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Measuring Impulse-DSI and its Derivatives Via the Isometric Belt Squat: Assessing Relationships with Sprint Ability Among Division I Team Sport Athletes

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Chapter 1: Introduction

Background Information

Force-plate data collection is becoming increasingly diverse within the practice of strength and conditioning/sports performance training. For strength and conditioning professionals, deciding which of the many metrics and tests one could track to inform the training focus over time is also becoming increasingly difficult. With limited time and assistance, coaches may struggle to balance the amount of actionable data they can attain without distracting from the overall training goal and training environment. Therefore, choosing efficient test batteries that provide as much usable information as possible is important. In this regard, impulse as a test metric has received significant interest over instantaneous metrics, such as peak force because it is more context-specific to the explosive sporting environment.

A common athlete profiling technique that utilizes peak force is the dynamic strength index (DSI). The traditional DSI is a standard performance metric that is defined as the ratio between the peak concentric force generated during a countermovement jump (CMJp) and the peak force generated during an isometric mid-thigh pull (IMTPp). This ratio outputs a number between 0 and 1. Athletes with a DSI score greater than or equal to .80 are recommended to focus on training for maximal strength. Conversely, athletes with scores less than or equal to .60 are recommended to focus on training ballistic strength/speed. Athletes between .60 and .80 may train with a more balanced approach, depending on preference or the time of the year (Sheppard et al., 2011; Suchomel, Sole, Bellon, & Stone, 2020).

A novel impulse-based dynamic strength index metric (iDSI) has been proposed within the last three years (Haischer et al., 2021). iDSI is the ratio of the concentric impulse generated during the countermovement jump (CMJ) and the isometric impulse generated during the isometric mid-thigh pull (IMTP). Two different iDSI calculation methods have been suggested and validated. First, the IMTP impulse may be calculated by equating the concentric contraction time of the athlete's CMJ, generally between 100-400ms. Alternatively, a pre-determined and standardized time may be chosen to calculate the impulse for the CMJ and IMTP. (James & Comfort, 2022). Utilization of the isometric belt squat (IBSq) over other isometric tests has also been recently proposed as it may better reflect the true force capacity of the lower body (Layer et al., 2018). The purpose of the current paper is to strive to validate the IBSq-derived iDSI, its derivatives, and assess potential relationships with the different phases of 40m sprint performance.

There are various ways coaches may contextualize physical performance data by utilizing different test batteries. Merrigan et al. (2022) reduced countermovement jump performance among Division 1 collegiate football players to four principal component metrics. These included reactive strength modified (RSImod), eccentric peak velocity, braking duration, and jump height. However, the researchers concluded it is still up to the coach's discretion to decide which of these metrics are modifiable over time, relevant to their sport, or directly related to specific sports performance activities. Merrigan et al. (2021) described a physical assessment protocol in tactical populations that utilized 4 different force plate tests, 9 associated force-time variables, their z-scores, and the relationships between them to assign training recommendations. The authors concluded that supportive, confounding metrics must also be considered alongside primary performance metrics when making training decisions. For example, changes in countermovement velocity and depth in a CMJ will contextualize changes in metrics like jump height, concentric power, eccentric RFD, etc. While contextualization is important for accurately describing neuromuscular status, it was unclear if any of these metrics are directly related to the key performance tasks in tactical populations.

Alternatively, impulse has been a target of further investigation for its implications as a monitoring tool for sports performance and may provide more actionable information per test conducted compared to other common metrics. The unit for impulse is Newton-seconds and can be described as the area underneath the curve of a force by time graph. When an athlete performs any sporting movement, the total impulse applied to the ground or other object determines the subsequent motion. For example, during each step of a sprint from acceleration to maximal velocity, the foot contacts the ground for ~40 to 200 milliseconds (Colyer et al., 2018). The athlete's velocity change during each of these steps will be determined by how much force they can apply over this epoch (their impulse). As an athlete increases their running velocity, experienced sprinters can spike their peak ground reaction forces sooner and their force-time curves of each step resemble sharp ridges at the beginning of each ground contact. Less experienced sprinters exhibit longer times to peak force and a more bell-shaped force-time curve (Clark & Weyand, 2014). As contact times decrease during each step of a sprint, it becomes increasingly important that time to peak force is diminished. This may explain why evidence suggests that impulse and RFD metrics at 100-300ms in the IMTP/ISqT have greater relationships with longer sprint performances (20+ meters) compared to maximal strength metrics which are not constrained by time (Lum et al., 2020). Conversely, an athlete could also increase the impulse of any sporting movement by increasing the time over which they apply their force. For example, in a countermovement jump, an athlete could utilize a larger displacement during the countermovement to increase the time available to apply force. Sporting actions are often time-constrained, and therefore, it is advantageous to increase force application over a similar or lesser epoch.

The traditional DSI has been utilized for its apparent diagnostic value and practicality. However, previous research regarding its determinants, peak force in the CMJ and IMTP, has called into question its diagnostic power. For example, it has been demonstrated that peak force in the IMTP is not associated with any dynamic jumping, change of direction, or sprint performance variables (Wang et al., 2016). CMJp has small to moderate associations with jump height and moderate associations with sprint velocity between 5m and 20m (Morris, Weber, & Netto, 2022). Conversely, the peak rate of force development (PRFD) during the IMTP has been associated with pro-agility and 5-10m sprint times. CMJ height (a result of concentric impulse) has been more strongly associated with CMJ peak power, RSImod, and 20m sprint speed than CMJp (Wang et al., 2016; Suchomel, Sole, Bellon, & Stone, 2020; Morris, Weber, & Netto, 2022). A final critique of the traditional DSI is that the IMTP may not be a true test of an athlete's maximal strength because of the potential muscular inhibition involved when trying to evoke a maximal lower-body muscle contraction in the presence of significant upper-body and spinal loading components (Layer et al., 2018).

Gaps in Research and Scholarship

Limited research on iDSI suggests that it has a moderate correlation with DSI, although each measure has distinct physical qualities (Haischer et al., 2021; James & Comfort, 2022). When comparing DSI and iDSI values, previous research indicates that approximately 40% of athletes may be miscategorized based on the .60-.80 recommendations. Specifically, when using DSI, athletes may be prescribed general maximal strength work when they would be better served learning how to apply maximal strength within a smaller time window. Comparing the traditional DSI and iDSI may further contextualize physical traits (Haischer et al., 2021; James & Comfort, 2022).

Different protocols and setups have been used to measure lower body isometric strength. For example, the isometric barbell back squat (ISqT), isometric leg press, trap bar IMTP, barbell IMTP, and IBSq have been proposed (Layer et al., 2018). The setup and technical execution involved with performing an IMTP (strapping the hands, upper body involvement, joint slack, muscular inhibition, and anchoring mechanism) poses both practical obstacles and questions of reliability/validity. The IBSq may be a more valid test of explosive and maximal lower body isometric strength (2.67 n/BW ISqT vs. 3.15 n/BW IBSq) because it significantly decreases the upper body involvement from the test and requires relatively little technical skill, spinal load, and trunk muscle activity, which otherwise may prevent an athlete from exerting maximal effort through the lower body (Joseph et al., 20; Layer et al., 2018). The IBSq is performed by placing the force plates on top of a steel anchor plate, which is attached to the athlete via a chain and belt around the hips. When the athlete is cued to push, relatively little joint movement or slack needs to be taken out of the system, which is hypothetically ideal for an explosive isometric test. This contrasts with a traditional IMTP, in which the hands, shoulders, spine, and anchor system may all contribute inherent slack before maximal force production can be achieved.

It is important to consider that a favorable change in DSI or iDSI over time does not necessarily mean that an athlete improved from a practical standpoint. For example, an athlete with a low DSI or iDSI may have increased it by getting weaker in the isometric test with no change in jump performance. Therefore, assessing differences among the individual determinants when comparing athletes with similar DSI scores is important for contextualization (James, &

Comfort, 2022). Furthermore, the diagnostic power of a DSI test would be enhanced if the test derivatives were also related to sporting activities like sprinting. These activities can be termed key performance indicators (KPI) and should be related to success in sports. Research is currently conflicting regarding the relationship between IMTP/ISqT and CMJ impulse metrics and sprint performance. There is currently no published research that has utilized the IBSq for the collection of these metrics.

Currently, evidence suggests that iDSI is a reliable metric with moderate correlations (r = .64 when using propulsive time, r = .37 when using 150ms impulse) with the traditional DSI when using the IMTP. (James & Comfort, 2022). It is unclear if DSI, iDSI, and its derivatives are also reliable when utilizing the IBSq. It is unclear how DSI and iDSI derivatives are related to different phases of sprint performance.

Problem Statement

The current problem identified was that the efficient collection of physical performance data requires that the various test metrics are useful in predicting performance or inferring training foci. It was unclear whether there is a relationship between iDSI derivatives and any relevant KPIs associated with sports performance. It was also unknown how DSI and iDSI scores compare when utilizing the IBSq.

Hypothesis

The current study hypothesized that the iDSI derivatives (CMJ relative concentric impulse and IBSq relative impulse) would be reliable (%CV<10 and ICC >.8). CMJ relative concentric impulse and IBSq relative impulse would be linearly correlated with 0-10m, 10-30m, and 30-40m sprint times. CMJ relative peak force and IBSq relative peak force would be linearly correlated with 0-10m but not 10-30m or 30-40m sprint times. DSI and iDSI scores will be moderately correlated (r = .4-.6).

Definitions

Dynamic Strength Index **(**DSI) is the ratio between the peak force in a CMJ (newtons) and peak force in an IMTP (newtons) and is generally a number between 0 and 1.

Impulse Dynamic Strength Index (iDSI) is the ratio between CMJ concentric impulse (newtons) and IMTP impulse (newtons) measured during an equated contraction time.

Isometric Mid-Thigh Pull (IMTP) is a measurement of lower body isometric strength which is performed with a barbell placed at the position of the 2nd pull during an Olympic clean. The athlete produces maximal force against an immovable bar for 3-5 seconds.

Isometric Squat (ISqT) is a measurement of lower body isometric strength which is performed with a barbell placed across the shoulders, typical for a back squat. Knees and hips are placed at the position of the 2nd pull during an Olympic clean. The athlete produces maximal force against an immovable bar for 3-5 seconds.

Isometric Belt Squat Relative Peak Force (IBSqp) is the maximum force relative to body weight that an athlete can exert against an immovable belt across the hips, and consequently, the maximum force exerted against the force plate.

Isometric Belt Squat Relative Impulse (IBSqimp) is the maximal 200ms impulse relative to body weight that an athlete can exert against an immovable belt across the hips, and consequently, the maximum 200ms impulse exerted against the force plate.

Counter Movement Jump Relative Peak Force (CMJp) is the maximum force relative to body weight that an athlete exerts against the force plate at the onset of the concentric phase of a countermovement jump.

Counter Movement Jump Relative Impulse (CMJimp) is the 200ms impulse relative to body weight that an athlete can exert against the force plate at the onset of the concentric phase of a countermovement jump.

Assumptions and Limitations

Male and female athletes of different sports with moderate to high sprinting demands were included in the study. The sample size was n= 43, based on an a priori analysis for multiple regression with predictor correlations ranging from r = .4-.74 based on previous research and α = .05, β = .95 (Brady et al., 2020; Scanlan et al., 2020). A familiarization period was provided, and it was assumed that each athlete was equally proficient with the three testing procedures. Data collection was conducted near the start of the athlete's competitive season to account for the effect that the in-season period can have on force-velocity characteristics of sprint performance (Jiménez-Reyes et al., 2022).

The current study was cross-sectional, and therefore, cause and effect cannot be established. For female athletes, the phase of the menstrual cycle was not controlled, and therefore, it cannot be asserted that this did not affect the performance results. Weight room training volume was held similarly across groups in the four weeks leading up to data collection. However, practice demands and practice schedules were not controlled. Despite the readiness assessment via the force-plate metrics, it cannot be asserted that practice demands did not affect the study results.

Significance of Study

To the researcher's knowledge, this was the first study to utilize the IBSq in the measurement of DSI, iDSI, and their derivative metrics. This was also the first study to assess the relationship between IBSq-derived peak force and impulse with split times in the 40m sprint. The current study contributes to the knowledge body by clarifying the current metrics' descriptive and predictive ability.

Chapter 2: Literature Review

Introduction

The traditional DSI and its derivatives have demonstrated limited associations with fundamental sports actions such as sprinting and jumping (Čoh & Mackala, 2013; Thomas et al., 2017; Wang et al., 2016). This has been attributed to the utilization of instantaneous forces (peak force) in the IMTP and CMJ, which may lack relevance to the force-time demands of common sports actions. The iDSI is an alternative assessment that measures impulse over an equated epoch in the CMJ and IMTP (Haischer et al., 2021; James & Comfort, 2022). The traditional DSI is an assessment comparing a subject's un-constrained maximum voluntary peak force production and their time-constrained dynamic peak force production. Alternatively, iDSI is an assessment comparing a subject's time-constrained force production under a zero-velocity demand (isometric) and their time-constrained force production under a high-velocity demand (concentric jump phase).

Limited evidence is conflicting for the relationship between isometric impulse and sprint ability, with some indicating better associations with acceleration performance than isometric peak force and some indicating no association (Scanlan et al., 2020; Thomas et al., 2015). Inconsistent findings may be explained by evidence that the IMTP does not accurately measure the maximal force-producing capabilities of the lower body (Brady et al., 2018; Layer et al., 2018). Alternatively, the IBSq may allow for the expression of over 30% greater maximal voluntary force relative to the IMTP (Layer et al., 2018). However, research has yet to investigate an impulse-related IBSq assessment or its potential relationship with sprint performance.

The scope of the current review has been limited to published research in English within the last 10 years. Only investigations into athletic populations have been included. Establishing reliability for the current metrics is important because the utility of these tests lies in their ability to track worthwhile changes in physical qualities over time. Intra-session reliability for measuring isometric impulse in the IMTP is slightly less than for measuring peak force, coefficient of variation (%CV) = 8.5 and 7.1 for impulse and peak force, respectively (Merrigan et al., 2020). For reasons that will be discussed in future sections, a squat pattern has demonstrated greater intra-session reliability for isometric impulse than an IMTP (%CV = 6.7 and 9.4 for ISqT and IMTP, respectively) (Brady et al., 2018). Intra-session reliability for CMJ impulse has been reported as good (%CV = 3.5) (James & Comfort, 2022).

Qualitative movement differences have been observed in subjects with similar DSI scores and different relative peak force values, suggesting the need to contextualize DSI scores to optimize exercise prescription. The rationale for using impulse as a contextualizing metric will be discussed in the following sections (Comfort et al., 2018; Suchomel et al., 2020; Thomas et al., 2017). The potential relationships between these force-plate metrics and relevant KPIs such as sprinting are important because they help to rank the relative importance of trainable physical qualities. Furthermore, visualization of relationships may help coaches determine to what extent these physical qualities should be trained to achieve a specific outcome. For sprint performance, there is agreement that the IMTP and ISqT peak force is correlated with 5m sprint performance ($r = .62$ and $.71$ for IMTP and ISqT, respectively). Impulse at 100-300ms in the IMTP has been correlated with 5m sprint performance ($r = .40 - .58$). (Brady et al., 2020; Scanlan et al., 2020). CMJ concentric impulse and jump height (a result of impulse) have been demonstrated to be better discriminators of elite and sub-elite sprinters than CMJ peak force (Čoh & Mackala, 2013).

Issues identified with the reliability of iDSI metrics and their associations with other performance variables have been attributed to the uncomfortable nature of producing maximal explosive force through the spine. Furthermore, utilizing an impulse epoch greater than 150ms and up to 300ms may improve the reliability of iDSI testing. Removing the spine/upper body component from the isometric test may enhance validity (James & Comfort, 2022; Joseph et al., 2020; Layer et al., 2018). These concepts will be discussed further to support the rationale for utilizing the IBSq for the first time in the current study for the calculation of iDSI.

Physiology of Isometric and Dynamic Muscle Force

Isometric and dynamic muscle contractions differ in aspects of neurological control and utilization of intrinsic muscle properties. For example, maximal voluntary motor unit recruitment may be maximized during isometric vs. dynamic contractions (Babault et al., 2001). Furthermore, at the sarcomere level, cross-bridge dynamics can help to explain the force-velocity relationship of muscle contraction (Seow & Seow, 2022). Understanding this force-velocity relationship can help to elucidate why assessments such as the IMTP and CMJ are complementary to each other.

When utilizing isometric and dynamic muscle contraction assessments, one should consider the effect that contraction intent has on both the assessment outcome and potential training-induced adaptations. Oranchuk et al. (2019) performed a systematic review of isometric training-induced adaptations on various body systems. A relevant finding was that the ability to produce isometric force measured in the 0-150ms range was an independent quality relative to the isometric force capacity at maximum voluntary contraction. Furthermore, only ballistic training with an intent to produce force as fast as possible improved this metric. Similarly, slowly ramped contractions held for longer durations showed greater improvements in the force measured at maximum voluntary contraction. These findings were supported by increased EMG amplitude during the specific time frames. Increased neural drive at specific time frames and joint angles is one of the many components within the principle of training specificity.

Muscle activation patterns are different between isometric, eccentric, and concentric contractions. Babault et al. (2001) explained that when compared to electrically evoked contractions of the same type, voluntary contraction levels during concentric and eccentric actions were reduced. This suggests that inhibitory neural mechanisms are preventing maximal force production. Potential sources of inhibitory signals could be from various mechanoreceptors within the muscle and joint, which may be less active during an isometric contraction. Skeletal muscle can produce about 40% more force eccentrically compared to isometrically. However, greater EMG amplitude during submaximal eccentric or concentric contractions is a product of lesser efficiency, and therefore, a greater neural drive is required to produce the same relative force. Intrinsic properties of the sarcomere can help to explain differences in efficiency and force-velocity potential.

Fenwick et al. (2017) showed that the efficiency of muscle force production decreases as shortening velocity increases. The fraction of bound myosin heads to actin filaments increases when contractions are slow or isometric. Conversely, ATPase activity increases with faster cross-bridge cycling and the percentage of cross-bridges formed decreases with increasing shortening velocity. Cross-bridge stiffness also contributes to changes in the force-velocity relationship. A stiffer cross-bridge produces more force per contraction. However, this stiffness also leads to fewer cross-bridges formed as contraction velocity increases. Furthermore, a stiffer cross-bridge may not tolerate as much deformation before detaching, limiting shortening velocity. Similarly, Seow and Seow (2022) showed that fast muscles have greater cross-bridge detachment rates which are proportional to shortening velocity. Cross-bridges may also adapt to detach at a lower velocity threshold, increasing efficiency and decreasing the occurrence of negatively strained bridges against the direction of contraction. Practically, this means that there are distinct trade-offs in performance when optimizing for slow/isometric and fast dynamic contractions. Therefore, while there may be an overlap in the physical qualities tested during explosive or maximal isometric and dynamic strength, each assesses a distinct intrinsic quality of muscle contraction.

Khamoui et al. (2011) examined the relationship between isometric and dynamic force-time variables among recreationally trained lifters in the isometric mid-thigh pull, clean pull, and vertical jump. An interesting finding of this study is that maximal isometric strength was negatively correlated (r = -.6) with peak velocity in the clean pull using a 30% load. While other studies refute this finding, muscle sarcomere characteristics like the ones described by Seow and Seow (2022) could explain how having a high maximal strength ability could interfere with the ability of the muscle to achieve high shortening velocities. When looking at the force-time and time-velocity graphs comparing the IMTP and CMJ presented by Khamoui et al. (2011), one can see the effect that velocity has on force and impulse generation. At the onset of contraction during an IMTP, force increases quickly to a plateau and maximum force can generally be achieved within 1 second. Conversely, during the CMJ, force is greatest at the onset of the concentric phase and decreases rapidly as velocity increases. The time over which force is applied during the CMJ depends on individual differences; however, this generally occurs within half a second. The total force applied to the ground during the concentric phase is the concentric impulse and is a direct determinant of jump height.

Based on the studies presented, one can theorize about the overlapping or unique physiological qualities assessed during different physical performance tests. For example, an explosive isometric test like the IMTP may assess the early motor unit recruitment and maximal impulse-generating ability of a muscle in the absence of known force-limiting factors such as velocity and the inhibitory signals involved with joint motion (Babault et al., 2001; Fenwick et al., 2017; Seow & Seow, 2022). Conversely, a CMJ may assess the impulse-generating capacity of a muscle when factors like high velocity and joint motion are present. Both tests likely assess feed-forward neurological aspects of explosive muscle contraction, which explains why isometric and dynamic tests have been correlated with each other (Fenwick et al., 2017; Khamoui et al., 2011; Seow & Seow, 2022).

The spring-mass model of sprinting can help to explain how characteristics of muscle force production contribute to enhanced sprinting performance. The behavior of a traditional spring will depend on its stiffness. Stiffness can be described as the amount of vertical force required to compress a spring over a certain displacement. A stiffer spring is one in which more force is stored per unit of compression (Brughelli & Cronin, 2008). Extrapolate this to a human model, the entire leg could be thought of as a spring during sprinting gait. The joints of the leg will undergo a certain amount of flexion at mid-stance which will determine the amount of vertical displacement of the center of mass. A stiffer leg will cause less vertical displacement per amount of force applied to the ground. Less vertical displacement will contribute to shorter ground contact times. Decreasing ground contact times with equal or greater force application is the primary contributor to enhanced maximal sprint velocity (Brughelli & Cronin, 2008).

During all phases of the sprint, isometric muscle actions are important for performance. As discussed previously, the force-velocity relationship explains that force production decreases as the velocity of movement increases. One can imagine that if sprinting at high speeds required predominantly concentric muscle actions, force production would be greatly compromised. Luckily, the human body utilizes the spring-like properties of the muscle-tendon unit to optimize force production while sprinting. Not only do isometric contractions allow for greater force production than concentric contractions (Fenwick et al., 2017), but they also allow the tendon to store and release elastic energy. Tendon stiffness during maximal isometric contraction has been significantly correlated with maximal sprint speed ($r = .52$) (Rogers et al., 2017). The ability of the muscles of the leg to rapidly generate isometric force, combined with the mechanical properties of the tendons they attach to, contributes to global stiffness and enhanced sprint speed (Holt et al., 2014).

In contrast to the maximal velocity phase of sprinting, the acceleration phase is characterized as having greater hip and knee displacements as well as a greater reliance on concentric muscle actions. However, shorter ground contact times in the acceleration phase also distinguish between slower and faster accelerators. These shorter ground contact times in acceleration are achieved by a reduced time to peak force and consequently, greater impulse. (Lockie et al., 2011). Ground contact times in a sprint range from roughly 200 ms to less than 100 ms (Colyer et al., 2018). This contact time range can be considered a fast stretch-shortening cycle (SSC) action (Flanagan, 2009). Fast SSC muscle actions are described as being less than 250 ms of ground contact. When ground contact is limited to this range, both elastic return from tendons and reflexive force potentiation are maximized (Flanagan, 2009). It is important to note that sprinting involves quasi-isometrics, meaning that there are brief periods of eccentric and concentric actions taking place. However, from a practical standpoint, these are still considered isometric (Flanagan, 2009). Furthermore, it has been demonstrated that concentric actions during sprinting close to max velocity are a result of passive recoil from the explosive eccentric-isometric phase. This recoil improves the mechanical efficiency of running by effectively bypassing the downsides related to force production at high concentric velocities (Holt et al., 2014). Taken together, the current studies suggest that explosive isometric and concentric impulse production of the leg musculature are important for the utilization of the spring-like properties of the muscle-tendon unit to decrease contact times and enhance sprint speed.

Measuring Isometric and Dynamic Lower Body Force Production

Previous research has detailed the differences in motor unit recruitment and force production between dynamic eccentric/concentric and isometric contractions. Specifically, maximal voluntary isometric contractions demonstrate greater motor unit recruitment than both eccentric or concentric contractions and comparable force production compared to eccentric contractions (Piitulainen et al., 2013). This has been attributed to reduced neural inhibition and reduced need for fine neuromuscular control during isometric contractions. Isometrics, therefore, have advantages for the assessment of maximal voluntary strength and various tests have been developed including the IMTP, ISqT, and IBSq. Identifying reliable force-time metrics between isometric and dynamic contraction types has utility for identifying relative strengths and weaknesses in physical preparedness.

The IMTP and ISqT are currently the two most popular methods of assessing lower body isometric strength today. Brady et al. (2018) compared the reliability of different maximal strength and force-time metrics derived from the IMTP and ISqT. Both male and female athletes with an average age of 23 years from a variety of different sports were included in the study. Hip and knee angles associated with the second pull position in Olympic Weightlifting (130-140 degrees) were standardized by a goniometer for both the IMTP and ISqT. A familiarization session utilizing the same warm-up and testing protocol was performed 1 week before testing. During the testing session, subjects were randomized to either IMTP or ISqT as their first test. %CV and intraclass correlation coefficient (ICC) were equal for peak force in the IMTP and ISqT. 0-300ms impulse met sufficient reliability (%CV = 9.4-6.7, ICC = .92-.96) for both IMTP and ISqT. 0-200ms impulse was reliable only for ISqT (%CV =9.9, ICC = .92). Subjects were able to produce 16% more force on average during the ISqT. Layer et al. (2018) examined the differences in lower extremity kinetics during the ISqT and IBSq. The study included men and women aged 18-31 who actively engaged in resistance and sports training. Peak force, ankle moments, and knee moments were significantly greater, and low back moments were significantly smaller when comparing ISqT and IBSq. Subjects produced about 20% more force during the IBSq compared to the ISqT.

Joseph et al. (2020) compared muscle EMG among two subjects during barbell back squats and belt squats. The muscles sampled were the erector spinae, rectus abdominis, external obliques, gluteus maximus, gluteus medius, quadriceps, and biceps femoris. A weakness of the current study was that subjects performed repetitions with loads relative to body mass as opposed to relative to maximal strength. Furthermore, all reps performed were submaximal and it is not clear how EMG would change during a maximal contraction. It was found that for submaximal reps, gluteus maximus muscle activity and all trunk muscle activity were significantly lower during belt squats. This was attributed to the fact that the hip moment arm is greater for back squats compared to belt squats.

While there is much evidence for the standardization of IMTP and ISqT knee joint angles, standard joint angles for the IBSq are lacking. Treece & Nordin (2023) performed IBSq tests among 24 female and 9 male college students. Tests were categorized by knee joint angles of 80-100 degrees, 100-120 degrees, 120-140 degrees, 140-160 degrees, and 160-180 degrees. Each condition was performed by each participant in a randomized order. Peak ground reaction forces were significantly greater in the 120-140 degree and 140-160 degree conditions. There was a non-significant favor for the 120-140 degree condition compared to the 120-140 degree condition. Since only one trial was performed at each condition, test reliability could not be established.

Merrigan et al. (2020) investigated the intrasession reliability of CMJ and IMTP force-time variables. Male and female athletes from Division 1 NCAA sports were included in the study. CMJs were performed while holding a dowel across the shoulders. IMTPs were performed by placing the knee angle at 130-140 degrees and the hip angle at 145 degrees with the bar set to half the distance between the greater trochanter and lateral epicondyle. No familiarization sessions were included in this study. CMJ peak force %CV and ICC were 2.9 and .98, respectively. CMJ concentric impulse %CV and ICC were 1.6 and .98, respectively. IMTP peak force %CV and ICC were 7.1 and .94, respectively. IMTP impulse at 100ms was deemed unreliable (ICC < .8) and %CV and ICC for impulse at 200ms were 8.5 and .87, respectively.

Taken together, the current studies suggest that familiarization with the isometric testing protocol and utilization of a squat-type test over a pull-type test is important when the metrics being collected are time-dependent. For example, Brady et al. (2018) demonstrated reliability for the rate of force development (RFD) during the IMTP, but Merrigan et al. (2020) did not. The primary methodological difference between these two studies was familiarization with the protocol. Furthermore, Brady et al. (2018) found greater reliability for impulse measures during the ISqT than IMTP (%CV = 6.7 vs. 9.4 and ICC = .96 vs. .92). There was no difference in reliability for peak force measures between ISqT and IMTP. IMTP peak force reliability was also greater in Brady et al. (2018) compared to Merrigan et al. (2020) (%CV = 4.6 vs. 7.1 and ICC = .97 vs. .94). Lastly, Layer et al. (2018) and (Joseph et al., 2020) help to explain why peak force, impulse, and reliability seem to be more significant for the ISqT while also explaining the implications of a novel IBSq test. Squatting or “pushing” assessments impose greater loading on the musculoskeletal system compared to an IMTP due to greater ankle and knee moments with reduced low back moments, placing the subject in a more vertical position. This is demonstrated even further with the IBSq, reducing low back moments, and increasing knee/ankle moments. Treece & Nordin (2023) demonstrated that the IMTP recommendation of 130-140 degrees for the knee joint angle is likely sufficient. However, it may not be necessary to restrict knee joint angles within 10 degrees. Furthermore, an athlete may find a more comfortable pulling position outside this range due to differences in anthropometrics and chain-link segment length. Therefore, a range of 120-140 degrees is recommended. Subjects in Brady et al. (2018) were 16% stronger in the ISqT than the IMTP, and subjects in Layer et al. (2018) were 20% stronger in the IBSq than the ISqT. One may speculate about the validity of the IMTP in accurately measuring maximal force-producing capabilities of the lower extremity. This may affect the diagnostic utility of ratios such as the DSI, which aims to compare maximal and dynamic capabilities.

The Dynamic Strength Index

Previous research has studied the traditional DSI as a monitoring tool for training-induced changes in physical performance, a differentiating tool between athletes of different sports, and a prescription tool for assigning training foci to athletes of seemingly different strengths/weaknesses. The limitations of utilizing the traditional DSI for these ends will be discussed.

Useful metrics for strength and conditioning coaches should be reliably modifiable with training. Sheppard et al. (2011) evaluated the reliability and ability to detect training-induced changes in the DSI. 18 male and female athletes with an average age of 26 years were included in the study. A familiarization period was included in the testing protocol and reliability testing occurred 48 hours apart. Longitudinal case studies took place over 8-10 weeks to assess training-induced changes. %CV and ICC for the DSI ratio were 2.94 and .95, respectively. It was found that all 4 of 5 athletes included in the case study analysis increased their IMTP peak force and changed their DSI score above the standard error associated with both measures. No athlete made statistically significant changes in jump concentric peak force despite participating in relevant ballistic training activities.

Thomas et al. (2015) applied a similar methodology to Sheppard et al. (2011) among 19 collegiate athletes. Uniquely, they found that the smallest worthwhile change (SWC) for IMTP peak force lies within its %CV (SWC = 3.1, %CV = 3.8) and cannot detect the SWC. The SWC for the DSI score was found to be 5.1%, which is outside the %CV (4.6%). The authors noted that reliability during the IMTP may have been altered due to unfamiliarity with maximal isometric effort and limitations of the back, shoulder, and forearm strength. A limitation of this study was that there was no standardization of the technique, and subjects chose a self-selected knee and hip angle during IMTPs. Finally, DSI scores were proposed to be collected to establish normative data for athletic groups and not to infer an athlete’s performance level.

Thomas et al. (2017) continued their research by assessing DSI values among 115 team sport athletes. Testing procedures were like all previous research, except with a familiarization period. The authors found statistically significant differences in IMTP peak force, CMJ peak force, and DSI between teams. The authors primarily attributed these differences to the demands of their respective sports. However, significant differences were largely found only between sports of different sexes. For example, the only same-sex sports team comparison yielding significant differences was between male soccer and basketball players for IMTP peak force and female netball and soccer players for CMJ peak force. No same-sex comparisons yielded significant differences for DSI. A limitation of this research is the lack of control for playing position and biological maturity when assessing sport-specific differences in DSI.

McMahon et al. (2017) aimed to address the contextual limitations of the DSI by assessing the relationship between the DSI score and qualitative variables of the CMJ. For example, it is noted that CMJ peak force is influenced by the jump strategy utilized. 53 male collegiate athletes from soccer and ruby participated in a single testing session. Interestingly, the authors chose to utilize flight time to calculate jump height instead of impulse-momentum, which is considered the gold standard. When ranking athletes into high DSI (.92 average) and low DSI (.55 average) groups, the low DSI group demonstrated significantly greater eccentric power, displacement, velocity, and impulse during the braking phase of the CMJ, which led to greater displacement, velocity, and impulse during the concentric phase. Low DSI subjects will inherently produce smaller CMJ peak forces due to a longer muscle length and center of mass at the onset of propulsion and will compensate by producing a more significant impulse over a larger distance. The protocol for prescribing training foci based on DSI score to achieve a specific performance outcome is called into question. Specifically, prescribing ballistic training to low DSI subjects and observing an increase in CMJ peak force may be due to decreases in CMJ displacement, with or without improvements in jump performance. Similarly, prescribing strength training to high DSI subjects may unintentionally enhance CMJ peak force due to greater utilization of the braking phase. Prescribing training based on the DSI score may achieve predictable improvements in CMJ and IMTP peak force, however, these changes may not occur for the specific reasons that were originally proposed.

Comfort et al. (2018) evaluated the effects of a four-week resistance training program on DSI scores of 24 male and female collegiate athletes. The exercise program included power cleans, push presses, back squats, mid-thigh pulls, and RDL performed twice per week. Subjects were categorized as high and low DSI at the beginning of the training period. Expectedly, DSI decreased in the high DSI group in response to increased IMTP peak force. CMJ peak force did not change after training in either group despite the ballistic nature of some of the resistance training exercises. Jump height increased in the high DSI group due to an increase in CMJ displacement and therefore, impulse. A seemingly overlooked component of the current study is that CMJ peak force values pre- and post-training were not different between the high and low DSI groups, despite significantly different IMTP peak force values between groups. A combination of strength and power training did not significantly alter CMJ peak force in either group, despite changes in jump performance or jump strategy. This study further questions CMJ peak force as a worthwhile variable to monitor in training.

Sheppard et al. (2011) noted that a lack of change in concentric peak force did not necessarily reflect a lack of change in jumping performance or impulse. Unfortunately, these other jump metrics were not reported. Strength training is associated with increases in isometric strength and decreases in DSI scores. However, it is unclear how or if ballistic training significantly affects concentric peak force, therefore, calling into question the diagnostic utility of peak force as a useful jump metric. This notion is corroborated by the more recent investigations of McMahon et al. (2017) and Comfort et al. (2018), who demonstrated that lowering the DSI causes qualitative differences in jump strategy, which may or may not affect CMJ peak force as an unintended consequence. There seems to be uncertainty about the prescription of training based on DSI due to the relative importance of different DSI values among various sports (Thomas et al., 2017).

The Relationship Between the IMTP, CMJ, and Sprint Ability

Evidence is not conflicting that there is a relationship between maximal lower body strength and sprint ability, especially concerning the acceleration phase of a sprint. During the acceleration phase, the foot applies force to the ground for a relatively longer duration per step compared to the maximum velocity phase (Colyer et al., 2018). Furthermore, relatively larger horizontal impulses must be applied to the ground to overcome the inertia of the body in acceleration. In this regard, it makes sense as to why assessing peak forces would capture a relationship, albeit with hypothetically less precision. As an athlete increases their velocity from acceleration to max velocity and as contact times decrease, it is advantageous to be able to spike peak ground reaction forces as soon as possible during ground contact (Clark & Weyand, 2014). This helps to explain why various IMTP and CMJ metrics correlate differently to different phases of the sprint. The following discussion presents the literature regarding time-independent (peak force) and time-dependent (impulse) force plate metrics and their relationship to sprint ability.

Concentric peak force typically occurs immediately at the onset of the concentric phase of a vertical jump (deepest position during the countermovement). Because of this, the concentric peak force is also highly related to the eccentric jump strategy. The acceleration phase of a sprint can be described as mostly a concentric overcoming effort. Therefore, one may hypothesize that a force-time metric that is highly related to eccentric muscle function would not be highly related to sprint performance. Čoh and Mackala, (2013) assessed the relationship between CMJ force-time variables and elite-level status among 12 highly trained sprinters. Elite and sub-elite sprinters were categorized based on their 60m and 100m sprint times. It was revealed that concentric impulse and jump height were significantly greater in elite sprinters compared to sub-elite sprinters. Concentric peak force was not significantly different between groups. A limitation of the current study is that even though biological age and minimum sprint training experience were controlled, absolute training experience, resistance training experience, body mass, and body height were not controlled. The current study cannot conclude that higher jump heights/impulses are responsible for competitive status.

Morris et al. (2022) evaluated force-time characteristics of the CMJ and their relationship to 40m sprint performance among 14 elite Australian football athletes. CMJ peak force was correlated with 5-10m sprint times, but not 20-40m sprint times ($r = .615$ and $.563$, respectively). Concentric impulse at a designated epoch was not assessed in the current study. However, jump height (a product of impulse) was correlated with 20m sprint times. The identified limitations of the current study are a small sample size, lack of impulse metric reporting, and the utilization of a CMJ with arm swing. The utilization of arm swing during CMJ testing is not standard practice when assessing DSI, making comparisons difficult.

Thomas et al. (2015) assessed the relationship between various IMTP force-time variables and sprint performance among 14 male collegiate athletes. Knee and hip angles were self-selected during the IMTP, in contrast to similar research. Subjects were pulled from soccer and rugby, suggesting moderate familiarity with technical sprinting skills. It was found that IMTP peak force was correlated with 5m and 20m sprint performance ($r = .57$ and $.69$, respectively). IMTP impulse at 100ms was correlated with 5m and 20m sprint performance ($r = .71$ and $.75$, respectively). IMTP impulse at 300ms was correlated with 5m and 20m sprint performance ($r = .74$ and $.78$, respectively). Slightly stronger correlations between impulse and sprint times may be due to greater task specificity between ground contact times during the acceleration phase of sprinting and 100-300ms impulse during the IMTP.

Wang et al. (2016) applied a similar methodology to Thomas et al. (2015) among 15 collegiate rugby players. However, the current study included 11 forwards and 4 backs. Forward position players are traditionally much larger and perform less maximal effort linear sprinting during competition and practice. Furthermore, this limitation is compounded by the fact that the current study utilized net peak force instead of peak force relative to body weight, which is more descriptive of an athlete's relative strength. No correlation was found between IMTP peak force and any sprint times. Peak RFD was associated with 5m sprint time, however, the research discussed previously has questioned its reliability (Merrigan et al., 2020).

Thomas et al. (2017) assessed the relationship between relative IMTP peak force, 5m, and 10m sprint performance among 26 female netball players with an average age of 16 years. The current study also utilized self-selected knee and hip angles for the IMTP, which may be considered a limitation. IMTP peak force had a small significant correlation with 5m sprint performance, but not 10m sprint performance ($r = .49$, $p<.05$). Like the limitations identified in

Wang et al. (2016), limited correlations between the IMTP and sprint performance may have been due to the nature of netball, specifically, limited experience with linear sprinting.

Brady et al. (2020) uniquely compared the ISqT and IMTP force-time variables and their associations with sprint performance among 25 sprinters with at least two years of sprint and resistance training experience. Familiarization sessions were performed one week before testing and hip and knee angles were standardized at about 140 degrees for each test. As discussed in previous sections, peak force and impulse were greater for the ISqT than the IMTP, which agrees with this author's previous work (Brady et al., 2018). It was found that peak force in the ISqT had a greater correlation with 5m sprint performance than peak force in the IMTP (r = .714 vs. .626). Impulse at 200ms was also similarly correlated with 5m sprint performance for the IMTP and ISqT (r = .582 and .517, respectively). Interestingly, the current investigation found significant correlations between IMTP peak force, but not ISqT peak force, and 20m to 30m sprint performance. The greater peak force achieved in the ISqT relative to the IMTP in this study was lower than what has been reported previously by Brady et al. (2018). This lower peak force may explain the lack of correlation between ISqT peak force and longer sprint distances in the current study. While the potential for larger force-time variables in the ISqT exists, note that previous studies have discussed issues related to athletes being uncomfortable with producing maximal explosive force with loads through the spine.

Scanlan et al. (2020) investigated peak force and impulse metrics of the IMTP and their association with sprint performance among 24 male adolescent basketball players. Two familiarization sessions were included in the study before testing and knee and hip angles were standardized to 140 degrees. IMTP relative peak force, but not absolute peak force, was correlated with 5m and 10m sprint time (r = .44 and .45, respectively). IMTP peak force was not correlated with 20m sprint time. Impulse at 100ms, but not 250ms, was correlated with 5m sprint time (r = .40). Fewer and smaller correlations in the current study may be partly explained by the nature of basketball and technical sprint skills.

To the researcher's knowledge, Ojeda et al. (2021) is the only published study that utilized the IBSq within an athletic population and evaluated its relationship with short sprint performance. This study had several limitations including a small sample size (n=7) and the use of 90-degree hip and knee angles instead of the 2nd pull position or "power position." A strength was that the sample was made up of high-level sprinters. P-values were large and statistical significance was not achieved; however, the analysis suggested a small-moderate association between peak force and 5m sprint time.

The relationship between DSI score and relevant KPIs or sprint ability has been given little attention, despite the common recommendation that a score of .6-.8 is "optimal" for sports performance. The lack of evidence may be partly explained by the fact the DSI score is a ratio and does not reflect the absolute force-producing capabilities of an athlete. However, one could hypothesize that when comparing athletes of similar absolute capabilities, the athlete with an optimized DSI score would be better able to apply their strength to a task such as sprinting. To the researcher, Chan (2020) is the only study correlating DSI score to sprint performance. This was done with a small sample (n=14) of professional rugby 7's players. Interestingly, they found a quadratic relationship between the DSI score and 30-40m (max velocity) sprint speed. Sprint speed was maximized among individuals with DSI scores around .7-.75. The proposed explanation for this result is that the DSI score is mostly affected by maximal strength and secondarily by dynamic strength. Therefore, the athletes with high DSI scores have relatively greater levels of explosive reactive strength compared to their maximal strength, and the athletes with low DSI scores have relatively lower levels of explosive reactive strength compared to their maximal strength (Chan, 2020).

Taken together, the presented evidence suggests that there is a general agreement that peak force relative to body weight in the IMTP and ISqT is correlated with 5-10m sprint performance (Brady et al., 2020; Scanlan et al., 2020; Thomas et al., 2015, 2017). Correlations between IMTP variables may be affected by sprint skill, as evidenced by trends among the current studies in which non-sprint dominant sports or positions demonstrated less correlation (Scanlan et al., 2020; Thomas et al., 2017; Wang et al., 2016). Studies are conflicted when comparing impulse and peak force in the IMTP and ISqT as more significant predictors of sprint performance. Differences may be explained by different study populations and practical issues involved in producing explosive force into an immovable object (Brady et al., 2020; Scanlan et al., 2020; Thomas et al., 2015). For CMJ peak force, evidence is less conclusive for a relationship with different sprint distances. Based on the limited availability of research, it may be speculated that with more skilled sprinters or longer sprint distances, impulse-related metrics in the CMJ are more predictive of performance. Conversely, CMJ peak force may be more related to short sprint distances between 5-10m (Čoh & Mackala, 2013; Morris et al., 2022). Based on the state of the current literature, impulse-type isometric and dynamic assessments require further investigation. Still, they show promise due to their task specificity relative to actions such as sprinting.

The Impulse-Based Dynamic Strength Index

As mentioned previously, relative impulse (the area underneath the force curve of the force-time graph) is more suggestive of an object's motion than peak force values. Athletes with similar isometric and dynamic peak force values may exhibit significantly different movement strategies and time-relevant force production. The validity/reliability of iDSI will be discussed and current gaps in knowledge will be elucidated.

Suchomel et al. (2020) aimed to contextualize DSI scores utilizing other strength-power characteristics among 155 Division 1 collegiate athletes. A case study analysis was also used similar to Sheppard et al. (2011) to assess the effectiveness of training recommendations. It was found that IMTP peak force explains about 72% of the variance in DSI and CMJ peak force only explains about 8.8% of the variance. Athletes with similar DSI scores were evaluated based on normative data of CMJ and IMTP performance and other force-time characteristics. It was discovered that athletes with the same DSI differed significantly in the percentile rankings of relevant IMTP and CMJ characteristics as well as qualitative components of the CMJ. Athletes who would be prescribed ballistic training based on their low DSI score were found to demonstrate jump characteristics that would indicate they would still benefit from continuing to improve eccentric and concentric strength characteristics. The authors concluded that attention should be paid to percentile rankings of CMJ and IMTP performance and time-normalized characteristics.

Haischer et al. (2021) were the first to propose a time-normalized DSI metric based on impulse in both the IMTP and CMJ. The authors noted the previously discussed limitations of peak force as a predictor of dynamic performance. They proposed that iDSI reflects a ratio of force that is more relevant to the time domains over which an athlete applies force. 19 female Division 1 lacrosse players were included in the study. Knee and hip angles were standardized according to previous research; however, it is not clear if hand straps were used during the IMTP. Not including hand straps during the explosive pull would be a major limitation of the current study. Both peak and impulse values for both tests were analyzed. %CV and ICC for IMTP impulse were 7.6 and .974, respectively. %CV and ICC for CMJ concentric impulse were 2.2 and .93, respectively. A moderate correlation existed between iDSI and DSI (r = .644) suggesting that iDSI represents at least a partly separate physical quality. Based on previous suggestions, iDSI scores classified 7 of the 19 subjects differently compared to DSI scores. When evaluating subjects based on both their DSI and iDSI values, one can achieve even greater diagnostic value. For example, a subject with a low DSI but high iDSI would benefit more from improving their explosive maximal strength as opposed to general strength. Conversely, a subject with a high DSI but low iDSI may still benefit from ballistic training to better utilize their force-producing potential during high-velocity actions.

James & Comfort (2022) recently investigated the reliability of different methods of calculating iDSI among 23 resistance-trained males. Two familiarization sessions were performed before official testing. Uniquely, the ISqT was utilized over the IMTP, which can be considered a strength of the current study, considering previously discussed limitations of the IMTP. DSI, iDSI at 100ms, iDSI at 150ms, and iDSI normalized to the propulsive phase of the CMJ were calculated. All iDSI metrics showed acceptable CV and ICC values (2.71-7.7 and .8-.97, respectively). Impulse over the longer propulsive epoch, >150ms, was more reliable than in the shorter epochs. Moderate relative reliability was not reached for impulse metrics. Therefore, the current findings suggest that iDSI may only be used to assess within-individual changes over time. Lower relative reliability was again partly attributed to the cautious application of maximal explosive force into an immovable bar across the shoulders.

Haischer et al. (2021) and James & Comfort (2022) are conflicting in their findings of relative reliability for IMTP impulse. A combination of different impulse epochs and utilization of the ISqT vs. IMTP may explain these differences. Currently, limited evidence only agrees that iDSI and its derivatives achieve acceptable absolute reliability for monitoring within-subject change.

Conclusion

When assessing explosive maximal isometric strength, there are apparent pros and cons to the methods utilized which affect their utility in predicting other performance characteristics. Specifically, the IMTP may benefit from greater comfort and relative reliability, while the ISqT may benefit from more accurately assessing maximal force-producing potential, given familiarization with the protocol (Brady et al., 2018, 2020; James & Comfort, 2022). Furthermore, the identified issues with the IMTP and ISqT tests may be ameliorated by substituting the IBSq. The IBSq may further enhance the characteristics that make the ISqT a better test of maximal strength potential while concurrently reducing the low back moments and hesitancy involved in exerting explosive force through the trunk (Layer et al., 2018). Peak forces in the IMTP and CMJ also suffer from apparent strengths and weaknesses. Specifically, both metrics have demonstrated excellent absolute and relative reliability (Merrigan et al., 2020; Thomas et al., 2015, 2017) and have low to moderate associations with short sprint performance (Brady et al., 2020; Morris et al., 2022; Scanlan et al., 2020; Thomas et al., 2015, 2017). However, impulses in the IMTP and particularly CMJ have demonstrated potential as better predictors of sprint performance, especially in populations familiar with linear sprinting (Brady et al., 2020; Čoh & Mackala, 2013; Morris et al., 2022; Thomas et al., 2015). Finally, iDSI has been proposed as a more force-time-relevant metric in athletic populations and may help solve the DSI contextualization issue. Specifically, contextualization is needed due to the apparent qualitative and quantitative dynamic performance differences among individuals with similar

DSI scores and absolute strength levels (McMahon et al., 2017; Sheppard et al., 2011; Suchomel et al., 2020).

Research is unclear about the relationship between iDSI, its derivatives, and any relevant KPIs such as sprint performance. Furthermore, it is unclear if predictive ability differs between DSI and iDSI for sprint performance. Limited research investigating iDSI also conflicts regarding the relative reliability of impulse in the IMTP and ISqT. Future research should aim to resolve this issue. A potential solution is the application of the novel IBSq impulse assessment as an alternative to the IMTP or ISqT.

Chapter 3: Methodology

Introduction

The focus of the current study was to produce generalizable knowledge comparing the DSI and iDSI utilizing a novel measurement technique (the IBSq) and assessing their relationship with sprint performance. To this end, the rationale for participant selection, instrument selection, test selection, data analysis, and ethical considerations will be discussed.

Participants

43 Division 1 male (30) and female (13) collegiate athletes were recruited for the current study. This sample size was estimated using an a priori analysis for multiple regression in G*Power for 6 predictor variables with $\alpha = .05$, $\beta = .95$, and $r^2 = .16\text{-}.54$ based on previous research (version 3.1.9.2; G*Power, University of Düsseldorf, Düsseldorf, Germany) (Brady et al., 2020; Scanlan et al., 2020). Athletes were sampled from three different sports including baseball, soccer, and track and field. Athletes who had lost practice time due to injury within the last month were excluded from the study. The CMJ and IBSq were part of the athlete's normal weekly monitoring program. This means that the individual tests will have been performed at regular intervals before data collection for the current study. All athletes included in the study had participated in the USF strength and conditioning program for at least 1 semester. Familiarity with sprinting has been identified as a possible confounding variable for the relationship between DSI metrics and sprint ability, therefore, the current subjects were pulled from sports in which linear sprinting is both a part of competition and training (Merrigan et al., 2020; Scanlan et al., 2020; Thomas et al., 2017; Thomas et al., 2015).

Instruments

Vald ForceDecks (dual force plate system) and Vald SmartSpeed (timing gate system) were used to collect the force-time and sprint variables for the current study. A previous comparison between Vald ForceDecks and custom MATLAB force plate analysis demonstrated that the ForceDecks software identifies several force-time landmarks differently which results in significant bias for certain metrics including RFD and impulse, but not peak force. The percent difference between MATLAB and ForceDecks calculations for IMTP force and RFD at 50-200ms is 4-15% and 11-36%, respectively (Merrigan et al., 2022). When using the ForceDecks software, it is important to manually adjust for the pre-tension force generated above body weight in any isometric test when time-dependent metrics are being considered (Merrigan et al., 2022). This is done by manually analyzing the raw data and force-time curves. A custom-built steel platform and Spud Inc. weightlifting belt were used to perform IBSq tests in conjunction with the ForceDecks system. Force-time variables collected via the IBSq were IBSqp (N/Kg) and IBSqimp (200ms impulse relative to bodyweight, N*s/kg). No published CV or ICC is available for the IBSq. However, previous investigations utilizing the ISqT suggest ICCs of .98 and .92 and CVs of 3.5% and 9.9% for peak force and 200ms impulse, respectively (Brady et al., 2018; Layer et al., 2018). Impulse calculated below 200ms has been demonstrated to be less reliable than longer intervals, however, longer intervals can fall outside of some athletes' concentric CMJ phase duration. The first step of a sprint begins with a ground contact time of about 200ms and decreases to about 100ms by the 10th step (Colyer et al., 2018). Therefore, the epoch 200ms was chosen as the best standard measurement which also has relevance to the ground contact times experienced in sports (Merrigan et al., 2020). Force-time variables collected via the CMJ were CMJp (N/kg) and CMJimp (200ms concentric impulse relative to bodyweight, N*s/kg). The ICCs and CVs for CMJ peak force and impulse have shown to be .93 and 4%, and .98 and 1.6%, respectively (Haischer et al., 2021; Merrigan et al., 2020). The iDSI was calculated as the ratio between IBSqimp and CMJimp. The DSI was calculated as the ratio between IBSqp and CMJp.

Sprint times collected via the SmartSpeed 4-gate system were 0-10m, 10-30m, and 30-40m. A benefit of the SmartSpeed system is error correction processing (ECP) which has been demonstrated to correct for limbs crossing a gate before the center of mass. Measurement error reduction due to ECP may be between .102-.009s for sprint distances between 0-10m (Altmann et al., 2018). Even with ECP, there are other limitations when using laser timing gates to compare athletes in short acceleration distances. Specifically, acceleration posture within the first several steps of a sprint can significantly affect the reported sprint time when using an in-beam or trip-beam start (Altmann et al., 2018). Due to the cross-sectional nature of the current study and the importance of comparisons between subjects, the current study utilized a contact mat to standardize the start of the sprint instead of using a trip or in-beam start gate.

Procedures

All subjects were familiarized with the force-plate testing procedure at the time of data collection as they are part of the standard USF student-athlete monitoring protocol. Subjects entered the USF athletic performance training center wearing appropriate training attire and the same training shoes across individuals and testing sessions. On each occasion, subjects were guided through a standardized warm-up progressing from lower body calisthenic exercises to explosive ballistic exercises (see Appendix A). Subjects first performed three maximal effort CMJs with 30s of rest between trials. The CMJ was performed with hands on hips and feet placed shoulder-width apart. After five minutes of passive recovery, three maximal effort IBSqs were performed, each separated by 2 minutes of passive recovery. The IBSq was performed with arms by the side with a closed fist. Knee angles were set between 120-140 degrees by a goniometer. All slack was taken out of the belt chain to ensure the athlete did not jerk upon initiating the pull. Subjects were instructed to place their feet shoulder-width apart and push their feet into the ground as fast and as hard as possible for 5 seconds with verbal encouragement given throughout the test. The CMJ and IBSq were performed within the same testing session. Sprint times were collected during a separate session within the same week. Subjects underwent testing during periods when physical readiness was high and no physical fatigue was apparent (for example, not testing the day after a competition or an exhausting training session). Readiness was defined as the athlete being within one standard deviation of their best CMJ height upon testing. Due to the seasonal changes that may occur in force-velocity characteristics of sprint performance (Jiménez-Reyes et al., 2022), athlete data was sampled close to the start of the athlete's competitive season. In the 4 weeks leading up to data collection (pre-season), weight room training volume was held constant across groups.

Sprint times were collected within the same week of force plate testing and followed a standardized dynamic warm-up (see Appendix A). Subjects had undergone at least two familiarization sessions with the sprint testing procedures. Subjects arrived for sprint testing wearing appropriate training attire and the same training shoes across testing sessions. Following the dynamic warm-up, subjects were given a 3-minute rest period. The starting position was a three-point stance with the dominant leg placed at 90 degrees of knee flexion. The front hand was placed on the contact mat which was aligned with the start line. The contact mat method starts the timer immediately when the athlete's hand leaves the running surface and has been validated in previous research (Brady et al., 2020). Subjects performed three maximal-effort 40-meter sprints with 0-10m, 10-30m, and 30-40m split times. Five minutes of recovery were provided between each sprint and the best time for each split was taken for analysis.

Design and Data Analysis

The design of the current study was a quantitative, cross-sectional, correlational investigation. This design and topic were chosen for feasibility and applicability to problems of practice in the assessment of physical traits related to sports performance. My relationship with the participants was that of a strength of conditioning coach at the University of San Francisco. My role as a strength and conditioning coach also extends to making evidence-based decisions about performance testing, data collection, data analysis/interpretation, and guided intervention.

The independent variables were IBSq relative peak force, IBSq relative 200ms impulse, CMJ concentric relative peak force, and CMJ 200ms relative impulse. The dependent variables were 0-10m sprint time, 10-30m sprint time, and 30-40m sprint time. Data analysis was split into male, female, and combined male/female groups. Reliability for the novel IBSqimp and CMJimp was determined by calculating the CV and ICC with acceptable reliabilities set at <10% and >.8, respectively (Brady et al., 2018; Merrigan et al., 2020). DSI and iDSI were calculated as the ratio between peak force values and impulse values, respectively. The IBSq and CMJ independent variables were assessed for their relationship with each 40m split time via multiple regression. The relationship between DSI and iDSI was assessed via Pearson product-moment correlation. The assumptions of correlation and regression analysis (multicollinearity, linearity, and homoscedasticity) were assessed via the Tolerance and variance inflation factor and scatter plots of the data.

Ethical Considerations

Written permission to collect data was obtained from the coaches of each respective sport. The nature of the project was shared with the participants and written informed consent was obtained from each athlete. Participation in the research study was voluntary and all data collected was anonymous with personal data being made available to the participants at their request. At no point was identifiable data shared with coaches unless at the request of the athlete. There were two primary risks that athletes faced while participating in the proposed research. First, athletes risked their performance data being interpreted by sports coaches or others in positions of power. This risk was important because it could alter how athletes are treated relative to their peers. One potential manifestation could have been that athletes were prescribed extra training sessions based on poor extrapolations from study findings. Second, athletes risked their data affecting their social status among their peers. For these reasons, no data was shared during testing sessions and coaches could not interact with the athletes during testing sessions. Furthermore, performance data could not be seen by any athlete during the testing sessions to prevent athletes from comparing themselves to each other. Individual data was made available at the request of the athlete in a private manner. The IRB reference number for the current study is 2023_073.

Chapter 4: Results

Introduction

The current investigation and results presented in this chapter aimed to address three primary research problems. First, no published research had demonstrated reliability for any isometric impulse metrics utilizing the IBSq, nor while correcting for the variations in start-of-movement force when calculating impulse. Second, it was unknown how both DSI and iDSI derivatives were related to the different phases of sprint performance, especially when the derivatives were measured via the IBSq. Third, the DSI and iDSI had previously only been measured using the IMTP or ISqT, and therefore, it was unclear how the IBSq test may change these metrics. Similarly, it was unclear how these new DSI and iDSI metrics relate to each other as athlete profiling tools.

It was hypothesized that the iDSI derivatives (CMJimp and IBSqimp) would be reliable (%CV<10 and ICC >.9). It was hypothesized that IBSqimp and CMJimp would be significantly correlated with 0-10m, 10-30m, and 30-40m split times. Lastly, it was hypothesized that DSI derivatives (IBSqp and CMJp) would only be significantly correlated with 10m split time.

Sample Demographics

30 male and 13 female college students were included in the final analysis (n=43). Of the 30 male subjects, 21 were sampled from baseball and 9 from soccer. Of the 13 female subjects, 7 were sampled from soccer and 6 from track and field.

Descriptive Statistics of Independent and Dependent Variables

Refer to Table 1B for minimum, maximum, mean, and standard deviations for all independent and dependent variables.

Table 1B

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
MEN IBSq P	30	48.99	100.11	78.1274	14.17714
WOMEN IBSq P	13	44.57	86.09	64.9915	11.96850
MEN IBSq IMP	30	3.33	7.53	5.5371	1.13918
WOMEN IBSq IMP	13	3.44	6.01	4.7541	.78031
MEN CMJ P	30	21.44	33.00	27.2613	2.54773
WOMEN CMJ P	13	21.90	27.80	24.6777	1.78931
MEN CMJ IMP	30	3.92	5.17	4.6585	.30685
WOMEN CMJ IMP	13	3.44	4.63	4.1815	.31907
DSI	43	.27	.58	.3683	.06854
iDSI	43	.63	1.39	.8811	.16865
0-10m	43	1.844	2.353	2.02100	.121717
10-30m	43	2.209	2.880	2.46877	.161192
30-40m	43	1.077	1.380	1.17807	.079602

IBSq P = Relative isometric peak force (n/kg). IBSq IMP = Relative 200ms isometric impulse (n*s/kg). CMJ P = Relative dynamic peak force (n/kg). CMJ IMP = Relative concentric 200ms impulse.

Reliability Analysis

The novel IBSqimp metric demonstrated excellent average measures ICC (.937, lower bound = .896, upper bound .964) and good single measures ICC (.833, lower bound = .741, upper bound = .900). The average COV for IBSqimp was 9.6% (min = 2%, max = 23%). CMJimp demonstrated excellent average measures ICC (.976, lower bound = .961, upper bound = .986) and excellent single measures ICC (.933, lower bound = .891, upper bound = .960). The average COV for CMJimp was 2.5% (min = 0%, max = 7%).

Combined-Groups Correlation Analysis

Refer to Table 2B for the correlation matrix of all independent and dependent variables among the entire sample.

Table 2B

Combined-Groups Correlation Matrix

		IBSq P	IBSq IMP	CMJ P	CMJ IMP	0-10m	10-30m	30-40m
IBSq P	Pearson Correlation	1	.363*	.507**	.369*	-.422**	-.443**	-.318*
	Sig. (2-tailed)		.017	<.001	.015	.005	.003	.038
	N	43	43	43	43	43	43	43
IBSq IMP	Pearson Correlation	.363*	1	.579**	.507**	-.585**	-.533**	-.540**
	Sig. (2-tailed)	.017		<.001	<.001	<.001	<.001	<.001
	N	43	43	43	43	43	43	43
CMJ P	Pearson Correlation	.507**	.579**	1	.757**	-.599**	-.535**	-.481**
	Sig. (2-tailed)	<.001	<.001		<.001	<.001	<.001	.001
	N	43	43	43	43	43	43	43
CMJ IMP	Pearson Correlation	.369*	.507**	.757**	1	-.703**	-.753**	-.658**
	Sig. (2-tailed)	.015	<.001	<.001		<.001	<.001	<.001
	N	43	43	43	43	43	43	43
0-10m	Pearson Correlation	-.422**	-.585**	-.599**	-.703**	1	.923**	.873**
	Sig. (2-tailed)	.005	<.001	<.001	<.001		<.001	<.001
	N	43	43	43	43	43	43	43
10-30m	Pearson Correlation	-.443**	-.533**	-.535**	-.753**	.923**	1	.899**
	Sig. (2-tailed)	.003	<.001	<.001	<.001	<.001		<.001
	N	43	43	43	43	43	43	43
30-40m	Pearson Correlation	-.318*	-.540**	-.481**	-.658**	.873**	.899**	1
	Sig. (2-tailed)	.038	<.001	.001	<.001	<.001	<.001	
	N	43	43	43	43	43	43	43

IBSq P = Relative isometric peak force (n/kg). IBSq IMP = Relative 200ms isometric impulse (n*s/kg). CMJ P = Relative dynamic peak force (n/kg). CMJ IMP = Relative concentric 200ms impulse.

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

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

Men’s Correlation Analysis

Refer to Table 3B for the correlation matrix of independent and dependent variables for men.

Table 3B

Men's Correlation Matrix

		MEN IBSq P	MEN IBSq IMP	MEN CMJ P	MEN CMJ IMP	0-10m	10-30m	30-40m
MEN IBSq P	Pearson Correlation	1	.209	.418*	.217	-.216	-.188	-.126
	Sig. (2-tailed)		.268	.022	.250	.253	.321	.507
	N	30	30	30	30	30	30	30
MEN IBSq IMP	Pearson Correlation	.209	1	.453*	.393*	-.505**	-.379*	-.463*
	Sig. (2-tailed)	.268		.012	.032	.004	.039	.010
	N	30	30	30	30	30	30	30
MEN CMJ P	Pearson Correlation	.418*	.453*	1	.696**	-.470**	-.330	-.383*
	Sig. (2-tailed)	.022	.012		<.001	.009	.075	.037
	N	30	30	30	30	30	30	30
MEN CMJ IMP	Pearson Correlation	.217	.393*	.696**	1	-.512**	-.654**	-.649**
	Sig. (2-tailed)	.250	.032	<.001		.004	<.001	<.001
	N	30	30	30	30	30	30	30
0-10m	Pearson Correlation	-.216	-.505**	-.470**	-.512**	1	.923**	.873**
	Sig. (2-tailed)	.253	.004	.009	.004		<.001	<.001
	N	30	30	30	30	43	43	43
10-30m	Pearson Correlation	-.188	-.379*	-.330	-.654**	.923**	1	.899**
	Sig. (2-tailed)	.321	.039	.075	<.001	<.001		<.001
	N	30	30	30	30	43	43	43
30-40m	Pearson Correlation	-.126	-.463*	-.383*	-.649**	.873**	.899**	1
	Sig. (2-tailed)	.507	.010	.037	<.001	<.001	<.001	
	N	30	30	30	30	43	43	43

IBSq P = Peak relative isometric force. IBSq IMP = 200ms relative isometric impulse. CMJ P = Peak relative dynamic force. CMJ IMP = 200ms relative concentric impulse.

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

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

Women's Correlation Analysis

Refer to Table 4B for the correlation matrix of independent and dependent variables for women.

Table 4B

Women's Correlation Matrix

		WOMEN IBSq P	WOMEN IBSq IMP	WOMEN CMJ P	WOMEN CMJ IMP	0-10m	10-30m	30-40m
WOMEN IBSq P	Pearson Correlation	1	.494	.292	.050	-.238	-.347	-.255
	Sig. (2-tailed)		.086	.333	.870	.434	.245	.400
	N	13	13	13	13	13	13	13
WOMEN IBSq IMP	Pearson Correlation	.494	1	.795**	.491	-.672*	-.725**	-.695**
	Sig. (2-tailed)	.086		.001	.088	.012	.005	.008
	N	13	13	13	13	13	13	13
WOMEN CMJ P	Pearson Correlation	.292	.795**	1	.656*	-.476	-.449	-.456
	Sig. (2-tailed)	.333	.001		.015	.100	.123	.117
	N	13	13	13	13	13	13	13
WOMEN CMJ IMP	Pearson Correlation	.050	.491	.656*	1	-.546	-.566*	-.544
	Sig. (2-tailed)	.870	.088	.015		.054	.044	.055
	N	13	13	13	13	13	13	13
0-10m	Pearson Correlation	-.238	-.672*	-.476	-.546	1	.923**	.873**
	Sig. (2-tailed)	.434	.012	.100	.054		<.001	<.001
	N	13	13	13	13	43	43	43
10-30m	Pearson Correlation	-.347	-.725**	-.449	-.566*	.923**	1	.899**
	Sig. (2-tailed)	.245	.005	.123	.044	<.001		<.001
	N	13	13	13	13	43	43	43
30-40m	Pearson Correlation	-.255	-.695**	-.456	-.544	.873**	.899**	1
	Sig. (2-tailed)	.400	.008	.117	.055	<.001	<.001	
	N	13	13	13	13	43	43	43

IBSq P = Peak relative isometric force. IBSq IMP = 200ms relative isometric impulse. CMJ P = Peak relative dynamic force. CMJ IMP = 200ms relative concentric impulse.

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

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

Combined-Groups Regression Analysis

IBSqimp and CMJimp together demonstrated the best predictive ability of 0-10m sprint performance (r^2 = .564, adjusted r^2 = .542, SEE = .082, F = 25.894, p = <.001). CMJimp alone demonstrated the best predictive ability of 10-30m sprint performance (r^2 = .566, adjusted r^2 = .556, SEE = .107, F = 53.528, p = <.001). IBSqimp and CMJimp together demonstrated the best predictive ability of 30-40m sprint performance (r^2 = .491, adjusted r^2 = .465, SEE = .058, F = 19.258, p = <.001) (See table 5B).

Table 5B

Combined-Groups Regression Model Summary for 0-10m, 10-30m, and 30-40m Sprint Time

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
0-10m	.703[a]	.494	.481	.087662	.494	39.972	1	41	<.001
0-10m	.751[b]	.564	.542	.082335	.071	6.477	1	40	.015

a. Predictors: (Constant), CMJ IMP

b. Predictors: (Constant), CMJ IMP, IBSq IMP

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
10-30m	.753[a]	.566	.556	.107445	.566	53.528	1	41	<.001

a. Predictors: (Constant), CMJ IMP

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
30-40m	.658[a]	.433	.419	.060655	.433	31.339	1	41	<.001
30-40m	.700[b]	.491	.465	.058220	.057	4.501	1	40	.040

a. Predictors: (Constant), CMJ IMP

b. Predictors: (Constant), CMJ IMP, IBSq IMP

Men's Regression Analysis

IBSqimp and CMJimp together demonstrated the best predictive ability of 0-10m sprint performance (r^2 = .371, adjusted r^2 = .325, SEE = .063, F = 7.967, p = .002). CMJimp alone demonstrated the best predictive ability of 10-30m sprint performance (r^2 = .427, adjusted r^2 = .407, SEE = .068, F = 20.878, p = <.001). CMJimp alone demonstrated the best predictive ability of 30-40m sprint performance (r^2 = .422, adjusted r^2 = .401, SEE = .036, F = 20.419, p = <.001) (See Table 6B).

Table 6B

Men's Regression Model Summary for 0-10m, 10-30m, and 30-40m Sprint Times.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
0-10m	.512[a]	.262	.236	.067330	.262	9.953	1	28	.004
0-10m	.609[b]	.371	.325	.063304	.109	4.675	1	27	.040

a. Predictors: (Constant), MEN CMJ IMP, MEN IBSq IMP

b. Predictors: (Constant), MEN CMJ IMP, MEN IBSq IMP

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
10-30m	.654[a]	.427	.407	.068045	.427	20.878	1	28	<.001

a. Predictors: (Constant), MEN CMJ IMP

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
30-40m	.649[a]	.422	.401	.035653	.422	20.419	1	28	<.001

a. Predictors: (Constant), MEN CMJ IMP

Women's Regression Analysis

IBSqimp alone demonstrated the best predictive ability of 0-10m sprint performance (r^2 = .451, adjusted r^2 = .401, SEE = .092, F = 9.040, p = .012). IBSqimp alone demonstrated the best predictive ability of 10-30m sprint performance (r^2 = .525, adjusted r^2 = .483, SEE = .117, F = 12.198, p = .005). IBSqimp alone demonstrated the best predictive ability of 30-40m sprint performance (r^2 = .483, adjusted r^2 = .436, SEE = .084, F = 10.26, p = .008) (See table 7B).

Table 7B

Women's Regression Model Summary for 0-10m, 10-30m, and 30-40m Sprint Time

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
0-10m	.672[a]	.451	.401	.092398	.451	9.040	1	11	.012

a. Predictors: (Constant), WOMEN IBSq IMP

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
10-30m	.725[a]	.526	.483	.117466	.526	12.198	1	11	.005

a. Predictors: (Constant), WOMEN IBSq IMP

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
30-40m	.695[a]	.483	.436	.084236	.483	10.260	1	11	.008

a. Predictors: (Constant), WOMEN IBSq IMP

DSI and iDSI Analysis

The average DSI score was .58 across all groups (min = .27, max = .58, SD = .07). The average iDSI score across all groups was .88 (min = .63, max = 1.39, SD = .17). There was no significant correlation between DSI and iDSI score (see table 8B).

Table 8B

Descriptive Statistics For DSI and iDSI

	Mean	Std. Deviation	N
DSI	.3683	.06854	43
iDSI	.8811	.16865	43

Correlation Between DSI and iDSI

		DSI	iDSI
DSI	Pearson Correlation	1	.139
	Sig. (2-tailed)		.375
	N	43	43
iDSI	Pearson Correlation	.139	1
	Sig. (2-tailed)	.375	
	N	43	43

DSI = Dynamic Strength Index. iDSI = Impulse-Based Dynamic Strength Index

Chapter 5: Discussion

The Isometric Belt Squat

The relative peak forces reported in the literature among similar athletic populations for the IMTP and ISqT range from ~21.9n/kg to 63.8n/kg (Brady et al., 2020; Scanlan et al., 2020; Suchomel et al., 2020; Thomas et al., 2017). In the current study, the minimum peak force achieved by an athlete was 48.99n/kg and the maximum achieved was 100.11n/kg (see Table 1B). This finding supports the speculation that the IBSq test may be a more accurate reflection of true lower body maximal force production, possibly due to reductions in low back moments, reductions in upper body loading, and reductions in the apprehension to put maximal force into an immovable object (Layer et al.2018; Joseph et al., 2020).

Previous literature suggested that isometric impulse metrics in the IMTP and ISqT have good to excellent reliability above 150ms and generally have improved reliability with longer epochs, and therefore, it was hypothesized that the same would be true for the IBSq (Brady et al., 2018, 2020; James & Comfort, 2022; Merrigan et al., 2020; Scanlan et al., 2020). This hypothesis was found to be true, with IBSqimp demonstrating an ICC of .937 and an average COV of 9.6%. However, it should be noted that COV was >15% in 8 of 43 observations. This could have been due to variations in acclimation to the testing procedures or accumulated test fatigue. However, this may suggest that while the IBSqimp can be used to discriminate between individuals, it may be difficult to detect training-induced changes over time.

In the current study, the force-time curves of the IBSq were analyzed manually, outside of the ForceDecks software. This was because time-dependent results in any isometric test can be confounded by variations in the start-of-movement force or pre-tension before the initiation of contraction (Merrigan et al., 2022). The athlete was cued to remain still and to put just enough force into the apparatus to remove slack from the system. Even when visually inspecting the force-time curve on the computer screen before the pull, there were still slight variations in the start-of-movement force across tests and athletes. Accounting for this force in the analysis may have helped to improve both the reliability and predictive utility of the IBSqimp metric. The units for the IBSqimp are newtons seconds per kilogram (n*s/kg). In the known literature, isometric impulse has generally been reported as net impulse, which is the impulse above body weight (as opposed to impulse relative to body weight in the current study) (Brady et al., 2018, 2020). The highest average net 200ms impulse reported among a similar athletic population for either the IMTP or ISqT has been 253n*s for men and 173n*s for women (Brady et al., 2020; Merrigan et al., 2020). In the current study, the average net 200ms impulse for men in the IBSq was 325n*s and for women was 212n*s (28% and 22% larger, respectively). Again, this may support the notion that the IBSq is a more accurate reflection of true lower body force potential. This discrepancy may also help to explain why previous research struggled to find a significant correlation between the IMTP and ISqT metrics and sprint performance.

It was hypothesized that IBSq peak force would be significantly correlated with 0-10m sprint time, but not 10-30m or 30-40m split times. This hypothesis is partially supported by the current results (see Table 2B). In the combined analysis of men and women (n=43), IBSq peak force was significantly correlated with all three split times, albeit lower than all other independent variables. These correlations would agree with previous research for the 0-10m split, but not for longer splits (Brady et al., 2020; Scanlan et al., 2020; Thomas et al., 2015, 2017; Wang et al., 2016). When looking at men and women individually, there was no significant correlation between peak force and any of the three split times (see Table 3B and 4B). The sample sizes in the current analysis for men ($n=30$) and women ($n=13$) were comparable to previous research and may not help to explain these results. The increase in maximal force potential and increase in knee/ankle moments in the IBSq compared to the IMTP or ISqT may explain the reduced relationship between maximal strength and 0-10m sprint acceleration.

It was hypothesized that the IBSq 200ms impulse would be correlated with all three split times. This hypothesis was found to be true for both the combined-groups analysis and individual analysis of men and women. Interestingly, the correlation was stronger at every split for women compared to men ($r = -.725$ to $r = -.672$, $p = <.01$ Vs. $r = -.379$ to $r = -.505$, $p = <.05$). respectively). This finding may suggest that maximal isometric force/impulse is more related to speed in relatively weaker individuals compared to force production under high-velocity conditions (like a CMJ). This notion is supported by the fact that the correlation between IBSq peak force and IBSq impulse in women approached significance ($r = .494$, $p = .086$). In men, the non-significant correlation between IBSq peak force and impulse was $r = .209$, $p = .268$. The average IMTP relative peak force value for male sprinters found by Brady et al. (2020) was ~27n/kg and a significant correlation was demonstrated for 0-5m sprint time. Conversely, Scanlan et al. (2020) found an average IMTP relative peak force value of ~35n/kg for male basketball players and demonstrated no correlation for 0-5m sprint time. It could be speculated that this lack of correlation in Scanlan et al. (2020) was in part due to the athletes being relatively stronger on average. From these results, one could hypothesize that the ability to produce maximal strength or impulse under zero velocity conditions is a measure of general/foundational force potential that may set the stage for greater high-velocity force production. Furthermore, there may be a point of diminishing returns, at which point dynamic peak force and impulse become better predictors of sprint speed. This notion is supported by the fact that CMJimp had either a greater or more significant correlation with all split times in men than it did in women, who were not as relatively strong. Furthermore, there was no correlation between CMJp and any split time for women, nor was there a significant correlation between CMJimp and 30-40m split time for women.

The CMJ

Relative peak force and jump height (a direct result of relative impulse) in the CMJ have shown significant correlations with sprint speed out to about 20m in previous research (r = -.55 to r = -.65) (Morris et al., 2022; Thomas et al., 2017). The current hypothesis was that CMJp would only be correlated with 0-10m time, while CMJimp would be correlated with all split times, this was only partially true. It was found that for men, CMJp was moderately correlated with 0-10m time (r = -.470, p = .009) and modestly correlated with 30-40m time (r = -.383, p = .037). CMJimp had comparatively stronger correlations at all split times for men and stronger correlations with longer distances (0-10m r = -.512, p = .004, 10-30m r = -.654, p = <.001, 30-40m r = -.649, p = <.001). For women, CMJp was not significantly correlated with any of the three split times while CMJimp was only significantly correlated with 10-30m split time (r = -.566, p = .044). For both men and women, CMJimp had the strongest correlation with 10-30m time. Suchomel et al. (2020) demonstrated that the maximal strength level measured by the IMTP may influence the type of jump strategy that an athlete uses. For example, stronger athletes may tend to have faster counter-movements and greater eccentric braking forces. These increased braking forces will also inflate CMJp. This is supported by the current results in that IBSqp had a greater correlation with CMJp than it did with CMJimp (r = .507, p = <.001 Vs. r = .369, p = .015). During the stance phase of sprinting, the propulsive muscle contractions are primarily concentric or quasi-isometric (Monte et al., 2020). Through this lens, it makes conceptual sense that CMJimp would have a greater relationship with sprint time because it may be less influenced/confounded by eccentric RFD, jump strategy, and maximal strength.

Predicting Sprint Performance

For the combined groups and men's analysis, IBSqimp and CMJimp together demonstrated the best model fit and explained 37-56% of the variance in 0-10m sprint time (see table 5B and 6B). For 0-10m sprint time, the inclusion of IBSqimp in the model was the only common denominator across all the analysis groups (for women, IBSqimp alone best predicted 0-10m time). During a short sprint acceleration, one cannot utilize the force-potentiating benefits of a countermovement or stretch-shortening cycle. This contrasts with what occurs during a CMJ test and precedes the measurement of CMJimp. It could be hypothesized that the inclusion of IBSqimp improves the model because it demonstrates the athlete's ability to ramp up force quickly from a static position or without contribution from an eccentric phase. Furthermore, the potential to produce high total ground impulse is greatest during the first step of a sprint and decreases with every step thereafter (Morin et al., 2015). Similarly, the potential to produce a high 200ms impulse is also greatest in the IBSq compared to the CMJ.

A unique finding of the current study was that for the combined-groups analysis, IBSqimp was dropped from the prediction model only for 10-30m time (CMJimp alone explained 57% of the variance in 10-30m time). This raises the question of why IBSqimp would be included for 0-10m time and again only for 30-40m time. One possible explanation for this is that as one approaches top speed, the knee joint becomes increasingly ridged to take greater advantage of the series elastic component of the muscle-tendon unit (Monte et al., 2020). The knee extensor muscles act quasi-isometrically to spike vertical ground reaction forces quickly while ground contact times are at their smallest (Clark & Weyand, 2014; Colyer et al., 2018).

The last unique finding of the regression analysis was that for women, CMJimp was not included in the final prediction model for any split time (IBSqimp alone explained 45-53% of the variance in split time) (see Table 7B). On average, women were about .08 to .25 seconds slower across each split time (see Table 1B). Whether this difference is statistically significant was beyond the scope of the current study. As mentioned previously, it could be that for relatively less strong or less fast individuals, IBSqimp is a more relevant predictor of sprint performance because it may represent a foundational component of general force production.

DSI and Impulse-DSI

Recent research investigating an impulse-based DSI has demonstrated moderate to large correlations with the traditional DSI (Haischer et al., 2021; James & Comfort, 2022). These correlations ranged from $r = .37$ to $r = .94$ and increased as the epoch increased over which impulse was calculated. The current study was unique in that DSI and iDSI scores were measured utilizing the IBSq and with impulse relative to body mass over 200ms. The hypothesis that DSI and iDSI scores would be moderately correlated was demonstrated to be false. There was no significant correlation between DSI and iDSI in the current study ($r = .319$, $p =.375$), suggesting that the iDSI measured here represents a unique profiling metric (see Table 8B).

Previous studies investigating the DSI using the IMTP and ISqT found average DSI scores of about .7 with the lowest recorded scores being about .45 (Comfort et al., 2018; Sheppard et al., 2011; Thomas et al., 2017). In the current study, the average DSI score was .37 and the lowest score recorded was .27. This can be attributed to the greater peak forces achieved with the IBSq, and therefore, it may not be appropriate to utilize the previously suggested thresholds of .60 - .80 for training prescriptions. The previous research on iDSI variables reported average iDSI scores of .77 - .94, depending on the length of the epoch utilized to calculate iDSI (Haischer et al., 2021; James & Comfort, 2022). Generally, the shorter the epoch the larger the iDSI value tends to be. The current study found an average iDSI of .88 and utilized an epoch of 200ms, which could be considered moderate relative to the 100ms and >300ms used in previous studies. Again, new thresholds may need to be developed to guide training prescriptions with these new values.

Practical Applications

IBSqimp consistently demonstrated predictive utility for 0-10m sprint ability among male and female division 1 athletes. Secondarily, it seems to also have utility for predicting max-velocity sprint ability which could be attributed to the quasi-isometric nature of max-velocity sprinting. IBSqimp also demonstrated good to excellent reliability in discriminating between athletes. Therefore, IBSqimp may be a useful metric to collect as part of an athlete profiling test battery in which sprint ability is important. Using various force-plate tests to set performance benchmarks for athletes has been done previously (McMahon et al., 2022). For example, McMahon et al. (2022) collected CMJ height and momentum metrics among 121 professional rugby players. It was suggested that these normative values could be used to describe where certain athletes stand concerning their successful peers in the same positional group. An important task, however, is choosing tests that have relevance to sporting success. With enough normative data, the DSI and iDSI values reported here could be used to prescribe training foci (explosive, low-velocity force Vs. explosive, high-velocity force). It should be noted, however, that the current study is cross-sectional, and therefore, it is unclear if prescribing exercises based on IBSqimp or changing IBSqimp over time would directly lead to enhanced sprint speed.

Based on the combined groups and men's analysis, CMJimp was generally a better predictor of sprint performance than IBSqimp at all three splits. However, the two metrics are not collinear, and each contribute uniquely to the regression model. Again, categorizing athletes based on the individual magnitudes and relationship (iDSI) between these two metrics may aid in athlete profiling.

One of the problems of practice identified in the conception of this study was the collection of as much actionable information as possible, as efficiently as possible. In the current study, by completing a single test of the IBSq and CMJ, one can derive a reliable DSI and iDSI score simultaneously. These scores can help contextualize each other. For example, a low DSI score alone would suggest that an athlete works on more ballistic activities. However, if this same subject had a high iDSI score, it may indicate they would be best-served training either accelerative strength (lower velocity RFD) or explosive eccentric strength (more related to peak force in the CMJ). The final layer of value here is that these metrics, especially IBSqimp and CMJimp, have also demonstrated significant relationships with sprint ability.

Limitations

As mentioned previously, it is still unclear if prescribing specific exercises would reliably modulate changes in IBSqimp or CMJimp metrics or if these longitudinal changes would coincide with predictable changes in sprint performance. Furthermore, it was assumed that the relationships among the independent and dependent variables were linear. A curvilinear regression of IBSqp and 0-10m time revealed an r^2 of .188, $p = .004$ Vs. the linear regression revealed an r^2 of .178, p = .005. It could be hypothesized that for the variables discussed, there are points of diminishing returns on sprint speed, which could explain a curvilinear relationship. Future research may seek to demonstrate diminishing returns among any of the current variables. Though each group received at least two familiarization sessions, some groups had more experience than others with either the force plate or sprint testing procedures. While proximity to the competitive season was attempted to be controlled, weather and other uncontrollable factors caused some testing sessions to be rescheduled. Furthermore, the final sample size for women (n=13) was smaller than anticipated and a post-hoc power analysis revealed a power of .71 for women and .95 for men. It cannot be asserted that these limitations did not affect the study results.

Recommendations for Future Research

In the present study, the IBSq variables were measured concurrently, and the subjects were cued to push as fast and as hard as possible for five seconds in each test. Future research may benefit from utilizing a separate approach. For example, using a ramp protocol for testing maximal strength and a short (~1 second) protocol for measuring isometric impulse/RFD. This approach might further enhance the repeatability/reliability of the explosive isometric metrics on par with the CMJ metrics. Future research may also aim to generate normative data for the IBSq which will aid athlete profiling. Athlete profiling involves finding various performance metrics that are related to success on the field of play and categorizing athletes of similar positions or skill sets based on how they compare in these metrics. These comparisons are used to help infer training foci to help athletes improve in capacities that they lack relative to the demands of their position. For example, McMahon et al. (2022) found that CMJ takeoff momentum was important for rugby forwards who come into frequent collisions and must use their body mass to move other players. Normative data on CMJ takeoff momentum could then be used to identify forwards who could benefit from gaining either total mass or muscular strength qualities. For the metrics derived in the current study, normative data for different sports and positions can help to identify or narrow down limiting factors for sprint performance. For example, it may be possible to identify if a track athlete requires more maximal strength, accelerative strength, or ballistic strength relative to their successful peers. Finally, longitudinal research will help to validate the practice of prescribing exercises based on DSI and iDSI scores.

Conclusion

Despite the popularity and number of investigations regarding the DSI as an athlete profiling metric, research had struggled to find strong relationships between peak force metrics and relevant KPI’s such as sprint performance (Morris, Weber, & Netto, 2022; Wang et al., 2016). As an alternative to the previously standard IMTP or ISqT, the IBSq presented in the current study situates itself as a potentially more accurate test of true lower body force potential. Utilization of the IBSq over other isometric tests may at least partly explain the significant relationships found between isometric impulse and all phases of linear sprint performance (r = .379 to r = .725). Furthermore, in conjunction with the CMJ, the iDSI derivatives IBSqimp and CMJimp explained up to 57% of the variance in sprint time, depending on the split.

Haischer et al. (2021), who first proposed an impulse-based DSI, justified the iDSI by concluding that the ability to produce force over a specific epoch may be a better predictor of dynamic performance than peak force. Now, adding to the work that Haischer et al. (2021) began, the current investigation contributes empirical evidence that the iDSI derivatives may in fact have significant implications for predicting sprint speed among athletic populations.

Furthermore, confirming that the new iDSI metric is non-redundant and may add increased value to the athlete profiling process.

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Appendix A

Warm-up Procedures for Sprint and Force Plate Testing

SPRINT WARM-UP		CMJ/IBSq WARM-UP	
EXERCISE	**REPETITIONS**	**EXERCISE**	**REPETITIONS**
Forward / Backward / Lateral Skips	2 X 20 yards each	Goodmorning	X 20
Carioca	2 X 20 yards each	Bodyweight Squat	X 10
A Series: - A March - A Skip - A Run	2 X 10 yards each with an easy 3-step acceleration	Forward Lunge	X 10 each
B Series: - B Skip - Dribble B Skip - Dribble Run	2 X 20 yards each	Lateral Lunge	X 10 each
Plyo Series: - Straight Leg Bound - Skip For Height - Skip For Distance - Alternating Bound - Single Leg Pogo	2 X 20 yards each	Pogo Hops	X 20
Build-Ups: - 20m @80% - 30m @90%	1 each	Squat Jump	X 3
40m dash test W/5min recoveries. Front leg placed at 90deg.	3	Submaximal Alternating Split Jumps	X 6 (3 each leg)
		Submaximal Continuous CMJ	2 X 3
		CMJ test W/30s recoveries	3
		IBSq test following 5min rest W/2min recoveries. 120-140deg knee angles.	3

Appendix B

Table 1B

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
MEN IBSq P	30	48.99	100.11	78.1274	14.17714
WOMEN IBSq P	13	44.57	86.09	64.9915	11.96850
MEN IBSq IMP	30	3.33	7.53	5.5371	1.13918
WOMEN IBSq IMP	13	3.44	6.01	4.7541	.78031
MEN CMJ P	30	21.44	33.00	27.2613	2.54773
WOMEN CMJ P	13	21.90	27.80	24.6777	1.78931
MEN CMJ IMP	30	3.92	5.17	4.6585	.30685
WOMEN CMJ IMP	13	3.44	4.63	4.1815	.31907
DSI	43	.27	.58	.3683	.06854
iDSI	43	.63	1.39	.8811	.16865
0-10m	43	1.844	2.353	2.02100	.121717
10-30m	43	2.209	2.880	2.46877	.161192
30-40m	43	1.077	1.380	1.17807	.079602

IBSq P = Relative isometric peak force (n/kg). IBSq IMP = Relative 200ms isometric impulse (n*s/kg). CMJ P = Relative dynamic peak force (n/kg). CMJ IMP = Relative concentric 200ms impulse.

Table 2B

Combined-Groups Correlation Matrix

		IBSq P	IBSq IMP	CMJ P	CMJ IMP	0-10m	10-30m	30-40m
IBSq P	Pearson Correlation	1	.363*	.507**	.369*	-.422**	-.443**	-.318*
	Sig. (2-tailed)		.017	<.001	.015	.005	.003	.038
	N	43	43	43	43	43	43	43
IBSq IMP	Pearson Correlation	.363*	1	.579**	.507**	-.585**	-.533**	-.540**
	Sig. (2-tailed)	.017		<.001	<.001	<.001	<.001	<.001
	N	43	43	43	43	43	43	43
CMJ P	Pearson Correlation	.507**	.579**	1	.757**	-.599**	-.535**	-.481**
	Sig. (2-tailed)	<.001	<.001		<.001	<.001	<.001	.001
	N	43	43	43	43	43	43	43
CMJ IMP	Pearson Correlation	.369*	.507**	.757**	1	-.703**	-.753**	-.658**
	Sig. (2-tailed)	.015	<.001	<.001		<.001	<.001	<.001
	N	43	43	43	43	43	43	43
0-10m	Pearson Correlation	-.422**	-.585**	-.599**	-.703**	1	.923**	.873**
	Sig. (2-tailed)	.005	<.001	<.001	<.001		<.001	<.001
	N	43	43	43	43	43	43	43
10-30m	Pearson Correlation	-.443**	-.533**	-.535**	-.753**	.923**	1	.899**
	Sig. (2-tailed)	.003	<.001	<.001	<.001	<.001		<.001
	N	43	43	43	43	43	43	43
30-40m	Pearson Correlation	-.318*	-.540**	-.481**	-.658**	.873**	.899**	1
	Sig. (2-tailed)	.038	<.001	.001	<.001	<.001	<.001	
	N	43	43	43	43	43	43	43

IBSq P = Relative isometric peak force (n/kg). IBSq IMP = Relative 200ms isometric impulse (n*s/kg). CMJ P = Relative dynamic peak force (n/kg). CMJ IMP = Relative concentric 200ms impulse.

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

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

Table 3B

Men's Correlation Matrix

		MEN IBSq P	MEN IBSq IMP	MEN CMJ P	MEN CMJ IMP	0-10m	10-30m	30-40m
MEN IBSq P	Pearson Correlation	1	.209	.418*	.217	-.216	-.188	-.126
	Sig. (2-tailed)		.268	.022	.250	.253	.321	.507
	N	30	30	30	30	30	30	30
MEN IBSq IMP	Pearson Correlation	.209	1	.453*	.393*	-.505**	-.379*	-.463*
	Sig. (2-tailed)	.268		.012	.032	.004	.039	.010
	N	30	30	30	30	30	30	30
MEN CMJ P	Pearson Correlation	.418*	.453*	1	.696**	-.470**	-.330	-.383*
	Sig. (2-tailed)	.022	.012		<.001	.009	.075	.037
	N	30	30	30	30	30	30	30
MEN CMJ IMP	Pearson Correlation	.217	.393*	.696**	1	-.512**	-.654**	-.649**
	Sig. (2-tailed)	.250	.032	<.001		.004	<.001	<.001
	N	30	30	30	30	30	30	30
0-10m	Pearson Correlation	-.216	-.505**	-.470**	-.512**	1	.923**	.873**
	Sig. (2-tailed)	.253	.004	.009	.004		<.001	<.001
	N	30	30	30	30	43	43	43
10-30m	Pearson Correlation	-.188	-.379*	-.330	-.654**	.923**	1	.899**
	Sig. (2-tailed)	.321	.039	.075	<.001	<.001		<.001
	N	30	30	30	30	43	43	43
30-40m	Pearson Correlation	-.126	-.463*	-.383*	-.649**	.873**	.899**	1
	Sig. (2-tailed)	.507	.010	.037	<.001	<.001	<.001	
	N	30	30	30	30	43	43	43

IBSq P = Peak relative isometric force. IBSq IMP = 200ms relative isometric impulse. CMJ P = Peak relative dynamic force. CMJ IMP = 200ms relative concentric impulse.

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

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

Table 4B

Women's Correlation Matrix

		WOMEN IBSq P	WOMEN IBSq IMP	WOMEN CMJ P	WOMEN CMJ IMP	0-10m	10-30m	30-40m
WOMEN IBSq P	Pearson Correlation	1	.494	.292	.050	-.238	-.347	-.255
	Sig. (2-tailed)		.086	.333	.870	.434	.245	.400
	N	13	13	13	13	13	13	13
WOMEN IBSq IMP	Pearson Correlation	.494	1	.795**	.491	-.672*	-.725**	-.695**
	Sig. (2-tailed)	.086		.001	.088	.012	.005	.008
	N	13	13	13	13	13	13	13
WOMEN CMJ P	Pearson Correlation	.292	.795**	1	.656*	-.476	-.449	-.456
	Sig. (2-tailed)	.333	.001		.015	.100	.123	.117
	N	13	13	13	13	13	13	13
WOMEN CMJ IMP	Pearson Correlation	.050	.491	.656*	1	-.546	-.566*	-.544
	Sig. (2-tailed)	.870	.088	.015		.054	.044	.055
	N	13	13	13	13	13	13	13
0-10m	Pearson Correlation	-.238	-.672*	-.476	-.546	1	.923**	.873**
	Sig. (2-tailed)	.434	.012	.100	.054		<.001	<.001
	N	13	13	13	13	43	43	43
10-30m	Pearson Correlation	-.347	-.725**	-.449	-.566*	.923**	1	.899**
	Sig. (2-tailed)	.245	.005	.123	.044	<.001		<.001
	N	13	13	13	13	43	43	43
30-40m	Pearson Correlation	-.255	-.695**	-.456	-.544	.873**	.899**	1
	Sig. (2-tailed)	.400	.008	.117	.055	<.001	<.001	
	N	13	13	13	13	43	43	43

IBSq P = Peak relative isometric force. IBSq IMP = 200ms relative isometric impulse. CMJ P = Peak relative dynamic force. CMJ IMP = 200ms relative concentric impulse.

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

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

Table 5B

Combined-Groups Regression Model Summary for 0-10m, 10-30m, and 30-40m Sprint Time

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
0-10m	.703[a]	.494	.481	.087662	.494	39.972	1	41	<.001
0-10m	.751[b]	.564	.542	.082335	.071	6.477	1	40	.015

a. Predictors: (Constant), CMJ IMP

b. Predictors: (Constant), CMJ IMP, IBSq IMP

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
10-30m	.753[a]	.566	.556	.107445	.566	53.528	1	41	<.001

a. Predictors: (Constant), CMJ IMP

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
30-40m	.658[a]	.433	.419	.060655	.433	31.339	1	41	<.001
30-40m	.700[b]	.491	.465	.058220	.057	4.501	1	40	.040

a. Predictors: (Constant), CMJ IMP

b. Predictors: (Constant), CMJ IMP, IBSq IMP

Table 6B

Men's Regression Model Summary for 0-10m, 10-30m, and 30-40m Sprint Times.

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
0-10m	.512[a]	.262	.236	.067330	.262	9.953	1	28	.004
0-10m	.609[b]	.371	.325	.063304	.109	4.675	1	27	.040

a. Predictors: (Constant), MEN CMJ IMP, MEN IBSq IMP

b. Predictors: (Constant), MEN CMJ IMP, MEN IBSq IMP

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
10-30m	.654[a]	.427	.407	.068045	.427	20.878	1	28	<.001

a. Predictors: (Constant), MEN CMJ IMP

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
30-40m	.649[a]	.422	.401	.035653	.422	20.419	1	28	<.001

a. Predictors: (Constant), MEN CMJ IMP

Table 7B

Women's Regression Model Summary for 0-10m, 10-30m, and 30-40m Sprint Time

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
0-10m	.672[a]	.451	.401	.092398	.451	9.040	1	11	.012

a. Predictors: (Constant), WOMEN IBSq IMP

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
10-30m	.725[a]	.526	.483	.117466	.526	12.198	1	11	.005

a. Predictors: (Constant), WOMEN IBSq IMP

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
30-40m	.695[a]	.483	.436	.084236	.483	10.260	1	11	.008

a. Predictors: (Constant), WOMEN IBSq IMP

Table 8B

Descriptive Statistics For DSI and iDSI

	Mean	Std. Deviation	N
DSI	.3683	.06854	43
iDSI	.8811	.16865	43

Correlation Between DSI and iDSI

		DSI	iDSI
DSI	Pearson Correlation	1	.139
	Sig. (2-tailed)		.375
	N	43	43
iDSI	Pearson Correlation	.139	1
	Sig. (2-tailed)	.375	
	N	43	43

DSI = Dynamic Strength Index. iDSI = Impulse-Based

Dynamic Strength Index