Title: Reactive Strength Index: A Poor Indicator of Reactive Strength?

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Preferred Running Head: RSI: A Poor Indicator of Reactive Strength

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ABSTRACT

Purpose: The primary aim was to assess the relationships between reactive strength measures and associated kinematic and kinetic performance variables achieved during drop jumps. A secondary aim was to highlight issues with the use of reactive strength measures as performance indicators. **Methods:** Twenty eight national and international level sprinters, consisting of fourteen men and women, participated in this cross-sectional analysis. Athletes performed drop jumps from a 0.3 m box onto a force platform with dependent variables contact time (CT), landing time (T_{Land}), push-off time (T_{Push}), flight time (FT), jump height (JH), reactive strength index (RSI, calculated as JH / CT), reactive strength ratio (RSR, calculated as FT / CT) and vertical leg spring stiffness (K_{vert}) recorded. **Results:** Pearson's correlation test found very high to near perfect relationships between RSI and RSR (r = 0.91 to 0.97), with mixed relationships found between RSI, RSR and the key performance variables, (Men: r = -0.86 to -0.71 between RSI/RSR and CT, r = 0.80 to 0.92 between RSI/RSR and JH; Women: r = -0.85 to -0.56 between RSR and CT, r = 0.71 between RSI and JH). **Conclusion:** This study demonstrates that the method of assessing reactive strength (RSI versus RSR) may be influenced by the performance strategies adopted i.e. whether an athlete achieves their best reactive strength scores via low CTs, high JHs or a combination. Coaches are advised to limit the variability in performance strategies by implementing upper and / or lower CT thresholds to accurately compare performances between individuals.

KEY WORDS: drop jump, stretch shortening cycle, reactive strength ratio, contact time, jump height.

INTRODUCTION

The stretch shortening cycle (SSC) is utilised in many sporting movements e.g. in the leg extensor muscles during the ground contact phases of running, sprinting, jumping and hopping movements.[1] The SSC of muscle function has been characterised by an eccentric (lengthening) muscle action quickly followed by a concentric (shortening) muscle action. In this state, greater positive work and more power is generated during the concentric muscle action relative to that of an isolated concentric muscle action.[2] Several mechanisms have been proposed to explain the greater positive work performed by the muscle: an increase in the time available to develop force, the storage and subsequent utilisation of elastic energy in the series elastic element of a muscle fibre, force potentiation from individual cross-bridges and the stretch reflex i.e. the capacity of additional sensory feedback to enhance the activation of motor neurons during concentric muscle action.[3] The relative contribution of each potential mechanism will vary across movement type as factors such as tendon loading and SSC duration are not identical in all SSC activities[4]. Therefore, generalisations about the SSC should not be made from one specific muscle and from one condition only.[4]

Direct methods using in vivo force measurements have been employed to characterise SSC function in isolated muscles during human locomotion. Based on these methods, three fundamental conditions have been identified for effective SSC function: a well-timed pre-activation of the muscle prior to impact, a short and fast eccentric phase and a near immediate transition between eccentric and concentric phases.[1,3,5] Consequently, coaches have attempted to evaluate specific sports movements which utilise the SSC. To accomplish this, the concept of reactive strength was developed.[6] Reactive strength has been described in numerous ways throughout the literature with the most commonly used definition being the capacity of an athlete to bear a stretch load and subsequently switch rapidly from an eccentric to concentric muscle action.[7] Other authors have focussed on a more mechanical definition i.e. an athlete's ability to rapidly generate force under high eccentric load.[8] Regardless, reactive strength has been assessed during various sports movements e.g. drop jumps, vertical hops, rebound jumps and countermovement jumps.

Within the literature SSCs have been generally classified as either fast or slow based on contact times (CTs) < 0.250 s and > 0.250 s, respectively.[9] The current paper exclusively examines reactive strength as assessed during a fast SSC movement, i.e. the drop jump where, an athlete drops from a set height and upon landing performs a vertical jump at maximal effort. The drop jump can be broken into two distinct temporal phases, the contact phase, which can be further sub divided into landing time ($T_{Landing}$) and push off time (T_{Push}), and the flight phase i.e. time spent in the air. The manipulation of these two temporal phases has led to the identification of three drop jump techniques. The bounce drop jump, where an athlete attempts to minimise CT which occurs at the expense of higher JHs; the countermovement drop jump, where an athlete attempts to achieve maximal flight time (FT) and thus maximal jump height which results in much longer CTs than the aforementioned method; and the combination technique, whereby an athlete attempts to get off the ground as quickly as possible while also aiming to jump as high as possible.[10, 11]

It has been suggested that reactive strength can be assessed in the drop jump using the reactive strength index (RSI) performed using the combination technique.[7] Several authors have proposed that the RSI is an effective means of assessing the performance of a SSC task and can also provide an indication of an athlete's vertical stiffness (K_{vert}).[12, 13] Within the literature, RSI has been calculated using two calculation methods: the jump height (JH) in a drop jump, generally derived from flight time (FT), divided by the CT or alternatively the FT of the jump divided by the CT. [6, 14] The latter method has sometimes been referred to as the flight to contact time ratio or simply the reactive strength ratio (RSR).[15] The key distinctions between RSI and RSR values, from a calculation perspective, are highlighted in Table 1 below. The differences between RSI and RSR values as performance metrics have yet to be determined.

Table 1: Description of reactive strength measures.

Measure	Unit	Calculation	Explanation
Reactive Strength Index	$m \cdot s^{-1}$	$\frac{\text{Jump Height}}{\text{Contact Time}}$	A theoretical quantity that represents the predicted jump height that would be achieved with a ground contact time of one second
Reactive Strength Ratio	Unitless	$\frac{\text{Flight Time}}{\text{Contact Time}}$	The ratio of flight time to contact time

The purpose of the current study was to assess the relationship between RSI and RSR and assess the relationship between RSI, RSR values and other kinematic and kinetic drop jump variables. Finally we aimed to highlight problems with the use of both RSI and RSR as performance metrics using examples from two groups of sprint athletes. We hypothesized that both RSI and RSR would be correlated to the common variables used in their calculation i.e. CT and FT, but the strength of these correlations would differ due to differences in drop jump performance strategy. Additionally we hypothesised that individual athletes in both the male and female group would achieve similar RSI or RSR scores through different combinations of CT and JH values.

METHODS
Athletes

Twenty eight athletes, involved with sprint and hurdle events (IAAF Scoring Tables points range, Men: 731 - 1233 points, Women: 878 - 1128 points), consisting of fourteen males (mean ± SD, age: 22 ± 2 years; body height: 1.83 ± 0.06 m; body mass: 72.1 ± 6.5 kg) and fourteen females (mean ± SD, age: 22 ± 4 years; body height: 1.72 ± 0.07 m; body mass: 64.4 ± 4.6 kg) agreed to participate in this investigation. Fourteen of the athletes competed regularly at an international level (seven men and seven women) whereas the remaining eleven athletes competed regularly at a national level (seven men and seven women). Ethical approval was provided by the Institution’s Research Ethics Committee and written consent forms were completed by all athletes prior to testing in compliance with the Declaration of Helsinki.

Design

This cross-sectional study was designed to assess the relationship between bilateral drop jump variables (RSI, RSR, CT, $T_{Landing}$, T_{Push}, FT, JH and K_{vert}) in males and females with all drop jumps performed in a biomechanics laboratory. All athletes had at least two years of experience performing plyometric exercises and were well accustomed to performing drop jumps as part of their monitoring programme.

Methodology

Following a standardised dynamic warm up, athletes performed three maximal effort drop jumps with the first jump serving as a practice trial and the two subsequent jumps retained for analysis. Athletes were instructed to keep their hands on their hips throughout the entire movement, to step directly off of the box i.e. avoid stepping down from the box or jumping off of the box, avoid any tucking motion in the air, to land in the same position as take-off and to aim to minimise CT while also trying to maximise JH.[11] All drop jumps and drop jump force-time traces were visually assessed by the experimenter and trials were repeated if any of the instructions were not followed, if CT > 0.250 s or if the force-time trace contained initial impact transients i.e. force peaks. Thirty seconds of rest were provided between trials to avoid any deleterious effects of fatigue on performance. [16] Drop jumps were performed from a box height of 0.3 m with athletes landing on an AMTI NET force platform (Watertown, MA, USA) operating at 1,000 Hz.

The dependent variables were: CT, T_{Land}, T_{Push}, FT, JH, RSI, RSR and K_{vert}. CTs and FTs were obtained directly from the force-time trace using a threshold of >10 N to determine contact and <10 N to determine flight. Flight time was subsequently used to estimate JH using an adapted version of the second mathematical equation of linear motion

$$\mathrm{JH} = \mathrm{FT}^2 \times 1.22625$$

This method of estimating JH assumes that an athlete's centre of mass is the same on landing and take-off. Although athletes take-off with a fully extended knee and plantar-flexed ankle they may not land in a plantar-flexed position and therefore the centre of mass may be lower at landing than at take-off. This would result in an amplification of FT and thus errors in the subsequent calculation of JH. The instructions given to the athletes aimed to minimise these errors as much as possible. RSI and RSR were calculated as JH divided by CT, and FT divided by CT respectively. T_{Land} was calculated similar to previous investigations as the time elapsed between initial contact to the instant of maximal vertical displacement of the centre of mass.[17, 18] T_{Push} was calculated as CT minus T_{Land}. K_{vert} was calculated as the peak vertical ground reaction force divided by the maximum vertical displacement of the centre of mass.[19] Peak vertical ground reaction force was obtained directly from the landing phase of the force-time trace and vertical displacement was calculated through double integration of the vertical component of the ground reaction force.[13, 20] Initial landing velocity was derived using an adapted version of the fourth mathematical equation of linear motion:

$$\text{Landing velocity} = \sqrt{2 \times g \times Drop\ Height}.$$

To adjust for mass differences, K_{vert} values were reported relative to body mass.[21, 22] Similarly to previous investigations, the correlation coefficients between vertical force and vertical displacement were calculated for each trial, with all correlations > 0.9, to ensure the efficacy of spring-mass model.[22, 23]

The reliability of each variable was assessed by calculating both the single measure intraclass correlation coefficient (ICC) and typical error, expressed as a coefficient of variation (CV%).[24] The ICC was above > 0.9 (Range: 0.902 – 0.976) and the CV% was below 8% (1.7 – 7.4%) for all variables.

Statistical Analyses

Descriptive statistics for all variables were presented as mean ± SD. All variables were deemed to be normally distributed as the Shapiro-Wilk's test was found to have an alpha level > 0.05. Relationships between drop jump measures were determined using Pearson's product moment correlation. As multiple correlations were performed, a false discovery rate controlling procedure was used to account for the familywise error rate resulting in an alpha level for significance set at 0.0286. [25]. The strength of the correlations was evaluated as s: trivial (0 – 0.09), small (0.1 – 0.29), moderate (0.3 – 0.49), large (0.5 – 0.69), very large (0.7 – 0.89), near perfect (0.9 – 0.99) and perfect (1).[24] Non-significant correlations were not interpreted. All statistical analyses were performed using SPSS software (version 21.0, SPSS, Inc., IL, USA).

Between / Within Athlete Analysis

To highlight the variable nature of reactive strength measures, between-athlete differences in drop jump dependent variables (expressed as a %) were calculated in instances where athletes had near identical RSI or RSR values. Within-athlete differences were also assessed in instances where an athlete achieved their highest RSI and RSR in separate trials.

RESULTS

Descriptive statistics (mean ± SD) for all variables are given in Table 2. Inter-correlation matrices of drop jump measures are presented for men and women in Tables 3 and 4 respectively. Scatter plots illustrating the relationship between RSI and RSR and the key kinematic variables i.e. CT and JH, are presented in Figure 1 for male and female groups. Significant correlations were found between CT and RSI and RSR in men whereas CT was correlated to RSR only in women. JH was significantly correlated to RSI in men and women and RSR in men only.

Within-athlete differences for an exemplar athlete are given in Table 5 along with between-athlete differences from instances where athletes achieved near identical RSI or RSR values ($\Delta < 1\%$).

Table 2: Descriptive statistics (Mean ± SD) for drop jump variables.

	Men	Women
Contact Time (s)	0.164 ± 0.016	0.183 ± 0.028
Landing Time (s)	0.071 ± 0.011	0.081 ± 0.015
Push-off Time (s)	0.093 ± 0.008	0.102 ± 0.014
Flight Time (s)	0.516 ± 0.054	0.490 ± 0.046
Jump Height (m)	0.330 ± 0.067	0.296 ± 0.057
Reactive Strength Index ($m.s^{-1}$)	2.04 ± 0.49	1.65 ± 0.45
Reactive Strength Ratio	3.18 ± 0.52	2.73 ± 0.42
Vertical Leg Spring Stiffness ($kN.m^{-1}.kg^{-1}$)	0.648 ± 0.129	0.495 ± 0.211

Table 3: Inter-correlation matrix between drop jump variables in men. Results are presented as r (95% CI) with statistically significant correlations presented in bold.

	RSI (m.s^{-1})	RSR	CT (s)	T_{Land} (s)	T_{Push} (s)	FT (s)	JH (m)
RSI (m.s^{-1})	1						
RSR	**0.97**** **(0.91 to 0.99)**	1					
CT (s)	**-0.71**** **(-0.90 to -0.28)**	**-0.86**** **(-0.95 to -0.61)**	1				
T_{Land} (s)	**-0.85**** **(-0.95 to -0.57)**	**-0.91**** **(-0.97 to -0.74)**	**0.89**** **(0.68 to 0.96)**	1			
T_{Push} (s)	-0.28 (-0.70 to 0.30)	-0.48 (-0.81 to 0.07)	**0.80**** **(0.46 to 0.93)**	0.44 (-0.12 to 0.79)	1		
FT (s)	**0.93**** **(0.78 to 0.98)**	**0.82**** **(0.50 to 0.94)**	-0.41 (-0.77 to 0.15)	**-0.66*** **(-0.88 to -0.19)**	0.063 (-0.48 to 0.57)	1	
JH (m)	**0.92**** **(0.75 to 0.97)**	**0.80**** **(0.46 to 0.93)**	-0.38 (-0.76 to 0.19)	**-0.63*** **(-0.87 to 0.15)**	0.10 (-0.46 to 0.60)	**-**$^{\#}$	1
K_{vert} (kN.m^{-1}.kg^{-1})	**0.78**** **(0.43 to 0.93)**	**0.87**** **(0.63 to 0.96)**	**-0.89**** **(-0.96 to -0.68)**	**-0.94**** **(-0.98 to -0.82)**	-0.51 (-0.82 to 0.03)	0.55 (0.03 to 0.84)	0.54 (0.01 to 0.83)

RSI = Reactive strength index, RSR = Reactive strength ratio, CT = Contact time, T_{Land} = Landing time, T_{Push} = Push-off time, FT = Flight time, JH = Jump Height K_{vert} = Vertical leg-spring stiffness relative to body mass

***Correlation is significant ($p < 0.0286$), **Correlation is significant ($p < 0.007$)**

$^{\#}$The correlation between FT and JH was not performed as JH was directly derived from FT.

Table 4: Inter-correlation matrix between drop jump variables in women. Results are presented as r (95% CI) with statistically significant correlations presented in bold.

	RSI (m.s^{-1})	RSR	CT (s)	T_{Land} (s)	T_{Push} (s)	FT (s)	JH (m)
RSI (m.s^{-1})	1						
RSR	**0.91**** **(0.74 to 0.97)**	1					
CT (s)	-0.56 (-0.84 – 0.04)	**-0.85**** **(-0.95 to -0.58)**	1				
T_{Land} (s)	**-0.68*** **(-0.89 to -0.23)**	**-0.90**** **(-0.97 to -0.71)**	**0.96**** **(0.87 to 0.99)**	1			
T_{Push} (s)	-0.37 (-0.75 to 0.20)	**-0.70**** **(-0.90 to -0.28)**	**0.95**** **(0.84 to 0.98)**	**0.82**** **(0.50 to 0.94)**	1		
FT (s)	**0.72**** **(0.30 to 0.90)**	0.37 (-0.20 to 0.75)	0.16 (-0.40 to 0.64)	-0.01 (-0.54 to 0.52)	0.34 (-0.23 to 0.74)	1	
JH (m)	**0.71**** **(0.28 to 0.90)**	0.36 (-0.21 to 0.75)	0.18 (-0.39 to 0.65)	0.01 (-0.53 to 0.53)	0.35 (-0.09 to 0.84)	**-**$^{\#}$	1
K_{vert} (kN.m^{-1}.kg^{-1})	0.56 (0.04 to 0.84)	**0.82**** **(0.52 to 0.94)**	**-0.93**** **(-0.98 to -0.78)**	**-0.92**** **(-0.97 to -0.75)**	**-0.85**** **(-0.95 to -0.58)**	-0.14 (-0.62 to 0.43)	-0.15 (-0.63 to 0.41)

RSI = Reactive strength index, RSR = Reactive strength ratio, CT = Contact time, T_{Land} = Landing time, T_{Push} = Push-off time, FT = Flight time, JH = Jump height

K_{vert} = Vertical leg-spring stiffness relative to body mass

***Correlation is significant ($p < 0.0286$), **Correlation is significant ($p < 0.007$)**

$^{\#}$The correlation between FT and JH was not performed as JH was directly derived from FT.

Table 5: Within athlete differences for an exemplar athlete (A) who achieved their highest RSI and RSR in separate trials. Highest RSI and RSR values are marked in bold. Between athlete differences for four athletes who achieved near identical RSI (B and C) and RSR (D and E) values.

	RSI ($m.s^{-1}$)	RSR	CT (s)	T_{Land} (s)	T_{Push} (s)	FT (s)	JH (m)	K_{vert} ($kN.m^{-1}.kg^{-1}$)
Athlete A Trial 1	2.16	**3.61**	0.135	0.057	0.078	0.488	0.292	0.866
Athlete A Trial 2	**2.18**	3.49	0.146	0.060	0.086	0.509	0.318	0.794
% Δ	*-0.6*	*3.6*	*-8.1*	*-5.3*	*-10.3*	*-4.3*	*-8.8*	*8.3*
Athlete B	**2.36**	3.64	0.145	0.059	0.086	0.528	0.342	0.834
Athlete C	**2.34**	3.28	0.177	0.073	0.104	0.581	0.414	0.596
% Δ	*-0.8*	*-10.9*	*18.1*	*19.2*	*17.3*	*9.1*	*17.4*	*-40*
Athlete D	1.89	**2.79**	0.198	0.087	0.111	0.552	0.374	0.399
Athlete E	1.67	**2.81**	0.173	0.069	0.104	0.486	0.290	0.682
% Δ	*-12.7*	*0.8*	*-14.5*	*-26.1*	*-6.7*	*-13.6*	*-29*	*41.5*

RSI = Reactive strength index, RSR = Reactive strength ratio, CT = Contact time, T_{Land} = Landing time
T_{Push} = Push-off time, FT = Flight time, JH = Jump height, K_{vert} = Vertical leg-spring stiffness relative to body mass

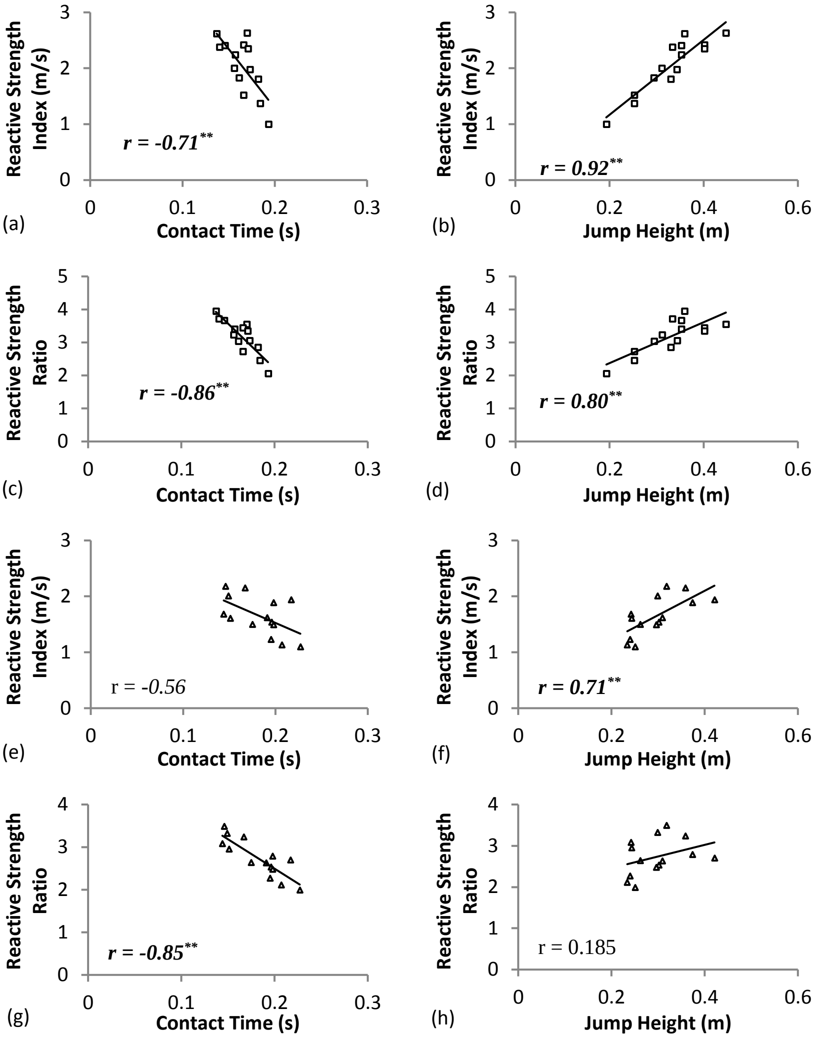

Figure 1: Scatter plots illustrating the associations between RSI / RSR and CT and JH. Male data presented as squares (a – d) and female data presented as triangles (e – h). *Correlation is significant ($p < 0.05$).**Correlation is significant ($p < 0.01$).

DISCUSSION

Relationship between RSI and RSR

The findings of this study indicate that RSI and RSR had a near perfect positive correlation in male and female athletes. These relationships can best be explained by the common variables, CT and FT, used in the calculation of both measures. The differences between RSI and RSR exist because of the quadratic relationship between FT and JH, i.e. JH is determined directly by the second mathematical equation of linear motion which is a second order polynomial equation. This difference is highlighted in Figure 2 which simulates the change in both RSI and RSR as JH increases when CTs are kept constant. RSR will always have a higher value than RSI up until the point at which the absolute value of FT equals the absolute value of JH; this occurs at an FT of 0.815 s. From this point onwards RSI is higher than RSR. In practical terms this would require an athlete to achieve a JH of 0.815 m which is higher than anything that has been reported within the literature to date. This numerical phenomenon creates a distinction between RSI and RSR and explains why an athlete can achieve higher values for RSI and RSR in separate trials. Consequently, RSI and RSR values should not be compared or used interchangeably. Coaches should consider this when deciding whether to use RSI or RSR as higher JHs will have a greater effect on RSI compared to RSR.

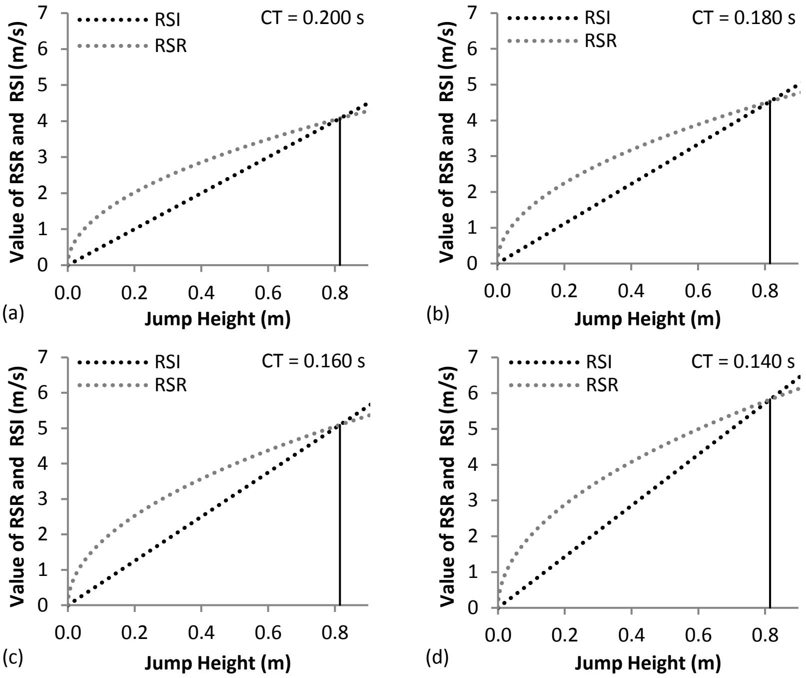

Figure 2: Value of RSI (black broken line) and RSR (grey broken line) as jump height increases at constant contact times of (a) 0.200 s, (b) 0.180 s, (c) 0.160 s and (d) 0.140 s. Solid black line denotes point at which RSI and RSR intersect, when jump height = 0.815 m.

Relationship between RSI, RSR and other performance variables

Given that both CT and FT (which was used to directly estimate JH) were used in the calculation of RSI and RSR it was expected that significant correlations would exist between these variables. In the male group, RSI and RSR were significantly related to CT (RSI: very high negative, RSR: very high negative) and JH (RSI: near perfect positive, RSR: very high positive). In the female group, CT was significantly related to RSR only (RSI: high negative, RSR: very high negative) whereas JH was related to RSI only (very high positive). These results suggest that higher RSI scores were typically achieved via a combination of higher JHs and lower CTs in the males and via higher JHs in females. Similarly, higher RSR values were also typically achieved via a combination of higher JHs and lower CTs in males whereas higher RSR scores were achieved by lower CTs in females. Lowering CT will reduce the time available to develop and apply force and thus generate an impulse. Net jump impulse is determined by the area of the force-time curve during the ground contact phase. The interaction between force and time is important to consider as a decrease in CT with a proportional increase in force will result in FT / JH being maintained which will result in a higher RSI / RSR value. However, if there is not a proportional increase in force then FT / JH will decrease. Whether or not this has a positive or negative impact on RSI / RSR will be dependent on the magnitude of the change in CT and FT / JH i.e. if the positive effect of a reduced CT outweighs the negative effect of a lower FT / JH.

K_{vert} had a significant negative relationship with CT in both male (very large) and female (near perfect) athletes with a significant large positive relationship found with JH in men only. A higher K_{vert} would suggest a greater ability to resist negative displacement of the COM and thus spend less time in the landing phase of a drop jump. This is supported by the near perfect negative relationship found between K_{vert} and T_{Land} in both male and female athletes. This is consistent with the literature on drop jumping as higher levels of K_{vert} have been found in jumps with lower CTs.[26, 27] The very large relationship between K_{vert} and CT explains why K_{vert} had a very high positive correlation with RSI and RSR in males. Recent research by Kipp et al. [13] also found a large positive relationship between K_{vert} and RSI using the same box height (0.3 m) as the present investigation. In the female group, avery high correlation was found with RSR only. The lack of a significant relationship between K_{vert} and RSI in females can be explained, by the lack of association between CT and RSI. Although it may be tempting for coaches to use RSI as an indicator of K_{vert}, the data from this study illustrates that the strength of the relationship between K_{vert} and RSI will largely depend on the strength of the relationship between CT and RSI.

The differences in correlations between the male and female groups can be explained by differences in individual athlete's performance strategies (i.e. how an athlete achieves the outcome performance). Theoretically, the maximum number of performances yielding identical RSI / RSR scores depends on the difference between the longest allowable CT and the shortest CT achieved by an athlete in the group tested. In this study, this would be 0.250 s – 0.137 s = 0.114 s or 114 performances with distinct CT and JH / FT values. To put this into context, two athletes could achieve an RSI of 2 $m.s^{-1}$ by jumping with a CT = 0.137 and JH = 0.247 m or CT = 0.250 s and JH = 0.450 m. Examples of this are given in Table 5 where Athlete B and C achieved RSI values of 2.36 $m.s^{-1}$ and 2.34 $m.s^{-1}$ respectively. Athlete B had an 18.1% shorter CT and a 17.4% lower JH than Athlete C. This illustrates two alternative performance strategies that require different physical capacities i.e. a greater ability to tolerate a stretch load and thus achieve a shorter contact time and a greater ability to generate an impulse and thus achieve a higher JH. This highlights that an athlete's specific strengths, in tolerating a stretch load, rapidly developing an impulse or achieving a balance of both, cannot be clearly identified by an RSI or RSR value in isolation.

Problems with the calculation of RSI and RSR

There are problems related to the calculation of RSI and RSR measures. To express RSI values as a comparable measure between performances, the numerator in the equation i.e. JH must be expressed over a common denominator i.e. a CT of 1 s. For example, for an athlete with JH = 0.3 m and CT = 0.200 s, to achieve a denominator of 1 s, RSI would be calculated by multiplying both the JH and CT by five, yielding an RSI of 1.5 $m.s^{-1}$. Consequently, the calculation of RSI assumes that JH would increase in direct proportion to increases in CT. From a theoretical perspective, this assumption ignores one of the fundamental conditions for effective SSC function mentioned previously i.e. a short and fast eccentric phase.[5] The longer the CT the lower the benefit provided by mechanisms such as the stretch reflex on the performance of fast SSC movements such as the drop jump.[3]

The problem with RSR arises from the fact that JH does not increase in a directly linear proportion to FT. The vertical distance travelled by the COM in 1 ms of flight time is dependent entirely on the magnitude of the COM's vertical velocity at that time i.e. the greater the velocity the greater the distance travelled. This can result in misleading results when comparing RSRs. For example, two performances with a RSR of 3, representing a 3:1 ratio of FT to CT. One performance is achieved with CT= 0.140 s and the other achieved with a CT = 0.250 s. By calculating the JH based on the FT (calculated by tripling CT) we see that the first performance yielded a RSI of 1.55 $m.s^{-1}$ whereas the second yielded a RSI of 2.76 $m.s^{-1}$. (i.e. ~78% greater). The RSI of the second performance would be considered exceptionally high relative to the present data set and the extant literature, thus illustrating a major problem with RSR.

All of the aforementioned issues can be largely reduced by controlling for CT, therefore, to accurately compare RSI / RSR values, the variability in CT must be reduced so that any difference in RSI / RSR can largely be attributed to differences in JH. This can be accomplished by providing stricter instructions on maximally acceptable contact times or by emphasising the need to get off the ground as quickly as possible. These actions should narrow the range of CTs within a data set and in doing so, should maximise the relative importance of JH. A revised definition of reactive strength should therefore be adopted as: the ability to tolerate a stretch load and subsequently generate an impulse within a specified time.

PRACTICAL RECOMMENDATIONS

Practitioners are urged to consider the findings of this study when assessing RSI and RSR measures in their athletes. Firstly, coaches and clinicians should be aware of the difference between RSI and RSR especially when reading the scientific literature as very few authors have explicitly made the distinction between these two indices. Therefore, it is proposed that researchers use the terminology appropriate to the different calculation methods as outlined in this study i.e. RSI when JH is divided by CT and RSR or flight to contact time ratio when FT is divided by CT, when reactive strength measures are assessed.

Practitioners should also be wary of directly comparing athletes' RSI or RSR values or using RSI or RSR group normative values as aggregate scores may mask valuable information about individual strategies. Consequently, values should always be presented with the corresponding CTs and JHs or FTs to give greater context to the athlete's performance. For example if the reactive strength of a high jump athlete is being assessed, then JH is a critical factor as generating a large impulse at take-off is crucial to success. However if RSI / RSR improves over time through lower CTs but also lower JHs then this can potentially be considered a negative change. If between-athlete comparisons are desired, coaches are advised to enforce strict testing rules in relation to drop jump contact times in order to avoid reactive strength measures becoming confounded by differences in jumping strategy. This can be accomplished by determining more specific upper and / or lower contact time thresholds where jump trials are not accepted if the contact times fall outside of the pre-determined thresholds. The determination of upper and / or lower thresholds will depend on the capabilities of the group of athletes being tested, the demands of the specific sport e.g. < 0.200 s for the initial steps of a sprint, or simply whichever criteria yields the most reliable performances which can only be determined through "in-house" testing. Additionally, the height of the box used for the drop jump may need to be reduced if an athlete cannot achieve a contact time lower than the maximum threshold. This could be an indication that the athlete possesses poor levels of relative strength or poor stiffness capabilities.

Although jump mats, photoelectric cells and mobile applications are commonly used to assess drop jump performance measures (CT, JH, RSI, RSR), valuable kinetic data can only be assessed directly using more sophisticated equipment e.g. force platforms, which provide much greater information on an athlete's physical capacities.

CONCLUSIONS

This study found near perfect and very large correlations between RSI and RSR in male and female sprinters respectively. Although highly related, distinctions in measures do exist and can be explained by the quadratic relationship between FT and JH. The results also demonstrate that the method of assessing reactive strength (RSI versus RSR) may be influenced by the performance strategies adopted i.e. whether an athlete achieves their best reactive strength scores via low CTs, high JHs or a combined approach. Accordingly, drop jump RSI should not be used an indicator of K_{vert} as performance strategies that favour higher jump heights over shorter contact times will yield misleading results. Coaches are advised to limit the variability in performance strategies by implementing upper and / or lower CT thresholds in order to accurately compare performances between individuals.

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