Comparing drop jumps with 10/5 repeated jumps to measure reactive strength index

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OVERVIEW

The reactive strength index (RSI) indicates how efficiently an athlete can utilise the stretch shortening cycle. Our study aimed to compare RSI values between the 10/5 repeated jumps test (RJT) and drop jumps (DJs) from 30 (DJ30) and 40 cm (DJ40). Thirty males (age = 23.97 ± 5.94, height (m) = 1.80 ± 0.08 and mass (kg) = 81.14 ± 11.66) from multiple sports performed three trials of the DJ30, DJ40, and 10/5 RJT on a force platform, in a randomised order; ground contact time (GCT), jump height (JH) (derived from flight time), and RSI were compared between tasks. RSI derived from the RJT demonstrated excellent reliability and acceptable variability (intraclass correlation coefficient (ICC) = 0.975 and coefficient of variation (CV) = 6.3%). RSI from the DJs also showed excellent reliability but slightly greater variance (ICC = 0.946 – 0.929, CV = 8.2-11.2%). Repeated measures analysis of variance (RMANOVA) revealed no significant differences (p = 0.540, $d \leq 0.14$) in RSI between the RJT and DJs (r = 0.551-0.848) and only shared 30% common variance (r^2). Large and small significant differences in GCT ($p < 0.001$, d = 1.45-1.54) and JH ($p \leq 0.010$, d = 0.50-0.54) were observed between the RJT and DJs, respectively. Due to the low shared variance in RSI between the RJT and DJs, we suggest that the jumps cannot be used interchangeably to assess RSI, and that an athlete's reactive strength qualities are task-dependent.

Introduction

Reactive strength provides an indication of fast stretch-shortening cycle (SSC) function and is a fundamental athletic quality associated with acceleration,[1] sprinting,[2] and changing direction.[3] Reactive strength is commonly evaluated in strength diagnostic profiling to assist in the development of individualised training interventions. Monitoring of reactive strength qualities is also commonly performed as an indicator of neuromuscular fatigue.[4] As such, practitioners require simple, robust, and reliable methods for the evaluation of reactive strength.

An athlete's capability to efficiently utilise the SSC (an eccentric action immediately followed by a concentric action),[5] is calculated and evaluated using the reactive strength index (RSI), typically derived from a single or repeated vertical jumping task.[6] RSI is normally calculated by jump height (JH) (metres), derived by flight time, divided by the GCT (seconds), with the use of a force-plate considered the 'gold-standard' method.[7] Cost-effective and simpler field-based methods such as contact mats, smart phones, and laser devices are also used by practitioners for evaluating RSI during jump tasks.

The drop jump (DJ) is a commonly used test for evaluating athletes' RSI,[8,9] with drop heights traditionally ranging between 30 cm and 40 cm.[10,11] Although RSI values and the subsequent components JH and GCT display high levels of reliability during DJ testing,[10,12,13] there are several limitations. Firstly, a box is required, and for some practitioners who have limited resources, this method may be impractical. Secondly, there are issues associated with standardising actual fall height, because athletes lower or heighten their centre of mass (dependent on strategy) before 'dropping' off the box, resulting in inconsistent drop height distances.[14] This issue is difficult to verify live in the field, and because GCT and landing forces tend to increase with greater box and fall heights,[15] these inconsistencies have the potential to affect RSI values. As such, it is highly unlikely that actual fall heights can be standardised between athletes and when longitudinally monitoring athletes during DJ testing.

One assessment which overcomes the issues of standardising actual fall height during a DJ is the 10/5 repeated jump test (RJT). The 10/5 RJT, first introduced by Harper et al,[16] requires an athlete to perform a countermovement jump (CMJ), which is then immediately followed by ten repeated jumps, with the top five jumps that displayed the greatest JH with GCTs < 0.250 m being used for analysis.[16] Despite its recent popularity, published studies regarding this assessment are limited.[16–18] Harper et al[16] initially reported a coefficient of variation (CV) of 9%, as opposed to those observed for DJ of 4.2%[19] to 5.3%.[10] Recently, Comyns et al[17] investigated the reliability of the 10/5 RJT and 5_{Max} RJT (one CMJ followed by four rebound jumps). The authors reported excellent reliability (ICC ≥ 0.80) and acceptable variability (CV ≤ 10%) for RSI during both jump tasks in male and female athletes. The 5_{Max} RJT was rated 'good' at detecting the smallest worthwhile change (SWC) in female athletes (SWC: 0.10 > typical error [TE]: 0.07), and 'marginal' for male. The 10/5 RJT was rated as 'marginal' between sexes. Consequently, further research is required that quantifies RSI reliability during the 10/5 RJT.

To date, no study has directly compared the reliability of RSI values measured during the 10/5 RJT and DJ or compared the magnitude of RSI between the aforementioned tasks. McMahon et al[6] observed significant differences in DJ RSI and CMJ RSI modified values in professional rugby players, reporting a common variance of only 22%, indicating the task-dependent nature of reactive strength qualities. It is currently unknown whether different RSI magnitudes would be observed between the 10/5 RJT and DJ, and whether different interpretations of an athlete's reactive strength would be obtained between tasks. Practitioners require robust and reliable reactive strength testing methodologies and tests that result in a better representation of an athlete's reactive strength capabilities.

The aim of this study was to compare RSI values and reliability measures between the 10/5 RJT and DJ while also comparing the underpinning components of RSI: JH and GCT. It is hypothesised that similar RSI values and reliability measures will be observed between the 10/5 RJT and DJ.

Methodology

PARTICIPANTS

Thirty males (age = 23.97 ± 5.94; height (m) = 1.80 ± 0.08; and mass (kg) = 81.14 ± 11.66) from multiple sports were recruited and provided written informed consent prior to participation. Participants competed in both team and individual sports consisting of one competitive match and two skill-sessions per week. All possessed a minimum of one year's resistance training experience. The study was approved by the institutional faculty ethics committee and conformed to the Code of Ethics of the World Medical Association (Declaration of Helsinki).

DESIGN

A mixed, cross-sectional research design was used whereby subjects performed three reactive strength tasks (RJT, DJ30 and DJ40) in a randomised order during one session. The mean differences in and relationships between dependent variables (ie, RSI, JH, GCT) were examined across tasks. Testing occurred in a single session in a human performance laboratory setting. Before the testing procedures began, all subjects refrained from physical activity for at least 24 hours.

PROCEDURES

Subjects performed a total of 36 jumps: six maximal DJs and three sets of 10/5 repeated jumps, excluding the warm-up. Prior to the reactive strength assessments, each subject completed a standardised warm-up, consisting of a 60 s light jog, 10 squats, and 10 lunges followed by a self-selected range of dynamic stretches. Jumping test order was randomised to reduce the risk of any order effect, potentiation and fatiguing effects. This was done by simply changing the order of the two different jumps that subjects completed. Individuals completed two DJs and 10/5 repeated jumps before testing began to allow familiarisation to the jumps.

DROP JUMP

A built-in 90 x 60 cm Advanced Mechanical Technology, Inc (AMTI) force plate (Massachusetts, USA) was used to collect vertical GRF data and determine RSI for all jumps. The DJs were performed from two different heights: 30 cm[11] and 40 cm[10] and the DJ box was placed approximately 10 cm from the edge of the force platform. Before the athletes stood on the force plate, it was zeroed. The athlete was then instructed to 'drop off' the box, instead of stepping down, to control for a homogenous drop height distance, and to 'jump as high as possible, minimising time in contact with the ground' (≤ 250 ms). The subjects placed their hands on their hips to isolate the use of the lower-limbs. The data were recorded for 7 s, sampling at 1000 Hz, and collected using Qualisys Track Manager (Qualisys ltd, Gothenburg, Sweden), where the unfiltered vertical GRF data were exported as text files and analysed using a bespoke Excel spreadsheet (Microsoft Corporation, Washington, USA) to calculate RSI, JH and GCT. Subjects completed three trials of each DJ with 90 s rest between trials. Subjects were provided with 3-5 minutes rest between the DJ and the 10/5 RJT.

Flight time (FT) was defined as the time between take-off and landing.[21] The take-off and landing (touch-down) phases were identified by a 20 Newton (N) vertical ground reaction force (GRF) threshold. As stated previously, RSI was calculated using the formula: JH / GCT.

JH was estimated from flight time using the following formula:[20]

$$\frac{\text{Flight time}^2 \times \text{Gravity } (9.81 \text{ m/s})^2}{8}$$

10/5 REPEATED JUMPS TEST

Before the subject stood on the abovementioned force platform, it was zeroed. For the RJT, 11 jumps were completed in total, but the first was excluded because it was a CMJ that initiated the 'bounce' technique for the remaining 10 repeated jumps. GRF data were collected for 15 s at a sampling rate of 1000 Hz. Each subject placed their hands on their hips to isolate the contribution from the lower limbs. Athletes were given verbal instruction to 'jump as high as possible and minimise time in contact with the ground'. From the 10 jumps recorded, the five that displayed the highest JH while maintaining a GCT of ≤ 250 ms was used in calculating RSI. This test was administered three times with 90 s rest between trials.

Statistical analysis

Statistical analyses were performed using SPSS software version 23 (SPSS, Chicago, Ill, USA) and Microsoft Excel. The mean and standard deviation (SD) for all variables were calculated for all tasks. A Shapiro-Wilk test was used to inspect normality. Within-session reliability was determined using ICCs (two-way mixed effect, average measures, absolute agreement) where these ICC values were interpreted in accordance to previous research.[22] Additionally, the CV was calculated (mean/SD x 100) to identify the variability of the measures recorded, with CV values <10% considered as acceptable variability.[23]

To examine the relationships between reactive strength assessments, Pearson's (parametric) correlations were used for RSI along with the coefficient of determination (r^2), while Spearman's correlations were used for GCT and JH as these were not normally distributed. The correlation coefficient was interpreted as trivial (0.0-0.1), small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9) and nearly perfect (0.9-1.0), using Hopkins' scale.[24] Additionally, a repeated measures analysis of variance (RMANOVA) with Bonferroni post-hoc comparisons were used to examine any differences in dependent variables across tasks and trials. To examine the magnitude of differences, Cohen's *d* effect sizes were calculated and interpreted using Hopkins' scale.[24] The magnitude of these differences were classed as follows: trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2), very large (2.0-2.4) and extremely large (>4.0). 95% confidence intervals were calculated for ICCs, CV, effect sizes, and correlation values. The average of five and three trials were used for the RJT and DJ, respectively. Statistical significance was defined $p \leq 0.05$ for all tests.

Table 1. Reliability (ICC) and the variability of measures

VARIABLE	ICC (95% CI)	RELIABILITY	%CV (95% CI)
RJT – GCT (s)	0.915 (0.833 – 0.958)	Excellent	4.35 (3.86 – 4.85)
DJ30 – GCT (s)	0.817 (0.664 – 0.907)	Good	8.23 (6.48 – 9.98)
DJ40 – GCT (s)	0.851 (0.728 – 0.924)	Good	7.94 (5.86 – 10.03)
RJT – JH (m)	0.976 (0.955 – 0.987)	Excellent	6.05 (5.11 – 6.99)
DJ30 – JH (m)	0.945 (0.900 – 0.972)	Excellent	6.85 (5.25 – 8.45)
DJ40 – JH (m)	0.944 (0.896 – 0.972)	Excellent	8.35 (5.62 – 11.08)
RJT – RSI	0.975 (0.954 – 0.987)	Excellent	6.32 (5.24 – 7.40)
DJ30 - RSI	0.946 (0.901 – 0.972)	Excellent	8.17 (6.46 – 9.89)
DJ40 - RSI	0.929 (0.864 – 0.964)	Excellent	11.20 (8.62 – 13.79)

Abbreviations: RJT, repeated jumps test; GCT, ground contact time; DJ30, 30 cm drop jump; DJ40, 40 cm drop jump; JH, jump height; RSI, reactive strength index; CI, confidence interval

Results

The RJT demonstrated the highest reliability (excellent ICCs) for JH, GCT and RSI with acceptable variability. Meanwhile, DJs demonstrated good (GCT) to excellent (JH and RSI) reliability. Only DJ40 RSI demonstrated higher variability (all results in Table 1).

Significant differences in GCT were shown between tasks (Table 2). Moreover, small and significant differences in JH were observed between RJT and both DJ30 and DJ40 (Table 2). Trivial and non-significant differences in JH were demonstrated between DJ30 and DJ40 (Table 2). Trivial and non-significant differences were observed in RSI values between tasks (Table 2); however, RSI for the RJT displayed a slightly higher mean value in comparison to the DJs (Table 2).

Large to very large associations existed between DJ30 and DJ40 for RSI, GCT and JH variables (Table 3). Additionally, a large association between the RJT and DJs for RSI was observed (Table 3). Conversely, trivial to moderate correlations for GCT were shown between the RJT and both DJ heights, whereas moderate to large relationships were observed between RJT and DJ30, as well as RJT and DJ40 (Table 3). Shared common variance was high between DJ30 and DJ40 for JH and RSI (Table 3). In contrast, the RJT and DJ30/DJ40 shared lower variance for JH and RSI (~ 30%) and meaningful relationships were even less apparent with GCT (Table 3).

Table 2. Overall mean and SD for each jump and variable, P value and effect size and its magnitude

	RJT		DJ30		DJ40		ANOVA	RJT V DJ30			RJT V DJ40			DJ30 V DJ40		
	MEAN	SD	MEAN	SD	MEAN	SD	P	P COMP	ES ± 95% CI	MAG	P	ES ± 95% CI	MAG	P	ES ± 95% CI	MAG
RSI	1.25	0.32	1.20	0.24	1.20	0.29	0.540	1.000	-0.14 ± 0.51	Trivial	1.000	-0.13±0.51	Trivial	1.000	0.00 ± 0.51	Trivial
Ground contact time	0.198	0.018	0.235	0.031	0.235	0.034	<0.001	<0.001	1.54± 0.58	Large	0.000	1.45 ± 0.57	Large	1.000	0.08 ± 0.51	Trivial
Jump height	0.25	0.06	0.28	0.05	0.28	0.06	0.010	0.004	0.54 ± 0.52	Small	0.003	0.50 ± 0.51	Small	1.000	0.00 ±0.51	Trivial

Abbreviations: RSI, reactive strength index; RJT, repeated jumps test; DJ30, 30 cm drop jump; DJ40, 40 cm drop jump; SD, standard deviation; ES, effect size; CI: Confidence interval; Mag, magnitude; P

Table 3. Pearson's correlation co-efficient between exercises and variables with association and r²

	RJT V DJ30			RJT V DJ40			DJ30 V DJ40		
	R OR Ð ± 95% CI	ASSOCIATION	R²	R OR Ð ± 95% CI	ASSOCIATION	R²	R OR Ð ± 95% CI	ASSOCIATION	R²
RSI	0.547 ± 0.263	Large	30%	0.551±0.261	Large	30%	0.848±0.112	Very large	72%
Ground contact time	0.046 ± 0.360	Small	0%	0.378±0.315	Moderate	14%	0.552±0.272	Large	30%
Jump height	0.499 ±0.280	Moderate	25%	0.564±0.315	Large	32%	0.880±0.090	Very large	77%

Abbreviations: r², co-efficient of determination; CI: confidence interval; RJT: repeated jumps test; DJ: drop jump; RSI: reactive strength index

Discussion

The primary aim of this study was to compare and examine the relationship between RSI, JH and GCT attained from the 10/5 RJT and DJs from 30 and 40 cm.[10,11] We also examined the reliability of the aforementioned variables for each task. GCT, JH and RSI all demonstrated excellent reliability during the RJT (Table 1). The performance results indicate that mean RSI values from the RJT were slightly higher in comparison to those derived from the DJs (Table 2), despite differences between the jumps being non-significant and trivial. However, GCT and JH were significantly different between jump tasks, indicating different jump strategies were employed to attain similar RSI values, supporting the study hypothesis. Due to the low common variance between the RJT and DJ assessments for RSI, JH, and GCT, the 10/5 RJT cannot be used interchangeably with the DJ protocols when determining reactive strength capacity (Table 3).

This study is one of the first to comprehensively investigate the 10/5 RJT since it was first introduced.[16] RSI, GCT, and JH, derived from the RJT, all showed excellent reliability and acceptable variability, and these measures were better than those of the DJs. Additionally, the 10/5 RJT reliability measures were slightly better than those observed by Comyns et al.[25] Harper et al[16] reported an average CV of 9% utilising only two jump variables – JH and GCT – whereas lower CV values were observed in the present study. The improved reliability measures observed in the present study in comparison to previous research[25] may be attributed to the use of force plates, providing a greater sampling frequency than field-based alternatives (ie, optojump).

The present study demonstrated similar RSI values between the 10/5 RJT and two DJs. Although no other study has compared RSI values between the 10/5 RJT and DJs, Kipp et al[26] reported no significant differences ($p = 0.367$) in RSI across a variety of drop heights (30, 45 and 60 cm), but unfortunately did not examine JH and GCT. Actual fall height may differ due to subjects either lowering or jumping up when completing the DJ task.[1] Kipp et al[26] stated that the absence of significant differences could be explained by a decrease in concentric work at greater drop heights, which may be similar in the present study. Nonetheless, concentric work was not measured and therefore we cannot be certain of the impact this variable has in the context of our findings. However, concentric work can be estimated from JH which was identical between the two DJ tasks, suggesting that concentric work was the same.

Although RSI values were similar between tasks, large differences existed in GCT between the RJT and DJs. Shorter GCTs were shown with the RJT, but this was accompanied with a smaller JH in comparison to the DJs. A shorter GCT can lead to a decrease in net impulse, resulting in a lower JH, which mostly likely explains the lower RJT JHs observed. Additionally, correlations between the RJT and DJ tasks for JH and GCT were small to moderate, indicating slightly different jump strategies were demonstrated between tasks, further highlighting the task-dependent nature of reactive strength assessments.

It is well documented that landing forces increase concomitantly with elevated drop heights.[27,28] Furthermore, as DJ height continues to increase, the GCTs generally become more prolonged.[15,29] Interestingly, no significant differences occurred in GCT between DJ30 and DJ40 in this study ($d = 0.08$), and almost identical RSI values were observed between the two DJ tasks. This finding confirms those of previous research which showed no meaningful differences in GCT during a DJ from different box heights.[27,28]

Actual fall height will vary, with subjects stepping down or jumping up in the DJ task. Theoretically, the actual fall height could have been similar between DJ30 and DJ40 due to the small (10 cm) difference between each box height. This study did not calculate actual fall height compared to box height and consequently, the statements made are only hypothetical.

A low coefficient of determination was observed between the RJT and DJs (0-32%). Therefore, the RJT and DJ assessments cannot be used interchangeably when measuring RSI. Reactive strength qualities are task-dependent, as indicated by the individual variation illustrated in Figures 1 and 2. Hypothetically, the biomechanical demands of the two types of jump are completely different. For example, the RJT requires the subject to complete 10 maximal repeated jumps as high as they can while minimising contact time (≤ 250 ms), and the repeated nature allows greater overall preparatory periods due to the ascent and decent phases during the flight phase prior to the rebound. Conversely, a DJ involves lower preparation time as the athlete only descends from the box prior to the rebound.

However, subjects can pre-plan prior to executing the DJ (when standing on the box). Additionally, there is also a possible fatigue-related component with the 10/5 RJT, where arguably the latter reps may display lower RSI values. However, this confounder may be

removed due to the five best repetitions being used for analysis. Further research is required to confirm whether ten repeated jumps are necessary when evaluating reactive strength.

Furthermore, performing 10 repetitions across numerous sets may induce fatigue, and it could be argued that performing 20-30 repeated landings may predispose athletes to a greater risk of lower limb joint injuries.

A limitation of this study was that only RSI, JH and GCT were examined. To fully understand the underpinning biomechanical rationale as to why the RJT and the DJs achieved different RSI (and differences in the RSI components: JH and GCT), more key variables need to be assessed such as braking and propulsive impulse. Secondly, further research is recommended to determine if ten repeated jumps are necessary, when only five of those jumps are used for analysis. Theoretically, because participants are required to perform ten repeated jumps, they may adopt a pacing strategy. Future research could compare RSI values provided from three and five repeated jumps in comparison to the ten introduced by Harper et al.[16]

Finally, due to the uncertainty surrounding actual fall height and box height, a limitation of this study is that values reported have not taken into consideration the potential lowering or slight elevation of the centre of mass during DJ tasks, and thus, failure to calculate actual fall height. It is recommended that future research explores this area in more detail to try and identify whether subjects lower themselves or increase their actual drop height during DJ trials when comparing RSI values to the 10/5 RJT.

In addition, this study did not calculate optimal drop height during DJ trials. Future research may want to compare RSI and associated variables (JH and GCT) derived from the optimal DJ height to the 10/5 RJT to see whether the outcomes would have differed.

Finally, the results of this study are limited to university-level athletes of generally low-to-moderate RSI performance levels; caution is therefore advised against generalising these results to different athletic populations.

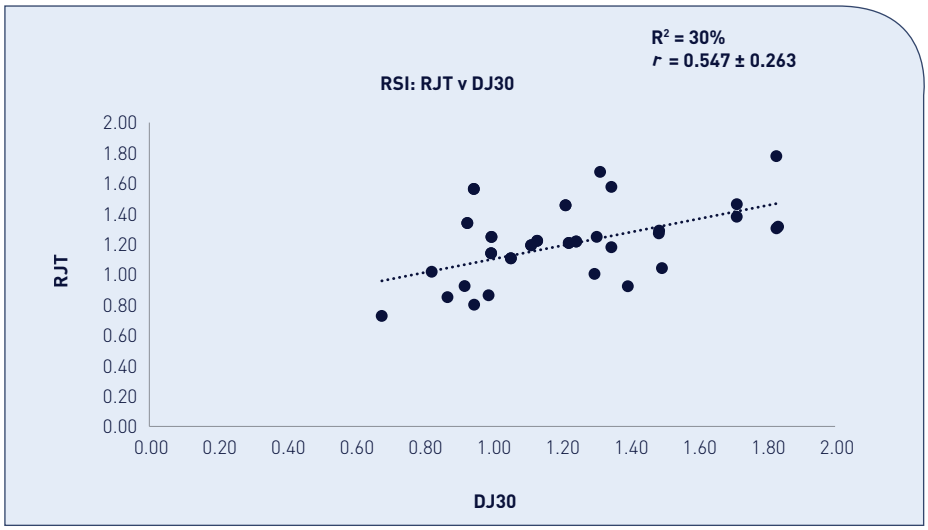


Figure 1. Scatter plot with trendline for RSI derived from the RJT to DJ30

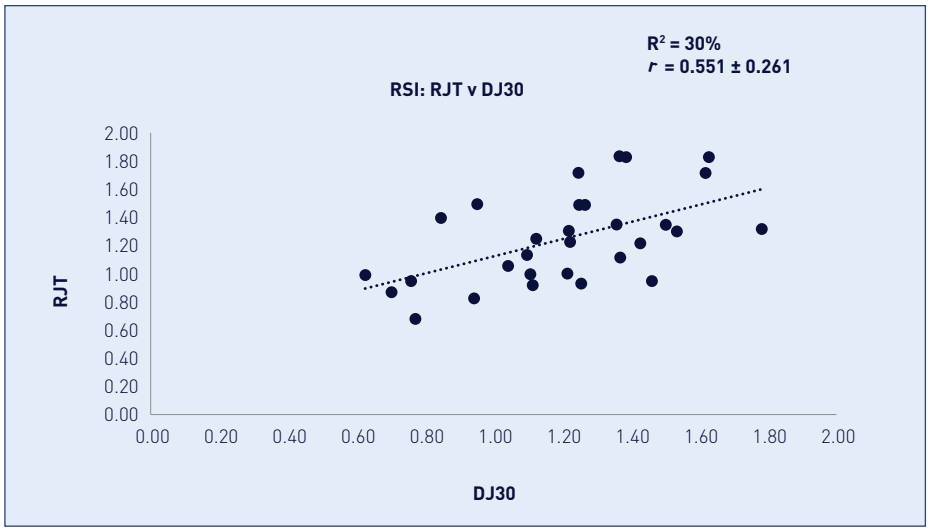


Figure 2. Scatter plot with trendline for RSI from the RJT to DJ40

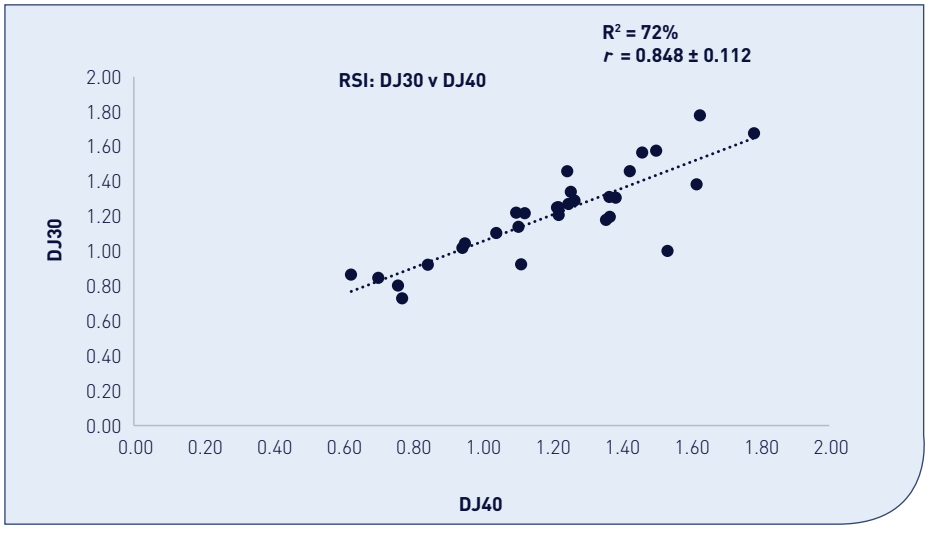


Figure 3. Scatter plot with trendline comparing RSI from both DJs

Practical applications

Practitioners, who are limited on time and resources but are interested, however, in evaluating their athletes' reactive strength, should consider using the 10/5 RJT, due to similar RSI values and increased reliability compared to DJ assessments. The 10/5 RJT also overcomes issues, such as standardising and controlling for actual fall height from the box, which is a significant limitation associated with DJ testing. Due to the low levels of common variance (r^2 = 30%) between the RJT and DJ protocols, the results of the study indicate that an athlete's reactive strength qualities are task-dependent and that practitioners should not use these assessments interchangeably when longitudinally monitoring changes in an athlete's RSI.

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References

1. Lockie RG, Murphy AJ, Knight TJ, Janse de Jonge XA. Factors That Differentiate Acceleration Ability in Field Sport Athletes. *J Strength Cond Res*, 25(10): 2704-2714. 2011.
2. Nagahara R, Naito H, Miyashiro K, Morin JB, Zushi K. Traditional and ankle-specific vertical jumps as strength-power indicators for maximal sprint acceleration. *J Sports Med Phys Fitness*, 54(6):691-699. 2014.
3. Young WB, James R, Montgomery I. Is muscle power related to running speed with changes of direction? *J Sports Med Phys Fitness*, 42(3):282-288. 2002.
4. Hamilton D. Drop Jumps As An Indicator Of Neuromuscular Fatigue And Recovery In Elite Youth Soccer Athletes Following Tournament Match Play. *J Aust Strength Cond*, 17(4):3. 2009.
5. Nicol C, Avela J, Komi P V. The Stretch-Shortening Cycle A Model to Study Naturally Occurring Neuromuscular Fatigue. *Sports Med*. Vol 36; 2006.
6. McMahon JJ, Suchomel TJ, Lake JP, Comfort P. Relationship Between Reactive Strength Index Variants in Rugby League Players. *J Strength Cond Res*, 30(2):547-554. 2018.
7. Patterson M, Caulfield B. A method for monitoring reactive strength index. *Procedia Eng*, 2(2):3115-3120. 2010.
8. Markovic G. Does plyometric training improve vertical jump height? A meta-analytical review. *Br J Sport Med*, 41(6):349-355. 2007.
9. Markwick WJ, Bird SP, Tufano JJ, Seitz LB, Haff GG. The intraday reliability of the Reactive Strength Index calculated from a drop jump in professional men's basketball. *Int J Sports Physiol Perform*, 10(4):482-488. 2015.
10. Beattie K, Flanagan E. Establishing the reliability & meaningful change of the drop-jump reactive strength index. *J Aust Strength Cond*, 23(5):12-18. 2015.
11. Flanagan EP, Ebben WP, Jensen RL. Reliability of the Reactive Strength Index and Time to Stabilization During Depth Jumps. *J Strength Cond Res*, 22(5):1677-1682. 2008.
12. Flanagan EP, Comyns TM. The Use of Contact Time and the Reactive Strength Index to Optimize Fast Stretch-Shortening Cycle Training. *Strength Cond J*, 30(5):32-38. 2008.
13. Ramirez-Campillo R, Alvarez C, García-Pinillos F, et al. Optimal Reactive Strength Index: Is it an Accurate Variable to Optimize Plyometric Training Effects on Measures of Physical Fitness in Young Soccer Players? *J Strength Cond Res*, 32(4):885-893. 2018.
14. Baca A. A Comparison of Methods for Analyzing Drop Jump Performance. *Med Sci Sport Exerc*, 31(3):437-442.1999.
15. Young W, Wilson G, Byrne C. A Comparison of Drop Jump Training Methods: Effects on Leg Extensor Strength Qualities and Jumping Performance. *International J Sport Med*, 20:295-303.1999.
16. Harper D, Hobbs S, Moore J. The 10 to 5 repeated jump test. A new test for evaluating reactive strength. British Association of Sports and Exercises Sciences Student Conference, Chester. year???
17. Comyns TM, Flanagan EP, Fleming S, Fitzgerald E, Harper DJ. Inter-Day Reliability and Usefulness of Reactive Strength Index Derived From Two Maximal Rebound Jump Tests. *Int J Sports Physiol Perform*, 14(9):1200-1204. 2019.
18. Browne D, Flanagan E. Reactive Strength Endurance: Part 1 The response of reactive strength to fast stretch-shortening cycle fatigue. *sportperfsci*, 1:1-3. 2018.
19. Byrne DJ, Browne DT, Byrne PJ, Richardson N. Interday Reliability of the Reactive Strength Index and Optimal Drop Height. *J Strength Cond Res*, 31(3):721-726. 2017.
20. Klavora P. Vertical-jump tests: A critical review. Strength Cond J, 22(5):70-75. 2000.
21. Pérez-Castilla A, McMahon JJ, Comfort P, García-Ramos A. Assessment of loaded squat jump height with a free-weight barbell and Smith machine. *J Strength Cond Res*. 2017.
22. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med*, 15:155-163. 2016.
23. Cormack SJ, Newton RU, McGuigan MR, Doyle TLA. Reliability of Measures Obtained during Single and Repeated Countermovement Jumps. *Int J Sports Physiol Perform*, 3(2):131-144. 2008.
24. Hopkins W. How to Interpret Changes in an Athletic Performance Test. *Sportscience*, 8:1-7. 2004.
25. Comyns T, Flanagan E, Harper D, Fleming S, Fitzgerald E. Interday reliability and usefulness of reactive strength index derived from the ten to five repeated jumps test. *J of Sports Sciences*, 35:80. 2017.
26. Kipp K, Kiely MT, Giordanelli MD, Malloy PJ, Geiser CF. Biomechanical Determinants of the Reactive Strength Index During Drop Jumps. *Int J Sports Physiol Perform* 13(1):44-49. 2018.
27. Walsh M, Arampatzis A, Schade F, Brüggemann G. The Effect of Drop Jump Starting Height and Contact Time on Power, Work Performed, and Moment of Force. *J Strength Cond Res*, 18(3):561-566. 2004.
28. Makaruk H, Sacewicz T. The Effect of Drop Height and Body Mass on Drop Jump Intensity. *Biol Sport*, 28(1):63-67. 2011.
29. Peng H-T, Kernozek TW, Song C-Y. Quadricep and hamstring activation during drop jumps with changes in drop height. Phys Ther Sport, 12(3):127-132. 2011.