a small sample size.

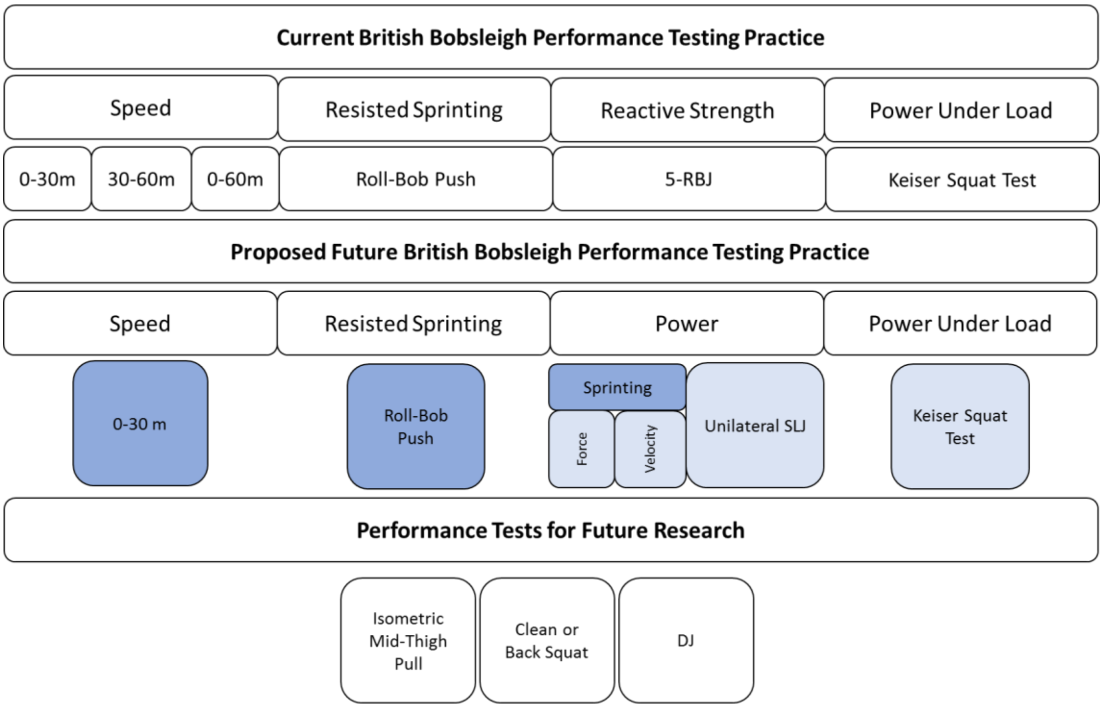

Figure 8.2 Current performance testing practice at British Bobsleigh, proposed modifications to practice based on the outcomes of this thesis and the performance tests that still require attention from future research. DJ = Drop Jump, SLJ = Standing Long Jump, 'blue shading' = strong evidence and rationale for the test and 'light blue shading' = moderate evidence and rationale for the test.

8.3 Limitations

The present author believes that this thesis has made a significant and original contribution to the bobsleigh literature, particularly surrounding the use of performance testing in the sport. However, it is important to acknowledge several limitations throughout the thesis including;

1. Firstly, not all the potential performance tests highlighted from the literature review and outlined in Figure 8.1 as being potentially worthwhile for bobsleigh were investigated. As highlighted in Figure 8.2 more work is required to examine the importance of maximal and reactive strength qualities for push-start performance in bobsleigh. However, the present thesis did investigate several novel variables and performance tests. Additionally, given that this work was undertaken in the elite sport environment, it was limited to how many new tests could be introduced.

2. Secondly, there was only a small number of male and female bobsleigh athletes used throughout the studies included in this thesis, this is particularly evident in studies 3, 4 and 5. However, the author had access to and recruited from the entire British Bobsleigh population, including both WCP and ND squad athletes where practically possible. Therefore, there were no other available bobsleigh athletes in the country and thus either the entire population (study 2) or almost the entire population (studies 3, 4 and 5) were studied. Hence the findings of this thesis are valid for the population with which they are applied i.e. British Bobsleigh squad athletes.

3. Another limitation of this thesis is that there was no direct measure of push-start performance used in study 3, 4 or the training aspect of study 5. However, the heavy back roll-bob push which was selected as the push-start criterion measure in each instance, represents high ecological and predictive validity for the push-start. This is a result of the test apparatus and protocol being designed to mimic an actual sled and actual push-start, as well as study 2 demonstrating a very large relationship between the roll-bob push and the bobsleigh push-start.

4. Finally, although this thesis has added to our knowledge of the key determinants of the bobsleigh push-start, the study only considered the push-start from the brake-man or brake-women handle. Thus, it is not clear if the key determinants of the push-start vary depending on what handle the athlete is pushing from i.e. the drivers handle, the left handle, the right handle or the brake-man/brake-women handle.

8.4 Future Research

Despite this thesis, there is still a paucity of literature surrounding the use of performance testing in bobsleigh. Therefore, there is a vast scope for future research to be undertaken within the area. Following completion of this specific applied research project in conjunction with British Bobsleigh, the following areas warrant attention from future research:

1. Firstly, future research should consider the other performance tests identified in the literature review and outlined in Figure 8.1 that were not included in any of the specific research projects in this thesis (see Figure 8.2). These performance tests include measures of maximal isometric strength (isometric mid-thigh pull), maximal isoinertial strength (clean or back squat) and reactive strength (DJ).

2. Secondly, research into the specific performance determinants of pushing from each of the handles on the 4-man bobsled is warranted, i.e. the drivers handle, the left handle, the right handle and the brake-man/brake-women handle.

3. Additionally, future research is required to assess the “sensitivity to change” of all the performance tests outlined in the proposed British Bobsleigh performance testing practice moving forward (see Figure 8.2). This research should investigate the translation of performance test changes into changes in push-start performance across a longitudinal training study.

4. Finally, future work could investigate the effectiveness of individualised training interventions based on the measures that have been identified by this thesis as important qualities for push-start performance in bobsleigh. While the training programme implemented in study 5 was somewhat individualised, this was not based on the individual athlete testing profiles collected in this thesis e.g. individual sprint force-velocity profiles.

8.5 Reflections on the Research Context

As previously described in the thesis introduction (see Section 1.1), the candidate was imbedded within the British Bobsleigh support staff structure for an entire Olympic Cycle, preparing athletes for the 2018 Winter Olympic Games in Pyeongchang, South Korea. As British Bobsleigh's 'sport scientist', the candidates' role was to validate the core principles and scientific underpinnings of squad monitoring and talent identification specific to 'brake-men'/'brake-women' push-start performance in bobsleigh. The following section will now reflect on British Bobsleigh's performance at the 2018 Winter Olympic Games using the presented thesis to provide context.

In the Olympic season, British Bobsleigh were still implementing the full 'evaluation test' battery outlined at the beginning of this thesis (see Section 1.5), i.e. a 60 m sprint, a 5-RBJ and 4 x roll-bob pushes. Thus, based on the findings of this thesis and the subsequent practical applications highlighted above (see Section 8.2), the British Bobsleigh programme should seek to better integrate the key findings of this thesis into their squad monitoring and talent identification practices leading into the 2022 Winter Olympic Games in Beijing, China.

The bobsleigh race track in Pyeongchang was specifically designed and built for the 2018 Winter Olympic Games. Thus, the relative importance of the push-start at the Alpensia Sliding Centre in Pyeongchang has yet to be explored. Exploratory analysis using the publicly available 2018 Winter Olympic Games race data published online (IBSF 2018a), demonstrated the track to be push-start dominant for 2-man bobsleigh (common variance = 64 %) and drive dominant with a moderate push-start component for 4-man and female bobsleigh (common variance = 47 and 44 % respectively). However, when just considering the top 10 crews, the push-start was shown to be a small component of performance in 2-man and 4-man bobsleigh (< 7 %), but the track was identified as push-start dominant for the female format (52 %). These findings are in line with study 1 of this thesis, which identified a fast push-start time as a pre-requisite for successful performance, but at the top end of elite races (i.e. Top 10) it generally represents less importance.

At the Olympics, on average, the British Bobsleigh #1 4-man crew achieved the best push-start performances when compared to the other 4-man crew, as well as the 2-man and female crews (average start rank 7 compared to 12 respectively). However, this crew finished 17th which was five and ten places lower than the 2-man crew (12th) and female crew (8th) respectively. Thus, providing further support for the notion that a fast push-start performance is a pre-requisite for successful performance, but does not necessarily determine overall finish rank. Subsequently, based on this race data it appears that the #1 4-man crew produced the pre-requisite push-start performances to put themselves in contention for a medal (push-start ranks; 4th, 11th, 5th and 6th), thus their overall result performance may have been influenced by other factors outside of their push-start performances i.e. the sled and equipment or the skill of the driver. In contrast, the 2-man and female crew demonstrated some scope for improvement in their push-start performances that could have a beneficial impact on their overall race performance, as both crews had no push-start ranks less than 10th. To summarise, British Bobsleigh's performances at the 2018 Winter Olympic Games, in conjunction with the findings of this thesis suggest that a crew's preparation focus leading into a major championship should consider the relative importance of the push-start at the race venue. Also, if the selected crew have the physical and technical capabilities to produce the pre-requisite push-start performance required for success at the given track should be considered. Therefore, the proposed future practice for British Bobsleigh's performance testing outlined in Figure 8.2, can be used by practitioners to assess the physical capabilities of their athlete's and help further individualise targeted training interventions. Ultimately helping to inform performance-based decisions of the British Bobsleigh program moving forward.

Chapter 9

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Chapter 10

Appendices

Appendix 1

Participant information sheets and signed consent form.

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PARTICIPANT INFORMATION SHEET

Project Title: Validation of a performance test battery to predict push-start performance in elite level bobsleigh

Ethical Approval Reference Number: 14/11/05R

Investigator: Mr Robert James Condliffe (rocondliffe@cardiffmet.ac.uk)

You have been invited to take part in an applied sport science research study run by Robert James Condliffe from Cardiff Metropolitan University. The research will contribute to an MPhil/PhD research project. The following sheet will provide you with information highlighting the importance of undertaking this research and what it will require from you. Please read the following information carefully.

Background: The aim of this research study is to validate the current test battery (SWISS test) used by Great Britain Bobsleigh for talent identification and squad selection purposes. The research intends to determine whether or not each individual test within the battery as well as the test battery as a whole is a strong predictor of push-start performance. Results could help to validate the current test battery used by Great Britain Bobsleigh and help understand the relative importance of each test as well as highlight areas for improvement or development, for example by adding additional tests.

What does the study involve?

Volunteering to take part in this study will require you (Great Britain Bobsleigh) to provide the researcher in question with the following data:

- Performance testing data (SWISS test) collected by Great Britain Bobsleigh at talent identification and monitoring sessions from 2012 to 2014.
- Push testing data collected from 2012 to 2014 for athletes involved in the Great Britain Bobsleigh testing programme.

Are there any exclusion criteria?

Data provided by you could be excluded from the study if it matches any of the three following conditions:

1. The athlete did not complete the full SWISS test.
2. The athlete did not complete the push test within seven days of the initial SWISS test.
3. The athlete sustained an injury during testing.

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What are the risks of taking part in the study?

The risks of taking part in this study are very minimal given that the data has already been collected at talent identification and squad monitoring weekends between 2012 and 2014. All data provided to the researcher will be coded and safely stored electronically under password protection.

What are the benefits of taking part?

Taking part in this study will allow you to gain a better understanding of how well the SWISS test and the individual tests involved within the battery correlate with push-start performance in bobsleigh. Also, it could help to highlight areas where your talent identification and squad selection methods need to be developed to ensure you select the athletes with the greatest potential of winning medals on ice.

Privacy

All information you provide me with will remain strictly confidential. Individual data will be coded to maintain anonymity. Any data that is reported in the final thesis will only refer to the group as a whole and no individual data or names will be reported. You have the right not take part in the study or withdraw without reason at any point. Should you wish to receive information regarding the outcome of the study, I will be happy to share this with you. Research from the study will not be published without the prior approval of Great Britain Bobsleigh.

Interested in taking part?

If you would like to volunteer to participate in this study or have any further questions please do not hesitate to contact me.

PLEASE NOTE

You will be given a copy of both this participation information sheet and your consent form for your records.

Contact Details

Robert James Condliffe (rocondliffe@cardiffmet.ac.uk)

Dr Jon Oliver (joliver@cardiffmet.ac.uk)

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PARTICIPANT CONSENT FORM

Title of Project: Validation of a performance test battery to predict push-start performance in elite level bobsleigh
Ethical Approval Reference Number: 14/11/05R
Name of researcher: Robert James Condliffe
Participant Name: Gary Anderson (Great Britain Bobsleigh Performance Director)

The participant must complete this section (please initial ea ch box)

1. I can confirm that I have fully read and understood the information sheet that has been provided to me. I have had the opportunity to ask any questions I may have and all the answers I have been provided with are satisfactory. ✓
2. I understand that taking part in this study is completely voluntary and I have the right to withdraw without reason at any point. ✓
3. I fully understand that any information provided to the researcher listed above may be reported in the final thesis but no individual data will be personally identified or reported. ✓
4. I agree to take part in the study listed above. ✓

Name of Participant: ROB CONDLIFFE	Name of person taking consent: GARY ANDERSON
Signature of Participant: [signature]	Signature of person taking consent: [signature]
Date: 14/5/2015	Date: 14/5/2015

Please Note: Two copies should be completed; one copy for th
the researcher's file.

British Bobsleigh

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Version 1.2

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RESEARCH INFORMATION SHEET

Project Title: Development of a physiological test battery to predict push-start performance in elite level bobsleigh

Ethical Approval Reference Number: 16/6/02R (revised from 14/11/05R on 13th of June 2016)

Investigator: Mr Robert James Condliffe (rocondliffe@cardiffmet.ac.uk)

You have been invited to take part in an applied sport science study run by Robert James Condliffe from Cardiff Metropolitan University. The research will contribute to a PhD research project. The following sheet will provide you with information highlighting the importance of undertaking this research and what it will require from you. Please read the following information carefully.

Background: The aim of this research study is to improve and develop the current test battery used by British Bobsleigh at talent identification and squad selection events. The research intends to collect additional measures within the current test battery and examine additional field tests that may show a stronger correlation with push-start performance, than those already included within the present evaluation battery. Results could help to develop and improve British Bobsleighs current test battery to ensure they select those athletes who have th e greatest potential of winning medals on the ice.

What does the study involve?

Volunteering to take part in this study will require you (British Bobsleigh) to provide the researcher in question with all testing data (physiological and push start) collected by British Bobsleigh during the 2016 pre-season. As well as this you will be required to allow the researcher to collect additional data during 2016 squad testing and talent transfer events, beyond those included in the standard evaluation test battery. Finally, you will be required to permit the primary investigator to run a series of testing sessions outside the current 2016 summer schedule, focused on additional physiological tests that are believed to correlate with push start performance. These additional tests will include unilateral/bilateral vertical and horizontal jumps and the Keiser AIR300 squat. Following these additional testing sessions, it's expected that you will provide the researcher in question with access to all the data collected.

Are there any exclusion criteria?

Athlete's data provided by you may be excluded from the study if it matches any of the four following conditions;

1. The athlete did not complete the full evaluation test battery.
2. The athlete did not fully complete one or all of the additional testing sessions.
3. The athlete did not complete a push/evaluation test within 21 days of their initial test session.
4. The athlete sustained an injury during testing.

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What are the risks of taking part in the study?

The risks to your athletes of taking part in the exercise required for the testing sessions are very minimal. As long as all athletes follow the instructions of the test administrator, the risks associated are no greater than participating in a sprint and/or jump based training session.

What are the benefits of taking part?

Taking part in this study will allow you to get an insight into how a variety of other performance tests may show a stronger correlation with push-start performance, than those tests already included in the evaluation test battery. Therefore, this could allow you to make modifications to this battery to enhance your talent identification and selection process, ensuring you select the right athletes.

Data ownership

If you volunteer to take part in this study, it is vital that all data provided to the researcher is legally the property of British Bobsleigh, for the study to proceed without the need for individual athlete consent. Therefore, by signing the accompanying consent form you are confirming this to be true.

Privacy

All the information that is collected during testing and you provide will remain strictly confidential. Individual data will be coded to maintain anonymity. Any data that is reported in the final thesis will only refer to group data as a whole and no individual data will be reported or identified. You have the right to not take part or withdraw from the study at any point without reason. Should you wish to receive information with regards to the results from testing, I will be happy to provide you with this. Research from the study will not be published without the prior approval of British Bobsleigh.

Interested in taking part?

If you would like to volunteer to participate in the study or have any further questions please do not hesitate to contact me.

PLEASE NOTE

You will be given a copy of both this participation information sheet and your consent form for your records.

Contact Details

Robert James Condliffe (rocondliffe@cardiffmet.ac.uk)

Dr Jon Oliver (joliver@cardiffmet.ac.uk)

Version 1.2

Cardiff Metropolitan University | Prifysgol Metropolitan Caerdydd

RESEARCH CONSENT FORM

Title of Project: Development of a physiological test battery to predict push-start performance in elite level bobsleigh
Ethical Approval Reference Number: 16/6/02R (revised from 14/11/05R on 13th of June 2016)
Name of Researcher: Robert James Condliffe
Participant Name: Gary Anderson (British Bobsleigh Performance Director)

The participant must complete this section (please initial each box)

1. I can confirm that I have fully read and understood the information sheet provided to me. I have had the opportunity to ask any questions I may have and all answers I have been provided with are satisfactory.
2. I understand that taking part in this study is completely voluntary and I have the right to withdraw without reason at any point.
3. I confirm that all data that will be provided to the researcher is legally the property of British Bobsleigh.
4. I fully understand that any information provided to the researcher listed above may be reported in the final thesis, but no individual data will be personally identified or reported.
5. I agree to athletes being video recorded during testing sessions.
6. I agree to take part in the study listed above.

GARY ANDERSON
Name of Participant

Signature of Participant

26-06-2016
Date

ROB CONDLIFFE
Name of person taking consent

Signature of person taking consent

26-06-2016
Date

Please Note: Two copies should be completed; one copy for the participant's file and one copy for the researcher's file

Appendix 2

British Bobsleigh 'Evaluation Test' general performance tests reliability analysis from study 2's data for male athletes (see Chapter 4).

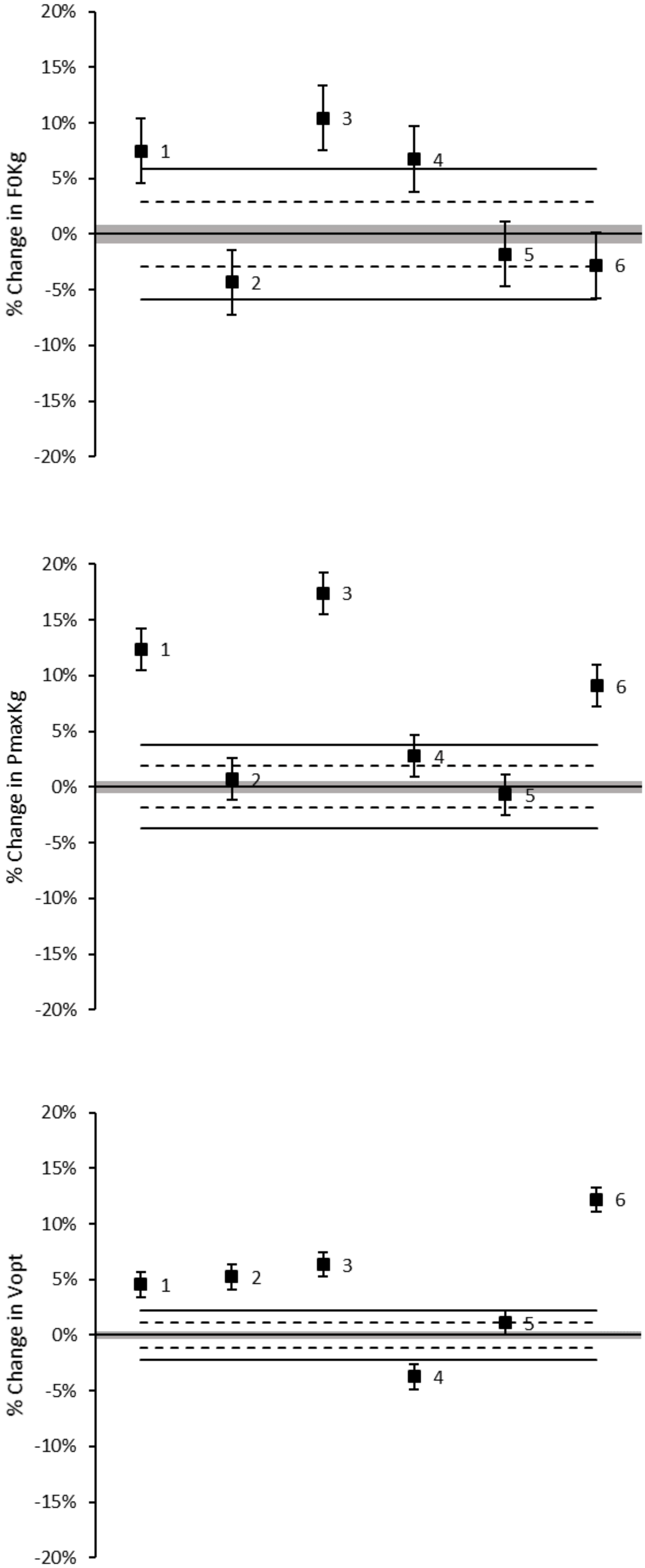
Appendix 2. Mean (±SD) times for all general performance physiological tests and between trial ICC, TE and CV values for male athletes (n = 6).

	Mean (± SD)			Trial 1 to 2			Trial 2 to 3		
Test	Trial 1	Trial 2	Trial 3	ICC	TE	CV (%)	ICC	TE	CV (%)
Body Mass (kg)	97.9 (± 9.2)	97.8 (± 9.0)	95.8 (±8.3)	1.00	0.14	1.2	1.00	0.13	1.1
30 m Sprint Time (s)	3.77 (± 0.04)	3.75 (± 0.06)	3.72 (±0.04)	0.66	0.94	1.0	0.92	0.45	0.6
30 m Flying Sprint Time (s)	3.07 (± 0.10)	3.05 (± 0.09)	3.03 (± 0.07)	0.91	0.46	1.3	0.81	0.68	1.5
60 m Sprint Time (s)	6.84 (± 0.14)	6.80 (± 0.14)	6.75 (± 0.10)	0.84	0.61	1.1	0.88	0.54	0.9
5-RBJ (m) (n = 5)	16.23 (± 0.33)	16.29 (± 0.45)	16.51 (± 0.42)	0.85	0.71	1.4	-0.04	N/A	2.7

5-RBJ = 5-reeated bound jump, ICC = intraclass correlation coefficients, TE = typical error & CV = coefficient of variation, N/A = not available.

Appendix 3

Individual athlete responses to the 16-week training phase for ‘sprint mechanical variables not represented graphically in Chapter 7 (see Section 7.3.3).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Appendix 4

PhD thesis contribution acknowledgments from British Bobsleigh.

Mr Robert Condliffe
Cardiff Metropolitan University
Cyncoed Road,
Cardiff
CF23 6XD

RE: Contribution acknowledgement

Dear Robert and your PhD supervisory team (Dr. Jon Oliver, Dr. Rhodri Lloyd & Professor John Cronin)

On behalf of British Bobsleigh I would like to take this opportunity to acknowledge the contribution your second PhD study has made to the organisation (Importance of the push-start in elite bobsleigh). The findings of this research are being used as scientific evidence and justification for our elite performance strategy aiming to achieve medal success at the PyeongChang 2018 Winter Olympic Games. We are excited by the future direction of your PhD and are looking forward to receiving the findings of its remaining studies.

Kind regards,

Lauren Forrow
World Class Performance Programme Manager
British Bobsleigh & Skeleton Association
lauren.forrow@thebbsa.co.uk
07973352761

Mr Robert Condliffe
Cardiff Metropolitan University
Cyncoed Road,
Cyncoed Campus
Cardiff,
CF23 6XD

RE: Contribution acknowledgement

Dear Robert and your PhD supervisory team (Dr. Jon Oliver, Dr. Rhodri Lloyd & Professor John Cronin)

On behalf of British Bobsleigh I would like to take this opportunity to acknowledge the contribution your first PhD study has made to the organisation (Validation of a physiological performance test battery to predict push-start performance in elite bobsleigh). The findings of this research study are currently forming the scientific evidence base behind our talent identification and squad selection testing methods working towards the PyeongChang 2018 Winter Olympic Games. We look forward to the future outcomes and applied applications of your PhD project but for now many thanks and keep up the hard work.

Kind regards,

Lauren Forrow
World Class Performance Programme Manager
British Bobsleigh & Skeleton Association
lauren.forrow@thebbsa.co.uk
07973352761

BRITISH BOBSLEIGH & SKELETON

British Bobsleigh and Skeleton Association
University of Bath
Claverton Down
Bath
BA2 7AY

28/03/2018

Rob Condliffe
PhD Student
Strength & Conditioning
Cardiff Metropolitan University
Cyncoed Road, Cyncoed Campus
Cardiff. CF23 6XD X

Dear Rob,

Re: Physiological predictors of performance in elite level bobsleigh.

Thank you for all your hard work and commitment to the Bobsleigh program over the last few years. I know that all the athletes and coaches hugely enjoyed working with you and your PhD work has undoubtedly influenced a number of critical decisions made by the program

I understand that the work that you have undertaken within your PhD over recent years has been subject to embargo while the British Bobsleigh program co-funds your research which, to my knowledge has included the following studies:

- Study 1: Importance of the push-start in elite bobsleigh
- Study 2: Validation of a physical performance evaluation battery to predict push-start performance in elite bobsleigh
- Study 3: The application of vertical and horizontal jump testing in elite bobsleigh
- Study 4: Keiser Squat testing
- Study 5: Force-velocity profiling

I recognise that given the financial situation within British Bobsleigh, the program is unable to continue to support your role as Performance Assistant and any further financial support you require to complete your PhD. In doing so the Bobsleigh program loses the right to maintain an embargo on your research as a competitive advantage to the program.

As the current Performance Director for British Bobsleigh I hereby provide consent for you (Rob Condliffe) and the associate research team (Dr. Jon Oliver; Dr. Rhodri Lloyd; Professor Jon Cronin) to publish any data collected as part of the PhD thesis within the public domain should British Bobsleigh not be in receipt of World Class Program funding after June 2018.

I wish you all the best and future success in your career.

Yours sincerely,
Lee Johnston(Interim Performance Director & Head Coach, British Bobsleigh)

Appendix 5

Abstract submitted for the Cardiff Metropolitan University Academic Associate Committee Annual Poster Symposium. May 2016

IMPORTANCE OF THE PUSH-START IN ELITE BOBSLEIGH.

Condliffe, R.12, Oliver, J.13, Lloyd, R.13, Cronin, J.3, Anderson G. 2., Forrow, L. 2. 1: Cardiff Metropolitan University (Cardiff, UK), 2: British Bobsleigh (Bath, UK), 3: Auckland University of Technology (Auckland, New Zealand).

Importance of the Push-Start in Elite Bobsleigh

In bobsleigh, the push-start is often denoted by the first published interval time (50m) and is represented by a crew of athletes accelerating and loading a sled from a standing start before descending down the track. It is widely accepted by many athletes and coaches within the sport that a crew's push start is a vital aspect of any successful performance. However, a limited number of studies within the academic literature have attempted to confirm this belief. Much of this research has focused on specific tracks as well as single events in a given season. Therefore, the aim of this study was to undertake a comprehensive examination of the relationship between push start time and final run time across all the formats and tracks on the elite bobsleigh circuit. A total of 3882 individual runs from World Cup, World Championship and Olympic races across three seasons (2012-2015) were used within the study. This included data from 11 different venues, as well as each of the three bobsleigh formats; 2-man, 4-man and female. For each format, tracks were classified based upon the relationship between push start and final run time using the following descriptors; $r \geq 0.95$ = pure push start track, $r \geq 0.71$ = push start dominant with a modest driving component, $r \geq 0.32$ = drive dominant with a modest push start component, $r < 0.32$ = pure driving track. Significant but weak correlations ($P < 0.05$) were observed between push start and final run time for all data, across all tracks and seasons (2-man $r = 0.38$, 4-man $r = 0.34$ & female $r = 0.37$). However, there was large variability in the observed correlations across the different tracks and formats ($r = 0.29$-0.80). The results identified no pure push start tracks and only 4-man racing at Lake Placid was classified as a pure driving track. Of the remaining 32 analysed track/format combinations 9 were determined to be push dominant and 23 drive dominant. In conclusion, the importance of the push start can vary depending on format and track, but in the majority of cases the push start can be considered either a dominant or

modest factor in determining final run time. Therefore, it could be suggested that the push start should be identified as a target area for performance enhancement within bobsleigh.

Appendix 6

Abstract submitted for the Cardiff Metropolitan University Academic Associate Committee Annual Poster Symposium. May 2017.

VALIDATION OF A PHYSICAL PERFORMANCE EVALUATION BATTERY TO PREDICT PUSH-START PERFORMANCE IN ELITE BOBSLEIGH.

Condliffe, R.12, Oliver, J.13, Lloyd, R.13, Cronin, J.3, Anderson G. 2., Forrow, L. 2. 1: Cardiff Metropolitan University (Cardiff, UK), 2: British Bobsleigh (Bath, UK), 3: Auckland University of Technology (Auckland, New Zealand).

In elite bobsleigh, previous literature has shown that the push-start is an important component of performance in the sport (Brüggemann et al. 1997; Condliffe et al. 2016; Smith et al. 2006). Condliffe et al. (2016) suggests that a 0.01s push-start improvement, can translate to a 0.06-0.07s improvement at the bottom of the track. Hence, it is vitally important to select those athletes who can generate the greatest speed and acceleration in a bobsleigh-specific environment. To assist with quantification of athlete's push-start capabilities and distinguish between squad members, British Bobsleigh uses a testing battery that includes general physical performance tests, as well as push-start specific roll-bob tests (pushing a wheeled apparatus designed to mimic a bobsleigh). However, the validity of these tests as predictors of the push-start is not known. Hence, the aim of this study is to validate the British Bobsleigh physical performance evaluation battery and the individual tests within it, as a means of predicting push-start performance. Twenty-one male international-level bobsleigh athletes took part in the study. Athlete's participated in two testing sessions; one completing the physical performance evaluation and the other a gold standard push-start assessment. The evaluation battery consists of the following; a 60m sprint with 30m split times, a 5-repeated bound jump and four roll-bob pushes. A very large relationship was observed between overall evaluation score and push-start performance (r = -0.86). Similar strength correlations were detected when the push-start was compared to any of the four roll-bob pushes (r = 0.83-0.85). When examining the remaining tests, a large correlation was observed between body mass and the push-start (r = -0.50). Also, both 30m and 60m sprint splits (r = 0.30), as well as the 5-repeated bound jump (r = -0.47), were shown to be moderately related to the push-start. A multiple regression analysis for the push-start excluding the roll-bob pushes and only including body mass, sprint and jump performance, revealed that a combination of 30m sprint time and body mass can account for

55% of the performance variance in male athletes. In conclusion, the British Bobsleigh physical performance evaluation is a valid predictor of push-start performance, however this is largely a result of the strength of the correlations observed between the roll-bob pushes and the push-start. Attempts to explain push-start performance using only the physical qualities measured in the evaluation battery, highlighted a large physiological aspect of performance that is still not fully understood.

Appendix 7

Abstract submitted for the European College of Sport Science (ECSS) conference in Dublin, Ireland. July 2018.

SPRINT FORCE-VELOCITY PROFILING: ABILITY TO PREDICT BOBSLEIGH PUSH START PERFORMANCE

Condliffe, R.12, Oliver, J.13, Lloyd, R.13, Cronin, J.3, Woolley, C.2. 1: Cardiff Metropolitan University (Cardiff, UK), 2: British Bobsleigh (Bath, UK), 3: Auckland University of Technology (Auckland, New Zealand).

Introduction

In bobsleigh, the push start has been identified as an important component of successful performance (Brüggemann et al. 1997). Previous literature has shown a link between the push start and sprint time over distances up to 100m (Osbeck et al. 1996). However, which mechanical properties of sprint performance underpin this relationship is not fully understood. Therefore, the aim of this study was to compare the bobsleigh push start predictive ability of traditional sprint split times measured in elite bobsleigh and force-velocity mechanical variables quantified during sprinting.

Method

Eleven elite male bobsleigh athletes (mean ±SD: age 27 ± 4 yrs.; mass 98.4 ± 8.3 kg; height 185 ± 6 cm) performed a maximal 60m sprint. Split times were collected using the standard elite bobsleigh protocol of 30m and 60m timing gates. Also, during the sprint each athletes force velocity mechanical profile was modelled using the validated split time method (Samozino et al. 2016), with additional gates placed at 5m intervals up to 25m. On a separate occasion, all athletes undertook a push start assessment on an outdoor track, with performance measured over a 50m section (15-65m). Pearson correlation coefficients were determined to assess the push start predictive ability of traditional sprint split time measurements (30m, 30-60m & 60m), as well as sprint force velocity mechanical variables.

Results

Moderate to large relationships were observed for push start performance with 30m (r = 0.69, $p < 0.05$), 60m (r = 0.59, $p < 0.10$) and 30-60m flying sprint time (r = 0.42). A very large correlation was detected between the push start and absolute maximal power (r = -0.80, $p < 0.05$). Finally, the push start was shown to be either moderately or largely related to the remaining force velocity mechanical variables; relative maximal power (*r* = -0.55, *p* < 0.10), theoretical maximal force (*r* = -0.58, *p* < 0.10), relative theoretical maximal force (*r* = -0.37), theoretical maximal velocity (*r* = -0.37) and velocity at maximal power (*r* = -0.38).

Conclusions

The results indicate that force velocity profiling during sprinting may have better push start predictive value than traditional split time measurements. Hence, practitioners in bobsleigh looking to enhance push start performance should tailor training programmes towards optimising power during sprinting.

References

Brüggemann GB. Morlock M. Zatsiorsky V. (1997). J Appl Bio. 13. 98-108.

Osbeck J. Maiorca S. Rundell K. (1996). JSSR, 10(4), 239-245.

Samozino P. Rabita G. Dorel S. Slawinski J. Peyrot N. Saez de Villarreal E. Morin JB. (2016). Scand J Med Sci Sports, 26(6), 648-658.

Appendix 8

Abstract submitted for the United Kingdom Strength and Conditioning Association (UKSCA) conference in Milton Keynes, England. August 2018.

TRAINING INDUCED CHANGES IN SPRINT FORCE-VELOCITY PROFILES AND PUSH-START PERFORMANCE IN ELITE BOBSLEIGH ATHLETES.

Condliffe, R.12, Oliver, J.13, Lloyd, R.13, Cronin, J.3, Woolley, C.2. 1: Cardiff Metropolitan University (Cardiff, UK), 2: British Bobsleigh (Bath, UK), 3: Auckland University of Technology (Auckland, New Zealand).

Introduction:

Research has highlighted sprint speed and power as key determinants of the bobsleigh push-start (Condliffe et al. 2018). However, literature has yet to investigate whether training improvements in sprint speed and power translate into enhanced push-start performance. Therefore, the aim of this study was to explore the influence of training on bobsleigh athletes' sprint speed, force-velocity characteristics and any associated changes in push-start performance.

Methods:

Six elite male bobsleigh athletes (mean ± SD: 29 ± 3 yrs; 101.6 ± 9.8 kg; 185 ± 7 cm) performed a 60-m sprint and push-start assessment before and after a 16-week training block. During the sprint, speed was measured using the bobsleigh protocol of 0 to 30-m and 0 to 60-m, as well as force-velocity profiles being modelled using 5-m splits up to 25-m using a validated method (Samozino et al. 2015). Paired sample t-tests and Cohen's effect sizes were used to detect any group changes. At an individual level, percentage changes were determined to detect any meaningful changes. A threshold of 0.3 CV was set as the SWC and typical error was applied to the individual changes to provide confidence intervals. Using magnitude based inferences, changes were deemed to be either positive, negative or trivial as previously advocated (Batterham & Hopkins 2006). Any positive or negative changes were classified as moderate or large if they were ≥ 1.0 or ≥ 2.0 x CV respectively.

Results:

Moderate changes were observed in push-start performance (p < 0.05; ES = 1.06) and the force-velocity variables maximal power (P_{max}), relative P_{max}, theoretical maximal velocity and velocity at Pmax (ES = 0.61-0.83). Also, significant but small changes were detected in 30-m and 60-m sprint times ($p < 0.10$; ES = 0.38-0.46). At an individual level, the clearest change was observed in Pmax, with all athletes displaying a moderate or large improvement (2.24-16.24%). Additionally, push-start improvements were detected for 4/6 of these athletes (1.23-3.00%). However, the small to moderate magnitude of these changes were typically lower than that observed for Pmax.

Practical Applications:

At a group level, the training block facilitated improvements in push-start performance, which coincided with improvements in sprinting, particularly P_{max}. However, at an individual level the improvement crossover between the push-start and sprinting power was more variable. Hence, practitioners should consider targeting other variables beyond sprint speed and power (e.g. technical ability) when attempting to improve push-start performance. Also, this study highlights the individualised training needs of elite-level athletes.