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The development and evaluation of a testing protocol to assess upper body pressing strength qualities in high performance athletes

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The Development and Evaluation of a Testing Protocol to Assess Upper Body Pressing Strength Qualities in High Performance Athletes

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ABSTRACT

The Development and Evaluation of a Testing Protocol to Assess Upper Body Pressing Strength Qualities in High Performance Athletes

Kieran P. Young

PURPOSE: The purpose of this study was to evaluate the reliability of an isometric force assessment (isometric bench press) across 4 standardised angles and an isoinertial force and velocity assessment (ballistic bench throw) utilising a relative load based on a percentage of one repetition maximum (1RM) in the bench press; and to evaluate whether the use of the dynamic strength deficit (DSD) ratio can guide training and detect changes induced by training over a 5 week period.

METHODS: Twenty four elite male athletes (age = 19.9 ± 2.7yrs; mass = 79.1 ± 13.0kg) performed the isometric bench press and a 45% 1RM ballistic bench throw on 2 separate days with 48 hours between testing occasions. Peak force, peak power, peak velocity, peak displacement and peak rate of force development were assessed using a force plate and linear position transducer. Reliability was assessed by Intra-Class Correlation (ICC), Percent Coefficient of Variation (%CV) and Typical Error (TE). The athletes' DSD ratios were then calculated using the peak force values obtained during the BBT and IBP (DSD = IBP peak force/BBT peak force). Athletes were then placed in to 2 groups as matched-pairs based on their DSD ratio and their strength in the 1RM bench press. The Bench Press (BP) Group performed high intensity bench press while the Ballistic Bench Throw Group performed moderate intensity ballistic bench throws. Both groups trained twice a week for 5 weeks.

RESULTS: All performance measures except for peak rate of force development were considered reliable (ICC = 0.85-0.97, %CV = 1.2-3.3). The DSD ratio was sensitive to the disparate training methods between groups, with the BP Group increasing their IBP peak force ($p = 0.035$), the BBT Group increasing their bench throw performance ($p \leq 0.001$), and as a result, yielding a significant change ($p \leq 0.001$) in the DSD for both groups.

CONCLUSIONS: Performance measures such as peak force in the isometric bench press and ballistic bench throw are reliable when assessing upper body pressing strength qualities in elite male athletes. Further, the DSD can be used to detect qualities of relative deficiency and guide specific training interventions based on test results.

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CHAPTER 1: INTRODUCTION

1.1 Background to the Research

The accurate assessment of strength and power qualities is a key component of strength and conditioning and sport science. As such, it is critical that an appropriate testing regime be implemented to not only evaluate training effects, but also to determine the efficacy of a particular strength and conditioning program.

However, there appears to be a paucity of information relating to the assessment of upper body strength and power qualities, and the translation of these data into appropriate training prescriptions. Furthermore, there is still much debate on which tests are most suitable for the assessment of strength and power qualities in high performance athletes. Therefore, the first part of the study determined the reliability of the isometric bench press (IBP) at varying elbow positions in order to establish the optimal elbow angle for the reliable development of peak force (PF). The second part of this study investigated the relationship of the IBP to the ballistic bench throw (BBT) and one repetition maximum bench press (1RM BP). Data was then used to determine the subsequent dynamic strength deficit (DSD) and finally, training interventions were structured to target a performance attribute highlighted in the DSD by using either high load BP or moderate load BBT.

1.2 Purpose of the Study

The purpose of this study was twofold: 1) to evaluate the reliability, among a group of high performance athletes, of an isometric force assessment (isometric bench press) and an isoinertial force and velocity assessment (ballistic bench throw) utilising a relative load based on the 1RM BP; and 2) to evaluate whether the use of the dynamic strength deficit (DSD) can guide training and detect changes induced by training over a 5 week period.

1.3 Significance of the Study

Currently, the ability to generate peak forces in an IBP has been investigated at standardised elbow angles of 90° and 120°. Additional data on the effect of elbow angle on peak force generating capacity is necessary in order to determine the optimal angle for assessing PF during the IBP. Additionally, there is a paucity of research examining the optimal elbow angle for assessing PF during an IBP and which angle results in peak forces that most relate to a dynamic muscle action such as the 1RM BP or the BBT. Furthermore, there is no established protocol for translating the results of a DSD assessment into training interventions that attempt to maximise performance gains. If the optimal elbow angle is established for PF development in the IBP test, this data can be translated into a DSD ratio that can be used as a guiding factor in the development of training interventions that target specific areas of relative deficiency.

1.4 Research Questions

1) Will performance variables in the isoinertial and isometric assessments be highly reliable?
2) Can the use of the DSD guide training interventions and induce more specific performance gains over a 5 week training period?

1.5 Hypotheses

The following hypotheses were tested:

1) Assessing performance variables such as PF and RFD at 90° and 120° of elbow flexion in the IBP has been shown to be reliable (59). Therefore, it is hypothesized that performance variables across 4 different elbow angles will all be reliable. Additionally, it is hypothesized that the larger joint angles may be most appropriate to achieve superior maximal force, and thereby preferable for use in assessment.

2) The use of a DSD in the lower body has shown to be sensitive to training induced changes (69) and is able to guide specific training interventions (69, 80). Therefore, it is hypothesized that the use of an upper body DSD ratio will be able to guide training interventions and will be able to induce more specific performance gains over a 5 week period.

1.6 List of Abbreviations and Definitions

1RM BP: One repetition maximum in the bench press.

BBT: Ballistic bench throw.

DSD: Dynamic strength deficit (ballistic bench throw peak force / isometric bench press peak force).

IBP: Isometric bench press.

N: Newtons.

W: Watts.

Peak Displacement (PD): The maximum distance achieved by an object.

Peak Force (PF): The maximum amount of force produced in a muscular contraction.

Peak Power (PP): Highest level of power (work / time; force x velocity) in muscular contractions (35).

Peak Rate of Force Development (PRFD): The maximum rate at which force is developed; calculated by dividing the change in force by the change in time (30msec epoch was used in the current study).

Peak Velocity (PV): The maximum speed of movement of an object. It is calculated by dividing distance by time.

Reliability: The degree of consistency of a measurement.

Validity: Whether or not a test is actually measuring what it is supposed to measure.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The literature review is comprised of three parts. The first section, regarding upper body test procedures, will report and critique literature related to establishing the reliability and validity of new testing procedures and the subsequent application to training programs. Research supporting the need to address upper body strength and power training in high performance athletes will also be reviewed. The second section will review the current research relating to isometric assessments and its relationship with dynamic performance. The third section will investigate the use of a dynamic strength deficit ratio in elite athletes. The final section will outline how the literature reviewed has created a logical pathway for the completion of this research project.

It is the aim of this literature review to critique the relevant original research regarding the use of isometric and isoinertial tests, the methods of testing, and the application of these tests to indicate the need for establishing a practical, reliable, and valid protocol for assessing upper body pressing strength in high performance athletes.

2.2 Strength Diagnosis

Strength and power assessments can be used for a variety of purposes, these include monitoring training progress, talent identification, and identifying specific physical qualities of relative deficiency that need to be addressed in individual resistance training programs to maximise athletic performance (80). This concept of assessing specific neuromuscular performance qualities is referred to as a ‘strength diagnosis’ (49, 60, 77) and provides acute insight into the training status of an individual’s strength and power qualities, thereby establishing a basis of rationale from which to design individually tailored strength training programs (69).

A variety of test variables can be used in a strength diagnosis provided the tests are measuring qualities that are important for performance in the athlete's sport and are modifiable by specific forms of training (80) (see Figure 1). As identified by Newton & Dugan (60), "by targeting specific strength qualities with prescribed training, greater efficiency of training effort can be achieved resulting in enhanced athletic performance". They classify the neuromuscular performance qualities as either strength, speed-strength (ballistic strength) or strength endurance. Specificity of these qualities is inherent to the particular sport and the level of development for each of these qualities will be different depending upon the individual athlete's needs and capacities, as well as the sport being prepared for (60). The tests employed in the strength diagnosis may also vary as the athlete progresses through their periodised plan and athletic career. However, caution should be used when interpreting strength diagnosis results as they merely provide additional information from which to base further training prescriptions. The long-term goal of the individual's preparation should not be discarded based solely on these results. Nevertheless, while logical arguments exist supporting this concept, there is a paucity of research examining its implementation and effectiveness (80).

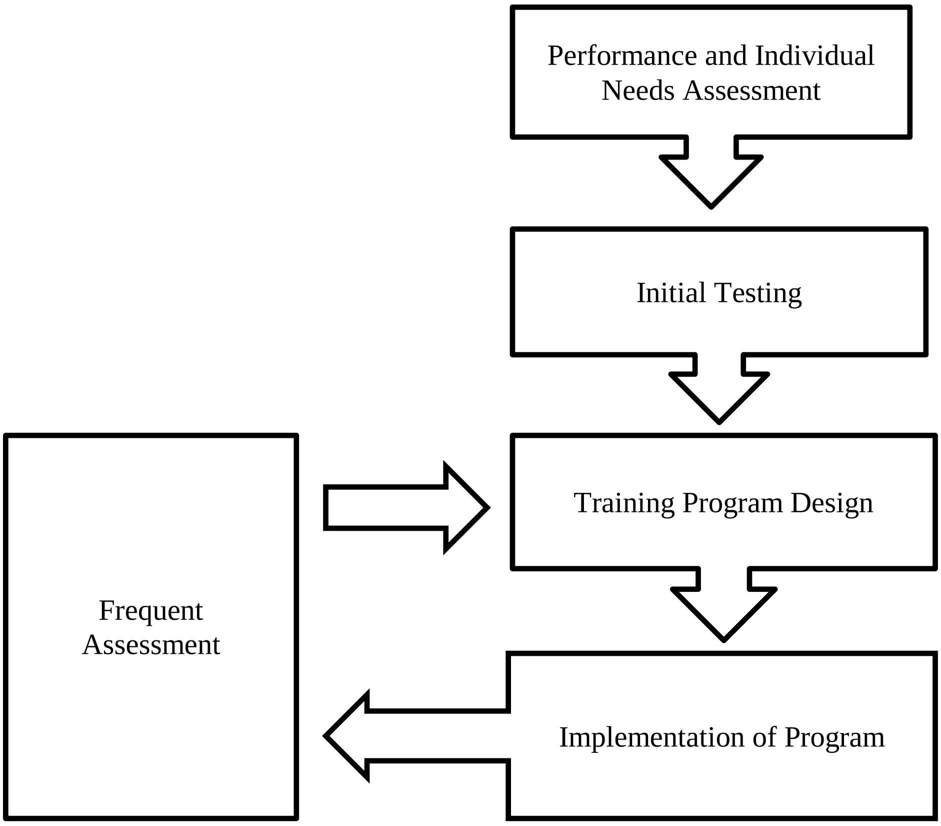


Figure 1: Test-retest cycle for a strength diagnosis. Note: Adapted from Newton and Dugan (60)

In one of the few long-term studies on this topic, Wilson & Murphy (80) determined that significant improvements in cycling performance (10.8 ± 6.6% increase) can occur as a result of weight training when subjects possessed a higher rate of force development (RFD) / peak force (PF) ratio (3.0 ± 1.0 vs. 2.6 ± 1.5). Conversely, subjects with a low RFD / PF ratio (2.4 ± 0.5 vs. 3.1 ± 0.7) improved performance (10.0 ± 5.0% increase) to a greater extent with the use of plyometric training. As such, it was concluded that isometric tests of PF and RFD and the subsequent translation into a diagnostic ratio were able to identify individuals who were most likely to benefit from specific training interventions.

Further, one of the benefits of a strength diagnosis is the ability to detect an athlete's individual area of weakness by identifying the relative deficiencies in athletic performance that could be improved with specific training (80). For example, if an athlete can produce high levels of force in an isometric contraction but produces low levels of force in a dynamic movement, then the athlete would benefit from more ballistic exercises, as strength adaptations are load and velocity specific (52, 80). It is possible that focusing on the least developed component contributing to dynamic peak force will prompt the greatest neuromuscular adaptation and thus result in superior performance improvements (23, 81).

It is clear that the concept of strength diagnosis has extensive benefits when used to impact athletic performance; however a paucity of applied research exists involving elite athletes. In order to fully understand the advantages of such a concept, a strength diagnosis was used in an attempt to identify the relative deficiencies among a group of elite athletes that could be improved with specific training.

2.3 Upper Body Assessments of Strength and Power

The ability to accurately assess an elite athlete's strength qualities and determine meaningful changes in performance requires the assessment protocol to be reliable, valid and sensitive to training induced changes (69). Reliability can be defined as the repeatability or reproducibility of a measure (39). Whether a test can be considered reliable depends upon the acceptability of the measurement error for practical use (76, 79). Considerable debate exists in the literature as to the best method of quantifying reliability, as several different methods are available. For the present study, inter-day test-retest reliability was used. Test-retest reliability has to do with the degree to which a test can produce the same measurements at different times under the same conditions (39). When assessing training induced changes, a measure must possess good relative (ICC) and absolute consistencies (TE and %CV). While it is important to have high levels of both measures, from an applied perspective, the absolute measures of reliability are easily interpreted by the sport scientist and strength and conditioning practitioner. For example, if the change in performance is greater than the TE or %CV then the change could be considered of practical importance.

Validity is defined as the extent to which an assessment protocol measures what it is supposed to measure (31). Using isoinertial and isometric tests are all effective measures of the force capabilities of an athlete and is therefore measuring the intended quality, which is a key aspect of validity (69, 75).

Practically, Newton & Kraemer (61) argue that success in most sports depends upon the attainment of a threshold level for maximum strength, power and speed. Therefore, it would seem logical for strength and conditioning practitioners and sport scientists to properly assess an athlete's strength and power qualities. A variety of methods have been used to investigate and substantiate the use of experimental upper body testing protocols (3, 5, 9, 13, 28, 63, 67). These strength qualities are generally evaluated through isoinertial and isometric assessments in non-laboratory settings.

Isoinertial assessments are typically used to assess a physical quality such as maximal strength, strength endurance or ballistic strength. They involve using a constant external load that allows for the acceleration and deceleration of that particular load. The bench press and ballistic bench throw are two of the more popular means of isoinertial upper body testing (15, 62). They allow for strength and conditioning practitioners and sport scientists to accurately assess force, velocity and power capabilities of the upper limb in movements that are functionally similar to many athletic activities.

The one repetition maximum bench press (1RM BP) is commonly used to assess maximal strength (12, 13, 51) due to its high reliability (ICC = 0.98) (54, 55) and its ability to discriminate between performance levels of athletes across a variety of sports (5, 8, 13, 30, 34). As such, the inclusion of a maximal strength assessment is a vital component of any strength diagnosis protocol when evaluating the strength characteristics of high performance athletes. The following section will discuss in greater detail the validity and impact of maximal strength on athletic performance.

2.3.1 Validity of Maximal Strength Assessments

The ability of maximum upper body strength to discriminate between playing ability has recently received a significant amount of attention. Through a number of studies, Baker (4, 5, 12, 15) has shown that maximal strength is not only a key component of performance but is also able to discriminate between playing ability.

Baker (4) found that upper body measures of strength and power, as assessed by a 1RM BP and a series of loads in the BBT, differed as a result of playing rank. Specifically, professional athletes were stronger in the BP (134.8 ± 15.2kg) and were more powerful in the BBT (610 ± 79W) compared to their semi-professional team members (110 ± 15.3kg and 515 ± 78W, respectively). As such, Baker concluded that athletes wishing to achieve professional status must concentrate on increasing upper body maximal strength followed by improving power output.

In a similar study using the 1RM BP and a 20kg BBT, Baker (5) concluded that maximal strength was a ‘potent descriptor’ of playing achievement levels. Among a group of rugby league players ranging from untrained high school athletes to full time professional athletes, the latter group possessed the greatest 1RM BP (144.5 ± 15.1kg), which was significantly different ($p \leq 0.05$) to all other playing groups. Additionally, mean power output assessed in the 20kg BBT was also significantly ($p \leq 0.05$) different between groups with the professionals having the highest mean power output (341 ± 24W). Comparable to his previous study, he concluded that high levels of upper body strength and power were required to play rugby league at the elite level.

In further support of the importance of maximal strength, Baker & Newton (15) assessed the upper body strength, power, speed and strength-endurance of 60 rugby league players of differing playing rank using a series of bench press related exercises. Maximum strength was assessed by the 1RM BP. Mean power was assessed during the concentric phase of a BBT with a range of resistances (40-80kg). Maximum speed testing was conducted using a 20kg BBT. Finally, strength-endurance testing entailed performing as many repetitions till fatigue in the bench press with a 60kg load. Of all the tests undertaken, although maximum power, speed testing and strength endurance were descriptors of playing rank, maximum strength had the greatest ability to discriminate between higher and lower performers, with national level players possessing the highest BP values (141.4 ± 15.4kg) compared to their intra-state (126.6 ± 13.1kg) and intra-city (108.1 ± 11.6kg) counterparts ($p \leq 0.05$). This further strengthens the notion that high levels of upper body strength and power are required to achieve elite status in rugby league.

In a later study, Baker (12) further investigated the role of upper body strength endurance in discriminating playing rank in professional rugby league players using the BP. Three different methods of assessing strength endurance were investigated. The first test was a 60% 1RM repetition till fatigue test with the following two tests using absolute loads of 60kg and 102.5kg, all performed until complete fatigue (inability to perform another repetition). The 60% 1RM test did not distinguish between elite and non-elite players (20.5 ± 3.1 vs. 20.7 ± 3.2 repetitions respectively, not significant). When comparing the absolute 60kg test, significant differences ($p \leq 0.05$) were found between elite and non-elite players (36.1 ± 7.2 vs. 28.0 ± 5.6 repetitions, respectively). The number of repetitions when using the 102.5kg load were also significantly different but was deemed to be invalid as it was not true strength endurance test (average of 9 repetitions).

It is clear from the work carried out by Baker and colleagues (4, 5, 12, 15) that upper body maximal strength and to a slightly lesser extent, power output and strength endurance play a vital role in rugby league athletes wishing to achieve professional status. Although only rugby league players were used, the practical implications set out by Baker of first improving maximal strength followed by targeting maximal power output has potential benefits to all sports.

2.3.2 Impacts of Maximal Strength Training

Relatively little research is available investigating the changes in upper body maximal strength after high intensity strength training in elite athletes. One of the reasons for this is the lack of availability of a control group when dealing with athletes. It is obvious that by not training, i.e. being the control, athletic performance would be negatively affected. This concept is demonstrated in a recent study involving elite handball players (38). Athletes were divided into a heavy resistance (HR) training group (80-95% 1RM) or a control group that solely performed handball skills training. After 8 weeks of training the HR training group significantly ($p \leq 0.001$) improved 1RM BP from 80.4 ± 5.0kg to 96.2 ± 3.6kg whereas the control group experienced no change in BP performance (80.7 ± 5.3kg to 79.4 ± 5.4kg). The improvement in upper body maximal strength was also complemented with an increase in ball-throwing velocities ($p \leq 0.001$) suggesting that high intensity strength training can have a positive effect on several key performance measures required in handball. Even though the athletes were considered to be weak (relative 1RM BP = 0.99/kg) the results demonstrate the need and impact that maximal strength training has on performance.

Another method used in the current literature has focused on comparing within-groups, such as dividing the cohort of athletes in to elite or sub-elite and tracking the neuromuscular changes over an extended period of time. One such within-group study by Baker and Newton (13) found significant ($p \leq 0.05$) improvements in the 1RM BP across a 4 year period in a group of elite and sub-elite rugby league players. The sub-elite group (who were weaker) improved BP performance to a greater extent than the stronger elite group (24.9% vs. 6% increase) suggesting a diminishing degree of potential adaptation with increased training experience. In other words, by focusing on the least developed component, which in the case for the sub-elite group was maximal strength, high intensity strength training contributed to the greatest neuromuscular adaptation and superior performance improvements.

In a similar study using professional rugby union players, Appleby and colleagues (2) found significant ($p = 0.000 - 0.002$) improvements across a 2 year period in both absolute and relative 1RM BP after high intensity strength training. Interestingly, they found a significant ($p \leq 0.05$) negative relationship between initial strength levels and the magnitude of change in upper body strength ($r = -0.569$). These results support Baker and Newton’s (13) findings in elite rugby league with respect to the principle of diminished returns when dealing with highly trained athletes.

Recently, Hrysomallis and Buttifant (42) demonstrated that both experienced (> 3 years of professional experience) and inexperienced (< 3 years of professional experience) Australian Rules football players could maintain maximal upper body strength (113.8 ± 10.5kg to 110.5 ± 14.6kg and 102.8 ± 14kg to 104.3 ± 10.1kg, respectively) over an entire season while Baker (6) found that less experienced rugby league players significantly ($p \leq 0.05$) improved 1RM BP by 4.9% over a 19 week season. These findings are in contrast to previous results in American (27) and Canadian (68) football that have demonstrated a decline in maximal upper body strength over the course of the season. This inability to maintain or improve strength levels may be attributed to the training age, strength levels of the athletes or the type of in-season resistance training program (42).

Nevertheless, it is clear that upper body maximal strength is a desirable quality that is required in a variety of sports (4, 38, 42). Evidently, further research is warranted to assess the impacts of long-term maximal strength training on athletes other than rugby league players. As such, the role of maximal strength testing and the subsequent impact on training will be thoroughly investigated in the present study.

2.3.3 Impacts of Ballistic Strength Training

Similarly, ballistic strength training is commonly used to improve maximal power output and performance (22). Furthermore, the use of ballistic exercises, such as the BBT, is increasingly being assessed in sports that require upper body power (7, 9, 13, 18). Ballistic strength training involves exercises that require the athlete to exert as much force as possible to project the accelerated object (in the case of BBTs, that object would be the barbell) in to free space (22). In the context of the current study, BBTs have also been shown to elicit higher PF outputs when compared to the traditional BP. This is due to the higher accelerations produced throughout the entire range of motion, whereas acceleration is limited to the first 40% of range of motion in the BP (19, 63). Despite this limitation, the use of traditional resistance exercises such as the BP are still popular in the literature when assessing force and power outputs in an 'explosive' training session (43, 44).

Few studies have examined the role of PF in BBTs, with the majority concentrating on identifying loads that maximise peak power output (18) or strategies to improve peak power output (10, 61). However, a significantly greater amount of research exists when examining the impacts of ballistic strength training on lower body strength and power measures (22, 52, 83). Although considerable biomechanical differences exist between popular lower body ballistic exercises such as the jump squat and the BBT, the underlying mechanisms responsible for performance improvements are similar. A brief look in to the lower body literature reveals improvements in a variety of performance measures after periods of ballistic strength training (22).

An often cited study (52) investigating the effects of heavy (80% 1RM squat) and light (30% 1RM squat) load ballistic jump squats on various physical performance measures, found that both groups significantly ($p \leq 0.05$) improved absolute and relative 1RM squats as well as PF when assessed using a 55% 1RM jump squat. It appears that training with a specific load, and therefore at a specific velocity, will dictate the neuromuscular mechanisms of adaptation. In other words, the light load group increased PF application by improving acceleration capabilities while the heavier group improved PF output by increasing peak force application capabilities. In light of this, it would appear that improvements in various physical performance measures are velocity-specific and can provide valuable insight in to areas of relative deficiencies in athletes. For example, if an athlete can produce large amounts of force at a slow velocity then the window of opportunity to improve neuromuscular adaptations may lie at the other end of the force-velocity curve with high velocity, low force training.

More recently, Cormie and colleagues (22) compared the effects of maximal and ballistic strength training on athletic performance in relatively weak men. Significant ($p \leq 0.05$) improvements in jump and sprint performance were found in both groups after training with no significant between-group difference. The maximal strength-training group also displayed significant ($p \leq 0.05$) improvements in the absolute and relative 1RM squats that were significantly ($p \leq 0.05$) greater than the ballistic strength training group. Contrary to McBride (52), the lighter ballistic group did not improve any of these variables. In conclusion, the authors reported that improvements in athletic performance were mediated through neuromuscular adaptations specific to the training stimulus and, similar to Baker and Newton's (13) findings, maximal strength training was a more effective training modality for relatively weak individuals (22).

Unfortunately, few comparative studies exist assessing the impact of maximal strength training and ballistic strength training on the force producing capabilities of elite athletes in the BBT. In a recent study, Mangine and colleagues (51) reported that the inclusion of ballistic training to high intensity strength training further increased maximal upper body strength in recreationally trained men. Although BBTs were used during the 8 week training program, a ballistic push-up was used to assess changes in muscular power, but no PF measures were reported. Similar to the lower body studies (22, 52), the authors suggested that the addition of ballistic exercises allowed for training at higher velocities that may not have been as well developed as the slower resistance training velocities. Again this highlights the potential deficiencies that may have existed among the subjects, suggesting that individual profiling could be useful in making decisions on training priorities.

Wilson and co-workers (82) investigated the effects of strength and plyometric training on a series of upper body isoinertial tests including a concentric only 30% 1RM BBT. The 1RM BP and the BBT PF significantly ($p \leq 0.05$) increased in the strength group compared to the plyometric group. A closer look at the initial strength levels and the training interventions reveal the subjects were relatively weak (81.5 ± 12.9 kg 1RM BP) and furthermore, the training interventions used were either very generic in terms of the strength training group (repetitions ranging from 6-10 with no set periodisation) or very low load (4kg and 10kg medicine ball throws) in the plyometric group. Not surprisingly, the plyometric group did not improve 1RM BP or PF in the BBT, most likely due to the low intensity of the medicine ball throws. It appears that if force adaptations are sought after, then higher intensities are required when using ballistic exercises.

In a similar study, Cronin and colleagues (24) examined whether velocity-specific strength training affected the velocity of a netball chest pass. Although athletes were used in the study, none had any previous strength training experience and were considered quite weak. For this reason, the change in total volume of weight lifted was used instead of changes in 1RM BP to track strength adaptations. Athletes were divided in to strength (80% 1RM BP) and power (60% 1RM BP) groups and trained for 10 weeks with both groups using the BP as the main training exercise. Both groups were instructed to lift the concentric portion of the lift as fast as possible. The results showed that the strength training group produced significantly ($p = 0.007$) greater improvements in mean volume of weight lifted in the BP compared with the power training and control groups. Also, when tested using a predicted 40% 1RM

BBT, similar improvements in peak velocity, mean and peak power output were found in the strength training group as compared to the power group. Interestingly, both groups significantly ($p \leq 0.05$) increased PF with no difference between groups. Once again the results highlight the potential benefits of using a strength diagnosis. Upon initial testing it was evident that maximal strength was the main area of deficiency, which was further emphasised in the greater gains reported in the strength training group post-training.

2.3.4 Reliability of Ballistic Bench Throws

Even though the BBT is a popular assessment and training tool, there is clear lack of data regarding its reliability among elite athletes. While research has demonstrated that it is a reliable upper body performance test when reporting peak power, velocity, force and displacement. (1, 20, 28) a more thorough investigation is required to assess the reliability of several key performance measures of a relative BBT among a group of elite athletes. In light of this, a number of limitations exist when attempting to compare studies (Cronin and Sleivert (25) provide a thorough review). One of the key factors to consider is the determination of load used, as practitioners have the choice of using absolute or relative loads in a BBT. Additionally, the strength levels of the subjects must be taken in to account as maximal strength has a strong association with overall ballistic performance (70), and therefore a comparison of results could be misleading if strength levels differ. Finally, the type of assessment setup (i.e. linear position transducer, force plate or a combination) and the number of repetitions used throughout the assessment must be constant. Therefore, when comparing between studies it would seem logical to use studies of similar methodology. Nonetheless the following section will provide a brief review of the current literature available on the reliability of BBTs.

In a widely cited study, Alemany and colleagues (1) reported high ICCs for peak velocity (0.91 – 0.95) and peak power (0.92 – 0.96) as well as %CV ranging from 3.0 – 7.6%. However, there are several concerns that need to be addressed regarding the methodology used. First, only a small number (n = 10) of untrained subjects were used. Second, one might assume that due to the subjects' initial level of training experience that perhaps performing the BBT might not give a proper indication of ballistic strength. Finally and most importantly, a 30 repetition BBT was used. From a practical perspective, it is widely accepted that when trying to improve or assess kinetic and kinematic variables in the BBT that no more than 5 repetitions be used due to the rapid decline of performance measures (14). In other words, unless a 30 repetition BBT is used with untrained subjects, any comparisons made may be misleading.

In a more recent study, Drinkwater and colleagues (28) investigated the reliability of mean power in a 40kg BBT with high levels relative reliability found (ICC = 0.92) and a TE of 14W. Using a stronger cohort of athletes and a 60kg BBT, Clark and co-workers (20), reported high levels of relative reliability for PF (ICC = 0.83) and peak displacement (ICC = 0.95). In terms of absolute reliability, the TE for PF and peak displacement was found to be 183N and 1.3cm, respectively.

The inclusion of a BBT assessment is an important component of any testing protocol used with high performance athletes. First, the higher PF values and greater specificity to functional upper body movements obtained in the BBT compared to the BP make the BBT a more appealing test of ballistic strength. Although the BBT has shown previously to be reliable in certain specific measures, further investigation is required to assess the relative and absolute reliabilities among a group of high performance athletes, across several meaningful kinetic and kinematic measures.

Finally, the effects of maximal and ballistic strength training on PF production in the BBT also need to be investigated, as a measure's sensitivity to training is an important aspect of its validity, and this has not been well researched.

2.4 Isometric Assessments

Isometric assessments involve measuring a maximal voluntary contraction performed at a specific joint angle against an un-yielding resistance which is in series with a force platform (81). These assessments are generally performed to quantify PF, RFD and / or impulse. According to Wilson & Murphy (81), some of the benefits of using isometric assessments include the fact that they are highly reliable, easily administered, require minimal skill, are not confounded by velocity, and are easily standardised.

Several considerations need to be taken into account before selecting the appropriate isometric assessment for quantifying PF, as they will have a direct impact on the obtained data. These include:

- Familiarisation: subjects need to be accustomed to performing isometric efforts as it is not a typical movement found in most sports.
- Type of instruction: different instructions will elicit specific responses from the neuromuscular system therefore the type of instruction i.e. 'hard and fast as possible' or 'slow and steady' will affect performance variables (17).
- Joint angle: isometric force producing capabilities change as a function of joint angle (59).

One commonly used method to ascertain the ability of isometric force-time measures to perform assessment tasks is to investigate the relationship between isometric measures and dynamic performance. This type of assessment has continued with varying results (11, 36, 37, 46, 47, 54, 55, 64, 66, 67, 72, 80, 85). Notwithstanding, the research has predominantly concentrated on lower body strength qualities, as well as the relationship between isometric PF and / or isometric RFD and dynamic PF. Therefore this section will briefly review studies that have examined the reliability and relationship between lower body isometric assessments and dynamic performance.

2.4.1 Effect of Joint Angle on the Reliability and Production of Peak Force

Briefly, research has demonstrated that lower body isometric PF values are highly reliable, ranging from ICC = 0.94 to 0.99 (47, 50, 54, 55, 64, 69, 74, 80, 83). With regard to the reliability of upper body isometric assessments and its relation to dynamic measures of sport performance, there are limited research studies available (58, 59, 65). Nevertheless, a brief look at the current body of scientific evidence suggests that upper body isometric assessments, such as the IBP, are also highly reliable.

Both Kilduff and colleagues (48) and Pryor and colleagues (65) used a 90° elbow angle during an IBP for the assessment of PF and RFD and both found the test to be highly reliable (ICC = 0.95 and 0.82, respectively). Specifically, Pryor and colleagues (65) investigated the relationship and validity of quantifying maximum RFD between a variety of tests. Elbow angle was controlled (90°) among the isoinertial tests however it was not controlled for the ballistic tests, which may have biased the results. A significant relationship ($r = 0.73$, $p \leq 0.01$) was determined between the isometric RFD and the 100% concentric test. Unfortunately, one of the limitations of this study is that reliability was only determined for the 90° elbow angle and only this angle was related to the dynamic tests. Additionally, no measures of PF were reported in the manuscript.

Murphy and co-workers (58) developed a new isoinertial test of muscle function and determined its relationship to an IBP performed with a 90° elbow angle. The PF collected during the IBP was highly reliable (r = 0.92, $p \leq 0.01$) and significantly correlated with the 1RM BP (r = 0.78, $p \leq 0.01$). These data support the use of the IBP performed with a 90° elbow angle as a means of assessing PF. This type of assessment would alleviate the time constraints associated with 1RM and would allow for regular testing of PF. While this is a significant finding, only one elbow angle was investigated and further research is warranted to examine the effect of multiple elbow angles on the relationship between isometric PF and the 1RM BP.

When investigating the effect of elbow angle (90° and 120°) on IBP and dynamic performance in the BBT (15%, 30%, 60% 1RM), Murphy and colleagues (59) found that performing the IBP with a 90° elbow angle was more strongly correlated (r = 0.78, $p \leq 0.01$) to performance in the BBT and 1RM tests when compared to a 120° elbow angle (r = 0.47, not statistically significant). They hypothesised that a 90° angle was more specific to the range of motion where PF was developed in the BBT and 1RM tests (59). Further research has shown that PF occurs in the BP and BBT within 0.3 ± 1.9% and 0.63 ± 1.4%, respectively, of the onset of the concentric range of motion phase (62). This would represent a significantly smaller elbow angle than the 90° and 120° elbow angles previously investigated. Likewise, Newton and colleagues (63) found that PF was produced in the BBT at the point when the muscle action changed from eccentric to concentric i.e. when the muscle was contracting isometrically. This smaller variation of elbow angle would explain why a 90° elbow angle was more strongly related to the dynamic tests. Further, Murphy and colleagues (59) also established that both the 90° and 120° elbow angles were highly reliable with ICCs ranging from 0.82 to 0.92. Moreover, the

120° joint angle produced higher PF values compared to the 90° test, perhaps reflecting the superior mechanical advantage at that joint angle. This suggests that the 90° joint angle may be optimal in terms of its relationship to a dynamic performance, but the 120° test may be better suited for the determination of PF generating capacity (84). This is because the 120° elbow angle would result in a higher PF than the PF produced in the BP due to its more mechanically advantageous force-producing position (84). In conclusion, the results of this study show that the angle at which isometric testing takes place should not be arbitrary as the relationship between the isometrics tests themselves, and between the dynamic tests varies substantially as a function of joint angle (59).

2.4.2 Relationship between Force- and Velocity-Time Characteristics of Lower Body Dynamic and Isometric Muscle Actions

Haff and colleagues (37) correlated isometric force-time characteristics and dynamic muscle actions in several lower body exercises. Using dynamic mid-thigh pulls at varying intensities (80, 90 and 100% 1RM) and body weight vertical jumps (countermovement and static movement) in comparison with an isometric mid-thigh pull (IMTP), they found moderate to strong correlations (r = 0.65 – 0.8, $p \leq 0.05$) for the dynamic and isometric force-time characteristics. Further, there were strong correlations between isometric RFD and static jump performance (r = 0.82, $p \leq 0.05$). They concluded that the closer the isometric testing protocol is to the actual dynamic movement, the stronger the relationship.

In a similar study on elite female weightlifters, Haff and colleagues (36) further supported this claim. Using a similar methodology, strong correlations between the dynamic and isometric muscle actions were also found. Specifically, nearly perfect correlations between isometric PF and dynamic mid-thigh pulls and maximal snatch were found (r = 0.93 – 0.99, $p \leq 0.01$). They too suggested that when body positions are similar between the isometric and dynamic actions, the higher the correlation (36).

In four related studies, the IMTP has been shown to correlate well with 1RM testing in a variety of sports such as college wrestling (56), college football (55), college soccer (53) and recreationally trained men (54). All four studies used the same isometric force-time testing protocols as Haff and colleagues (36, 37) and found very strong to nearly perfect correlations between isometric PF and 1RM testing, particularly between isometric PF and 1RM squat (r = 0.72 – 0.97, $p \leq 0.05$). These results are similar to those found by Haff and colleagues (36) who reported a nearly perfect correlation between 1RM snatch and isometric PF (r = 0.93, $p \leq 0.01$).

Kawamori and colleagues (46) further investigated the relationship between isometric and dynamic force-time variables in weightlifting type activities. A variety of loads for the dynamic mid-thigh pull were used (30 – 120% 1RM). They found an increasing relationship between isometric and dynamic PF as the external load increased for the dynamic actions (from r = 0.51 – 0.82, $p \leq 0.05$). Further, there were no correlations between isometric and dynamic RFD at any load. Additionally, isometric PF and dynamic RFD were shown to be strongly correlated with vertical jump performance (r = 0.82 – 0.85, $p \leq 0.05$ and r = 0.65 – 0.72, respectively). It appears that relatively specific qualities are being assessed during isometric and dynamic force-time curve assessments, especially when using lighter dynamic loads (46). From an applied point of view, athletes who possessed greater isometric strength and dynamic RFD were more likely to jump higher (46).

A study by Nuzzo and co-workers (64) investigated the relationship between countermovement jump (CMJ) performance and various methods used to assess isometric and dynamic multi-joint strength. The IMTP and isometric squat were used to assess isometric strength, while the 1RM squat and power clean were used to determine dynamic strength. Performance variables recorded during the CMJ included PF, peak power, peak velocity and jump height. Both absolute and relative measures were recorded. When considering absolute measures of isometric and dynamic strength and their relationship to CMJ performance, significant correlations ($p \leq 0.05$) were found between isometric squat peak force, 1RM squat, 1RM power clean and CMJ peak force (r = 0.64, 0.79 and 0.84, respectively) while significant relationships ($p \leq 0.05$) existed between both isometric squat and mid-thigh pull peak force, squat and power clean 1RMs and CMJ peak power (r = 0.70, 0.75, 0.84 and 0.86, respectively). Significant relationships were also found between relative squat and power clean 1RMs and CMJ peak power, peak velocity and height (r = 0.64 – 0.73, $p \leq 0.05$).

Recently, Khamoui and colleagues (47) investigated the relationship between force-time and velocity-time characteristics in weightlifting type exercises. Significant relationships were found between dynamic high pull velocity-time parameters and explosive force production 50 and 100 milliseconds from the onset of contraction (r = 0.56, $p \leq 0.05$). Interestingly, no significant correlations were found between PRFD and vertical jump performance, most likely due to the method used to calculate PRFD (calculated from the slope of the force-time curve using peak force and the elapsed time between 0 and peak force as values). Nevertheless, they concluded that training to develop explosive strength in the early phase of the lift may enhance acceleration and velocity (47). From an applied point of view, maximising relative strength may positively influence vertical displacement by athletes participating in jumping events (47).

Finally, it seems that dynamic tests (1RM squat and power clean) are better correlated with CMJ performance than isometric tests. However, if choosing to use isometric tests, it appears that when body mass is taken into consideration, the correlation becomes stronger. Based on the findings from the previous studies, it appears that the correlation between isometric force-time measures and dynamic measures increases as a result of the similarity between isometric and dynamic body positions and when the external dynamic load increases.

In summary, it is apparent that both upper and lower body isometric force-time characteristics are highly reliable. Furthermore, a correlation with dynamic performance exists provided that the movements being assessed are similar i.e. IMTP and static jump. Finally, as there is an overall paucity of data exploring the optimal angle at which to assess PF during an IBP, the current study was designed to establish the optimal elbow angle at which PF occurs during the IBP as the assessment angle should be chosen based on the desired outcomes i.e. PF producing angle or correlation with dynamic performance. Additionally, the present study also attempted to justify the use of an isometric assessment for the purpose of a strength diagnosis for an upper-body pressing action, and demonstrate whether performance measures such as PF are sensitive to training induced changes.

2.5 Dynamic Strength Deficit Ratio

An athlete's DSD can be used to indicate the extent to which the athlete is able to apply force dynamically, in relation to their total maximal force capabilities (69). It is expressed as a ratio of ballistic PF to isometric PF and is typically presented based upon the following formula:

$$\frac{Ballistic\ \ Peak\ Force\ (N)}{Isometric\ Peak\ Force\ (N)}$$

Despite the limited research, the determination of the DSD may be a useful decision-making tool for the strength and conditioning practitioner as it may give evidence about the athlete's areas of weakness and may be used to guide the emphasis of training toward the development of this weakness. For example, if an athlete has a DSD well below the typical value found for that athlete group, it might indicate that, in addition to increasing maximal strength, the training program needs to increase the use of ballistic exercises in order for the athlete to better translate their maximal strength to dynamic or explosive movements. While this concept may have practical implications, further research is required before useful normative data can be used to prescribe specific resistance training programs (80).

Comparison of isometric and isoinertial tests is not entirely novel as this concept has existed for a number of years (67, 77, 85). However, there is very limited data available investigating the use of these data in the prescription of specific training interventions. Sheppard and colleagues (69) used the PF obtained during an IMTP test and the PF obtained from a squat jump (SJ PF / IMTP PF) to calculate a DSD ratio. It was concluded that a DSD ratio <0.60 would be indicative of a need to increase the training emphasis toward targeted ballistic strength training. Secondly, if the DSD ratio was >0.80 then targeting maximal strength would result in marked performance gains. Similarly, Wilson & Murphy (80) used a RFD / PF ratio in the isometric squat to calculate a DSD ratio. They concluded that recreational athletes would benefit most from an increased emphasis on maximal strength training to improve cycling performance if the ratio was >3.1. Conversely, if the ratio was <2.4 recreational athletes should concentrate more on plyometric training.

Limited research has been presented in the contemporary literature that attempts to examine the effectiveness of using the DSD as a programming tool. Therefore, one component of the present study is designed to investigate the use of the DSD as a means of assessing an athlete's upper body strength qualities and, in particular, whether the comparisons of the force measures appear to be a valid means to detect training induced changes in athletes (69). Furthermore, if the DSD appears to be a valid means of detecting training induced changes, then the testing protocol may be used as a means of prescribing more specific training interventions. It would also negate the need of testing the entire load-spectrum and 1RM thereby reducing a once lengthy process to 2 efficient and fast tests. Also, by directly comparing isometric PF and ballistic strength measures may also provide valuable insight into the training status, and training needs of an athlete across the spectrum of load-velocity in upper body pressing performance.

2.6 Summary and Implications of Literature Review

The assessment and training of fundamental strength and power qualities has received a considerable amount of attention. While there is still much debate on which tests and methods are most suitable, there are several well established principles that must be taken into consideration when attempting to improve performance in elite athletes.

First, the ability to produce high levels of upper body maximal strength has been identified as an important performance quality in elite athletes (4). In addition, the potential long term benefits of maximal strength training make it an ideal training modality to improve performance (22). Therefore, it is vital that any testing protocol and subsequent training intervention include a component of maximal strength.

Second, the use of ballistic exercises such as the BBT is increasingly being assessed and implemented in sports that require high levels of upper body strength and power (18, 51). However, there is limited research available on the relative and absolute reliability of key performance measures. Also, while typically used to improve power output, more research is required to investigate the impacts of maximal and ballistic strength training on the force producing capabilities of the upper body.

Further, isometric assessments have been shown to be reliable (59) when assessing upper and lower body force capabilities. However, there is scant research on the effect of joint angle on PF production in the IBP. Only 2 standardised angles have been investigated and therefore future research is warranted to assess the optimal angle at which to produce PF in the IBP. In addition, little information is available on the effects maximal and ballistic strength training has on isometric force production.

Finally, detecting an athlete's specific area of relative deficiency in order to improve performance is essential. By focusing on the least developed component will prompt the greatest neuromuscular adaptation and thus result in superior performance improvements (80). Incorporating a DSD ratio will allow strength and conditioning practitioners more insight into an athlete's areas of weakness and may be used to guide the emphasis of training toward the development of this weakness.

CHAPTER 3: METHODS

3.1 Athletes

Twenty four male athletes (age = 19.9 ± 2.8 yr; mass = 79.1 ± 13.0 kg), who were highly familiar with maximal and ballistic strength training, participated in this study. Athletes were members of a national sports training academy from the sports of water polo, field hockey, gymnastics and volleyball. They had been involved in a structured strength & conditioning program for at least one year prior to the commencement of the study; were void of any upper body injuries or contraindication within three months prior to the commencement of the study; and had represented their state or country in their respective sports and age groups. All athletes were in a specific preparation phase of their training. The risks and benefits of participation were explained to all athletes and/or guardians, and written informed consent was provided prior to commencing. All procedures were approved by the Human Research Ethics Committee at Edith Cowan University.

In order to achieve a power level greater than 80% at the α level of 0.05, a sample size of 12 was required to demonstrate a significant relationship (Version 3.1.1; G*Power, Kiel, Germany) (33). To ensure that adequate statistical power is achieved, a total of 24 athletes were recruited for the first part of the study. This number is significantly higher compared to previous studies (power level = 0.86, n = 14)(59). For the training study 12 athletes per group were recruited. This is similar to previously reported studies (power level = 0.85, n = 12)(13).

3.1.1 Conduct and Treatment of the Athletes

Athletes undertook a specific warm-up on each day of testing. This warm-up was identical on all testing days in regards to exercise selection, intensity and time. It consisted of:

- Five minutes of cycling followed by dynamic stretches
- Two sets of 15 push ups
- Two sets of 10 medicine ball chest passes
- Two sets of shoulder external rotation dynamic range of motion exercises

To avoid having athletes waiting for long periods, they were tested in groups of two staggered across the day. The athletes attended pre-determined session times to undergo testing, lasting no more than 45 minutes in duration.

The following controls were implemented to ensure maximum consistency:

1. All athletes underwent a familiarisation session prior to the initial testing session.
2. All athletes underwent testing at the same time of day on all test days.
3. All testing was conducted in the same weight training facility, under the same conditions.
4. Elbow angles, grip distance and position of bench on force plate were all recorded during the familiarisation session and kept constant throughout the subsequent testing sessions.
5. Athletes were asked to follow their usual diet and hydration protocols as prescribed by the squad nutritionists throughout the entire study.

See Appendix A for schematic of study design.

3.2 Study #1: Optimal Elbow Angle and Reliability Study

Prior to the start of the reliability assessment, the 1RM lift for the BP was assessed as a measure of maximal upper body pressing strength. It was performed in the standard supine position using an Olympic barbell and free weights according to the modified established protocols (54, 55, 73) that have been previously reported as being highly reliable (ICC = 0.98). Multiple warm-up sets trials were given before the actual 1RM testing. These consisted of 7 repetitions at 30% 1RM followed by 2 minutes rest, 5 repetitions at 50% 1RM followed by 2 minutes rest, 3 repetitions at 70% 1RM followed by 3 minutes rest, 1 repetition at 90% 1RM followed by 3 minutes rest (% given of subject's estimated 1RM using previous data from the athletes' training logs). Loading was increased through subject feedback on the level of repetition intensity so that 1RM could be achieved within 3 trials. Three minutes of rest was given between each 1RM efforts (73).

A repeated measures study design was used to assess the inter-day reliability of various performance measures in the IBP and BBT. Athletes were tested on two separate occasions at the same time of day, separated by 2 days. Reliability of measures was assessed by calculating the relative change in the mean observations, ICC ($\geq$ 0.80), technical error, and percent co-variance (1 - 5%) set at 90% confidence interval (39).

The isometric force assessment involved testing PF in a purpose-built, non-counter balanced smith machine that enables the bar to be fixed and adjusted at 2 centimetre intervals. Four fixed positions of i) 60°, ii) 90°, iii) 120° and iv) 150° of elbow flexion were used in a randomised order. As previously stated, only two of these positions have been investigated. The 30° difference between positions was chosen as this degree of variation in the IBP has shown to elicit significantly different performance measures (59). Appropriate elbow positions and grip distances were established during the familiarisation session with the use of a hand held goniometer (Patterson Medical, Bolingbrook, USA). Shoulder position was controlled by allowing athletes to self-select their 'strongest position', and this was kept constant through the 4 elbow positions.

Vertical ground reaction force data was collected using a portable force plate sampling at 600 Hz (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia) placed under the bench (as illustrated in Figures 2 and 3). The force plate was interfaced with computer software [Ballistic Measurement System (BMS)] that allows for direct measurement of force-time characteristics, and then analysed using the BMS software. Data was filtered using a fourth order Butterworth filter. Previous research has used this set up for analysing upper body force-time characteristics with valid and reliable results (32, 44, 48, 59). Athletes were instructed to apply force against the immovable bar as fast and hard as possible, as the intention of the test was to obtain PF and RFD measures (17, 37).

Specific verbal encouragement such as 'push as hard and fast as you can' (17, 37) was provided throughout the tests. Athletes performed a minimum of 3 x 10 second trials with 1 minute of rest between efforts (50). The live force trace was viewed by the tester so that encouragement could be given to the subject to achieve true PF during the trial. If the athlete or tester perceived the efforts to be less than maximal or if there was a greater than 250N difference between the peak force values the test was repeated until 3 efforts of within 250N difference were obtained (50).

The ballistic force assessment involved testing peak force, peak displacement, peak velocity, peak power and peak rate of force development using the BBT. Athletes were required to keep their head, shoulders and trunk in contact with the bench and both feet in contact with the ground. They were instructed to lower the bar from a fully extended position to the chest and explode the bar off the chest as rapidly as possible (62). All athletes performed 3 sets of 1 repetition with 45% of 1 RM BP with 4 minutes rest in between sets. The 45% of BP 1 RM load was chosen for this study as it is a load that is typical of the athletes' previous training programs and testing (71), and furthermore it is has been extensively used in research (62, 63). All trials were performed in a smith machine with a portable force plate (Fitness Technology, Adelaide, Australia) placed under the bench and a linear position transducer (LPT) (Fitness Technology, Adelaide, Australia) attached to the bar, as per the recommendations of Dugan and colleagues (29). Both the force plate and position transducer were interfaced with the BMS software to record displacement, velocity and force characteristics. The force place was used to collect force (kinetic) data and the LPT was used to collect displacement and velocity (kinematic) data. Finally, the athletes' DSD ratios were also calculated.

3.3 Study #2: Training Intervention Study

With performance measures deemed to be highly reliable in the IBP and BBT, a repeated measures study design was used to assess the impact of a 5 week training intervention on the athletes' DSD ratio (BBT PF / IBP PF). A matched-pairs methodology was used to assess the effectiveness of the 5 week training intervention. Athletes were placed in to 2 groups as matched-pairs based on their DSD ratio and 1RM strength in the bench press as maximal strength underpins ballistic strength (7, 8, 23).

Training for the BP Group consisted of high load BP consisting of 3-5 sets of 80-100% 1RM. Training for the BBT Group consisted of moderate load BBT comprising 4-5 sets of 40-55% 1RM (see Appendix B for detailed training intervention). Although the load (sets x repetitions x intensity) differed between groups, a previous pilot study (n = 10) revealed similar quantities of total work were performed. Both groups trained twice a week and additional upper body exercises were controlled to ensure equal volume and relative intensity between groups. Lower body strength and power exercises were not controlled and were dependent upon each athlete and their respective sports. However, these exercises were performed after the training interventions to control for any hormonal effects. At the conclusion of the 5 week intervention, athletes were re-tested in the BP, IBP and BBT to determine any training induced changes to the DSD.

3.4 Statistical Analyses

All data are presented as means and SD. Differences between the BBT and BP groups following training were compared using statistical significance testing and by using a practical approach based on the real-world relevance of the results (16). First, differences in absolute and relative BP, BBT and IBP performances between the two training groups were compared using a repeated measures (group x time) ANOVA. Greenhouse-Geisser corrections to the degrees of freedom were applied where appropriate and partial eta-squared (η_p^2). To reflect the magnitude of change after training intervention, Cohen's *d* values were computed, with 0.2, 0.5, and 0.8 considered small, moderate, and large, respectively (21). The chances that the true (population) differences were substantial were assessed (using 0.2 x between subject SD) and expressed as both percentages and qualitatively, using practical inferences (40). To make assumptions about true (population) values of the effect of the different training modalities on absolute and relative BP, BBT and IBP performances, the uncertainty of the effect was expressed as likelihoods that the true value of the effect represented substantial change, with <25%, 26-74%, >75% classified as "unlikely", "possibly", and "likely" (41) . Furthermore, both groups were divided in two, allowing for comparisons between athletes with high and low DSD's. Similarly, the uncertainty of the effect between groups was expressed as likelihoods. Additionally, Pearson's correlations were used to assess the magnitude of change between starting DSD values and the percent change in performance measures following training. Correlations were described as trivial (0-0.1), low (0.1-0.3), moderate (0.3-0.5), high (0.5-0.7), very high (0.7-0.9) and practically perfect (0.9-1)(16).

Figure 2: Set up for the IBP

Figure 3: Set up for the IBP

CHAPTER 4: RESULTS

4.1 Study #1 - Descriptive Statistics

The minimum, maximum, mean results and standard deviations of the basic anthropometric and performance variables are listed in Table 1. Table 2 and 3 contain the results for the IBP and BBT, respectively. Figure 4 illustrates the differences in peak force across the 4 joint angles assessed in the IBP, whilst Figure 5 and 6 contain a typical force-time trace for the IBP and BBT, respectively.

Table 1: Descriptive statistics of key variables (N = 24). Mean ± SD

Variable	Mean	Standard Deviation	Minimum	Maximum
Age (years)	19.9	2.8	15	27
Mass (kg)	79.1	13.0	52.3	114
1RM BP (kg)	90.9	16.7	70	130
Relative 1RM BP (/kg/bm)	1.17	0.25	0.82	1.68

Table 2: Descriptive statistics of key performance variables in the IBP (N = 24). Mean ± SD†

Variable	Mean	Standard Deviation
ISO60° PF (N)	772.5	130.3
ISO60° PRFD (N/sec)	5810.5	1130.2
ISO90° PF (N)	922.3	162.9
ISO90° PRFD (N/sec)	6979	1819.3
ISO120° PF (N)	1407.6	162.9
ISO120° PRFD (N/sec)	9872.4	3225.2
ISO150° PF (N)	1542	287.6
ISO150° PRFD (N/sec)	11358.1	3241.5

† PF = peak force; PRFD = peak rate of force development

Table 3: Descriptive statistics of key performance variables in the BBT (N = 24). Mean ± SD†

Variable	Mean	Standard Deviation
Peak Displacement (cm)	24.2	3.5
Peak Force (N)	1023.6	211.6
Peak Power (W)	835.6	187.9
Peak Velocity (m/sec)	1.5	0.1
PRFD (N/sec)	15944.5	3124.4

† PRFD = peak rate of force development

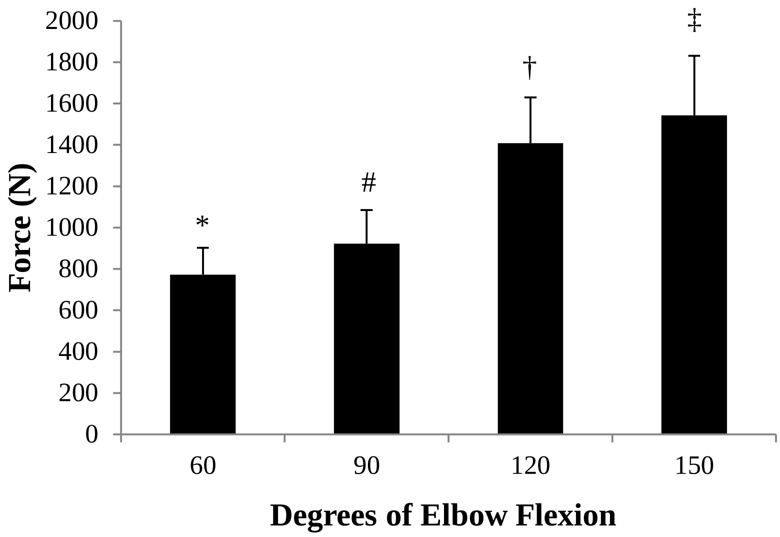


Figure 4: Average isometric PF across 4 angles. Mean ± SD

* Significantly different ($p \leq 0.001$) from 90°, 120° and 150°
# Significantly different ($p \leq 0.001$) from 60°, 120° and 150°
† Significantly different ($p \leq 0.001$) from 60° and 90°
‡ Significantly different ($p \leq 0.001$) from 60° and 90°

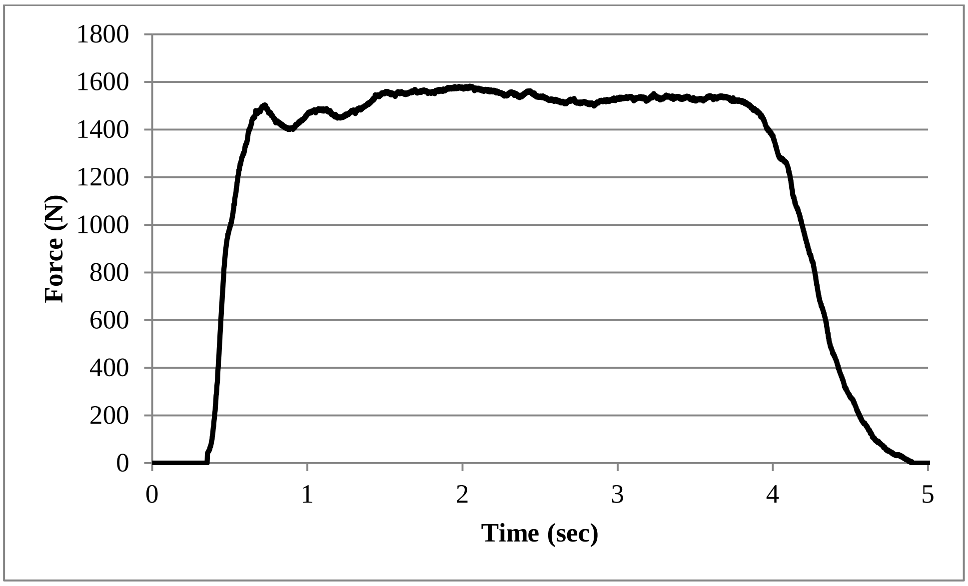


Figure 5: Force-time trace of a sample repetition in the IBP

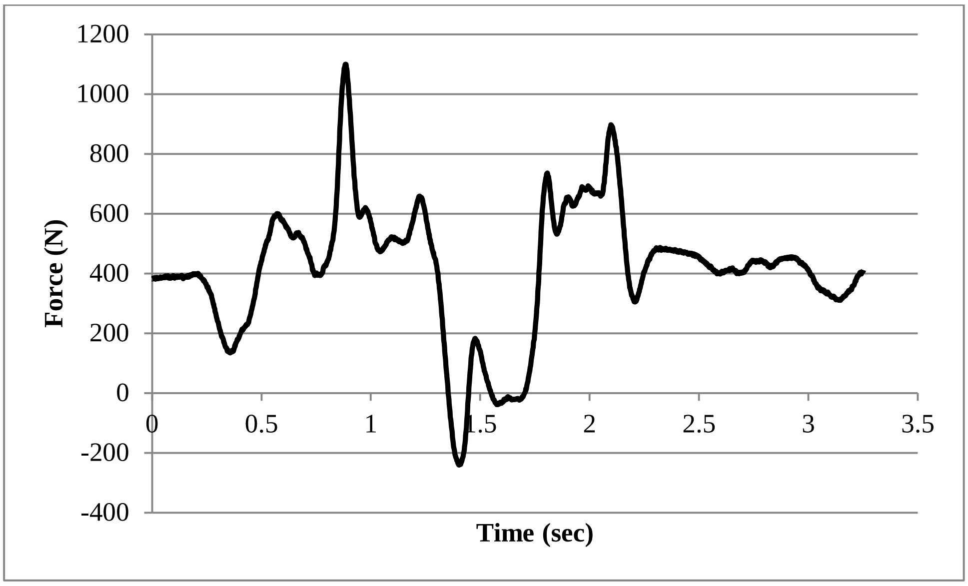


Figure 6: Force-time trace of a sample repetition in the BBT

4.2 Study #1 – Reliability of the Isometric and Isoinertial Assessments

Test-retest reliability of the isometric and isoinertial assessments are displayed in Tables 4 (absolute) and 5 (relative to body mass).

Table 4: Isometric and isoinertial reliability data (absolute) †

Isometric Bench Press Reliability Data (Absolute)				
Reliability values	TE	Change in the mean (%)	%CV (90% CI)	ICC (90% CI)
ISO60PF (N)	39.94	2.0	1.2 (0.97-1.59)	0.93 (0.87-0.97)
ISO60PRFD (N/sec)	1259.25	4.4	7.6 (6.15-10.1)	0.56 (0.28-0.76)
ISO90PF (N)	58.42	2.0	1.6 (1.29-2.1)	0.89 (0.79-0.94)
ISO90PRFD (N/sec)	1312.98	-10.0	0.5 (0.4-0.66)	0.65 (0.41-0.81)
ISO120PF (N)	60.59	1.2	1.5 (1.21-1.99)	0.94 (0.88-0.97)
ISO120PRFD (N/sec)	2195.71	-7.9	3.6 (2.91-4.77)	0.62 (0.36-0.79)
ISO150PF (N)	52.93	2.4	1.6 (1.29-2.12)	0.97 (0.93-0.98)
ISO150PRFD (N/sec)	2391.08	5.4	6.3 (5.09-8.35)	0.58 (0.3-0.77)
ISOPF (N)	55.07	1.7	1.4 (1.13-1.86)	0.97 (0.93-0.98)

Ballistic Bench Throw Reliability Data (Absolute)

Reliability values	TE	Change in the mean (%)	%CV (90% CI)	ICC (90% CI)
Peak Displacement (cm)	1.60	2.6	2.3 (1.86-3.05)	0.85 (0.71-0.92)
Peak Force (N)	61.59	0.0	2.9 (2.35-3.84)	0.92 (0.85-0.96)
Peak Power (W)	70.11	3.0	3.3 (2.67-4.37)	0.89 (0.79-0.94)
PRFD (N/sec)	2238.68	6.5	4.1 (3.32-5.43)	0.43 (0.12-0.67)
Peak Velocity (m/sec)	0.04	0.2	1.7 (1.37-2.25)	0.85 (0.72-0.92)

† PF = peak force; PRFD = peak rate of force development; ISOPF = maximal peak force production regardless of elbow angle; CI = confidence intervals

Table 5: Isometric and isoinertial reliability data (relative to body mass) †

Isometric Bench Press Reliability Data (Relative to Body Mass)

Reliability values	TE	Change in the mean (%)	%CV (90% CI)	ICC (90% CI)
ISO60FORCE (N/kg)	0.19	2.4	1.0 (0.81-1.33)	0.97 (0.93-0.98)
ISO90FORCE (N/kg)	0.78	2.5	-1.2 (0.97-1.59)	0.95 (0.91-0.98)
ISO120FORCE (N/kg)	0.81	1.7	-1.3 (1.05-1.72)	0.96 (0.91-0.98)
ISO150FORCE (N/kg)	0.75	2.3	0.2 (0.16-0.27)	0.99 (0.97-0.99)
ISOPF (N/kg)	0.13	1.7	-0.5 (0.4-0.66)	0.98 (0.97-0.99)

Ballistic Bench Throw Reliability Data (Relative to Body Mass)

Reliability values	TE	Change in the mean (%)	%CV (90% CI)	ICC (90% CI)
Peak Force (N/kg)	0.79	0.2	3.4 (2.75-4.51)	0.94 (0.87-0.97)
Peak Power (W/kg)	0.84	3.2	2.4 (1.94-3.18)	0.87 (0.75-0.93)

Dynamic Strength Deficit (DSD) Ratio

Reliability values	TE	Change in the mean (%)	%CV (90% CI)	ICC (90% CI)
DSD Ratio	0.28	-1.6	3.5 (2.83-4.64)	0.93 (0.86-0.96)

† PF = peak force; PRFD = peak rate of force development; ISOPF = maximal peak force production regardless of elbow angle; CI = confidence intervals

4.3 Study #2 – Between-group Comparisons

Table 6: Between-group comparisons. Data are mean ± SD

	Ballistic Bench Throw			Bench Press			Between Group Differences		
								Chances that the true differences are substantial	
	Pre	Post	Change	Pre	Post	Change	Effect Size	%	Qualitative
Body Mass (kg)	79.9 ± 14.3	80.4 ± 14.8	0.5 ± 1.1	78.3 ± 12.0	79.0 ± 12.5	0.6 ± 1.7	0.01	0%	Unlikely
BPAbs (kg)	92.7 ± 19.8	94.0 ± 19.9	1.3 ± 2.5	89.2 ± 13.5	95.2 ± 12.6	6.0 ± 2.7	0.29	91%	Likely
BPRel (/kg)	1.17 ± 0.23	1.18 ± 0.23	0.01 ± 0.03	1.17 ± 0.28	1.24 ± 0.27	0.07 ± 0.04	0.23	71%	Possibly
BBTPF (N)	1067.7 ± 244.7	1369.1 ± 292.5	301.4 ± 134.1	980.3 ± 178.5	1181.4 ± 280.6	201.1 ± 153.2	-0.47	83%	Likely
BBTPFRel (N/kg)	13.5 ± 2.6	17.3 ± 3.8	3.8 ± 2.0	12.9 ± 3.2	15.6 ± 4.2	2.6 ± 1.7	-0.42	79%	Likely
BBTPV (m/s)	1.49 ± 0.10	1.53 ± 0.10	0.04 ± 0.06	1.51 ± 0.11	1.53 ± 0.14	0.02 ± 0.10	-0.17	47%	Possibly
BBTPD (cm)	23.9 ± 3.4	25.4 ± 2.8	1.6 ± 2.4	24.4 ± 3.6	25.3 ± 5.5	0.9 ± 3.6	-0.20	50%	Possibly
BBTPP (W)	837.3 ± 224.9	947.6 ± 242.4	110.4 ± 162.8	833.8 ± 150.8	949.0 ± 400.7	115.3 ± 286.2	0.03	37%	Possibly
IBPPF (N)	1650.8 ± 298.0	1676.5 ± 301.8	25.7 ± 31.4	1555.2 ± 282.3	1619.4 ± 261.7	64.2 ± 127.6	0.13	31%	Possibly
IBPPFRel (N/kg)	21.3 ± 6.1	21.6 ± 6.1	0.3 ± 0.6	20.6 ± 6.5	21.2 ± 6.0	0.6 ± 1.7	0.05	4%	Unlikely
DSD	0.65 ± 0.14	0.83 ± 0.20	0.18 ± 0.09	0.64 ± 0.15	0.73 ± 0.17	0.09 ± 0.09	-0.60	93%	Likely

BPAbs = absolute bench press; BPRel = relative bench press; BBTPF = ballistic bench throw peak force; BBTPFRel = relative ballistic bench throw peak force; BBTPV = ballistic bench throw peak velocity; BBTPD = ballistic bench throw peak displacement; BBTPP = ballistic bench throw peak power; IBPPF = isometric bench press peak force; IBPPFRel = relative isometric bench press peak force; DSD = dynamic strength deficit ratio

Bench Press Performance

No difference in absolute and relative 1RM BP existed between groups prior to the training intervention. However, despite the very different training stimulus, both groups significantly improved absolute and relative BP performance post-testing ($p \leq 0.001$). The BP Group experienced a substantial increase in absolute maximal strength that was significantly greater than the BBT Group ($p \leq 0.01$). Similarly, the BP Group was significantly stronger relative to body mass than the BBT Group ($p \leq 0.001$). There was a 91% (likely) and 71% (possible) probability that the true difference in absolute and relative BP, respectively, between the 2 groups was practically meaningful.

Absolute 1RM Bench Press

While there was no significant main effect for group [$F(1,11) = 0.072$, $p = 0.794$, $\eta_p^2 = 0.006$], there was a significant main effect for time [$F(1,11) = 53.685$, $p \leq 0.001$, $\eta_p^2 = 0.830$], and significant group x time interactions [$F(1,11) = 18.015$, $p \leq 0.01$, $\eta_p^2 = 0.621$] for improvements in absolute bench press performance. The change in absolute bench press performance was greater in the bench press group than the ballistic bench throw group (likely substantial true difference, 91%).

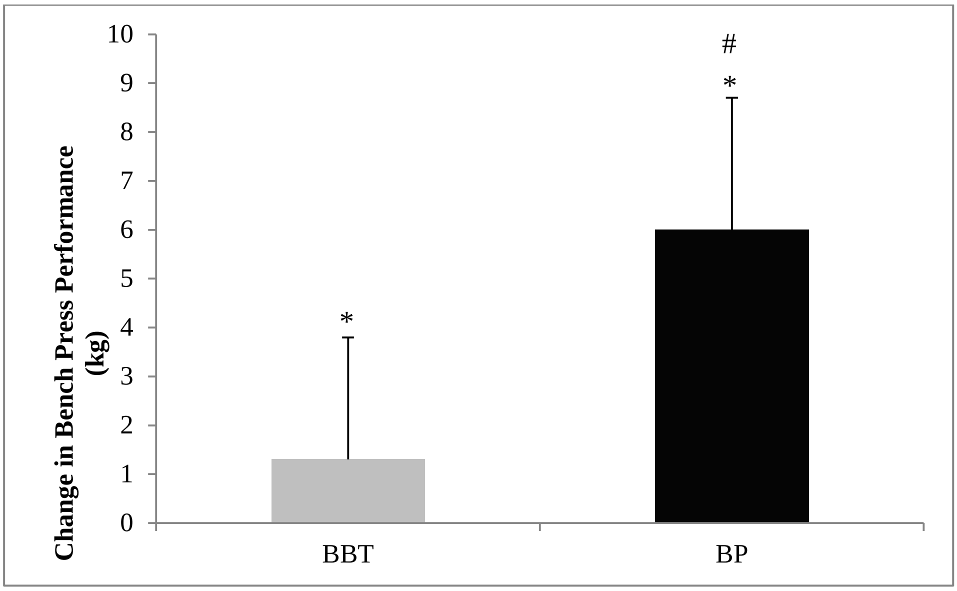


Figure 7: Change in bench press performance - absolute
*Significant change ($p \leq 0.001$) from pre-training.
Significantly different ($p \leq 0.001$) from BBT Group.
91% (likely) chance that both groups improved. Effect size = 0.29

Relative 1RM Bench Press

There was no significant main effect for group [$F(1,11) = 0.178$, $p = 0.681$, $\eta_p^2 = 0.016$], however there was a significant main effect for time [$F(1,11) = 37.044$, $p \leq 0.001$, $\eta_p^2 = 0.771$], and significant group x time interactions [$F(1,11) = 22.253$, $p \leq 0.001$, $\eta_p^2 = 0.669$] for improvement in relative bench press performance. The change in performance was greater in the bench press group than the ballistic bench throw group (possible substantial true difference, 71%).

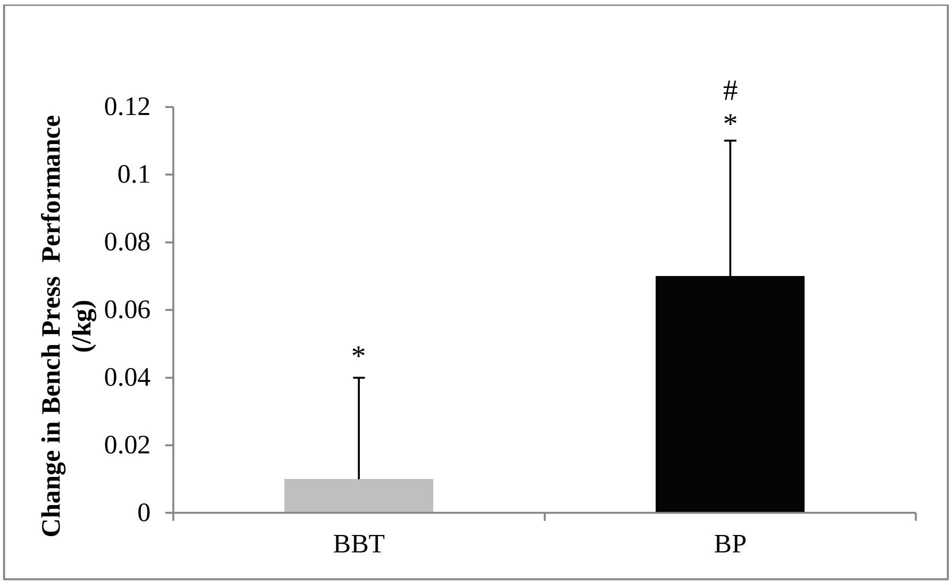


Figure 8: Change in bench press performance – relative to body mass
*Significant change ($p \leq 0.001$) from pre-training.
Significantly different ($p \leq 0.001$) from BBT Group.
71% (possible) chance that both groups improved. Effect size = 0.23

Ballistic Bench Throw Performance

Similar to the BP performance, no difference in absolute and relative BBT PF existed between groups prior to the training intervention. However, both groups significantly improved absolute and relative BBT PF post-testing ($p \leq 0.001$) with no significant differences between groups. The calculation of likelihoods shows that there was an 83% (likely) and 79% (possible) probability that the true difference in absolute and relative BBT PF, respectively, between the 2 groups was practically meaningful. Comparably, both groups significantly improved peak displacement ($p = 0.019$) with no significant differences between groups. There was a 50% (possible) probability that the true difference in peak displacement was practically meaningful. Finally, no significant differences existed between groups for peak velocity and peak power with the calculation of likelihoods showing a 47% (possible) and 37% (possible) probability, respectively.

Ballistic Bench Throw Peak Force

While there was no significant main effect for group [$F(1,11) = 3.454$, $p = 0.090$, $\eta_p^2 = 0.239$], or group x time interactions [$F(1,11) = 2.066$, $p = 0.178$, $\eta_p^2 = 0.158$], there was a significant main effect for time [$F(1,11) = 123.541$, $p \leq 0.001$, $\eta_p^2 = 0.918$] for the improvements in ballistic bench throw peak force. There was an improvement in performance for both groups post-training intervention (83% chance that both groups improved); however no differences existed between the post-training groups.

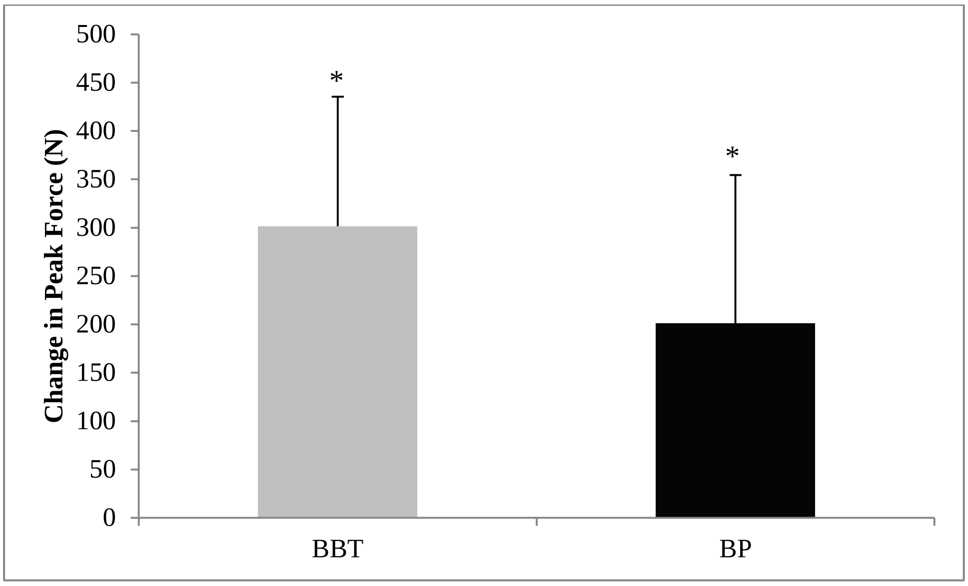


Figure 9: Change in ballistic bench throw peak force
*Significant change ($p \leq 0.001$) from pre-training.
83% (likely) chance that both groups improved. Effect size = -0.47

Relative Ballistic Bench Throw Peak Force

Similar to the absolute results, there was no significant main effect for group [$F(1,11) = 0.895$, $p = 0.364$, $\eta_p^2 = 0.075$], or group x time interactions [$F(1,11) = 1.559$, $p = 0.238$, $\eta_p^2 = 0.124$], however there was a significant main effect for time [$F(1,11) = 126.101$, $p \leq 0.001$, $\eta_p^2 = 0.946$] for the improvements in relative ballistic bench throw peak force. There was an improvement in performance in both groups post-training (79% chance that both groups improved) however, no differences existed between the post-training groups.

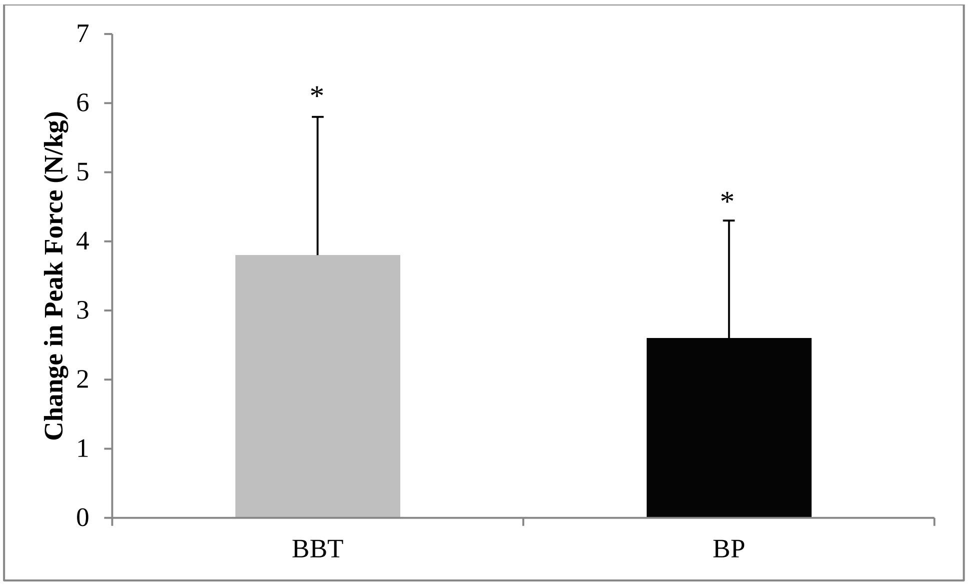


Figure 10: Change in ballistic bench throw peak force - relative to body mass
*Significant change ($p \leq 0.001$) from pre-training.
79% (likely) chance that both groups improved. Effect size = -0.42

Ballistic Bench Throw Peak Velocity

There were no significant main effects for group [$F(1,11) = 0.017$, $p = 0.899$, $\eta_p^2 = 0.002$], time [$F(1,11) = 2.359$, $p = 0.153$, $\eta_p^2 = 0.177$], or group x time interactions group [$F(1,11) = 0.602$, $p = 0.454$, $\eta_p^2 = 0.052$] for improvements in peak velocity. The calculation of likelihoods shows that there was a 47% (possible) probability that the true difference between the 2 groups was practically meaningful. The change in peak velocity was not different between groups.

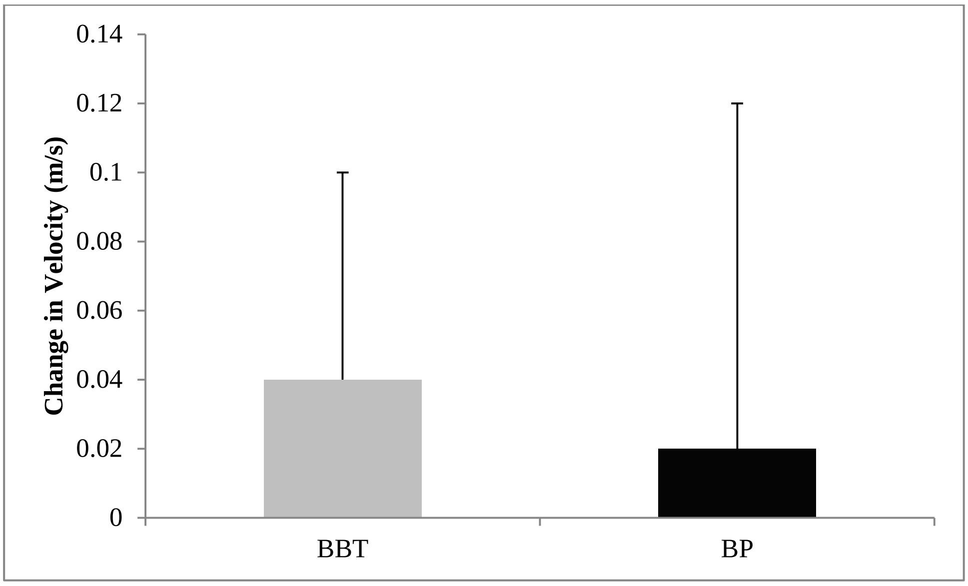


Figure 11: Change in ballistic bench throw peak velocity
47% (possible) chance that both groups improved. Effect size = -0.17

Ballistic Bench Throw Peak Displacement

There were no significant main effects for group [$F(1,11) = 0.013$, $p = 0.912$, $\eta_p^2 = 0.001$], or group x time interactions group [$F(1,11) = 0.201$, $p = 0.662$, $\eta_p^2 = 0.018$] for improvements in peak displacement. There was a significant main effect for time [$F(1,11) = 7.518$, $p = 0.019$, $\eta_p^2 = 0.406$]. The calculation of likelihoods shows that there was a 50% (possible) probability that the true difference between the 2 groups was practically meaningful.

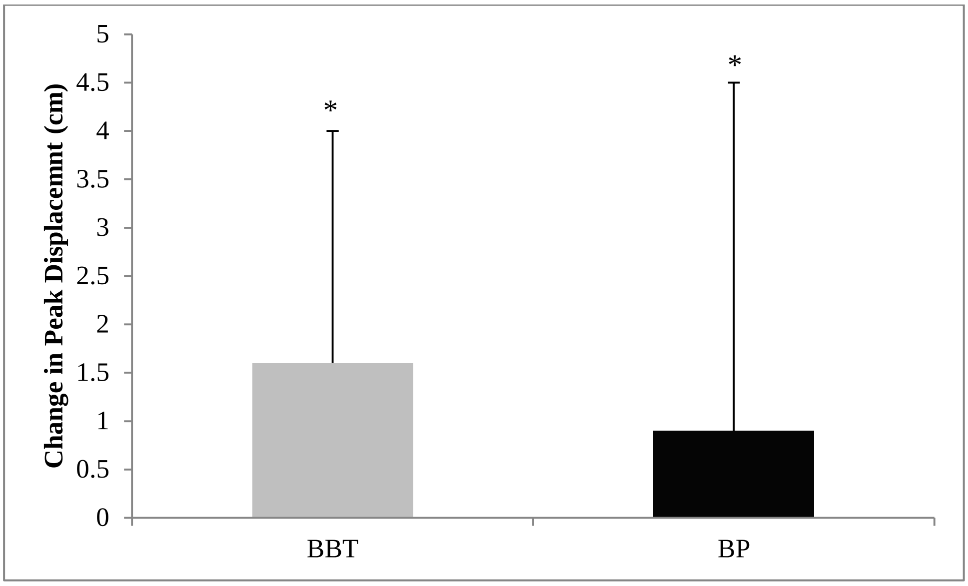


Figure 12: Change in ballistic bench throw peak displacement
*Significant change ($p \leq 0.05$) from pre-training.
50% (possible) chance that both groups improved. Effect size = -0.20

Ballistic Bench Throw Peak Power

There were no significant main effects for group [$F(1,11) = 0.000$, $p = 0.991$, $\eta_p^2 = 0.000$], time [$F(1,11) = 4.356$, $p = 0.061$, $\eta_p^2 = 0.284$], or group x time interactions group [$F(1,11)$ =0 .004, $p = 0.953$, $\eta_p^2 = 0.000$] for improvements in peak power. The calculation of likelihoods shows that there was a 37% (possible) probability that the true difference between the 2 groups was practically meaningful.

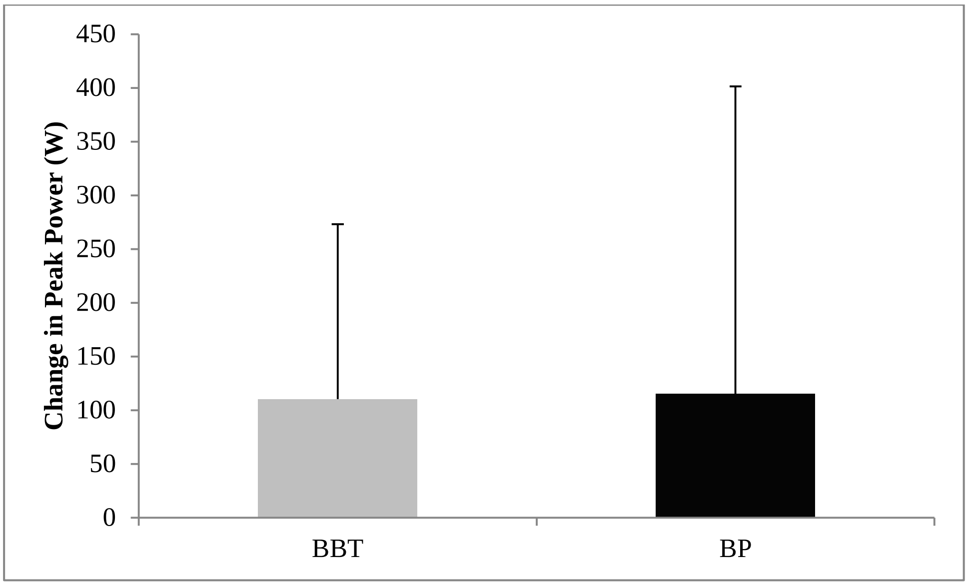


Figure 13: Change in ballistic bench throw peak power
63% (possible) chance that groups were different. Effect size = 0.03

Isometric Bench Press Performance

Both groups significantly improved ($p = 0.035$) absolute isometric PF post-training, with no difference between groups. There were no significant improvements for relative isometric PF. There was a 31% (possible) and 4% (unlikely) probability, respectively, that the true difference between the 2 groups was practically meaningful.

Isometric Bench Press Peak Force

There were no significant main effects for group [$F(1,11) = 0.718$, $p = 0.415$, $\eta_p^2 = 0.061$], or group x time interactions [$F(1,11) = 1.004$, $p = 0.338$, $\eta_p^2 = 0.084$] for improvements in isometric peak force. There was a significant main effect for time [$F(1,11) = 5.775$, $p = 0.035$, $\eta_p^2 = 0.344$]. The calculation of likelihoods shows that there was a 31% (possible) probability that the true difference between the 2 groups was practically meaningful.

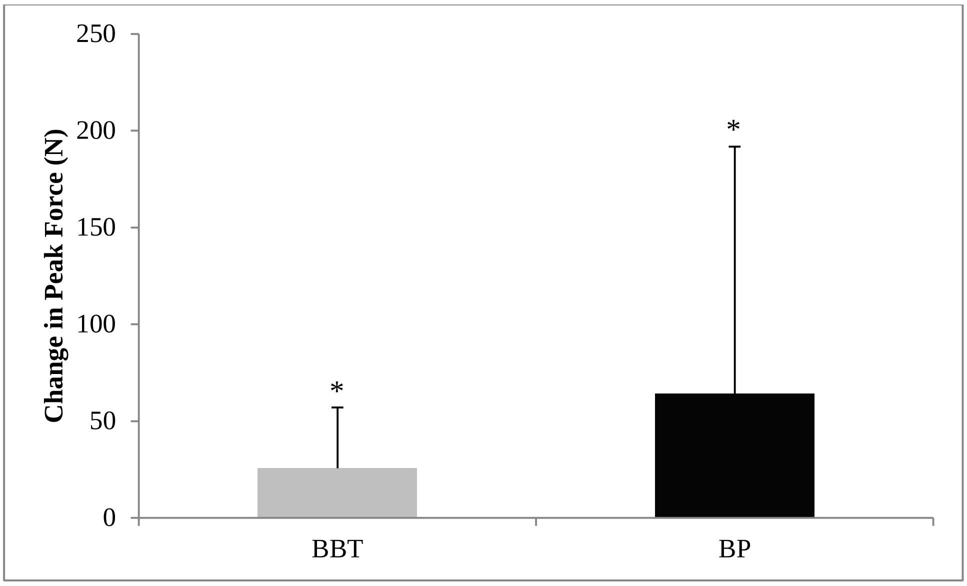


Figure 14: Change in isometric bench press peak force
*Significant change ($p \leq 0.05$) from pre-training.
69% (possible) chance that groups were different. Effect size = 0.13

Relative Isometric Bench Press Peak Force

There were no significant main effects for group [$F(1,11) = .121$, $p = 0.735$, $\eta_p^2 = 0.011$], time [$F(1,11) = 2.684$, $p = 0.130$, $\eta_p^2 = 0.284$], or group x time interactions group [$F(1,11) = 0.325$, $p = 0.580$, $\eta_p^2 = 0.029$] for improvements in relative peak force. The calculation of likelihoods shows that there was a 4% (very unlikely) probability that the true difference between the 2 groups was practically meaningful.

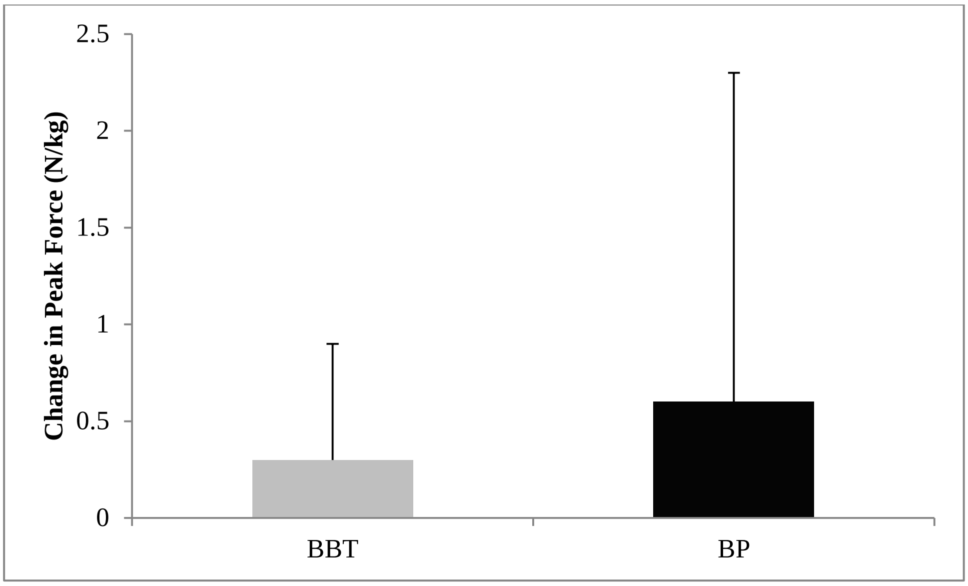


Figure 15: Change in isometric bench press peak force – relative to body mass
96% (likely) chance that groups were different. Effect size = 0.05

Dynamic Strength Deficit Ratio

No significant differences existed between groups prior to the training intervention. However, both groups experienced a significant ($p \leq 0.001$) increase in the DSD. While there was no significant main effect for group [$F(1,11) = 3.338$, $p = 0.095$, $\eta_p^2 = 0.233$], and group x time interactions [$F(1,11) = 4.777$, $p = 0.051$, $\eta_p^2 = 0.303$], there was a significant main effect for time [$F(1,11) = 56.797$, $p \leq 0.001$, $\eta_p^2 = 0.838$], for changes in the dynamic strength deficit ratio. The calculation of likelihoods showed a 93% (likely) probability that the true difference between the 2 groups was practically meaningful.

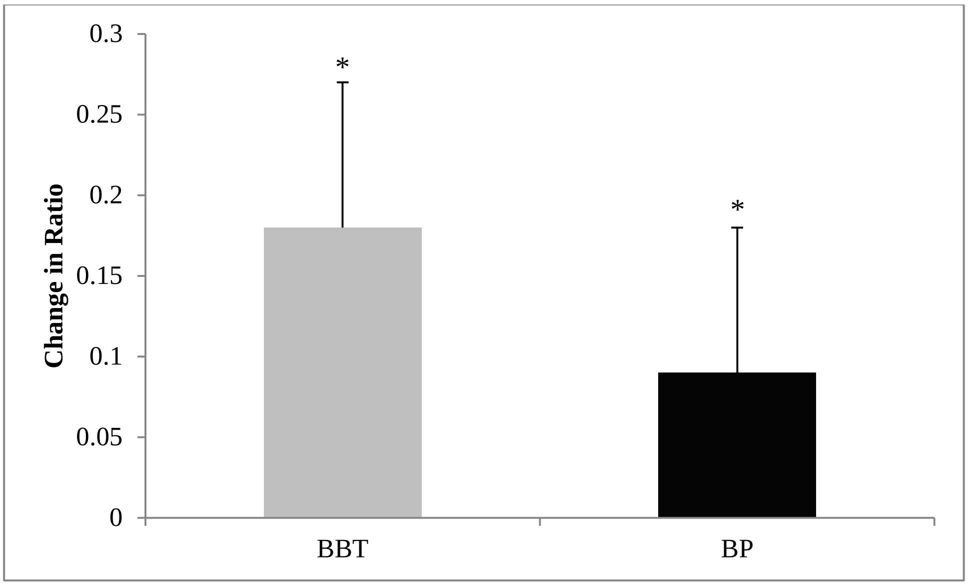


Figure 16: Change in dynamic strength deficit ratio
*Significant change ($p \leq 0.001$) from pre-training.
93% (likely) chance that both groups improved. Effect size = -0.60

4.4 Study #2 – Within-group Comparisons

Table 7: Within-group comparisons. Data are mean ± SD †

Ballistic Bench Throw

	High DSD (n = 6)			Low DSD (n = 6)			Chances that the true differences are substantial	
	Pre	Post	Change	Pre	Post	Change	%	Qualitative
IBPPF (N)	1611.0 ± 322.1	1649.1 ± 334.8	38.1 ± 21.0	1690.6 ± 296.4	1703.8 ± 294.2	13.2 ± 36.9	4%	Very Unlikely
BBTPF (N)	1204.3 ± 259.4	1488.3 ± 352.8	284.0 ± 185.2	931.15 ± 140.1	1249.9 ± 172.2	318.8 ± 67.2	43%	Possibly
DSD	0.75 ± 0.14	0.90 ± 0.22	0.14 ± 0.13	0.55 ± 0.03	0.74 ± 0.08	0.19 ± 0.05	60%	Possibly

Bench Press

	High DSD (n = 6)			Low DSD (n = 6)			Chances that the true differences are substantial	
	Pre	Post	Change	Pre	Post	Change	%	Qualitative
IBPPF (N)	1511.8 ± 343.8	1606.4 ± 255.1	94.6 ± 160.9	1598.7 ± 229.4	1632.5 ± 291.7	33.8 ± 87.9	52%	Possibly
BBTPF (N)	1108.8 ± 144.3	1382.6 ± 219.6	273.7 ± 165.5	851.7 ± 98.1	980.2 ± 166.9	128.5 ± 107.8	90%	Likely
DSD	0.75 ± 0.14	0.86 ± 0.09	0.12 ± 0.11	0.53 ± 0.05	0.59 ± 0.09	0.06 ± 0.07	68%	Possibly

† BBTPF = ballistic bench throw peak force; IBPPF = isometric bench press peak force; DSD = dynamic strength deficit ratio

Table 8: Correlations between pre-dynamic strength deficit values and percentage change in performance†

	BBTPF	**IBPPF**	**DSD**
High DSD BBT	0.51	0.47	0.57
Low DSD BBT	0.35	0.72	0.59
High DSD BP	0.31	0.70	0.80
Low DSD BP	0.51	0.63	0.29

†BBTPF = ballistic bench throw peak force; IBPPF = isometric bench press peak force; DSD = dynamic strength deficit ratio

CHAPTER 5: DISCUSSION

5.1 Introduction

The first hypothesis of this research study was that the isometric and isoinertial performance variables would be reliable across all of the investigated angles. From the reliability assessment conducted for this study, it was found that all measures other than PRFD were reliable to be included in a testing protocol. Further, the larger angles (≥ 120°) were better suited for assessing peak force. However, there was no statistical difference ($p = 0.08$) between the larger angles.

The second hypothesis of the study was that the DSD ratio would be sensitive to training induced changes and would be able to guide more specific training interventions. The current results indicate that short term exposure to either maximal strength or ballistic strength training elicits improvements in performance measures that directly impact an individual's DSD. As a result, the DSD is a reliable, valid means of assessing an athlete's maximal strength capacities. Further, the comparisons of PF values found in the DSD are sensitive to change and are able to guide more specific training interventions.

5.2. Study #1

Comparison of key performance variables in the IBP

Despite the fact that this is first study to assess the force-generating capabilities across 4 standardised angles in the IBP, similar values of PF have previously been reported across 2 angles (90° and 120°) in the IBP. Even though subjects possessed a higher 1RM BP (102.3 ± 14.8 vs. 90.0 ± 16.7kg), Murphy and colleagues (59) reported very similar levels of PF at both 90° and 120° (989.9 ± 130.9N and 1333.5 ± 237.2N, respectively). Interestingly, significantly higher values of PRFD were reported in the previous study. This could be due to differences in the methods used to obtain PRFD values. Murphy and colleagues (59) used a 5m/s epoch while the present study used a 30m/s epoch. Another reason for the large differences could be that the subjects used in the previous study possessed greater levels of musculotendinous stiffness, as this has been shown to dramatically affect isometric PRFD (84).

In a follow up study using a larger cohort of subjects, Murphy and Wilson (57) reported similar values of PF at 90° but lesser values of PF at 120° and PRFD at both angles. Unfortunately strength levels were not reported in the manuscript, but one might assume that the subjects possessed a lower 1RM BP to their previous study.

In a recent study (78), the authors investigated the force generating capabilities across 12 positions in the IBP (ranging from 0-31cm from the sternum). Importantly, it must be noted that elbow angles were not standardised and to allow comparisons to be made, several assumptions must be made. First, if it is assumed that the pre-sticking period (4cm from sternum) is equivalent to 60° of elbow flexion then subjects in the previous study produced significantly greater levels of PF (~875N – taken from graph) compared to the present study (772.5N). At 13cm from the sternum (~90°), similar levels of PF were reported (~1000N). When comparing the 2 larger angles, 31cm from the sternum would result in an elbow angle of roughly 150°. As a result, similar values for PF were reported (~1550N). In conclusion, it appears that Tillaar and colleagues (78) reported comparable results to the current study at all angles except for 60° of elbow flexion. It is unclear why this is the case, but perhaps the higher strength levels of the subjects used resulted in superior levels of PF at 60°.

Comparison of Key Performance Variables in the BBT

The average PF reported in this investigation was 1023.6 ± 211.6N. Similar values for PF in a 45% 1RM BBT have previously been reported by Newton and colleagues (62, 63). Furthermore, slightly higher values for peak displacement (24.2 ± 3.5cm) and peak velocity (1.5 ± 0.1m/sec) were found in the current study compared to those presented by Newton and co-workers (62, 63). More recently, Cronin and colleagues (26) reported similar results (1.48 ± 0.15m/sec) using a 40% 1RM BBT. Interestingly, the current group of athletes generated lower levels of PP compared to previously reported results (63) using similar loads. In a more recent study (18) using a similar methodology to this investigation, comparable results for PP were presented. Although relative loads of 40% and 50% 1RM BP were used, if we were to assume a linear relationship for the peak power profile (63), then PP output at 45% 1RM would be equivalent to approximately 851.9W, which is similar to the current results (835.6 ± 187.9W). At first glance, it appears that the athletes used were stronger (124 ± 19kg 1RM BP) compared with the present group of athletes (90.9 ± 16.7kg 1RM BP), however when relative strength is considered, both groups possessed similar levels of strength (1.22kg/bm vs. 1.17kg/bm). Based on the results, the athletes used in the present investigation possessed similar force- and velocity-generating capabilities as other elite athletes.

Optimal Angle for Force Production

Four positions were used to assess the angle at which PF was produced. Similar to the current findings, Murphy and colleagues (59) found a significant difference between IBP PF at 90° and 120° of elbow flexion ($p \leq 0.01$). The effect of joint angle on isometric force development was further investigated in a follow up study conducted by the same group of researchers (57) with similar differences ($p \leq 0.01$) found for PF at both 90° and 120°.

As expected, PF was achieved at either 120° or 150° for all athletes. As previously discussed, this may be a result of their more mechanically advantageous force-producing position compared to the smaller angles. Although it is unclear why PF was achieved at different joint angles, it may be due to differences in arm length, pennation angles of the musculature involved, the neural mechanism of motor unit recruitment or to the training history of the athlete. Interestingly, there was no statistical difference between the 2 larger angles (p = 0.08), suggesting that as the joint angle increases the difference in performance measures decreases. As a result, both angles could be used to assess PF and therefore in the context of the present study, the highest reported value of PF was considered as IBP PF regardless of joint angle.

In a practical sense, if practitioners wish to assess the maximal force producing capabilities of upper body pressing strength then both 120° and 150° of elbow flexion could be used. However, if practitioners wish to determine the relationship between dynamic and isometric PF production then smaller angles (60° – 90°) may be better suited (59, 63).

Reliability Assessment Study – Isometric Bench Press

Establishing the reliability of performance measures when assessing elite athletes is extremely important to sport scientists and strength and conditioning practitioners as it allows them to distinguish between a training induced change and a change solely based on chance or error. Previous research has shown the IBP to be reliable when assessing PF at 90° and 120° (59), however, this is the first study that has investigated the relative and absolute reliabilities of the force-producing capabilities in the IBP across 4 different angles (60°, 90°, 120° and 150°) of elbow flexion.

The results of this study showed that measures of IBP PF across all angles possessed high degrees of relative reliability (ICC ≥ 0.89) with the larger angles (120° and 150°) being more reliable (ICC ≥ 0.94). From a practical perspective, tests with low TE and %CV scores are also important as it allows for greater sensitivity to training induced changes. To the author's knowledge, this is the first study that has reported both the TE and %CV across 4 different angles of elbow flexion in the IBP with %CV values all considered to be extremely reliable (< 5%).

In attempting to directly compare the findings of other reliability studies, there are factors that vary between them. Such factors include measurement method, type of equipment, number of subjects and number of repetitions performed to name a few. Nonetheless, various studies have shown high levels of reliability. One such study by Murphy and colleagues (59) found similar findings to the present study with comparable measures of PF reliability being reported with ICCs ranging from 0.82 – 0.92.

When investigating the force-time characteristics, it appears that PRFD measures were not as reliable as PF measures. The relative reliability (ICC) for all angles was < 0.80 and only the 120° angle possessed an absolute reliability (%CV) of less than 5%. This is in contrast to the findings of Murphy and colleagues (59) who found high levels of relative reliability at both 90° and 120°. There may be several reasons for this. Firstly, applying force 'as fast and as hard as possible' is a very unique concept to many athletes, particularly those who are predominantly lower body athletes (e.g. field hockey). Even though all athletes underwent a full familiarisation trial, it could be speculated that for the cohort used in this study, further trials would be required if reliable PRFD values are to be obtained (48). Secondly, motivation appeared to have a significant impact on PRFD measures.

Athletes were required to produce as much force, as quickly as possible, and if they were not mentally prepared, then PRFD values would be negatively affected. Although the same encouragement was provided to all athletes, it may have had more of an impact on PF rather than PRFD. Interestingly, the majority of athletes performed a single trial (of the 6 performed over the 2 days) at every angle that significantly exceeded all other PRFD values. If the average across both days was used in the statistical analysis or if that trial was discarded then both the relative and absolute reliabilities would likely increase.

Reliability Assessment Study – Ballistic Bench Throw

Surprisingly, this is the first study that has thoroughly investigated the reliability of performance measures in a BBT. Several measures assessed in the BBT such as peak force, peak velocity, peak power and peak displacement possessed high levels of relative and absolute consistency while PRFD possessed only adequate levels of absolute reliability. One of the few studies on BBT reliability was recently conducted by Allemany and colleagues (1). When investigating a 30 repetition BBT, they found measures of peak power and peak velocity to possess a high level of relative reliability (ICC > 0.9) while peak velocity was the only measure considered to be reliable in absolute terms (%CV < 5). One such reason for the low absolute reliability may lie with the fact that 30 repetitions were performed which would have had a negative impact on peak power production (14). Unfortunately, peak force values were not presented in the study.

In a recent study by Clark and colleagues (20), the relative reliability of peak force and peak displacement was reported as 0.83 and 0.95, respectively. Although both values are greater than the accepted ranges, the opposite was found in the current investigation with peak force possessing a higher reliability (0.92) compared to peak displacement (0.85). The discrepancy between the studies may lie with the type of load used. For example, an absolute load of 60kg was used in Clark and colleagues' (20) study while relative loads were used in the present investigation. The 45% 1RM load is equivalent to 41kg in absolute terms, which is significantly less than the 60kg load. Similar results were found when investigating the absolute reliability with peak displacement and peak force possessing a TE of 1.3cm and 183N. This suggests that as the load increases, peak displacement is a more reliable measure compared to peak force.

Reliability Assessment Study – Dynamic Strength Deficit Ratio

It has been shown that the measures associated with the DSD ratio are highly reliable. However, if the ratio is to be used as a tool to guide training interventions then it is important to ensure that the ratio is also highly reliable.

Acceptable levels of relative (ICC = 0.93) and absolute (%CV = 3.5) reliability were found in the current investigation. Although this is the first study to assess the reliability of the DSD ratio in upper body strength qualities, similar values have been reported for lower body strength qualities (69). Interestingly, the TE found in the previous study was significantly lower than the current measure. It is unclear why this is the case, however it may be due to the type of dynamic movement (concentric only bodyweight jump squat) being more reliable compared to the reliability of a countermovement BBT.

In conclusion, a number of measures investigated in this study have the appropriate levels of relative reliability to allow for applications such as identifying specific physical qualities of relative deficiency. Additionally, several other measures possess the required levels of absolute reliability to confidently accept that training induced changes are a result of the training intervention and not due to chance. As a result, it appears that the measures associated with the DSD ratio, and the ratio itself, possess high levels of absolute and relative reliability. As such, the DSD can be used to identify areas of relative deficiency as well as detecting training induced changes.

5.3 Study #2

Relationship between BP performance and Training Intervention

While the addition of ballistic exercises to maximal strength training has proven to improve BP performance compared to maximal strength training alone (51), this is the first study that has investigated the separate impacts of maximal and ballistic strength training on BP performance.

As expected the BP Group significantly ($p \leq 0.001$) improved both absolute (6.0 ± 2.7kg) and relative (0.07 ± 0.04kg/bm) BP performance; while more surprisingly, the BBT Group also significantly ($p \leq 0.001$) improved absolute (1.3 ± 2.5kg) and relative (0.01 ± 0.03kg/bm) BP performance. There may be several reasons for this. First, it is possible that the load used for the BBTs was great enough to elicit a strength adaptation in the weaker athletes and offered a sufficient stimulus in the stronger athletes. Furthermore, the training interventions could have targeted separate areas of the force-velocity curve that lead to the improvements in BP performance. For example, if an athlete can produce large amounts of force at a slow velocity then the window of opportunity to improve neuromuscular adaptations may lie at the other end of the force-velocity curve with higher velocity, lower force training (i.e. ballistic strength training). Nevertheless, it appears that performing moderate load BBTs over a 5 week period does not decrease maximal strength, however performing high intensity BP will lead to a greater increase in BP performance.

Relationship between Change in BBT PF and Training Intervention

Similarly, both groups significantly ($p \leq 0.001$) improved absolute and relative BBT PF, with no significant difference between groups. Changes in BBT PF have previously been reported among weak athletes training at different velocities (24) however this is the first study to investigate changes in PF after maximal or ballistic strength training in elite athletes. Although not specifically measured in this study, one might assume that the increase in PF in the BBT Group was a result of the improved acceleration qualities developed, whereas the BP Group benefitted from an increase force production. Nonetheless, it appears that BBT PF can be positively affected by manipulating the force or acceleration qualities by performing either high intensity BP or moderate intensity BBTs.

Relationship between Changes in Peak Velocity, Peak Power, Peak Displacement and Training Intervention

Further investigations in to the BBT showed no differences were found for changes in peak velocity and peak power in both groups. Peak displacement was the only performance measure to increase in both groups. Somewhat similar findings have also been presented when examining maximal lower body strength training and ballistic training in untrained men (22). The researchers found significant ($p \leq 0.05$) improvements in peak force, peak velocity, peak power and peak displacement during a bodyweight jump squat after 5 weeks of training. Although the study consisted of untrained subjects performing lower body training, the mechanisms behind these adaptations would be similar when related to the upper body. Examining the force-velocity relationship in more detail provides a more in depth understanding of the mechanism mediating these changes. Their results indicated changes to the jump squat force-velocity relationship were specific to the type of training (22). Maximal strength training resulted in a decrease in the gradient of the force-velocity relationship as subjects were able to generate more force and power at a specified velocity of movement while subjects undertaking ballistic training experienced an increase in the gradient of the force-velocity curve (22). Similar to a recent study by Mangine and colleagues (51) no increases in peak power were found when recreationally trained men performed either maximal strength training or a combination of ballistic and heavy strength training. The reason for this may lie with the loads used in the BBT Group. They may have been too high to elicit any velocity or power specific adaptations. Although Baker and co-workers (9) found maximal mean power to occur within 55% 1RM BP, the relative loads used in the present study might have also caused a greater decrease in velocity compared with the proportional increase in force. One might assume that using lighter loads similar to the findings of Newton and colleagues (62) would have resulted in a greater change in peak velocity and peak power. Nonetheless it appears that improvements in PP, whether through optimal load, high force or high velocity training, may depend on the sport, training age and strength level of the athlete (45).

Relationship between Change in IBP PF and Training Intervention

Remarkably, both groups significantly improved absolute isometric PF (p = 0.035) with no difference between groups. However, from an applied perspective the BP Group was the only group to improve more than the TE, implying a practically worthwhile change.

While similar increases in relative isometric PF have been reported by Cormie and colleagues (22) after 5 weeks of strength training, this is the first study to report increases in absolute isometric PF after moderate intensity ballistic strength training. Similar to the increases in BP performance and BBT PF, perhaps the loads used were high enough to elicit force-related adaptations. Another reason may lie with the increased force production found in BBTs compared to BP, specifically during the end range of the movement. Evidently, larger elbow angles occur during the latter phases of the BBT and resulted in increases in PF production in the IBP PF. Finally, as both groups significantly improved both IBP PF and BP performance, it is apparent that assessing PF in the IBP is a valid test to assess changes in maximal strength in elite athletes.

Relationship between the DSD Ratio and Training Intervention

Both groups significantly ($p \leq 0.001$) increased their respective ratios with no difference between groups. However, there was a strong trend ($p = 0.051$) towards a greater increase in the BBT Group. This can be attributed to the greater change in BBT PF compared to IBP PF, perhaps due to the specificity of the ballistic strength test and training. Similar results have been presented by Sheppard and colleagues (69) when assessing lower body strength qualities. Surprisingly, the average change in the DSD ratio was not greater than the TE measure found in the reliability assessment. However, when using the DSD ratio, it is important to note the relative effect of a change on the PF in the IBP and BBT. An increase in both measures of PF, without a change in the DSD ratio should not be seen as a lack of improvement, as both measures have increased concurrently (69). Of importance is that a decrease or increase in the DSD ratio should not be interpreted as a positive or a negative outcome as the ratio will undoubtedly fluctuate as athletes will progress through the different phases of their training program. As such, a comprehensive approach is required when interpreting the change in the DSD ratio. Nevertheless, it is apparent that the DSD ratio is a valid means of assessing changes in PF after short-term exposure to maximal and ballistic strength training.

Within-group Comparisons

As noted in the Literature Review, there are very few studies examining the use of an assessment ratio and its ability to guide training interventions. More importantly, this is the first study that has used elite athletes in a controlled environment. The present results from the within-group comparisons indicate that the DSD is able to guide more specific training interventions and is a valid means of detecting training induced changes in PF in the IBP and BBT.

To better understand the observed changes to the DSD ratios, a brief outline explaining how the ratio is expected to work is warranted and is presented in the following table.

Table 9: Theoretical expectation when using a DSD ratio

DSD	Diagnosis	Training Intervention
Low	Athlete possesses inadequate levels of maximal strength, IBP PF and BBT PF	Maximal strength training is encouraged
Low	Athlete possesses adequate levels of maximal strength and IBP PF but low levels of BBT PF	Ballistic strength training is encouraged
High	Athlete has the ability to utilise peak force generating capabilities in a dynamic manner	Maximal strength training is encouraged

As maximal strength underpins an athlete's ballistic ability, it is vital that an athlete has the appropriate levels of strength required to successfully compete in their chosen sport. Evidently, the appropriate level of strength differs and it is the responsibility of the strength and conditioning practitioner to determine the required level. Additionally, practitioners should be aware that as athletes improve maximal strength, the rate of progress decreases and any further performance improvements may occur through other forms of training (13). Nevertheless, the potential long-term benefits of improved maximal strength make strength training an essential component of any athlete's training program.

Comparison between High and Low DSD Ratios in the Ballistic Bench Throw Group

From the guidelines developed in Table 8, it would be expected that the Low DSD Group would improve their ballistic force producing capabilities to a greater extent than the High DSD Group. The Low DSD Group already had a well-developed force producing capability (IBP PF = 1690.6 ± 296.4N) yet could not produce force in a dynamic manner (BBT PF = 931.15 ± 140.1N). Clearly the window of opportunity to improve performance would lie with improving the least developed physical quality, which in this case is BBT PF. Supporting this claim, the Low DSD Group experienced an improvement in BBT PF (318.8 ± 67.2N) much greater than the TE measure (61.6N). In addition, the DSD increased in both groups (60%, possible) with large relationships (r = 0.57-0.59) found between starting DSD ratios and the change in the ratio post-training. This suggests that improvements in ballistic force are possible in athletes with both high and low ratios. Further, this demonstrates a window of opportunity to increase BBT PF exists among both groups; however there is a greater scope of improvement among athletes with a low DSD ratio.

Comparison between High and Low DSD Ratios in the Bench Press Group

According to the established guidelines developed in Table 8, it would be expected that the High DSD Group would improve their maximal force producing capabilities in the IBP compared to the Low DSD Group. This is because athletes with a high DSD ratio would already possess the ability to produce an adequate level of force in a ballistic manner and therefore the window of opportunity to improve performance would be to increase maximal strength. This was reinforced with the High DSD

Group experiencing an improvement greater in IBP PF than the TE measure (55.1N). Further, very large relationships (*r* = 0.70) were found between starting DSD ratios and the change in the ratio post-training. Interestingly, it appears that maximal strength training positively affects PF production in the BBT (90% likely chance) with both groups improving PF values greater than the TE measure (61.6N). Finally, both groups experienced an increase in DSD ratios (68%, possible) suggesting that maximal strength training can positively affect an athlete's force producing capabilities; however there is a greater scope of improvement among athletes with a high DSD ratio (*r* = 0.8).

Correlations between High and Low DSD Ratios and Change in Performance Variables

When investigating the effects of starting DSD ratios and the change in performance variables, there are several remarkable findings that further support the validity of using the DSD ratio as a training diagnostic tool. First, as mentioned above, the window of opportunity for the Low DSD Groups lie in improving the ballistic force capabilities (provided the required level of maximal is achieved). Large relationships (*r* = 0.59) were found in the Low DSD BBT Group compared with the Low DSD BP Group (*r* = 0.29). This suggests that ballistic strength training in athletes with a low DSD ratio had a greater impact on the DSD ratio compared to those involved with maximal strength training. Furthermore, larger associations (*r* = 0.8) were found in the High DSD BP Group compared to the High DSD BBT Group (*r* = 0.57), suggesting that athletes with a high DSD had the potential to improve performance through maximal strength training.

Conclusion

The findings support the hypothesis that the DSD ratio is a valid means of detecting training induced changes and is able to guide more specific training interventions. In light of this, a combined approach is required when using a DSD ratio. Adequate levels of maximal strength need to be addressed before further ballistic training is implemented. Further, a change in the DSD ratio not greater than the TE does not imply a negative outcome as both dynamic and isometric measures of force can increase simultaneously. From a practical perspective, the following table can be used to improve areas of specific weakness identified using the DSD ratio.

Table 10: Proposed normative guidelines for the DSD ratio

DSD Ratio	**Training Intervention**
≥ 0.75	Increasing maximal strength is recommended
< 0.75	Provided adequate levels of maximal strength, increasing ballistic strength is recommended

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions of the Research Project

The following conclusions were made based on the results of this research project:

1. Measures of PF across 4 angles in the IBP are reliable.
2. PF is produced at either 120° or 150° of elbow flexion in the IBP, as a result either can be used in the assessment protocol to alleviate time constraints. However due to the potential technical limitations of testing at 150° the author suggests testing at 120°.
3. Measures of peak force, peak velocity, peak power and peak displacement are reliable in a 45% 1RM BBT.
4. The DSD ratio can effectively guide training and detect changes induced by training over a 5 week period.
5. Insight in to training interventions can be gained by using the DSD ratio.

6.2 Recommendations for Future Research

This study involved an investigation into a new test of assessing upper body pressing strength and guiding subsequent training interventions. With the exception of several past studies investigating the reliability of the IBP, this study was the first to quantify both absolute and relative reliabilities in the IBP across 4 different angles. Additionally, this is the first study to compare BBT PF to IBP PF and utilise this ratio to help guide training. The new method introduced in this study is reliable and valid for use in assessing upper body pressing strength in elite male athletes. It is recommended that further investigation focus on involving a broader range of loads used in the BBT. Moreover, the present study included only measures of PF as opposed to other possible performance variables. It is the responsibility of the practitioners to determine the potential benefits of using other variables.

Although Sheppard and colleagues (69) have briefly investigated the use of a lower body DSD, a thorough investigation into its use is warranted. Further, guidelines could be implemented specific to the training phase or age of the athlete. For example, during the general preparation phase, the strength and conditioning practitioner may place more emphasis on developing maximal strength and as a result the DSD would decrease as the aim would be increase maximal force production. However, during the specific preparation phase, the emphasis might shift towards more ballistic and power orientated exercises causing an upward shift in the DSD. By adopting this approach, it would allow for greater specificity of training for the athlete. If normative guidelines were created using a larger cohort from a specific sport, practitioners would be able to assess an athlete's DSD with the norms of similar athletes relative to their sport and playing level and then provide the appropriate training dependent on the strengths and weaknesses of each athlete.

Finally, correlations between DSD ratios and performance could also be explored. A more thorough predictive validity assessment is necessary. This investigation could explore the DSD values of a particular athlete that excels at a certain physical skill that is beneficial to performance. As mentioned previously, normative guidelines could be created using this elite athlete's DSD. For instance, if an athlete wishes to improve throwing velocity, in addition to practicing the skill itself, the athlete may need to improve the specific areas of weakness such as maximum strength or ballistic strength.

6.3 Implications for Testing

This study has highlighted several practical issues when testing isometric and isoinertial upper strength, including:

1. Athletes need to be extremely familiar with the testing protocols in the IBP. If PRFD values are important, then it is recommended that 2 or more familiarisation sessions be implemented and that the athletes are aware of the impact that motivation plays. If PRFD values are not important, and the practitioner wishes to only assess PF then he/she may wish to instruct the athletes to develop force in a gradual and steady manner. Anecdotally, the majority of athletes experienced extreme discomfort when performing the IBP 'as fast and as hard as possible' and therefore, to ensure compliance, the assessment of PRFD in the IBP should be kept to a minimum.
2. Statistically there is no difference between the PF generated at 120° and 150° and as a result, both angles could be used to assess upper body force-producing capabilities. If the 150° test is used, then caution must be exercised to ensure that athletes do not protract shoulders during the assessment as this would impact results, and potentially destabilize the shoulder area and thereby raise injury concerns.
3. The DSD ratio is influenced solely by PF values from the two assessments and further, only one load was used in the BBT. While it is acknowledged this a potential limitation, practitioners must consider what variables they consider important with their athletes and / or sport.

REFERENCES

1. Alemany, J.A., et al., Reliability assessment of ballistic jump squats and bench throws. **Journal of Strength and Conditioning Research**. 19(1): 33-38. 2005.

2. Appleby, B., R.U. Newton, and P. Cormie, Changes in strength over a 2-year period in professional rugby union players. **Journal of Strength and Conditioning Research**. 26(9): 2538-2546. 2012.

3. Baker, D., Acute effect of alternating heavy and light resistances on power output during upper-body complex power training. **Journal of Strength and Conditioning Research**. 17(3): 493-497. 2003.

4. Baker, D., Comparison of maximum upper body strength and power between profressional and college-aged rugby league football players. **Journal of Strength and Conditioning Research**. 15(1): 30-35. 2001.

5. Baker, D., Differences in strength and power among junior-high, senior-high, college-aged, and elite professional rugby league players. **Journal of Strength and Conditioning Research**. 16(4): 581-585. 2002.

6. Baker, D., The effects of an in-season of concurrent training on the maintenance of maximal strength and power in professional and college-aged rugby league football players. **Journal of Strength and Conditioning Research**. 15(2): 172-177. 2001.

7. Baker, D., A series of studies on the training of high-intensity muscle power in rugby league football players. **Journal of Strength and Conditioning Research**. 15(2): 198-209. 2001.

8. Baker, D. and S. Nance, The relation between strength and power in professional rugby league players. **Journal of Strength and Conditioning Research**. 13(3): 224-229. 1999.

9. Baker, D., S. Nance, and M. Moore, The load that maximizes the average mechanical power output during explosive bench press throws in highly trained athletes. **Journal of Strength and Conditioning Research**. 15(1): 20-24. 2001.

10. Baker, D. and R.U. Newton, Methods to increase the effectiveness of maximal power training for the upper body. **Strength and Conditioning Journal**. 27(6): 24-32. 2005.

11. Baker, D., G. Wilson, and B. Carlyon, Generality versus specificity, a comparison of dynamic and isometric measures of strength and speed strength. **European Journal of Applied Physiology**. 68(4): 350-355. 1994.

12. Baker, D.G., Ability and validity of three different methods of assessing upper-body strength-endurance to distinguish playing rank in professional

rugby league players. **Journal of Strength and Conditioning Research**. 23(5): 1578-1582. 2009.

13. Baker, D.G. and R.U. Newton, Adaptations in upper-body maximal strength and power output resulting from long-term resistance training in experienced strength-power athletes. **Journal of Strength and Conditioning Research**. 20(3): 541-546. 2006.

14. Baker, D.G. and R.U. Newton, Change in power output across a high-repitition set of bench throws and jump squats in highly trained athletes. **Journal of Strength and Conditioning Research**. 21(4): 1007-1011. 2007.

15. Baker, D.G. and R.U. Newton, Discriminative analyses of various upper body tests in professional rugby-league players. **International Journal of Sports Physiology and Performance**. 1(4): 347-360. 2006.

16. Batterham, A.M. and W.G. Hopkins, Making meaningful inferences about magnitudes. **International Journal of Sports Physiology and Performance**. 1(1): 50-57. 2006.

17. Bemben, M.G., J.L. Clasey, and B.H. Massey, The effect of the rate of muscle contraction on the force-time curve parameters of male and female subjects. **Research Quarterly for Exercise and Sport**. 61(1): 96-99. 1990.

18. Bevan, H.R., et al., Optimal loading for the development of peak power output in professional rugby players. **Journal of Strength and Conditioning Research**. 24(1): 43-47. 2010.

19. Clark, R.A., A.L. Bryant, and B. Humphries, A comparison of force curve profiles between the bench press and ballistic bench throws. **Journal of Strength and Conditioning Research**. 22(6): 1755-1759. 2008.

20. Clark, R.A., A.L. Bryant, and Y.-H. Pua, Examining different aspects of functional performance using a variety of bench throw techniques. **Journal of Strength and Conditioning Research**. 24(10): 2755-2761. 2010.

21. Cohen, J. **Statistical Power Analysis for the Behavioral Sciences**. Hillsdale, N.J: L. Erlbaum Associates, 1988.

22. Cormie, P., M.R. McGuigan, and R.U. Newton, Adaptations in athletic performance after ballistic power versus strength training. **Medicine and Science in Sports and Exercise**. 42(8): 1582-1598. 2010.

23. Cormie, P., M.R. McGuigan, and R.U. Newton, Developing maximal neuromuscular power: Part 2 - Training considerations for improving maximal power production. **Sports Medicine**. 41(2): 125-146. 2011.

24. Cronin, J., P.J. McNair, and R.N. Marshall, Velocity specificity, combination training and sport specific tasks. **Journal of Science and Medicine in Sport**. 4(2): 168-178. 2001.

25. Cronin, J. and G. Sleivert, Challenges in understanding the influence of maximal power training on improving athletic performance. **Sports Medicine**. 35(3): 213-234. 2005.

26. Cronin, J.B., P.J. McNair, and R.N. Marshall, Force-velocity analysis of strength-training techniques and load: Implications for training strategy and research. **Journal of Strength and Conditioning Research**. 17(1): 148-155. 2003.

27. dos Remedios, K.A., et al., Physiological and field test performance changes of community college football players over a season. **Journal of Strength and Conditioning Research**. 9(4): 211-215. 1995.

28. Drinkwater, E.J., et al., Training leading to repetition failure enhances bench press strength gains in elite junior athletes. **Journal of Strength and Conditioning Research**. 19(2): 382-388. 2005.

29. Dugan, E.L., et al., Determining the optimal load for jump squats. **Journal of Strength and Conditioning Research**. 18(3): 668-674. 2004.

30. Dupler, T.L., et al., Anthropometric and performance differences among high-school football players. **Journal of Strength and Conditioning Research**. 24(8): 1975-1982. 2010.

31. Enoka, R., Muscle strength and its development: New perspective. **Sports Medicine**. 6(3): 146-168. 1988.

32. Esformes, J.I., et al., Effect of different types of conditioning contraction on upper body postactivation potentiation. **Journal of Strength and Conditioning Research**. 25(1): 143-148. 2011.

33. Faul, F., et al., Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. **Behavior Research Methods**. 41(4): 1149-1160. 2009.

34. Fry, A.C. and W.J. Kraemer, Physical performance characteristics of American football players. **Journal of Strength and Conditioning Research**. 5(3): 126-138. 1991.

35. Gollnick, P.D. and W.M. Bayley. **Biochemical Training Adaptations and Maximal Power**. Champaign, IL: Human Kinetics, 1987.

36. Haff, G.G., et al., Force–time curve characteristics of dynamic and isometric muscle actions of elite women olympic weightlifters. **Journal of Strength and Conditioning Research**. 19(4): 741-748. 2005.

37. Haff, G.G., et al., Force-time dependent characteristics of dynamic and isometric muscle actions. **Journal of Strength and Conditioning Research**. 11(4): 269-272. 1997.

38. Hermassi, S., et al., Effects of 8-week in-season upper and lower limb heavy resistance training on the peak power, throwing velocity, and sprint

performance of elite male handball players. **Journal of Strength and Conditioning Research**. 25(9): 2424-2433. 2011.

39. Hopkins, W.G., Measures of reliability in sports medicine and science. **Sports Medicine**. 30(1): 1-15. 2000.

40. Hopkins, W.G., Spreadsheet for analysis of controlled trials with adjustment for a subject characteristic. **Sportscience**. 10: 46-50. 2006.

41. Hopkins, W.G., et al., Progressive statistics for studies in sports medicine and exercise science. **Medicine and Science in Sports and Exercise**. 41(1): 3-12. 2009.

42. Hrysomallis, C. and D. Buttifant, Influence of training years on upper-body strength and power changes during the competitive season for professional Australian rules football players. **Journal of Science and Medicine in Sport**. 15(4): 374-378. 2012.

43. Izquierdo, M., et al., Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. **European Journal of Applied Physiology**. 87(3): 264-271. 2002.

44. Jandacka, D. and J. Uchytil, Optimal load maximizes the mean mechanical power output during upper extremity exercise in highly trained soccer players. **Journal of Strength and Conditioning Research**. 25(10): 2764-2772. 2011.

45. Kawamori, N. and G.G. Haff, The optimal training load for the development of muscular power. **Journal of Strength and Conditioning Research**. 18(3): 675-684. 2004.

46. Kawamori, N., et al., Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. **Journal of Strength and Conditioning Research**. 20(3): 483-491. 2006.

47. Khamoui, A.V., et al., Relationship between force-time and velocity-time characteristics of dynamic and isometric muscle actions. **Journal of Strength and Conditioning Research**. 25(1): 198-204. 2011.

48. Kilduff, L.P., et al., Effects of creatine on isometric bench-press performance in resistance-trained humans. **Medicine and Science in Sports and Exercise**. 34(7): 1176-1183. 2002.

49. Komi, P.V. **Strength and Power in Sport**. Oxford: Blackwell Science, 2003.

50. Kraska, J.M., et al., Relationship between strength characteristics and unweighted and weighted vertical jump height. **International Journal of Sports Physiology and Performance**. 4(4): 461-473. 2009.

51. Mangine, G.T., et al., The effects of combined ballistic and heavy resistance training on maximal lower- and upper-body strength in recreationally trained

men. **Journal of Strength and Conditioning Research**. 22(1): 132-139. 2008.

52. McBride, J.M., et al., The effect of heavy- Vs. light-load jump squats on the development of strength, power and speed. **Journal of Strength and Conditioning Research**. 16(1): 75-82. 2002.

53. McGuigan, M.R., M.J. Newton, and J.B. Winchester, Use of isometric testing in soccer players. **Journal of Australian Strength and Conditioning**. 16: 11-14. 2008.

54. McGuigan, M.R., et al., Relationship between isometric and dynamic strength in recreationally trained men. **Journal of Strength and Conditioning Research**. 24(9): 2570-2573. 2010.

55. McGuigan, M.R. and J.B. Winchester, The relationship between isometric and dynamic strength in college football players. **Journal of Sports Science and Medicine**. 7(1): 101-105. 2008.

56. McGuigan, M.R., J.B. Winchester, and T. Erickson, The importance of isometric maximum strength in college wrestlers. **Journal of Sports Science and Medicine**. 108-113. 2006.

57. Murphy, A.J. and G.J. Wilson, Poor correlations between isometric tests and dynamic performance: relationship to muscle activation. **European Journal of Applied Physiology**. 73: 353-357. 1996.

58. Murphy, A.J., G.J. Wilson, and J.F. Pryor, Use of the iso-inertial force mass relationship in the prediction of dynamic human performance. **European Journal of Applied Physiology and Occupational Physiology**. 69(3): 250-257. 1994.

59. Murphy, A.J., et al., Isometric assessment of muscular function: The effect of joint angle. **Journal of Applied Biomechanics**. 11(2): 205-215. 1995.

60. Newton, R.U. and E. Dugan, Application of strength diagnosis. **Strength and Conditioning Journal**. 24(5): 50-59. 2002.

61. Newton, R.U. and W.J. Kraemer, Developing explosive muscular power: Implications for a mixed methods training strategy. **Strength and Conditioning Journal**. 16(5): 20-31. 1994.

62. Newton, R.U., et al., Kinematics, kinetics and muscle activation during explosive upper body movements. **Journal of Applied Biomechanics**. 12: 31-43. 1996.

63. Newton, R.U., et al., Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive upper-body movements. **European Journal of Applied Physiology and Occupational Physiology**. 75(4): 333-342. 1997.

64. Nuzzo, J.L., et al., Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. **Journal of Strength and Conditioning Research**. 22(3): 699-707. 2008.

65. Pryor, J.F., G.J. Wilson, and A.J. Murphy, The effectiveness of eccentric, concentric and isometric rate of force development tests. **Journal of Human Movement Studies**. 27(4): 153-172. 1994.

66. Requena, B., et al., Functional performance, maximal strength, and power characteristics in isometric and dynamic actions of lower extremities in soccer players. **Journal of Strength and Conditioning Research**. 23(5): 1391-1401. 2009.

67. Schmidtbleicher, D., Structural analysis of motor strength qualities and its application to training. **Science Periodical of Research and Technology in Sport**. 1-7. 1985.

68. Schneider, V., et al., Detraining effects in collge football players during the competitive season. **Journal of Strength and Conditioning Research**. 12(1): 42-45. 1998.

69. Sheppard, J.M., D. Chapman, and K.-L. Taylor, An evaluation of a strength qualities assessment method for the lower body. **Journal of Australian Strength and Conditioning**. 19(2): 4-10. 2011.

70. Sheppard, J.M., et al., Relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players. **Journal of Strength and Conditioning Research**. 22(3): 758-765. 2008.

71. Sheppard, J.M. and K. Young, Using additional eccentric loads to increase concentric performance in the bench throw. **Journal of Strength and Conditioning Research**. 24(10): 2853-2856. 2010.

72. Stone, M.H., Power outputs among explosive athletes, relationships to maximum strength, and strategies for improvement. **Medicine and Science in Sports and Exercise**. 39(Supplement): 60. 2007.

73. Stone, M.H. and H.S. O'Bryant. **Weight Training: A Scientific Approach**. Minneapolis: Burgess International, 1987.

74. Stone, M.H., et al., The importance of isometric maximum strength and peak rate-of-force development in sprint cycling. **Journal of Strength and Conditioning Research**. 18(4): 878-884. 2004.

75. Tanner, R. and C.J. Gore. **Physiological Tests for Elite Athletes**. 2nd ed. Champaign, IL: Human Kinetics, 2012.

76. Thomas, J.R., J.K. Nelson, and S.J. Silverman. **Research Methods in Physical Activity**. Champaign, IL: Human Kinetics, 2011.

77. Tidow, G., Aspects of strength training in athletics. **New Studies in Athletics**. 1: 93-110. 1990.

78. Tillaar, R.v.d., A.H. Saeterbakken, and G. Ettema, Is the occurrence of the sticking region the result of diminishing potentiation in bench press? **Journal of Sports Sciences**. 30(6): 591-599. 2012.

79. Vincent, W.J. **Statistics in Kinesiology**. Champaign, IL: Human Kinetics, 1995.

80. Wilson, G.J. and A.J. Murphy, Strength diagnosis: The use of test data to determine specific strength training. **Journal of Sports Sciences**. 14(2): 167-173. 1996.

81. Wilson, G.J. and A.J. Murphy, The use of isometric tests of muscular function in athletic assessment. **Sports Medicine**. 22(1): 19-37. 1996.

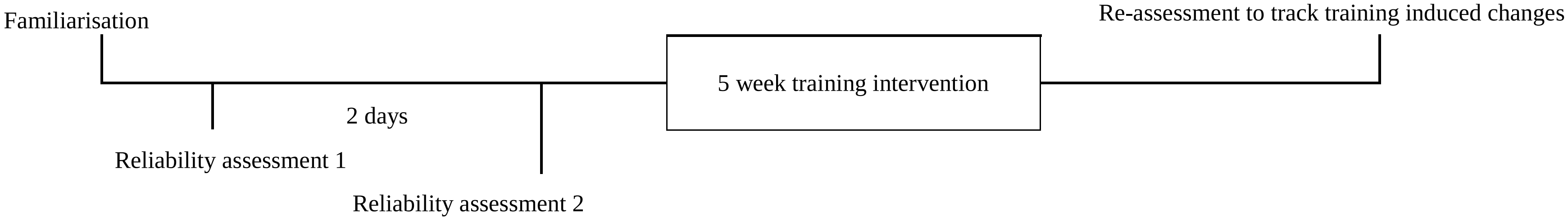
82. Wilson, G.J., A.J. Murphy, and A. Giorgi, Weight and plyometric training: Effects on eccentric and concentric force production. **Canadian Journal of Applied Physiology**. 21(4): 301-315. 1996.

83. Wilson, G.J., et al., The optimal training load for the development of dynamic athletic performance. **Medicine and Science in Sports and Exercise**. 25(11): 1279-1286. 1993.

84. Wilson, G.J., J.F. Pryor, and A.J. Murphy, Musculotendinous stiffness: its relationship to eccentric, isometric, and concentric performance. **Journal of Applied Physiology**. 76(6): 2714-2719. 1994.

85. Young, W., Laboratory strength assessment of athletes. **New Studies in Athletics**. 10(1): 89-96. 1995.

APPENDIX A: SCHEMATIC OF STUDY DESIGN



Week prior to reliability assessment	5 week training intervention study	After 5 week training intervention
Familiarisation: Isometric Bench Press (IBP) Ballistic Bench Throw (BBT) Optimal elbow angle and reliability study **Isometric Bench Press:** Peak Force (PF) Peak Rate of Force Development **Ballistic Bench Throw:** Peak Force / Velocity / Power Peak Displacement Peak Rate of Force Development	If IBP PF and BBT PF are deemed to be highly reliable then the dynamic strength deficit (DSD) ratio can be calculated. DSD: BBT PF / IBP PF Athletes placed in groups dependent on their DSD Training for the BBT Group consisted of 4-5 sets at 40-55%1RM Training for the BP Group consisted of 3-5 sets at 80-90%1RM	Athletes re-assessed in the BP, IBP and BBT to track any training induced changes

APPENDIX B: TRAINING PROGRAMS

Bench Press				
	Sets	Repetitions	%1RM	Volume Load
Week 1	4	4	90	1440
Week 2	4	3	93	1116
Week 3	4	2	95	760
Week 4	3	4	80	960
Week 5	4	1	100	400

Ballistic Bench Throw				
	Sets	Repetitions	%1RM	Volume Load
Week 1	4	5	40	800
Week 2	4	4	45	720
Week 3	5	3	50	750
Week 4	4	3	45	540
Week 5	5	3	55	825

Auxiliary Exercises				
	Sets	Repetitions	%1RM	Volume Load
Week 1	3	10	75	2250
Week 2	3	8	80	1920
Week 3	3	8	80	1920
Week 4	3	6	85	1530
Week 5	3	6	85	1530

APPENDIX C: INFORMED CONSENT FORM

Edith Cowan University

Plain Language Statement and Informed Consent

The Development and Evaluation of a Testing Protocol to Assess Upper Body Pressing Strength Qualities in High Performance Athletes

You are being asked to participate in a study, undertaken as part of the requirements of a Master of Science at Edith Cowan University that will take place at the Queensland Academy of Sport. Kieran Young will be the Chief Investigator for this study. Dr. Jeremy Sheppard will be the Edith Cowan University Faculty supervisor assisting Kieran Young. Your participation in this study is voluntary. You should read the information below, and ask questions about anything you do not understand before deciding whether or not you may participate.

- **PURPOSE OF THE STUDY**

  The purpose of this study is to develop and evaluate a new testing protocol to assess upper body strength. By identifying specific areas of weakness, a more individualized training program can be implemented to improve performance. It will involve a series of tests followed by a training intervention.

- **DURATION AND LOCATION**

  Your participation in this study will last for eight weeks and will occur during your normal strength training at the Queensland Academy of Sport.

- **PROCEDURE**

  If you wish to participate in this study, we would ask you to do the following things:

1. Participate in an isometric bench press assessment over two days of testing.

2. Participate in a ballistic bench throw assessment and a one repetition maximum bench press over one day of testing.

3. Participate in a five week training intervention whereby you will either perform high load bench press or light load ballistic bench throws. After the five weeks you will be retested in the isometric bench press, ballistic bench throw and one repetition maximum bench press.

- **POTENTIAL RISKS AND DISCOMFORTS**

  Risks involved in this study are minimal as you are already familiar with the tests and training involved.

- **ANTICIPATED BENEFITS TO SUBJECTS**

  You will receive no direct benefit from their participation in this study, but your participation may assist in developing more specialized training programs to improve your performance.

- **ALTERNATIVES TO PARTICIPATION**

  You have the right to not participate in this study. You may also choose to withdraw at any time from the study.

- **CONFIDENTIALITY**

  When the results of the research are published or discussed in conferences, no information will be included that would reveal your identity. If photographs of you will be used for educational purposes, your identity will be protected or disguised.

  Your information will be kept confidential and secure on a password protected laptop. All subjects will be identified by a code number. The list of code numbers with the subject names will be kept in a separate lock box in a different location. This information will be stored for five years and then destroyed.

- **PARTICIPATION AND WITHDRAWAL**

  Participation in this research is voluntary. If you do not wish to participate, that will not affect your relationship with Edith Cowan University or with the Queensland Academy of Sport.

- **WITHDRAWAL OF PARTICIPATION BY THE INVESTIGATOR**

  The investigator may withdraw you from participating in this research if circumstances arise which warrant doing so. The investigator will make the decision and let you know if it is not possible for you to continue.

- **RIGHTS OF RESEARCH SUBJECTS**

  You may withdraw from the study at any time without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, you may contact:

  Research Ethics Officer
  Edith Cowan University
  270 Joondalup Drive
  JOONDALUP WA 6027
  Phone: 6304 2170
  Fax: 6304 2661
  Email: research.ethics@ecu.edu.au.

- **OFFER TO ANSWER QUESTIONS**

If you have any questions about the research, please feel free to contact:

Kieran Young
Chief Investigator
Faculty of Computing, Health and Science
kieran.young@communities.qld.gov.au
07-3872-0109

Dr. Jeremy Sheppard
Primary Supervisor
Faculty of Computing, Health and Science
jeremy.sheppard@ecu.edu.au
04-3333-4849

❖ **SIGNATURE OF RESEARCH SUBJECT**

I have read the information provided above and I am aware of the risks and benefits associated with the study. I have been given an opportunity to ask questions and all of my questions have been answered to my satisfaction. I have been given a copy of this form.

____
Name of Subject

____
Signature of Subject *Date*

____
Address

SIGNATURE OF INVESTIGATOR

____
Signature of Investigator *Date*

APPENDIX D: STATISTICAL ANALYSES

Within-Subjects Factors

Measure:MEASURE_1

group	time	Dependent Variable
1	1	mass1group1
	2	mass2group1
2	1	mass1group2
	2	mass2group2

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source		time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
group	Linear		26.255	1	26.255	.103	.754	.009	.103	.060
Error(group)	Linear		2791.392	11	253.763					
time		Linear	3.685	1	3.685	4.391	.060	.285	4.391	.481
Error(time)		Linear	9.232	11	.839					
group * time	Linear	Linear	.092	1	.092	.075	.790	.007	.075	.057
Error(group*time)	Linear	Linear	13.526	11	1.230					

a. Computed using alpha = .05

Within-Subjects Factors

Measure:MEASURE_1

Group	time	Dependent Variable
1	1	BPAbs1group1
	2	BPAbs2group1
2	1	BPAbs1group2
	2	BPAbs2group2

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source		time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
group	Linear		15.755	1	15.755	.072	.794	.006	.072	.057
Error(group)	Linear		2413.932	11	219.448					
time		Linear	159.505	1	159.505	53.685	.000	.830	53.685	1.000
Error(time)		Linear	32.682	11	2.971					
group * time	Linear	Linear	68.880	1	68.880	18.015	.001	.621	18.015	.971
Error(group*time)	Linear	Linear	42.057	11	3.823					

a. Computed using alpha = .05

Within-Subjects Factors

Measure:MEASURE_1

Group	time	Dependent Variable
1	1	BPRel1group1
	2	BPRel2group1
2	1	BPRel1group2
	2	BPRel2group2

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source		time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Group	Linear		.007	1	.007	.178	.681	.016	.178	.067
Error(group)	Linear		.448	11	.041					
Time		Linear	.017	1	.017	37.044	.000	.771	37.044	1.000
Error(time)		Linear	.005	11	.000					
group * time	Linear	Linear	.009	1	.009	22.253	.001	.669	22.253	.990
Error(group*time)	Linear	Linear	.005	11	.000					

a. Computed using alpha = .05

Within-Subjects Factors

Measure:MEASURE_1

Group	time	Dependent Variable
1	1	BBTPF1group1
	2	BBTPF2group1
2	1	BBTPF1group2
	2	BBTPF2group2

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source		time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
group	Linear		227218.880	1	227218.880	3.454	.090	.239	3.454	.396
Error(group)	Linear		723685.612	11	65789.601					
time		Linear	757443.377	1	757443.377	123.541	.000	.918	123.541	1.000
Error(time)		Linear	67442.266	11	6131.115					
group * time	Linear	Linear	30155.200	1	30155.200	2.066	.178	.158	2.066	.260
Error(group*time)	Linear	Linear	160578.402	11	14598.037					

a. Computed using alpha = .05

Within-Subjects Factors

Measure:MEASURE_1

group	time	Dependent Variable
1	1	BBTPFRel1group1
	2	BBTPFRel2group1
2	1	BBTPFRel1group2
	2	BBTPFRel2group2

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source		time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
group	Linear		15.732	1	15.732	.895	.364	.075	.895	.139
Error(group)	Linear		193.356	11	17.578					
time		Linear	126.101	1	126.101	191.254	.000	.946	191.254	1.000
Error(time)		Linear	7.253	11	.659					
group * time	Linear	Linear	4.332	1	4.332	1.559	.238	.124	1.559	.208
Error(group*time)	Linear	Linear	30.567	11	2.779					

a. Computed using alpha = .05

Within-Subjects Factors

Measure:MEASURE_1

group	time	Dependent Variable
1	1	BBTPV1group1
	2	BBTPV2group1
2	1	BBTPV1group2
	2	BBTPV2group2

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source		time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
group	Linear		.000	1	.000	.017	.899	.002	.017	.052
Error(group)	Linear		.194	11	.018					
time		Linear	.012	1	.012	2.359	.153	.177	2.359	.289
Error(time)		Linear	.056	11	.005					
group * time	Linear	Linear	.001	1	.001	.602	.454	.052	.602	.109
Error(group*time)	Linear	Linear	.018	11	.002					

a. Computed using alpha = .05

Within-Subjects Factors

Measure:MEASURE_1

group	time	Dependent Variable
1	1	BBTPD1group1
	2	BBTPD2group1
2	1	BBTPD1group2
	2	BBTPD2group2

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source		time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
group	Linear		.333	1	.333	.013	.912	.001	.013	.051
Error(group)	Linear		288.892	11	26.263					
time		Linear	17.763	1	17.763	7.518	.019	.406	7.518	.705
Error(time)		Linear	25.992	11	2.363					
group * time	Linear	Linear	1.401	1	1.401	.201	.662	.018	.201	.070
Error(group*time)	Linear	Linear	76.514	11	6.956					

a. Computed using alpha = .05

Within-Subjects Factors

Measure:MEASURE_1

group	time	Dependent Variable
1	1	BBTPP1group1
	2	BBTPP2group1
2	1	BBTPP1group2
	2	BBTPP2group2

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source		time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
group	Linear		13.653	1	13.653	.000	.991	.000	.000	.050
Error(group)	Linear		1236659.772	11	112423.616					
time		Linear	152731.203	1	152731.203	4.356	.061	.284	4.356	.478
Error(time)		Linear	385724.302	11	35065.846					
group * time	Linear	Linear	71.053	1	71.053	.004	.953	.000	.004	.050
Error(group*time)	Linear	Linear	210655.712	11	19150.519					

a. Computed using alpha = .05

Within-Subjects Factors

Measure:MEASURE_1

group	time	Dependent Variable
1	1	IBPPF1group1
	2	IIBPPF2group1
2	1	IBPPF1group2
	2	IBPPF2group2

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source		time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
group	Linear		69875.541	1	69875.541	.718	.415	.061	.718	.121
Error(group)	Linear		1070705.549	11	97336.868					
time		Linear	24246.030	1	24246.030	5.775	.035	.344	5.775	.591
Error(time)		Linear	46184.750	11	4198.614					
group * time	Linear	Linear	4454.453	1	4454.453	1.004	.338	.084	1.004	.150
Error(group*time)	Linear	Linear	48808.317	11	4437.120					

a. Computed using alpha = .05

Within-Subjects Factors

Measure:MEASURE_1

group	time	Dependent Variable
1	1	IBPPFRel1group1
	2	IBPPFRel2group1
2	1	IBPPFRel1group2
	2	IBPPFRel2group2

Tests of Within-Subjects Contrasts

Measure:MEASURE_1

Source		time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
group	Linear		2.901	1	2.901	.121	.735	.011	.121	.062
Error(group)	Linear		264.064	11	24.006					
time		Linear	2.341	1	2.341	2.684	.130	.196	2.684	.322
Error(time)		Linear	9.594	11	.872					
group * time	Linear	Linear	.241	1	.241	.325	.580	.029	.325	.082
Error(group*time)	Linear	Linear	8.154	11	.741					

a. Computed using alpha = .05

Within-Subjects Factors

group	time	Dependent Variable
1	1	DSD1group1
	2	DSD2group1
2	1	DSD1group2
	2	DSD2group2

Tests of Within-Subjects Contrasts

Measure:DSD

Source		time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
group	Linear		.042	1	.042	3.338	.095	.233	3.338	.385
Error(group)	Linear		.138	11	.013					
time		Linear	.213	1	.213	56.797	.000	.838	56.797	1.000
Error(time)		Linear	.041	11	.004					
group * time	Linear	Linear	.024	1	.024	4.777	.051	.303	4.777	.514
Error(group*time)	Linear	Linear	.056	11	.005					

a. Computed using alpha = .05