A Novel Approach for Athlete Profiling: The Unilateral Dynamic Strength Index

ABSTRACT

The dynamic strength index (DSI) provides a ratio of the peak force an athlete can produce in both isometric and ballistic tasks. While the DSI measured during bilateral tests has been examined, unilateral DSI scores have not been reported to date and thus was the aim of the present study. Twenty-eight recreational sport athletes performed three trials of a unilateral isometric squat and countermovement jump (CMJ) to measure peak force in each task across two separate test sessions. The unilateral DSI was calculated using both left vs. right and dominant vs. non-dominant limbs. Good to excellent reliability was shown in the isometric squat (ICC = 0.86-0.96; CV ≤ 5.7%) and the CMJ (ICC = 0.83-0.93; CV ≤ 5.8%) on both limbs. The DSI showed moderate to good reliability (ICC = 0.71-0.79; CV = 7.54-11.9%). DSI scores of 0.52-0.55 and 0.55-0.59 were reported on the left and right limbs respectively, with no significant differences reported between limbs. A significant difference (p = 0.04) was seen for the CMJ between left and right during the second test session only. The dominant and non-dominant limbs reported mean DSI scores of 0.53-0.57, and significant differences were evident between limbs in both the isometric squat and CMJ ($p < 0.01$). The present study provides normative data for the unilateral DSI and indicates acceptable levels of reliability, while the consistency of individual measures of peak force can be considered good when quantified unilaterally.

Key Words: Unilateral, strength, power, testing, ratio

INTRODUCTION

When assessing the physical performance of athletes, it is common for practitioners to implement fitness testing procedures at various times of the training and competitive season. For team sport athletes, this process often takes place ~3 times annually with routine pre, mid, and post-season fitness testing conducted to provide an indication of baseline test scores and how these are being maintained throughout the season (31,32). While the needs analysis of a sport will largely dictate which physical qualities are required for testing, little argument exists as to the necessity for enhanced strength and power capacities for team sport athletes (9,14,34). With increased strength being suggested as an effective tool for protecting against injuries (27,28) and power positively associated with speed and change of direction speed (22,35), their assessment has become commonplace in sport research and practice. Typical tests include the isometric squat or mid-thigh pull for strength (10,15,29) and countermovement jumps (CMJ) for power (21,23), both of which have been suggested to be time-efficient methods for assessing and detecting meaningful differences for these physical qualities (18).

Given that both strength and power are frequently assessed in athlete test batteries, recent literature has highlighted the use of a Dynamic Strength Index (DSI) which provides a ratio of the peak force (PF) an athlete can produce in both isometric and ballistic tasks (25,30). The DSI is calculated by dividing the PF attained during either a squat jump (SJ) or CMJ by the PF during either an isometric squat or mid-thigh pull (7). Thus far, normative data suggests that scores between 0.7-0.8 are typical for both elite and sub-elite athletes (7,25,30), although it is not fully understood if this is optimal. Comfort et al. (7) reported that the use of either jump produced similar DSI ratios, but the CMJ should be the preferred type of vertical jump due to its enhanced reliability. In addition, literature has highlighted that both the isometric squat and mid-thigh pull are reliable for quantifying PF (10,15,29); however, the isometric squat may be the preferred option for assessing maximum lower limb strength due to its capacity to derive greater PF scores than the mid-thigh pull (4). In addition, athletes who are unfamiliar with pulling movements associated with weightlifting may find the action of 'pushing' during an isometric squat more favourable also.

The DSI has provided a useful tool for practitioners to assess strength and power qualities; however, current data only exists for bilateral testing. While the expression of force will always be greater on two limbs than one, multiple movement demands for team sport athletes are performed unilaterally such as sprinting, jumping, and changing direction (2). Thus, testing protocols should reflect the movement demands athletes are exposed to and quantifying the DSI for each limb separately may highlight existing strength and power discrepancies which may subsequently inform program design for practitioners.

The aims of the present study were to quantify the reliability of the unilateral isometric squat and CMJ PF in respect to reporting separate DSI ratios for right vs. left and dominant vs. non-dominant limbs. This provided data for the unilateral DSI which does not exist to date and could help practitioners make informed decisions about its utility. It was hypothesised that each test would display acceptable levels of reliability and that significant differences would exist between limbs for the DSI.

METHODS

Experimental Approach to the Problem

This study used a test-retest design enabling within and between-session reliability statistics to be computed for both PF measures during the unilateral isometric squat, CMJ, and DSI. When quantifying asymmetries, it has been shown that inter-limb differences rarely correspond between left vs. right and dominant vs. non-dominant limbs (11); thus, unilateral DSI scores were calculated both ways. Differences between limbs for PF were computed via paired samples *t*-tests with percentage change and effect sizes also computed. To the authors' knowledge, no study to date has investigated the unilateral DSI and with the heightened levels of instability associated with unilateral training (2), reporting on its reliability was critical to understand its future applicability for practitioners.

Subjects

Twenty-eight recreational male soccer and rugby athletes (age = 27.29 ± 4.6 years; mass = 80.72 ± 9.26 kg; height = 1.81 ± 0.06 m), with a minimum of 5 years' experience competing in their respective sport volunteered to participate in this study. A minimum of 27 participants was determined from a priori power analysis using G*Power (Version 3.1, University of Dusseldorf, Germany) implementing statistical power of 0.8 and a type 1 alpha level of 0.05 which has been used in comparable literature (10). Participants were required to attend on three occasions, inclusive of a familiarization and two experimental test sessions; all of which were separated by one week. Participants were required to complete informed consent forms to demonstrate that they were willing and able to undertake all testing protocols. Inclusion criteria required all participants to have a minimum of six months resistance training experience, with any participant excluded from the study if they had experienced a lower body injury at the time of testing. Ethical approval was granted from the appropriate research and ethics committee.

Procedures

Each participant performed three trials on each limb for the unilateral isometric squat and CMJ in a test-retest design; on a single force platform (PASPORT force plate, PASCO Scientific, California, USA) sampling at 1000 Hz. Test order was randomized so as to minimize the potential effects of fatigue for any one test. During the familiarization session, participants were provided with the relevant test instructions and instructed to practice each assessment until they reached a satisfactory level of technical competence and to reduce any learning effects. This was also assessed by an accredited strength and conditioning coach throughout. A standardized dynamic warm up was conducted prior to each session consisting of a wide variety of dynamic stretches (focusing on mobilising the ankles, hips, and thoracic spine) and three practice trials at 60, 80, and 100% perceived effort for each test. Three minutes of rest was provided after the final warm up trial before undertaking the first trial during the isometric squat.

Unilateral Isometric Squat. A custom built ‘ISO rig’ (Absolute Performance, Cardiff, UK) was used for this test protocol (Figures 1a and 1b). A goniometer was used to measure 140° of hip and knee flexion for each participant, with full extension of the knee joint equalling 180°. These angles were chosen in line with previous suggestions for this test (2,15), and previous literature pertaining to the DSI as well (7). Furthermore, these angles represented a relatively small amount of flexion at the hip and knee joints, which is likely favourable given the added instability of being on one limb. The fulcrum of the goniometer was positioned on the lateral epicondyle of the femur. The stabilisation arm was lined up along the line of the fibula (in the direction of the lateral malleolus) and the movement arm was lined up with the femur (pointing towards the greater trochanter at the hip). Subjects were instructed to position their stance foot directly underneath the steel bar (which was made clear during test familiarization), and position the bar on the upper trapezius as per typical high-bar back squat technique. The non-stance limb was required to hover next to the working limb, so as to try and keep the hips level during the isometric squat action; thus, aiding balance and stability. Once in position, participants were required to remain motionless for 2-seconds, without applying any upwards force (which was verified by manual detection of the force-time curve in real time). Each trial was then initiated by a "3, 2, 1, Go" countdown and participants were instructed to try and extend their knees and hips by driving up as "fast and hard as possible" (10) against the bar for three seconds. PF was defined as the maximum force generated during the test.

*** INSERT FIGURES 1a AND 1b ABOUT HERE ***

Unilateral Countermovement Jump. Participants were instructed to step onto the force plate with their designated test leg with hands placed on hips which were required to remain in the same position for the duration of the test. The jump was initiated by performing a countermovement to a self-selected depth before accelerating vertically as explosively as possible into the air. Legs were required to remain fully extended throughout the flight phase of the jump before landing back onto the force plate as per the set up. The uninvolved limb was required to remain slightly flexed at the hip and knee joint, so as to appear hovering next to the jumping limb and similar to test requirements for the isometric squat protocol. Each trial was separated by 60 seconds of rest. PF was again defined as the maximum force output during the propulsive phase of the jump.

Statistical Analyses

Initially all force-time data were exported to Microsoft Excel™, expressed as means and standard deviations (SD), and later transferred into SPSS (V.24, Chicago, IL, USA) for additional analyses. Normality was assessed via the Shapiro-Wilk test. Within-session reliability was quantified for each metric in both test sessions using the coefficient of variation (CV: SD[trials 1-3]/average[trials 1-3]*100), intraclass correlation coefficient (ICC) with absolute agreement, and standard error of the measurement (SEM). CV values < 10% were deemed acceptable (8) and ICC values were interpreted in line with suggestions by Koo and Li, (17) where scores > 0.9 = excellent, 0.75-0.9 = good, 0.5-0.75 = moderate, and < 0.5 = poor. The SEM was calculated using the formula SD x $\sqrt{1\text{-ICC}}$ (31). For between-session reliability, a pooled CV was computed as an average of the two values from both test sessions and best scores were used to calculate an ICC with absolute agreement. Paired samples *t*-tests were used to determine whether significant differences were present between limbs with statistical significance set at $p < 0.05$. These differences calculated for both left vs. right and dominant vs. non-dominant limbs, where dominance was defined as the limb with the greatest score (10). Finally, Cohen's *d* effect sizes were also calculated as ($Mean_R$ – $Mean_L$ / SD_{pooled}) or ($Mean_D$ – $Mean_{ND}$ / SD_{pooled}) to examine the magnitude of these differences and were interpreted in line with a previously suggested scale by Rhea (23) where trivial = < 0.25, small = 0.25-0.50, moderate = 0.50-1.0, and large = > 1.0.

RESULTS

All data were normally distributed ($p > 0.05$) and within and between-session reliability data is presented for each test and both test sessions (Table 1). The isometric squat showed excellent within-session reliability for PF (ICC range = 0.93-0.96) and acceptable consistency (CV values ≤ 5.7%) on both limbs. The CMJ showed good to excellent within-session reliability in both sessions (ICC = 0.89-0.93) with all CV values ≤ 5.83%. Between-session reliability results were similar in both tests. The isometric squat showed good to excellent reliability (ICC = 0.86-0.93; pooled CV = ≤ 5.6%) and the CMJ good reliability (ICC = 0.83-0.85; pooled CV = ≤ 5.35%) on both limbs. Between-session reliability of the DSI was computed (Table 2) and showed moderate to good reliability (ICC = 0.71-0.79). Pooled CV values for the DSI were (10.45-11.90%) when defining limbs as left vs. right, but noticeably better when defining via dominance (7.54-8.42%). Mean PF data and DSI values are presented for right vs. left (Table 3) and dominant vs. non-dominant limbs (Table 4). When limbs were defined as left vs. right, *t*-tests showed a significant difference ($p = 0.04$) between limbs during the CMJ in session two; no other significant differences were present and all effect sizes were trivial (≤ 0.2). However, when defined via dominance, significant differences ($p < 0.01$) were noted between limbs for both the isometric squat and CMJ in both test sessions; with effect sizes being trivial to small (≤ 0.38).

*** INSERT TABLES 1-4 ABOUT HERE ***

DISCUSSION

The aim of the present study was to determine the within and between-session reliability of PF measures and the unilateral DSI. Results showed good to excellent reliability for PF and high consistency during both test sessions. Between-session reliability for the DSI was moderate to good; however, greater consistency was noted for the DSI when defining limbs via dominance rather than left vs. right indicating this method should be used for strength and power assessment.

Within and between-session reliability data for the isometric squat and CMJ are presented in Table 1. The isometric squat showed excellent within-session reliability (ICC = 0.93-0.96) for both limbs and acceptable consistency (CV = ≤ 5.7%) during both test sessions. Between-session reliability was good to excellent (ICC = 0.86-0.93) with pooled CV values ≤ 5.6%. These data highlight that PF is a very useable metric for assessing lower limb maximal strength when quantified unilaterally. This is in line with previous research where Hart et al. (15) reported excellent reliability (ICC = 0.96-0.98; CV = ≤ 5%) during the unilateral isometric squat, also in recreational sporting subjects. Comparable research has also been conducted using the isometric mid-thigh pull (10,30), reporting this test to be reliable when quantifying PF unilaterally as well. Thus, it would appear that both variations of measuring isometric strength can be used to quantify PF. However, the isometric squat has been shown to provide greater PF scores when compared with the mid-thigh pull (4), and knowing greater PF values will affect the DSI score, it is suggested that the isometric squat could be the preferred option.

CMJ within and between-session reliability data is presented in Table 1. Similar to the isometric squat, within-session reliability was good to excellent (ICC = 0.89-0.93) and reported acceptable consistency (CV = ≤ 5.83%). Between-session reliability was good (ICC = 0.83-0.85) with acceptable pooled CV values also. These data suggest that PF is a useful metric to monitor during jump assessments from force plates, this also in line with previous suggestions (5,8,12). In addition, a significant difference (p = 0.04) was present between limbs for PF during the second test session, when limbs were quantified as left and right. Despite this significance not being present in the first session, effect sizes were almost identical for both sessions.

Higher variability was shown between sessions in the DSI (Table 2) compared to individual measures of PF. This is somewhat expected because the DSI is a resultant ratio created from two different tests and the associated error from both (isometric squat and CMJ) will impact the ratio's reliability. That said ICC's (0.71-0.79) can still be considered acceptable. It is interesting to note that improved variability is apparent when limbs are defined via dominance (7.54-8.42%) rather than left vs. right (10.45-11.9%), which may be because dominance was defined as the limb with the greatest score, in line with previous suggestions (10). This is likely a more appropriate method of defining limb dominance, given previous literature has highlighted limited consistency between left vs. right and limb dominance scores during the same tests (11). Furthermore, this definition resulted in significant differences ($p < 0.01$) being seen between limbs for both the isometric squat and CMJ tests (Table 4). This is expected given the data were organised in terms of maximum (dominant) and minimum (non-dominant) values. When analysed as left vs. right, inconsistencies may exist as to which score produced the largest value, which is more than likely given the similar DSI scores.

In respect to the DSI (Tables 3-4), results remained consistent in both test sessions which is likely due to the strong reliability of PF metrics in each test. To the authors' knowledge, this is the first study to report unilateral DSI values; thus, a true comparison with additional literature is not possible. Previous literature has highlighted DSI scores between 0.7-0.8 (7,25,30), and intuitively, it may be assumed that each unilateral score would be approximately half this. However, as the present study reports, these values were substantially greater than half of previous bilateral DSI values. The relevance here is that the potential for force production may be greater on one limb when comparing against the same limb during a comparable bilateral task, as in the present study (26). Therefore, in sports (such as soccer, rugby, or basketball) where sprinting, changing direction, and jumping frequently occur unilaterally, practitioners may wish to consider adding unilateral strength and jumping exercises into their athlete training programmes if they do not already do so.

However, from a monitoring perspective, further research is definitely warranted in an attempt to truly establish whether an optimal ratio exists during both bilateral and unilateral versions of the DSI.

Further to this, the addition of knowing limb differences in DSI scores may also have useful implications on athlete programme design. Previous research has highlighted that unilateral training may be favourable when reducing inter-limb differences (3,13). Gonzalo-Skok et al. (13) compared bilateral and unilateral strength and power training interventions over a 6-week period in youth male basketball players. Each group was required to perform bilateral or unilateral squats, CMJ, and drop jumps; depending on the group they were assigned to. For the bilateral group, a reduction in asymmetries from 6.9 to 4.4% was reported. However, the unilateral group showed substantially larger reductions in asymmetries from 9.6 to 4.8% (13). Thus, if practitioners choose to incorporate the unilateral DSI as part of their routine athlete monitoring process and find notable limb differences, previous research may indicate that the use of unilateral training can assist in reducing these imbalances (3).

Despite the usefulness of these findings, a few limitations should be acknowledged. Firstly, with the present study being the first to report unilateral DSI data, the findings are only applicable to the present sample; thus, practitioners are encouraged to establish their own DSI values. In addition, the present study only assessed PF at one joint angle (140°) during the isometric squat. Previous research has highlighted that force production reduces with greater hip and knee flexion in the isometric mid-thigh pull test (6). Although a different test, it seems plausible to suggest that the isometric squat would show a similar pattern. The relevance here being that reductions in PF during the strength assessment would impact the resultant DSI ratio. Thus, future research should aim to establish how the DSI changes across a range of isometric squat depths. Finally, previous research has highlighted the importance of verbal instructions during isometric test protocols (19). The present study instructed subjects to push as 'fast and hard as possible' which may have been more akin to improvements in rate of force development (19), given the first instruction was to push fast. Consequently, if the goal is to establish PF, practitioners may wish to provide more focus on pushing hard and potentially over a greater time frame (i.e., 5 seconds).

In summary, unilateral measures of PF using the isometric squat and CMJ show good to excellent reliability which in turn, supports the use of a unilateral DSI. Given that many sporting actions occur unilaterally, this can be considered as a viable and useful method for practitioners when strength and power assessments are being conducted.

PRACTICAL APPLICATIONS

The present study provides data on the unilateral DSI for practitioners who choose to assess an athlete's PF ability during isometric and ballistic tasks. Previous literature has highlighted PF asymmetries during tests used in the present study between 6-12% (1,15,16,21). Consequently, if significant differences are present in DSI scores between limbs, it is plausible that these differences could be exacerbated further if notable asymmetries exist. With that in mind, if practitioners establish meaningful differences in DSI scores, the principle of applying supplementary strength or power training for one limb may assist in evening out strength or power imbalances. This is supported in a recent critical review on asymmetry which highlighted that the very definition of this term suggests that the weaker limb has a greater 'window of opportunity' when aiming to reach its theoretical ceiling (20). Furthermore, given this is the first study to report unilateral DSI scores, an optimal value cannot be suggested; however, it is suggested that the application of strength and power interventions is prescribed where necessary to minimize large differences in DSI scores between limbs. Future research should aim to establish if unilateral DSI scores are related to measures of physical performance, which may further its usefulness as a means of subsequent data analysis in respect to strength and power assessments.

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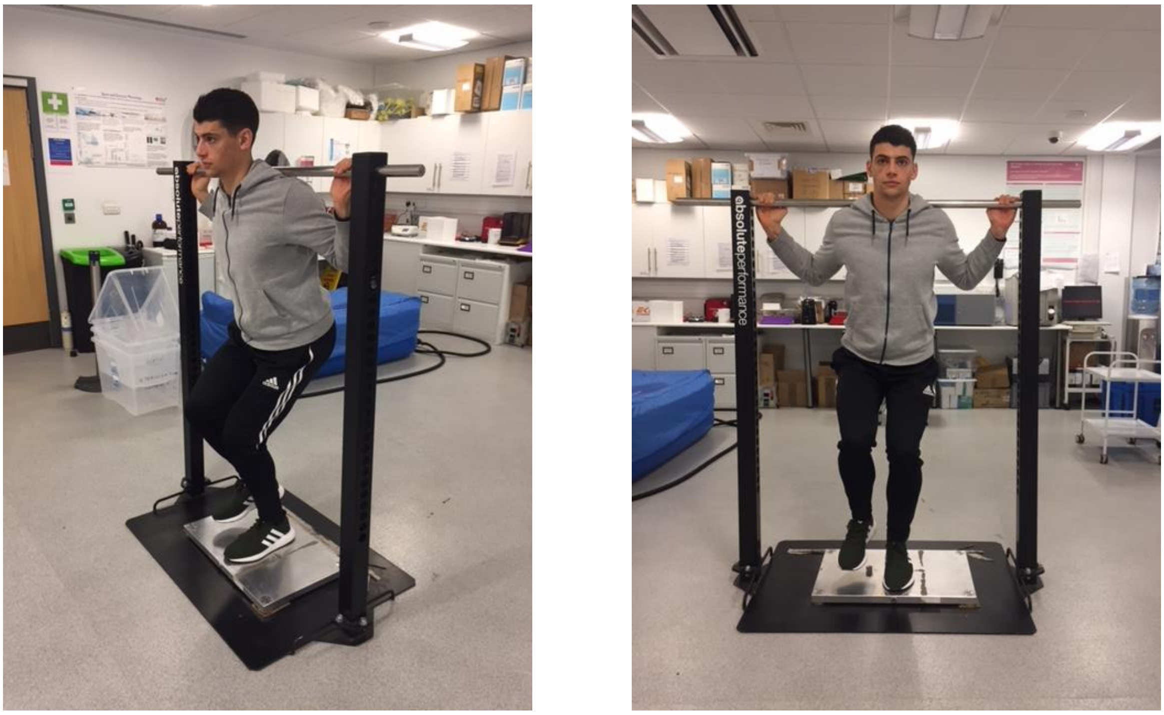

Figures 1a and 1b: Example positioning for the unilateral isometric squat protocol

Table 1: Within and between-session reliability data for peak force during the isometric squat and countermovement jump tests

	Session 1			*Session 2*			*Between Session*	
Metric	**ICC (95% CI)**	**SEM**	**CV (%)**	**ICC (95% CI)**	**SEM**	**CV (%)**	**ICC (95% CI)**	**Pooled CV (%)**
ISO Squat:								
Peak force (L)	0.94 (0.88-0.97)	107.52	5.44	0.96 (0.92-0.98)	78.84	4.86	0.93 (0.86-0.97)	5.15
Peak force (R)	0.93 (0.87-0.96)	105.12	5.70	0.94 (0.89-0.97)	106.16	5.49	0.86 (0.72-0.93)	5.60
CMJ:								
Peak force (L)	0.89 (0.80-0.94)	67.65	5.83	0.93 (0.88-0.97)	42.94	4.86	0.85 (0.71-0.93)	5.35
Peak force (R)	0.93 (0.87-0.96)	48.03	5.30	0.90 (0.82-0.95)	50.18	5.03	0.83 (0.67-0.92)	5.17

ICC = intraclass correlation coefficient, CI = confidence intervals, SEM = standard error of the measurement, CV = coefficient of variation, ISO = isometric, CMJ = countermovement jump, L = left, R = right

Table 2: Between-session reliability for the Dynamic Strength Index

	ICC (95% CI)	**Pooled CV (%)**
Dynamic strength index (left)	0.76 (0.54-0.88)	10.45
Dynamic strength index (right)	0.71 (0.47-0.85)	11.90
Dynamic strength index (dominant)	0.71 (0.47-0.86)	8.42
Dynamic strength index (non-dominant)	0.79 (0.59-0.89)	7.54
ICC = intraclass correlation coefficient, CI = confidence intervals, CV = coefficient of variation		

Table 3: Mean scores (expressed in newtons) and standard deviations (SD) for left and right limbs.

	ISO Squat (L)	**CMJ (L)**	**ISO Squat (R)**	**CMJ (R)**	**ISO Squat ES**	**CMJ ES**
Mean scores (S1)	1597.01 (438.93)	863.36 (203.97)	1595.14 (397.31)	830.79 (181.53)	< 0.01	0.17
Mean scores (S2)	1631.30 (394.19)	846.96 (162.30)[a]	1643.20 (433.40)	818.64 (158.69)	< 0.01	0.18
Percentage Change	-2.1	1.9	-3.0	1.5	-	-
Mean DSI (S1)	0.59 (0.26)		0.55 (0.17)		0.19	
Mean DSI (S2)	0.55 (0.16)		0.52 (0.14)		0.20	

[a] indicates significantly greater than CMJ on right limb in session 2 (p = 0.04)

ISO = isometric, CMJ = countermovement jump, L = left, R = right, ES = effect size, S = session, DSI = dynamic strength index

Table 4: Mean scores (expressed in newtons) and standard deviations (SD) for dominant and non-dominant limbs.

	ISO Squat (D)	CMJ (D)	ISO Squat (ND)	CMJ (ND)	ISO Squat ES	CMJ ES
Mean scores (S1)	1661.80 (408.67)[a]	883.43 (212.05)[a]	1530.35 (417.79)	810.71 (165.54)	0.32	0.19
Mean scores (S2)	1711.70 (405.30)[a]	862.50 (167.28)[a]	1562.79 (409.30)	803.11 (148.76)	0.37	0.38
Percentage Change	-3.0	2.4	-2.1	0.9	-	-
Mean DSI (S1)	0.57 (0.21)		0.57 (0.21)		< 0.01	
Mean DSI (S2)	0.53 (0.15)		0.54 (0.15)		0.07	

[a] indicates significantly greater than non-dominant limb ($p < 0.01$)

ISO = isometric, CMJ = countermovement jump, D = dominant, ND = non-dominant, ES = effect size, S = session, DSI = dynamic strength index