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Impulse-Based Dynamic Strength Index: Considering Time-Dependent Force Expression

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Abstract

Haischer, MH, Krzyzkowski, J, Roche, S, and Kipp, K. Impulse-based dynamic strength index: considering time-dependent force expression. *J Strength Cond Res* 35(5): 1177–1181, 2021—The dynamic strength index (DSI) is a useful tool to assess an athlete's capacity to effectively use maximum strength during dynamic tasks. Although DSI is traditionally calculated based on peak forces, the ability to express force over time (i.e., impulse) is a better predictor of dynamic performance. The purpose of this study was to investigate the association between DSI calculated based on peak force (fDSI) and impulse (iDSI). Nineteen female collegiate lacrosse players performed countermovement jumps (CMJs) and isometric midhigh pulls (IMTPs). Peak force and impulse were extracted from CMJ and IMTP force-time data. Countermovement jump impulse was calculated by integrating force over the concentric movement time, whereas IMTP impulse was calculated by integrating force over the CMJ-matched movement time. Ratios between CMJ and IMTP peak force and impulse were used to calculate fDSI and iDSI, respectively. A moderate positive correlation existed between iDSI and fDSI ($\rho = 0.644$ [0.283–0.840], $p = 0.003$). Based on thresholds established in the literature, the 2 indices suggest conflicting training recommendations for 37% of athletes. Because impulse is a better predictor of dynamic performance, iDSI may represent a more valid method for assessing an athlete's capacity to effectively use maximum strength during dynamic tasks. Practitioners and researchers may want to consider augmenting current training and research practices with an impulse-based DSI.

Introduction

The dynamic strength index (DSI) is defined as the ratio between peak forces produced during dynamic and isometric tasks. The DSI is often used to assess the current training status and to identify performance deficits of athletes (^{1,11,12,14,16}). With respect to lower-body assessments, DSI testing typically involves the countermovement jump (CMJ) and isometric midhigh pull (IMTP)—the resulting DSI is extremely reliable and has low variability (^{3,15}). Researchers and practitioners have proposed DSI thresholds to inform training foci (¹²). Specifically, it has been suggested that athletes with a DSI below 0.60 should focus on training the athlete's capacity to express their strength during dynamic tasks, whereas athletes with a ratio above 0.80 should focus on training maximal force production (¹²). Research suggests that DSI is related to CMJ curves using temporal phase analysis (⁹) and that DSI can be modified with training (e.g., a decrease in DSI is achieved with a focus on training maximal strength (⁴)). Dynamic strength index therefore seems to be a useful variable, which can help assess and track an athlete's capacity to express force during dynamic tasks.

Although previous literature demonstrated the usefulness of DSI for monitoring athletes (^{1,3,4,9,11,12,14–16}), more recent work has also emphasized the need to contextualize DSI scores to optimize training among individuals (¹³). Indeed, the use of discrete peak force in the DSI formula neglects temporal aspects of force production and does not reflect an athlete's ability to express force in the time domain (i.e., impulse). Moreover, peak force may be a poor predictor of CMJ performance compared with impulse (^{6,8}). Thus, the ability to effectively produce force over time is likely a better predictor of dynamic performance during the CMJ than the ability to produce a high peak force. Dynamic tasks are also often executed over shorter periods than those that are necessary to ramp-up to peak force during a maximal strength test. For example, although CMJ movement time is less than one second (⁶), IMTP trials may last up to 3 seconds (²). Consequently, even if occurring early in the trial, IMTP peak force may occur well after the time window available for force production during dynamic tasks.

Although impulse is a better predictor of vertical jump performance (^{6,8}), a problem with calculating DSI in the time domain is choosing a valid time interval for integrating force. Here, we address this problem with a novel method for calculating DSI based on the ratio of impulse during the CMJ and IMTP. The novelty of the method is that the integration time for the calculation of impulse during the IMTP is based on concentric (i.e., propulsive) movement time during the CMJ. Given that this time reflects the duration over which athletes produce

concentric force during a typical dynamic task, one would hypothesize that the subsequent impulse-based DSI (iDSI) ratios represent better functional and more ecologically valid estimates of the athletes' training status than force-based DSI (fDSI) ratios. Considering that greater peak forces do not necessarily translate into greater impulse or better performance (⁶), calculating and monitoring iDSI in addition to fDSI may be valuable, especially if the 2 DSI metrics are not strongly correlated with each other. In this case, contextualizing fDSI with a similar metric of individualized time-dependent force expression (i.e., iDSI) could help to clarify recommendations and better optimize training programs. Therefore, the purpose of this study was to investigate the association between DSI calculated based on peak force (fDSI) and impulse (iDSI). We hypothesized that fDSI and iDSI would exhibit a significant, but imperfect, correlation with one another, indicating that monitoring both metrics may be of use to performance practitioners attempting to optimize training among individual athletes.

Methods

Experimental Approach to the Problem

A cross-sectional study was used to explore the strength of the association between fDSI and iDSI and whether they provide congruent training recommendations based on the previous literature (¹²). Members of an NCAA Division I lacrosse team were recruited for one day of data collection. Players performed maximal effort CMJ and IMTP, with peak forces and impulses extracted from force plate data. Within-subject averages were used to create fDSI and iDSI values for each player, and the association between the 2 ratios was explored using correlation analysis.

Subjects

Nineteen female subjects (age: 19 ± 1 years age range: 18–22 years; height: 167.1 ± 4.0 cm; body mass: 67.8 ± 9.3 kg; These variables were measured as $\pm SD$) volunteered for this study. Although a priori power calculation indicated the need for a minimum of 9 subjects to obtain a correlation of 0.70 with an alpha level of 0.05 and statistical power of 0.80 (G*Power, Universität Düsseldorf, Germany), more data were included because it was available from a longitudinal athlete monitoring project. All players participated in a yearly training program that included dynamic and isometric exercises. The study was approved by Marquette University's Institutional Review Board, and all players provided written informed consent.

Procedures

Data collection occurred at the beginning of off-season training and was completed within one session. Players performed a standardized dynamic warm-up, followed by 2 submaximal CMJs and up to 4 maximal effort CMJs while holding a wooden dowel on their shoulders. Then, they performed 2 submaximal effort IMTPs, followed by 3 maximal effort IMTPs. For the IMTP, subjects were positioned with an upright torso and hip and knee angles set to approximately 145 and 135° with the help of a goniometer (²). Subjects were instructed to use maximal effort for each trial. In addition, verbal encouragement to “pull as hard and fast as possible” was provided during each IMTP. Rest periods between efforts lasted one minute.

Vertical ground reaction force (GRF) data during the CMJ were collected with 2 force plates at 1,000 Hz (Advanced Mechanical Technology, Inc., Watertown, MA) and summed into a single vector. Vertical GRF data during the IMTP were collected with one force plate (Kistler Instrument Corp., Novi, MI) at 1,000 Hz. Based on residual analyses, GRF data were smoothed with fourth-order zero-lag low-pass Butterworth filters and cutoff frequencies of 50 Hz for CMJ and 100 Hz for IMTP. Movement onset thresholds for CMJ and IMTP were defined as $5 * SD$ of resting force (^{5,10}). Peak forces during the CMJ were extracted from the concentric phase of the jump (i.e., between minimum center of mass position and takeoff), whereas IMTP peak forces were extracted from the entire trial (i.e., 3 seconds). Impulse during the CMJ was calculated as follows:

(1)

$$\int_{t_i}^{t_{to}} F_{\text{GRF}} dt - \int_{t_i}^{t_{to}} F_{\text{BW}} dt$$

where t_i and t_{to} indicate time of concentric phase onset and takeoff, respectively (Figure 1). Impulse during the IMTP was calculated as follows:

(2)

$$\int_{t_i}^{t_{\text{CMJ}}} F_{\text{GRF}} dt - \int_{t_i}^{t_{\text{CMJ}}} F_{\text{onset}} dt$$

where t_i and t_{cmj} indicate time of IMTP initiation and the impulse time (t_i to t_{to}) from CMJ testing (Figure 1). Thus, the impulse window of the IMTP is individualized to each subject by their CMJ concentric impulse time. The ratio between dynamic (CMJ) and isometric (IMTP) peak force and impulse data was used to calculate iDSI and fDSI, respectively. Data from IMTP trials that did not seem to be performed with maximal intent (e.g., slower ramp contraction), as based on visual inspection for the force-time curve, were excluded from further analysis. Within-subject averages were calculated and used for statistical analyses.

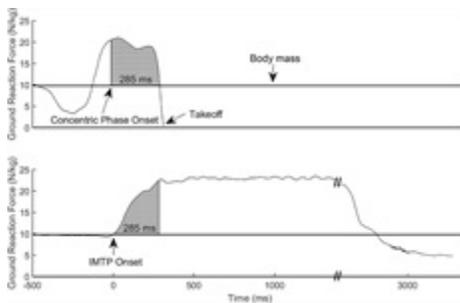


Figure 1.: Representative ground reaction force time-series data and impulse area for one subject. The countermovement jump (top) impulse, as indicated by the gray area of plot, is calculated as the integral of the force of the jump less the impulse due to the jumper's body mass during the concentric phase of the jump. The isometric midhigh pull (bottom) impulse is calculated as the integral of the force from the onset of the movement across the concentric impulse time of the countermovement jumps (CMJs) (i.e., 285 milliseconds).

Statistical Analyses

The reliability of CMJ and IMTP outcomes were assessed through the calculation of intraclass correlation coefficients (ICCs) and coefficients of variation (%) and their respective 95% confidence intervals (CIs). Intraclass correlation coefficient thresholds used for interpretation of reliability were based on previous literature recommendations (poor: ICC > 0.5; moderate: ICC = 0.5–0.75; good: ICC = 0.75–0.9; and excellent: ICC > 0.9) (7). Associations between fDSI and iDSI were investigated with a correlational analysis. Because of the violation of normality, nonparametric (Spearman's rho— ρ) correlations were used. Bootstrapping with 1,000 replicate samples was used to increase the robustness of the analyses and enable reporting of the 95% CI of the correlation between DSIs (SPSS 26.0, IBM Corp., Armonk, NY).

Results

All CMJ and IMTP outcomes exhibited excellent reliability between trials (Table 1). A moderate positive correlation existed between iDSI and fDSI ($\rho = 0.644$ [0.283–0.840], $p = 0.003$) (Table 2). Four subjects had iDSI values above 1.0 (Figure 2).

Table 1 - Reliability statistics of countermovement jump (CMJ) and isometric midthigh pull (IMTP) test variables.

| | ICC | 95% C.I. | | %CV | 95% C.I. | |
|---|-------|----------|-------|-----|----------|-------|
| | | Lower | Upper | | Lower | Upper |
| CMJ height (cm) | 0.928 | 0.828 | 0.974 | 4.7 | 3.2 | 6.3 |
| CMJ peak force ($\text{N}\cdot\text{kg}^{-1}$) | 0.939 | 0.855 | 0.978 | 4.0 | 2.5 | 5.5 |
| CMJ concentric impulse time (s) | 0.967 | 0.921 | 0.988 | 4.9 | 3.2 | 6.7 |
| CMJ concentric impulse ($\text{N}\cdot\text{s}^{-1}$) | 0.933 | 0.842 | 0.976 | 2.2 | 1.4 | 2.9 |
| IMTP peak force ($\text{N}\cdot\text{kg}^{-1}$) | 0.936 | 0.853 | 0.976 | 3.9 | 3.0 | 4.8 |
| IMTP impulse ($\text{N}\cdot\text{s}^{-1}$) | 0.974 | 0.939 | 0.990 | 7.6 | 5.3 | 9.8 |

ICC = intraclass correlation coefficient; CI = confidence interval; CV = coefficient of variation.

Table 2 - Descriptive statistics of countermovement jump (CMJ) and isometric midthigh pull (IMTP) test variables and the respective dynamic strength indices (DSIs).

| | Mean \pm SD | Minimum | Maximum |
|---|-------------------|---------|---------|
| CMJ height (cm) | 27.8 \pm 3.6 | 17.4 | 32.7 |
| CMJ peak force ($\text{N}\cdot\text{kg}^{-1}$) | 23.7 \pm 2.7 | 18.7 | 28.5 |
| CMJ concentric impulse time (s) | 0.248 \pm 0.038 | 0.190 | 0.321 |
| CMJ concentric impulse ($\text{N}\cdot\text{s}^{-1}$) | 146.5 \pm 12.9 | 126.2 | 175.2 |
| IMTP peak force ($\text{N}\cdot\text{kg}^{-1}$) | 31.7 \pm 3.1 | 26.2 | 38.8 |
| IMTP impulse ($\text{N}\cdot\text{s}^{-1}$) | 202.2 \pm 52.2 | 119.1 | 282.6 |
| Force-based DSI | 0.75 \pm 0.09 | 0.55 | 0.91 |
| Impulse-based DSI | 0.77 \pm 0.20 | 0.50 | 1.17 |

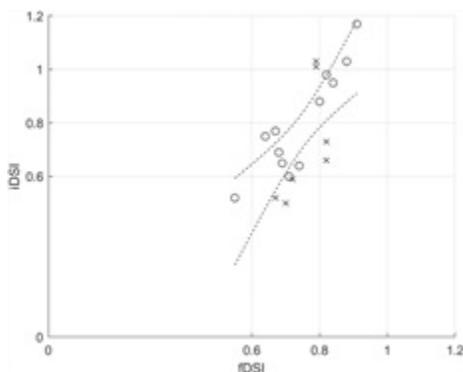


Figure 2.: Scatter plot of dynamic strength indices (DSIs). Vertical and horizontal gridlines indicate previously used thresholds for training recommendations (¹²). Dotted lines represent upper and lower 95% confidence intervals. iDSI = impulse-based DSI; fDSI = force-based DSI; o = congruent training recommendations ($n = 12$); x = conflicting training recommendations ($n = 7$).

Discussion

This study investigated DSI calculated from peak force (fDSI) and impulse (iDSI), and our hypothesis was confirmed as a moderate relationship was found between the 2 variables. Although the presence of the correlation is not surprising, the fact that the variables do not exhibit a stronger correlation with one another

suggests that iDSI partially represents a different metric, which may arguably better inform training recommendations because it accounts for an individual's movement time and therefore incorporates aspects related to the athlete's movement profile. Using a variable that accounts for the time over which an athlete functionally produces force may make more practical sense if the goal is to use DSI to personalize training recommendations because mechanical impulse determines jump height^(6,8). In addition, if assessing dynamic strength capacity, using peak IMTP force may be misleading because it can occur outside of the time that is available to an athlete to execute dynamic tasks such as the CMJ (Figure 1). The iDSI may therefore be a more valid measure of an athlete's capacity to express maximum force during dynamic tasks.

Dynamic strength index values are often used to provide training recommendations. Specifically, a DSI greater than 0.80 is believed to suggest that an athlete should focus on training maximum force generation, whereas a DSI smaller than 0.60 is believed to suggest that an athlete should focus on training to express force during dynamic tasks⁽¹²⁾. Based on these thresholds, the 2 calculated DSI variables provided conflicting training recommendations for 7 of the 19 (i.e., 37%) subjects. Such misclassifications could be important, especially considering that iDSI may be a more valid measure of force production capacity. For example, 3 subjects had fDSI values between 0.60 and 0.80 and had iDSI values below 0.60 (Figure 2). Although the training recommendations based on the fDSI values would be ambiguous, the recommendations based on the iDSI would suggest a need to improve these athletes' ability to express their maximum force more effectively during the CMJ. Thus, evaluating both DSI metrics may help to clarify training recommendations as the context of iDSI in this case may help a practitioner appropriately decide to train force expression during dynamic tasks for these athletes, as opposed to (perhaps erroneously) focusing on maximum force generation.

It should be noted that 4 subjects in the current study exhibited iDSI values greater than 1.0. However, in the context of IMTP and CMJ testing, fDSI values typically do not exceed 1.0 because peak dynamic force production generally does not exceed peak isometric force production. This discrepancy suggests that it is important to ensure that subjects perform both tests with maximal effort and follow directions closely (i.e., pull as hard and as fast as possible during the IMTP). At the same time, even if some subjects exhibit iDSI values greater than 1.0, the literature-based training recommendations would not differ for these subjects because their iDSI values are still greater than 0.8, which is the closest lower-bound threshold. Specifically, the training recommendation for subjects with fDSI values greater than 0.8 is to focus on training maximal force production, and iDSI values greater than 1.0 may simply emphasize the need for this specific focus to a greater extent because these subjects were able to express greater average force during the concentric phase of a dynamic task than during the matched time interval of an isometric task.

The current results and interpretations should be considered in light of several limitations. For example, the current results come from a correlational and cross-sectional study, therefore the findings may be limited to the population that was studied and may need to be investigated in the context of long-term training-induced changes in either IMTP or CMJ performance. In addition, future studies may want to examine different integration intervals to define the iDSI (e.g., combined eccentric-concentric impulse time vs. concentric-only impulse time).

The traditional fDSI and new iDSI do not always provide congruent training recommendations. Given that performance during dynamic tasks depends more on the ability to produce force over time than the ability to produce peak force independent of time, the iDSI may be a more valid index of an athlete's capacity to express their maximal strength during dynamic tasks. Practitioners may benefit from using iDSI for assessing and monitoring an athlete's capacity to functionally use their maximum strength during dynamic tasks under time-critical conditions.

Practical Applications

Although contemporary research suggests that the ratio between peak forces produced during a dynamic and an isometric task is useful for monitoring the training status of athletes (^{1,3,4,9,11,12,14–16}), using peak force in DSI calculations neglects the time available for force production. From a practical perspective, the ability to produce force over time is critical for athletic performance and may be a better predictor of dynamic performance than the applied peak force (⁶). We present an impulse-based alternative to force-based DSI and show 41% shared variance between the 2 indices ($\rho^2 = 0.415$). Importantly, interpretation of the DSI values based on previously used thresholds provides conflicting training recommendations in 37% of athletes. Thus, rather than using the proposed fDSI thresholds for iDSI-based training recommendations, different thresholds for use specifically with iDSI are worth exploring. Practitioners and researchers may benefit from using iDSI as it seems to be a more valid representation of an athlete's capacity to effectively express maximum strength during dynamic tasks under time-dependent constraints.

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