A RELIABILITY AND KINETIC ANALYSIS OF THE 10/5 REPEATED JUMP AND DROP JUMP TESTS TO DETERMINE THE USE OF A NOVEL REACTIVE STRENGTH MEASURE: THE REACTIVE QUALITY RATIO

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Original scientific paper
DOI 10.26582/k.56.2.2

Abstract:

The stretch-shortening cycle (SSC) plays an important role in locomotion, and tests such as the drop jump (DJ) and 10/5 repeated jump (RJ) are commonly used to determine this through the measure of reactive strength index (RSI). With an understanding that these tests emphasize different jump intensities and strategies, a novel measure called the reactive quality ratio (RQR) has been proposed to determine whether an individual is more dominant in RJ or DJ task. Furthermore, comparison of kinetic and temporal outputs of both tests were made during the RQR protocol. Therefore, twenty-four professional Australian footballers completed two testing sessions comprising of both the RJ and DJ test. Results indicated that whilst there was no significant difference in RSI output between RJ and DJ tests respectively (2.52±0.43 vs 2.46±0.38), there were several significant differences in underlying kinetic variables: ground contact time (180±25 vs 209±30ms), flight time (444±53 vs 500±39ms), impulse (524±67 vs 721±69 Ns), average force (2924±363 vs 2624±294N), landing RFD (73226±20555 vs 88159±35922N/s) and active stiffness (43852±11549 vs 32309±12006N/m). Additionally, good levels of reliability were found for RQR (ICC=0.76, CV=2.96%) indicating that this novel measure can be used to determine preferred jump strategy for individuals. Overall, this study confirms underlying differences between RJ and DJ tests.

Keywords: *reactive strength index, biomechanics, strength profiling, jump profiling*

Introduction

The stretch-shortening cycle (SSC) is a neuromuscular function that encompasses co-ordination of a muscle to undergo rapid eccentric contraction immediately followed by rapid concentric contraction, and is utilized in locomotion (Bosco, Ito, Komi, Luhtanen, Rahkila, Rusko, & Viitasalo, 1982; Hennessy & Kilty, 2001; Keiner, Sander, Wirth, & Hartmann, 2015; Komi & Bosco, 1978). Having greater SSC efficiency reflects the greater amounts of force that can be transferred from the eccentric to concentric contraction phase, thus reducing relative energy expenditure (Bosco & Rusko, 1983; Komi & Bosco, 1978). Reactive strength index (RSI) is a variable used to reflect the SSC and is calculated by dividing the flight time by the ground contact time, with a higher RSI indicating greater stretch-shortening cycle efficiency. Having a high RSI, requires sufficient muscle strength, to eccentrically control one's body mass upon ground contact as well as being able to produce sufficient propulsive force to create positive vertical displacement. This has been seen with moderate relationships between maximum strength and RSI, as well as stronger cohorts having higher RSI than their weaker counterparts (Jarvis, Turner, Read, & Bishop, 2021; Southey, Willshire, Connick, Austin, Spits, & Beckman, 2023b).

Plyometric tasks such as the drop jump (DJ) and 10/5 repeated jump (RJ) are typical tests used to assess RSI (Baker, Shillabeer, Brandner, Graham-Smith, Mills, & Read, 2021; Beattie, Carson, Lyons, & Kenny, 2017; Brian, Declan, & Dan, 2021; Douglas, Pearson, Ross, & McGuigan, 2018; Southey, Connick, Spits, Austin, & Beckman, 2023a). The DJ results in higher amplitude and greater intensity than the RJ due to greater landing rate of force development (RFD), power output, and ground reaction forces (GRF), causing greater muscle activations of the quadricep and gastrocnemius (Ebben, Fauth, Garceau, & Petushek, 2011; Ebben, Simenz, & Jensen, 2008). The low amplitude nature of the RJ means that it can be done more extensively with a higher volume and more rhythmical jump strategy than the DJ. These differences impact the commonality of RSI between these two tasks. Whilst RSI output may be similar between the DJ and RJ, there is little common agreement between these tests, reflecting the differences in jump strategy (Stratford, Dos'Santos, & McMahon, 2020). This difference is important for strength and conditioning coaches to understand when prescribing exercise and testing plyometric performance.

Often when prescribing plyometric exercise, particularly for developing athletes, practitioners will start with low amplitude, extensive exercises such as hopping and skipping, before progressing to more intensive exercises such as drop jumps or altitude landings (Davies, Riemann, & Manske, 2015; Ebben, 2007). This linear approach accounts for progressive overload; however, it is not always feasible for every athletic population. For instance, Australian footballers will be exposed to high training loads involving high intensity running, cutting and jumping on field throughout the preseason period (Harrison & Johnston, 2017). These athletes may benefit from exposure to high amplitude, intensive plyometrics earlier where they can develop reactive strength under this stress in a controlled environment, particularly if their extensive plyometric strength is sound. However, there is no profiling method that could guide this decision. Therefore, the reactive quality ratio (RQR) has been suggested in this study as a novel way to determine if an individual can produce reactive strength in high and/or low amplitude environments. This can then be used to determine programme prescription to develop the relative plyometric training needs of an individual. This is done by comparing the RSI between the DJ and RJ, with an RQR of 1.0 indicating an equal ability to produce reactive strength in both plyometric environments.

In order to determine the validity of the RQR, it is important to first understand the reliability of the metric and its underpinning component data, to minimize the risk of spurious results (Bishop, Shrier, & Jordan, 2023). Additionally, it is important to determine the kinetic differences in intensity between the two tests, to see if it concurs with previous findings (Ebben, et al., 2011). Therefore, the aims of this study were to: 1) to explore the reliability of the novel measure of the RQR and its component data, and 2) to observe the differences in kinetic output of the 10/5 repeated jump test and drop jump tasks whilst undertaking the RQR testing protocol. It is hypothesized that the RQR and component data will have good reliability levels, whilst the DJ would have significantly greater kinetic and temporal outputs than the RJ, despite similar RSI.

Methods

Experimental design

Participants were required to complete two testing sessions during the initial three weeks of the AFL preseason. Testing sessions were completed on a Monday and Friday during their allotted afternoon gym sessions, as this time had the greatest consistency in the training schedule. No lower body physical activity occurred on the day prior to testing, with regular field training occurring in the morning beforehand. On both days, a general warm up was completed before participants first performed one trial of the RJ, followed by three trials of the DJ off a 45cm box. Approximately 30 seconds rests was given to participants between tests as equipment was being set up. Participants were previously familiarized with the RJ and DJ tests as it was part of the regular testing schedule, which occurred 3-4 times a year over the past 1-3 years, depending on the age of the participant.

Participants

Twenty-four professional male Australian football players from a professional club volunteered for the study (age: 23.4 ± 3.2 years, range 18-30 years; body mass: 86.7 ± 6.3 kg, range 77.4-99.1 kg). Athletes either competed in the national competition, the Australian Football League (AFL) or in the reserves competition, the Victorian Football League (VFL). However, all athletes had the same training schedule. Every participant was physically fit at the time of testing and had previous strength, power and plyometric training experience as part of an AFL program (avg: 4.5 ± 3.1 years, range 1-12 years).

Gatekeeper approval from the club and player consent was attained for permission to participate and analyse data. Ethics approval was granted for this study by the university's ethics committee, application—2021/HE001957.

Testing procedures

All data were collected using a force platform (Vald Performance Force Deck Dual Platform FD4000; Newstead, Queensland, Australia) at a sampling rate of 1000Hz; capacity: 2000 kg; resolution: c.15 g/0.15 N. Reactive quality ratio (RQR) was calculated by dividing the RSI of the DJ with the RSI of the RJ. In addition to RQR and RSI variables being measured, variables such as ground contact time (GCT), flight time (FT), impulse (newtons of force produced during ground contact multiplied by time taken in seconds), peak force (the highest newton of force obtained during ground contact phase), average force (mean newtons of force measured throughout the ground contact phase), landing rate of force development (RFD) (newtons of force divided by the time taken from the initial ground contact to stabilize landing), and active stiffness (peak force divided by maximum centre of mass displacement during the concentric phase of ground contact) were also recorded for kinetic analysis.

10/5 repeated jump assessment

Participants performed one trial which required an initial countermovement jump followed by 10 consecutive reactive double-leg hops. The results from the best five hops (determined by the highest RSI) were then averaged to create the participants final value of variables. Athletes were verbally cued to "jump as high as possible, whilst minimizing ground contact time". Athletes were also instructed to hop using their ankles whilst keeping hips and knees stiff and having hands positioned on their waist. Deviation of their contact point on the force platform during the repeated hopping was common, however, only if a participant lost rhythm during his trial and could not stay on the force platform, were they required to redo the trial.

Drop jump

This test required participants to start from standing on top of a box and step off landing with both feet on the force platform before completing one reactive hop. Participants performed three trials with a drop height of 45cm. This height was to ensure that fall height, thus intensity, was significantly higher than the fall height from the RJ, which has been previously seen to be between 25 to 27cm in a similar population (Southey, et al., 2023a). An average of the three trials was used for analysis. Participants were cued to "minimize ground contact when landing and hop as high as they can" as well as "minimize knee bend on landing" and to have their hands positioned on their waist throughout the movement.

Statistical analysis

To determine the reliability of RSI and RQR methods, intraclass correlation coefficients (ICC) were calculated with 95% confidence intervals. ICC ratings were interpreted using the following criteria: <0.5 (poor), 0.5-0.75 (moderate), 0.75-0.9 (good), >0.9 (excellent) (Koo & Li, 2016). Coefficient of variation (CV) was calculated using the following formula:

(SD[Trials 1-2]/average[trials 1-2] x 100).

The average CV for squad was then calculated for both the interday and intraday tests, which was expressed as a percent. Additionally, acceptable reliability required a CV <10% (Turner, Brazier, Bishop, Chavda, Cree, & Read, 2015). Usefulness of test is a measure used to determine whether a small and moderate effect size change can be detected by the test. This was done by comparing whether the standard error measurement (SEM) was smaller than the SWC (Hopkins, 2000). The test had a usefulness rating of "good" at detecting smallest worthwhile change (SWC) if score was greater than SEM, "Ok" if they were similar, or "marginal" if less than SEM (Hopkins, 2000). SEM was calculated by dividing the between participants SD by the square root of the number of data points. SWC was calculated by multiplying between participants SD by 0.2. Moderate worthwhile change (MWC) was calculated by multiplying between participants SD by 0.5.

For group comparisons, a Shapiro Wilks test was used to determine data normality and distribution. For between trial comparisons and kinetic analysis, paired sample *t*-tests were used for parametric data, whilst Wilcoxon signed rank test was used for non-parametric data. Mean, standard deviation, median and inter-quartile range were all reported. Cliff's delta was used to calculate effect size as this calculation does not assume normal distribution of data (Macbeth, Razumiejczyk, & Ledesma, 2011). Effect size (0-0.0.146 = trivial; 0.147-0.329 = small; 0.330-0.146 = moderate; 0.147-1.0 = large) was used to indicate magnitude of difference (Romano & Kromrey, 2006). Cliff's delta also provided direction of effect size by being on a scale of -1 to +1, with positive values indicating that the RJ had higher results than the DJ. Negative effect size indicated vice versa (Macbeth, et al., 2011). All statistical analysis was completed using Rstudio (Rstudio Team, 2015), with the added package "irr" and "effsize" used to assist with intraclass correlation and effect size analysis. P value was set at <0.05.

Results

Results from the reliability and kinetic analysis can be found in Tables 1 and 2, respectively. For reliability analysis, RJ RSI data were non-parametric, whilst DJ RSI and RQR data were normally distributed when checking for normality. No statistical differences (p>.05) were seen in group comparisons between test 1 and test 2 for the RJ RSI, DJ RSI, and RQR metrics. All three metrics displayed good ICC relationships (r= >0.7) and had an acceptable CV of <10%.

For the kinetic and temporal variables, the following metrics were found to be not normally distributed: GCT, FT, and landing RFD. All other metrics were normally distributed. Significant

Table 1. Reliability analysis results

Metric	Test 1		Test 2		P value	Intra-class correlation			CV	SEM	Usefulness rating			
	Mean ± SD	Median (IQ range)	Mean ± SD	Median (IQ range)		ICC	95% CI	ICC rating			SWC	SWC rating	MWC	MWC rating
RJ RSI	2.53 ± 0.35	2.59 (2.29-2.78)	2.50 ± 0.39	2.56 (2.40-2.78)	0.348	0.86	0.71-0.94	Good	3.29%	0.08	0.07	Marginal	0.18	Good
DJ RSI	2.48 ± 0.38	2.45 (2.12-2.80)	2.46 ± 0.37	2.51 (2.27-2.70)	0.721	0.81	0.61-0.91	Good	4.02%	0.10	0.07	Marginal	0.18	Good
Reactive quality ratio (RQR)	0.98 ± 0.10	0.98 (0.94-1.04)	0.99 ± 0.11	1.00 (0.94-1.07)	0.488	0.76	0.52-0.89	Good	2.96%	0.03	0.02	Marginal	0.05	Good

Note. RJ = 10/5 repeated jump test; DJ = drop jump; SD = standard deviation; IQ = interquartile; ICC = intra-class correlation; CI = confidence interval; CV = coefficient of variation; SEM = standard error measurement; SWC = smallest worthwhile change; MWC = moderate worthwhile change; RSI = reactive strength index

Table 2. Kinetic and temporal analysis results

Metric	RJ		DJ		P value	Effect size
	Mean ± SD	Median (IQ range)	Mean ± SD	Median (IQ range)		
RSI	2.52 ± 0.43	2.57 (2.32-2.79)	2.46 ± 0.38	2.45 (2.21-2.71)	0.369	0.12 (trivial)
GCT (ms)	180 ± 25	176 (164-199)	209 ± 30	207 (186-232)	<0.0001	-0.54 (large)
FT (ms)	444 ± 53	454 (414-483)	500 ± 39	506 (472-522)	<0.0001	-0.65 (large)
Impulse (N s)	524 ± 67	521 (481-580)	721 ± 69	722 (670-773)	<0.0001	-0.97 (large)
Peak vertical force (N)	5529 ± 777	5497 (4975-5986)	5293 ± 1274	4894 (4276-6449)	0.139	0.17 (small)
Average vertical force (N)	2924 ± 363	2956 (2720-3117)	2624 ± 294	2613 (2477-2811)	<0.0001	0.48 (Large)
Landing RFD (N/s)	73226 ± 20555	70186 (59271-85432)	88159 ± 35922	84425 (58362-111641)	0.015	-0.29 (Small)
Active stiffness (N/m)	43852 ± 11549	42573 (36195-51821)	32309 ± 12006	30340 (23968-39282)	<0.0001	0.54 (Large)

Note. RJ = 10/5 repeated jump test; DJ = drop jump; SD = standard deviation; IQ = interquartile; RSI = reactive strength index; GCT = ground contact time; FT = flight time; RFD = rate of force development

statistical differences were seen between 10/5 repeated jump and drop jump tests for GCT, FT, impulse, average force, landing RFD, and active stiffness.

Discussion and conclusion

The purpose of the study was to determine the reliability of the novel RQR metric and observe any kinetic and temporal differences between the RJ and DJ whilst conducting the RQR protocol. It was hypothesized that the RQR and component RSI data would have good reliability and, whilst the RSI of the RJ and DJ would be similar, the DJ would have higher underlying kinetic outputs than the RJ. The main findings of this present study confirm the first hypothesis and partially support the second. Firstly, the reactive quality ratio (RQR) had a good intra-class correlation relationship (r=0.76) and low CV (2.96%) as a result of reliable component RSI data from the RJ and DJ. This gave strong indications that this novel measure can be used as a reliable method of reactive strength profiling. Secondly, whilst DJ had significantly higher impulse (avg: 721 ± 69 vs 524 ± 67 Ns) and landing RFD (avg: 88159 ± 35922 vs 73226 ± 20555 N/s), the RJ had significantly higher average vertical force (avg: 2924 ± 363 vs 2624 ± 294 N) and active stiffness (avg: 43852 ± 11549 vs 32309 ± 12006 N/m), highlighting the different intensities and kinetic requirements of these plyometric tasks.

The first aim of this study explored the reliability of the novel measure of reactive strength. The RQR had good ICC correlations (0.76 CI: 0.52-0.89), an acceptable CV of 2.96% and an ability to detect moderate worthwhile change. This followed similar trends with the component RSI data from the RJ and DJ, which also yielded good ICC scores of 0.86 and 0.81, respectively, along with acceptable CV of <10% (3.29 and 4.02%). Both tests could determine moderate worthwhile change, however, could not determine smallest worthwhile change as the standard error of measurement was higher than the small effect size. All these results have been similarly seen in previous literature (Baker, et al., 2021; Comyns, Flangan, Harper, Fleming, & Fitzgerald, 2017; Comyns, Flanagan, Fleming, Fitzgerald, & Harper, 2019; Markwick, Bird, Tufano, Seitz, & Haff, 2015; Stratford, et al., 2020). Thus, the RQR can be used to reliably assess reactive strength qualities of the lower limb and can be used by practitioners to guide programming prescription for athletes.

The second aim examined the kinetic and temporal differences between the RJ and DJ tests. The results confirm the findings from Stratford et al. (2020) with non-significant differences in RSI output (RJ = 2.52 ± 0.43 vs DJ = 2.46 ± 0.38), and confirm their hypothesis of different control strategies of the RJ and DJ. This was highlighted by the several underlying kinetic and temporal differences which concur with previous findings (Ebben, et al., 2011). There were large differences in GCT, with the RJ having shorter time spent on the ground compared to the DJ (avg: 180 ± 25 vs 209 ± 30 ms). Whilst the GCT for both tests engage the fast stretch-shortening cycle (fSSC) (GCT <250 ms), it was apparent that an individual can more efficiently overcome eccentric braking forces and transfer to propulsive force during the RJ. This would be due to the smaller fall height, and thus smaller eccentric force, that an individual must endure during the RJ test (Niu, Wang, Jiang, & Zhang, 2018; Verniba, Vescovi, Hood, & Gage, 2017). This was reflected with the significantly smaller impulse (avg: 524 ± 67 vs 721 ± 69 Ns) and landing RFD (avg: 73226 ± 20555 vs 88159 ± 35922 N/s) that occurred compared to the DJ, which was seen in previous research (Ebben et al., 2011). Furthermore, there were large differences in FT between the tests, with greater time in the air observed in the drop jump (avg: 500 vs 444 ms). This increased FT may be due to the greater potentiation of eccentric force from the 45 cm fall height to transfer into propulsion. This has been seen in accentuated eccentric loading protocols, where adding load during the eccentric portion of a jump can increase vertical jump performance (Lloyd, Howard, Pedley, Read, Gould, & Oliver, 2021; Sheppard, Newton, & McGuigan, 2007).

There was a large significant difference between the average vertical force between the RJ and DJ (avg: 2924 ± 363 vs 2624 ± 294 N). The larger average force experienced would reflect the smaller GCT during the RJ as there was less time to produce adequate force, relative to the flight time. Furthermore, the RJ had a significantly larger active stiffness score than the drop jump (avg: 43852 ± 11549 vs 32309 ± 12006 N/m), which indicates that there was greater concentric force produced relative to the centre of mass (CoM) displacement during GCT of the RJ test (Mudie, Gupta, Green, Hobara, & Clothier, 2017). This confirms the trend that the larger eccentric loads of the DJ required larger braking forces and/or greater CoM displacement to absorb and control bodyweight, thus reducing active stiffness output (Mudie et al., 2017). This decrease in active stiffness may have potentially come from a slight knee bend that may act to reduce eccentric load and compressive forces (Tsai, Ko, Hammond, Xerogeanes, Warren, & Powers, 2017), as the eccentric stress exceeds the activation threshold of purely the calf complex itself and requires greater engagement of the quadricep muscles (Ebben, et al., 2008; Peng, Kernozek, & Song, 2011).

Overall, when dropping from 45 cm, the DJ exposes an individual to greater eccentric stress and SSC intensity, whilst the smaller eccentric demand of the RJ allows for greater concentric force expression. Practically, this means if striving for an equal RQR of 1.0, as seen with near equal RSI outputs in this study and previous research (Stratford, et al., 2020), individuals who display a RQR greater than 1.0 indicate an ability to produce greater reactive strength in high amplitude intensive tasks such as the DJ. These individuals may benefit from greater focus on low amplitude extensive plyometric programming where there is greater room for improvement. Thus, the RQR can be used to reliably assess reactive strength qualities of the lower limb and can be used by practitioners to guide these programming intricacies.

There are a few considerations needed when interpreting results. Firstly, kinetic and temporal differences and comparisons are observed from the drop jump off a box 45 cm high. For some individuals, this height may have been above or below an optimal drop height, which could affect the highest RSI score they could attain. This is due to the concept that at optimal drop height, individuals have the optimal amount of eccentric load to enhance the concentric portion of the jump without increasing ground contact time (Tong, Chen, Xu, & Zhai, 2022). In this context, RSI output is relative to the individual; however, the purpose for the RQR protocol is to represent the plyometric intensities that one would be exposed to during training. Fundamentally, the DJ is an exercise aimed to promote high eccentric stress, introduced from the works of Verhoshanski's "shock method" (Verhoshanski, 1967), and thus should not be conducted at low intensities. Therefore, for the RQR to compare plyometric tasks with different levels of amplitude, the DJ drop height should be significantly greater than the jump height experienced in the RJ to challenge the SSC system differently. Secondly, the DJ was always assessed after the RJ, and this was to test the reliability of the RQR protocol in which practitioners could test an athlete in a single time efficient bout. Therefore, it was imperative that the testing order remained the same for all the tests, to attain reliable results. However, this would potentially have an impact on the kinetic output of the DJ and should be considered when interpreting results. Future research could explore whether this is in fact the optimal protocol in determining RQR and whether recovery time or alternating testing order would significantly impact results.

Overall, the novel measure of the reactive quality ratio (RQR), along with the RJ and DJ have been confirmed as reliable ways to measure reactive strength qualities of the lower limb; however, caution should be advised if trying to determine the smallest worthwhile change. Furthermore, whilst both the DJ and RJ are SSC tasks that are used to measure RSI, there are underlying kinetic and temporal differences between them observed during the RQR testing protocol. Whilst RSI output may be similar, the DJ has a greater eccentric demand that in turn creates a larger impulse, greater landing

RFD, and longer GCT to overcome the high eccentric load. On the other hand, the RJ has a greater average force and active stiffness, due to the lower eccentric demand, which allows for quicker absorption and transfer of eccentric energy and force into flight, represented by a shorter GCT. The RQR provides a useful way of comparing these differences that can be used by strength and conditioning practitioners to help guide athletic development programmes and plyometric training.

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Submitted: October 18, 2023
Accepted: June 29, 2024
Published Online First: November 9, 2024

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Acknowledgements

The authors would like to thank the participants for their involvement in this study.

Declaration of interest

All authors declare no conflict of interest.