Comparison of methods of calculating dynamic strength index

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Abstract

Purpose: To determine the reliability and variability of dynamic strength index (DSI) calculated from squat jump (SJ) (DSI-SJ) versus countermovement jump (CMJ) (DSI-CMJ) peak force (PF) and to compare DSI values between methods. **Methods:** Male youth soccer and rugby league players (*n* = 27; age = 17.2 ± 0.7 years; height = 173.9 ± 5.7 cm; body mass = 71.1 ± 7.2 kg) performed 3 trials of the SJ, CMJ and isometric mid-thigh pull (IMTP), on two separate days. DSI was calculated by dividing the PF during each jump by the IMTP PF. **Results:** DSI-SJ exhibited moderate (intraclass correlation coefficient (ICC) = 0.419) within-session reliability and high variability (percentage coefficient of variation (%CV) = 15.91) during session one; however, this improved noticeably during session two (ICC = 0.948; %CV = 4.03). Contrastingly, DSI-CMJ showed nearly perfect within-session reliability (ICC = 0.920-0.952) and low variability (%CV = 3.80-4.57) for both sessions. Moreover, DSI-SJ values demonstrated a small yet significant increase between sessions (*P* = 0.01, *d* = 0.37), whereas only a trivial and non-significant increase was observed for DSI-CMJ between sessions (*P* = 0.796 *d* = 0.07). Between-session reliability was very high for the DSI-SJ (ICC = 0.741) and nearly perfect for the DSI-CMJ (ICC = 0.924). There was no significant or meaningful difference (*P* = 0.261; *d* = 0.12) between DSI-SJ (0.82 ± 0.18) and DSI-CMJ (0.84 ± 0.15). **Conclusions:** Practitioners should use DSI-CMJ as it is a more reliable measure than DSI-SJ, although it produces similar ratios.

Introduction

Strength has been shown to underpin performance in numerous athletic tasks,[1] including sprint,[2-4] jump[5, 6] and change of direction performance.[6-8] However, strength is commonly assessed using a variety of methods, including one repetition maximum (1RM) testing, during different compound exercises,[2-4, 6] and peak force (PF) assessed during the isometric mid-thigh pull (IMTP)[5, 9, 10] and the isometric squat.[11]

While 1RM assessments are easy to conduct, can be incorporated within scheduled training sessions, demonstrate high reliability[12, 13] and are regularly used to prescribe training intensity, such testing can be fatiguing and only provide a maximal load lifted. In contrast, minimal fatigue is likely to result from performance of the IMTP, and additional information regarding rate of force development (RFD) [14, 15], impulse, and force produced across specific epochs (e.g. 0-100, 0-150, 0-200 ms) can be determined [15-17]. Such information may provide the practitioner with greater information regarding the athlete's ability to express not only maximal force, but their ability to rapidly produce force. It is worth noting however, that the reliability of the RFD calculation during the IMTP has been questioned, with peak RFD over short epochs (2-50 ms) being suggested to be the most reliable of the available measures.[14]

To provide greater insight into an athlete's training status, the ratio of ballistic PF, produced during a squat jump (SJ) or a countermovement jump (CMJ), and PF during the IMTP has been discussed within the literature.[9, 10, 18-21] This ratio is commonly referred to as the dynamic strength index (DSI) or the dynamic strength deficit and has been reported to be highly reliable (intraclass correlation coefficient (ICC) 0.952-0.987) with low variability (2.01-4.60% coefficient of variation percentage (CV%)).[19, 22] Recommendations for interpreting the ratio suggest focusing on ballistic force production when the ratio is low (< 0.60) and maximal strength development when the ratio is high (> 0.80).[19] However, it is important to note that in athletes with low relative strength, developing relative strength may be more advantageous than focussing on achieving a specific ratio.[23, 24]

As the calculation of DSI using both PF attained during the SJ and CMJ has been reported within the literature, it is important to determine whether the differences in these methods affects not only the reliability and variability of the measures, but also the resultant DSI ratios. Due to the CMJ incorporating the stretch-shortening cycle (SSC), it is likely that the PF will be higher when compared to the PF attained during the SJ.[25, 26] Additionally, it is not clear from the studies that have used the CMJ, if the PF was obtained during the braking or propulsive phase which may affect the resultant PF,[9, 10, 20, 21] as the phase in which PF occurs differs between individuals. The aim of this study, therefore, was to determine the reliability and variability of DSI ratios when calculated based on PF attained during the SJ (DSI-SJ) and CMJ (DSI-CMJ) and to compare the resultant DSI values between methods. It was hypothesised that both methods would be reliable, both within- and between sessions, with greater values derived from DSI-CMJ due to the higher PF compared to the DSI-SJ calculation, due to the use of the SSC during the CMJ.

Methods

Subjects

Male professional youth soccer and rugby league players (*n* = 27; age = 17.2 ± 0.7 years; height = 173.9 ± 5.7 cm; body mass = 71.1 ± 7.2 kg) participated in this study. All participants provided written informed consent, with consent from the parent or guardian of all subject under the age of 18 years. The study procedures were approved by the University Institutional Review Board, and procedures conformed to the Declaration of Helsinki.

Procedures

To determine between session reliability, participants were assessed on two separate occasions, at the same time of day, 7 days apart. Testing was conducted within the first 4 weeks of the season, during which time all participants were in full training comprising all the elements of performance including four sport-specific skill based training sessions, plus two lower body resistance training sessions each week. At the time of testing, participants had completed a 4-week strength mesocycle and were in the middle of a 4-week power mesocycle.

All athletes rested the day before testing and were asked to attend testing in a fed and hydrated state, similar to their normal practices before training. On arrival, all participants had their height (Stadiometer; Seca, Birmingham, United Kingdom) and body mass assessed (Seca Digital Scales, Model 707), measured to the nearest 0.1 kg and 0.1 cm, respectively. After performing a standardized dynamic warm up, which they were familiar with from all previous off-field training sessions, they performed three maximal effort SJ and CMJ trials, followed by three IMTPs, with five minutes of rest between each test.

Data from the second day of testing was used to compare between DSI-SJ and DSI-CMJ and to determine any relationships between the two methods.

Jump Testing

Both the SJ and CMJ trials were performed with the subjects standing on a force platform (type: 9286AA, dimensions 600 mm x 400 mm, Kistler Instruments Inc., Amherst, NY, USA) sampling at 1000 Hz, interfaced with laptop computer running Bioware software (version 5.11, Kistler Instruments Inc., Amherst, NY, USA). Subjects were instructed to stand still for the initial one second of the data collection period (known as the silent period immediately prior to performing the jumps) [27, 28] to allow for the subsequent determination of body weight. The raw, unfiltered, vertical force-time data for each jump trial were exported as text files and analysed, in line with previous recommendations to minimise sources of error, [29] using a customised Microsoft Excel spreadsheet (version 2016, Microsoft Corp., Redmond, WA, USA).

All jumps were performed whilst the subjects kept their hands on their hips, with any jumps that were inadvertently performed with the inclusion of arm swing omitted and additional trials performed after one minute of rest. For the SJ, subjects were instructed to squat down to a self-selected depth (approximately 90°), pause for a count of three and then jump as fast and as high as possible, without performing any preparatory countermovement. Resultant force-time data was visually inspected to determine if any countermovement had been performed, and if it had, subjects repeated the trial after one minute of rest. Subsequent analysis of the SJ force-time data revealed that no trial exceeded the threshold used to determine a countermovement (five times the standard deviation of body weight, as derived during the silent period), [27, 30] as described below. For the CMJ subjects were instructed to aim to jump as high as possible, performing a rapid dip, to a self-selected depth, which they believed would achieve their greatest jump height. To aid the standardisation of instructions and procedures all, assessments were performed by the same experienced researcher.

The start of the jumps were identified in line with current recommendations where the onset of movement for each jump trial was considered to have occurred 30 milliseconds prior to the instant when vertical force had reduced (CMJ) or increased (SJ) by five times the standard deviation of body weight, as derived during the silent period.[27, 30] The interpretation of the CMJ force-time curves attained in this study is in line with recent research.[30] Instantaneous centre of mass (COM) velocity was calculated by dividing vertical force (excluding body weight) by body mass and then integrating the product using the trapezoid rule. The concentric phase of the CMJ and SJ was then defined as occurring between the instant at which COM velocity exceeded 0.01 $m \cdot s^{-1}$ and take-off.[30] The instant of take-off was defined as the instant in time when vertical force was less than five times the standard deviation of the flight force following the onset of movement.[27] It was important to clearly identify the concentric peak force (propulsive phase) during the CMJ rather than the eccentric peak force (braking phase) (Figure 1), to ensure that this is comparable with the SJ which has no eccentric phase. Concentric PF was defined as the maximum value attained during the propulsion phase of the jumps. Jump height was derived from vertical velocity at take-off with take-off.[28, 30]

[***Insert figure 1 here***]

Isometric Mid-Thigh Pull Testing

The IMTP was performed using a portable force platform (type: 9286AA, dimensions 600 mm x 400 mm, Kistler Instruments Inc., Amherst, NY, USA) sampling at 1000 Hz, interfaced with laptop computer running Bioware software (version 5.11, Kistler Instruments Inc., Amherst, NY, USA). Raw force-time was subsequently exported and analysed in a custom-made Microsoft Excel spreadsheet. Subjects adopted a posture which replicated the position at which they would start the second pull phase of the clean, with their knee and hip angles within 140-150°, in line with previous research.[31, 32] An immovable, collarless cold rolled steel bar was positioned around mid-thigh, just below the crease of the hip, using a portable IMTP rig (Fitness Technology, Adelaide, Australia). Once the bar height was established, the athletes stood on the force platform, and their hands were strapped to the bar using standard lifting straps. The height of the bar and the resultant joint angles were replicated between trials and between testing sessions.

Each athlete performed two warm-up pulls, one at 50% and one at 75% of the athlete's perceived maximum effort, separated by one minute of rest. Once body position was stable (verified by visual inspection of the force trace), the subject was given a countdown of "3, 2, 1, Pull." Minimal pretension was allowed to ensure that there was no slack in the subject's body or IMTP rig before initiation of the pull. Athletes performed three maximal IMTP, with the instruction to pull against the bar with maximal effort pulling as fast and hard as possible, and push the feet down into the force platform. Each maximal IMTP trial was performed for five seconds, and all athletes were given strong verbal encouragement during each trial. Two minutes of rest was given between the maximal effort pulls. Trials were repeated if the PF values varied by >250 N in line with previous research.[16, 17, 31, 32] The maximum force recorded from the force-time curve during the five-second IMTP trial was reported as the PF. Each of the 3 trials was used to determine within session reliability, with the mean of the best two trials, based on PF, used to compare between sessions, in line with previous research.[31, 32]

The DSI was calculated by dividing jump PF by IMTP PF, with DSI-SJ using PF from the SJ and DSI-CMJ using PF from the CMJ.

Statistical Analyses

Within- and between-session reliability of dependent variables was examined using the ICC, and typical error of measurement (TE) expressed as a CV%. A CV of ≤ 10% was considered to be reflective of acceptable variability.[33] Specifically, a two-way random effects model ICC was used to determine within- and between-session reliability (internal consistency), with paired samples t-tests and Cohen's *d* effect sizes used to determine if any differences occurred between days, between the two methods of calculating DSI (DSI-SJ and DSI-CMJ) and between PF achieved during the SJ and CMJ. Finally, Pearson's correlation was performed to determine the relationship between both methods of assessing DSI, based on the resultant values from the second day of testing, due to the higher reliability and lower variability observed.

To assess the magnitude of the ICC, the values were interpreted as low (<0.30), moderate (0.30-0.49), high (0.50-0.69), very high (0.70-0.89), nearly perfect (0.90-0.99), and perfect (1.0), respectively.[34] The magnitude of differences, as determined using Cohen's *d*, between sessions were classified as trivial (≤ 0.19), small (0.20 – 0.59), moderate (0.60 – 1.19), large (1.20 – 1.99), and very large (2.0 – 4.0).[35]

Normality of data was assessed by Shapiro–Wilk statistic and Q-Q plot analysis. Relationships between variables were determined using Pearson's product-moment correlation coefficients. Correlations were evaluated as follows: small (0.10 − 0.29), moderate (0.30 − 0.49), large (0.50 − 0.69), very large (0.70 − 0.89), nearly perfect (0.90 − 0.99), and perfect (1.0).[35] Statistical analyses were conducted using SPSS software (version 23.0; SPSS, Inc.) with an alpha level of $P \leq 0.05$.

Results

DSI-SJ showed poor to moderate within-session reliability and high variability during session one; however, this improved during session two resulting in nearly perfect within-session reliability and reduced variability (Table 1). In contrast, DSI-CMJ showed nearly perfect within-session reliability and low variability for both testing sessions. Moreover, DSI-SJ demonstrated a small yet significant increase between sessions, whereas there was only a trivial and non-significant increase in DSI-CMJ between sessions (Table 1). Between-session reliability was very high for the DSI-SJ (ICC = 0.741) and nearly perfect for the DSI-CMJ (ICC = 0.924).

[***Insert Table 1 here***]

There was no significant or meaningful difference ($P = 0.261$; $d = 0.12$) between DSI-SJ (0.82 ± 0.18) and DSI-CMJ (0.84 ± 0.15) (Figure 2), with a trivial and non-significant difference ($P = 0.272$; $d = 0.19$) in PF between the SJ (1789 ± 350 N) and the CMJ (1854 ± 345 N). The results of Pearson's correlation analysis showed a very large positive relationship ($r = 0.797$; $R^2 = 0.635$) between DSI-SJ and DSI-CMJ (Figure 3).

[***Insert figure 2 here***]

[***Insert figure 3 here***]

Discussion

This study examined the reliability and variability of DSI-SJ and DSI-CMJ and compared the resultant DSI values between methods. The DSI-SJ demonstrated improved reliability and reduced variability between sessions, with a small and significant increase in values between sessions. In contrast, there was no notable change in reliability and variability, or any meaningful or significant change in DSI-CMJ between sessions (Table 1), highlighting that DSI-CMJ is a more stable method of assessing DSI compared to DSI-SJ. In contrast to our hypotheses, there was no meaningful or significant difference between DSI-SJ and DSI-CMJ, with strong associations between DSI values determined using either method.

The greater variability and lower reliability observed for DSI-SJ is likely due to the difficulties associated with subjects consistently performing the SJ, without any countermovement, while attempting to jump as high as possible from a static squat position. It is therefore plausible that greater familiarisation with the SJ is required, which is likely to improve the reliability and reduce the variability of the performances, as observed during the second day of testing. In line with previous observations,[25, 26] the inclusion of the countermovement during the CMJ resulted in a higher PF (3.6%) than that observed during the SJ, although this difference was trivial and non-significant. This non-significant difference in PF between the CMJ and SJ explain the trivial and non-significant differences in DSI-CMJ and DSI-SJ. In contrast, and as expected, a moderate and significantly greater jump height (12%) was achieved during the CMJ compared to the SJ, most likely due to the utilisation of the SSC resulting in increased force from the neurological potentiation and contribution from the elastic components.

The reliability and variability values in the current study are in line with those previously reported,[19, 22] although the reliability of the DSI-SJ from session one shows notably lower reliability and much higher variability than presented in previous research.[19, 22] This higher variability in the DSI-SJ, during session one, with an increased reliability and reduced variability during session two suggests a potential learning effect during the SJ. However, further research is needed to examine potential learning effects on SJ performance.

Given that CMJ testing is one of the most commonly used tools in athlete monitoring, it may be preferable to use DSI-CMJ ratios compared to DSI-SJ. In addition to DSI, the CMJ offers the opportunity to assess a variety of other performance characteristics that may not be possible with the SJ, namely the reactive strength index-modified.[36] Measuring both DSI and reactive strength index-modified will allow practitioners to assess both isometric and dynamic force production as well as the ability to utilise the SSC, respectively.[37] Such an approach may provide a more comprehensive assessment of an athlete's force production qualities.

The use of only three trials for each of the jumps, especially during the initial testing session, is a potential limitation of this investigation, due to the low reliability and high variability observed during the SJ. While such an approach is ecologically valid, and in line with applied practice, it is suggested that future research consider applying a similar approach to that commonly used with the IMTP, [16, 17, 31, 32] where a specific force threshold (<250 N) is used to determine if trials are acceptable. Additionally, future research should adopt a precise method to determine and standardise the squat depth during the performance of the SJ, which may aid in improving reliability and reducing variability of such performance.

Practical Applications

The results of the current study provide options to practitioners who would like to use DSI as an athlete monitoring tool. Both DSI-CMJ and DSI-SJ are reliable measures that give practitioners information regarding the ability of an athlete to produce maximal force during isometric and dynamic tasks. However, DSI-CMJ may provide a more consistent measurement as compared to DSI-SJ due to potential learning effects. Moreover, utilising a CMJ as opposed to a SJ may allow for the assessment of other force production characteristics.

Based on previous recommendations,[19] it would appear that the athletes in the current study, on average, should focus on developing greater levels of muscular strength. However, it is important to note that training recommendations should be made on an individual basis. In addition, practitioners should be aware that while DSI ratios may help guide training decisions, a paucity of research has been completed on the long-term monitoring of DSI during lower and upper body tasks. Thus, further research is needed that focuses on how specific types of training affect DSI ratios and how DSI ratios relate to other sport performance characteristics.

Conclusions

Based on the results of the current study it is suggested that DSI ratios are calculated based on PF during the propulsion phase of the CMJ, as this is more reliable and less variable compared to PF during the SJ. In addition, it is also easier to standardise performance of the CMJ compared to ensuring that athletes do not initiate the SJ with any form of countermovement.

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Table and Figure Legends

Figure 1: Illustration of the identification of the specific phases of the CMJ. The **dark line** represents force, while the grey line represents velocity of the centre of mass

Figure 2: Comparison of DSI calculated from SJ and CMJ peak force

Figure 3: Relationship between DSI calculated from SJ and CMJ peak force

Table 1: Descriptive statistics (mean ± standard deviation), within- and between-session reliability (ICC) and variability (CV%) of DSI calculated from peak force during the SJ and CMJ

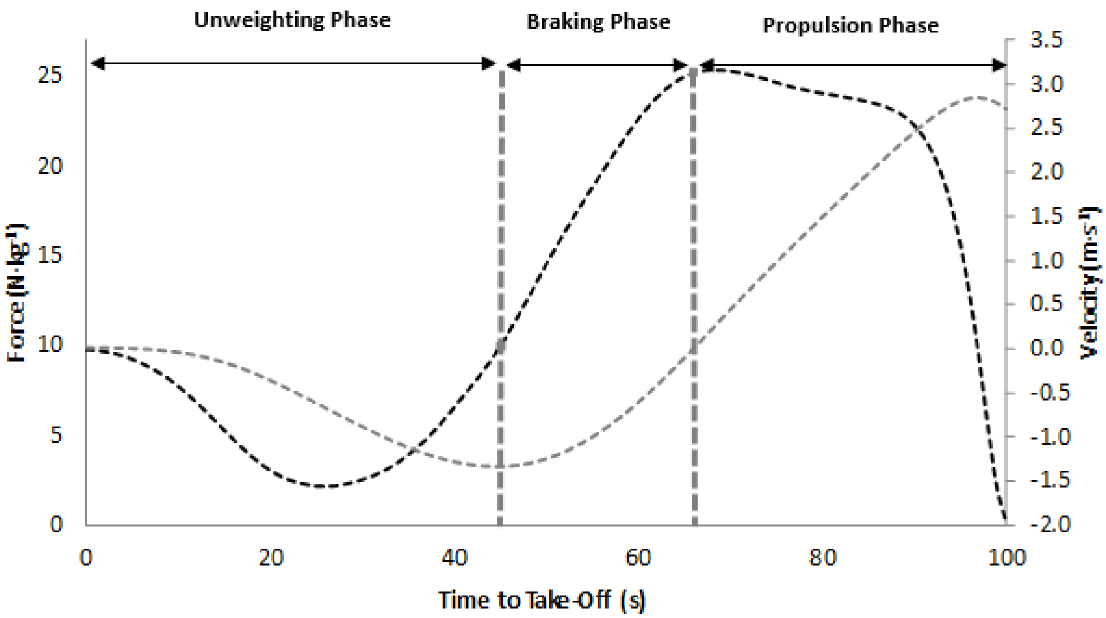

Figure 1: Illustration of the identification of the specific phases of the CMJ. The dark line represents force, while the grey line represents velocity of the centre of mass

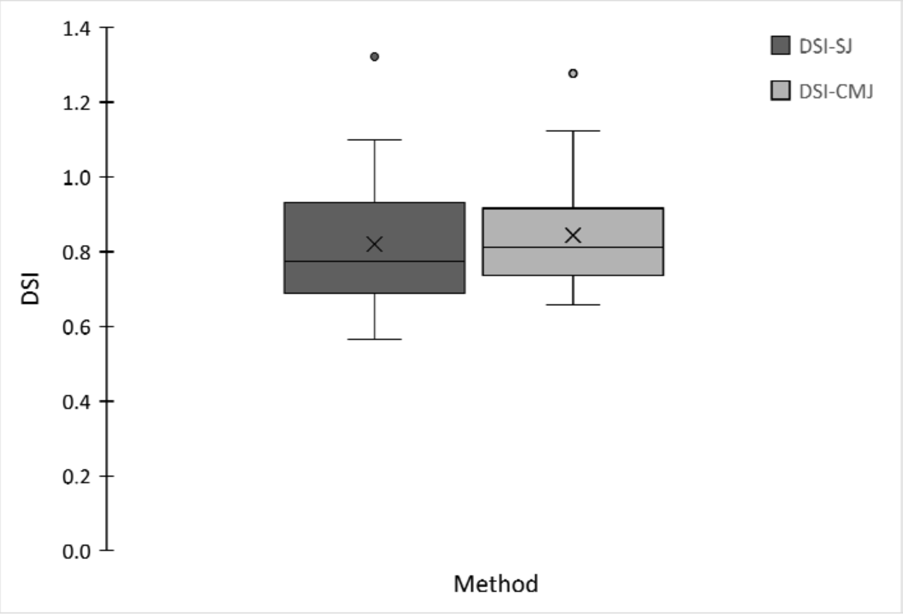

Figure 2: Comparison of DSI calculated from SJ and CMJ peak force

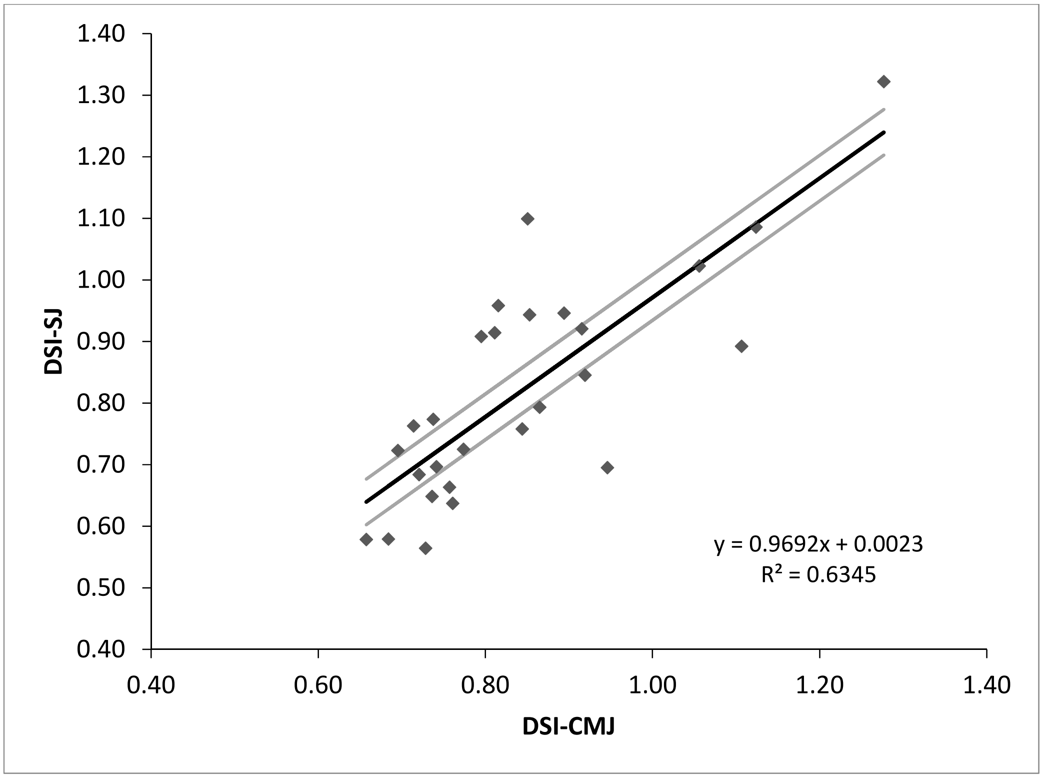

Figure 3: Relationship between DSI calculated from SJ and CMJ peak force (Grey lines depict upper and lower 95% confidence limits)