# RELATIONSHIP BETWEEN VERTICAL STIFFNESS AND REACTIVE STRENGTH INDEX MODIFIED IN COLLEGE-AGED MALES DURING JUMPING

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Vertical ground reaction forces (GRFz) that occurred during a counter-movement vertical jump (CMVJ) were analyzed for the interaction between propulsive assessment measures during the stretch-shortening cycle (SSC). Thirteen active males served as volunteer participants. GRFz collected at 1000Hz using a Kistler force plate were exported for analysis into an RStudio vertical jump program. A linear regression was determined for the relationship between vertical stiffness and modified reactive strength index ($RSI_{mod}$). $RSI_{mod}$ was found to be a significant predictor of vertical stiffness ($p$ = .010). These results suggest that further examination of the equation used for $RSI_{mod}$ to identify the most significant predictor variables while reducing variable confounding effects on the relationship between the leg stiffness measures and propulsive forces during a counter-movement vertical jump.

**KEYWORDS:** Reactive strength index modified, leg stiffness, vertical jumping

**INTRODUCTION:** The prevalence of athlete monitoring methods in sports performance has continued to develop as coaches and sports scientists have increased access to equipment due to greater affordability. Contact timing mats, video analysis, and portable force platforms offer team monitoring versatility at a variety of price points.

Reactive Strength Index (RSI) is a force plate-derived metric that has been used in sport performance applications to monitor training progress, as well as cumulative seasonal fatigue (Lloyd et al., 2009). RSI is calculated by the ratio of the assumed vertical displacement of the center of mass (CM) to the ground contact time (CT) during a depth jump. Using this ratio, one can ascertain an individual's ability to quickly change from an eccentric to concentric contraction during the take-off phase of the jump, indicating the rate of force developed.

A modified version of RSI ($RSI_{mod}$) has been developed to assess an individual's stretch-shortening cycle (SSC) characteristics by performing a counter movement jump (CMJ), eliminating the influence of increased gravitational forces involved in the depth jump. $RSI_{mod}$ is more applicable to a variety of individuals ranging from athletic to general populations for assessing elastic energy potential capabilities due to simplification of technique (McMahon et al., 2021). $RSI_{mod}$ is calculated as the ratio of CM vertical displacement in the CMJ to the total CT before take-off. The equation is: $\mathbf{RSI_{mod}} = \frac{\textbf{Jump Height (cm)}}{\textbf{Contact Time }(s)}$

Stiffness measures have been used in performance settings to assess lower extremity (LE) loading capabilities in movements that use $RSI_{mod}$ to represent the utilization of the SSC. The field-based stiffness equation, ($K_{field}$), has been developed utilizing CT and flight time (FT). It is based on an equation that models ground reaction forces as sine waves due to oscillations in the leg, as a pure spring-mass model, in the LE (Dalleau et al., 2004).

The equation is: $\mathbf{K_{field}} = \frac{\pi * (Tf + Tc)}{Tc^2 * \left(\frac{(Tf + Tc)}{\pi} - \frac{Tc}{4}\right)}$

Information on $RSI_{mod}$, and $K_{field}$ stiffness, can be used to modify an athlete's training and practice programs. To obtain valid measures, force platforms are used as the gold-standard. However, contact timing mats and video analysis are more affordable and accessible for coaches. Stiffness measures are not commonly used as performance metrics by practitioners outside of athletic populations. Examining the relationship between $RSI_{mod}$ and $K_{field}$ could be used as an efficient assessment of lower extremity movements utilizing the SSC due to minimizing the analysis process through the development of a regression equation to predict $K_{field}$ using $RSI_{mod}$. There is limited literature examining the interaction of $RSI_{mod}$ and $K_{field}$. Investigating the validity of utilizing both $RSI_{mod}$ and $K_{field}$ to quantify lower extremity SSC characteristics to analyze human movement can aid in developing training programs for athletes. The purpose of this study was to examine similar SSC measures and their relationship with other jump performance measures.

**METHODS:** All participants signed an informed consent and completed a Physical Activity Readiness Questionnaire (PARQ). Participants had their height, measured with a portable stadiometer, and weight was measured on the calibrated Kistler piezoelectric force platform. Anatomical data were collected for 13 recreationally active college males (age 23 ± 3 years, height 195.4 ± 9.0 cm, weight 93.7 ± 11.2 kg, leg length 100.37 ± 6.14 cm) as defined by the American College of Sports Medicine guidelines (Liguori, 2020). Leg length was measured from the anterior superior iliac spine to the medial malleolus, for each leg using a tape measure.

Participants then performed a standardized warm-up protocol, consisting of cycling on a Monark exercise bike ergometer for five minutes at 120 watts of resistance. Following this, one maximal counter-movement vertical jump was performed on the Kistler piezoelectric force platform sampling at the rate of 1000 hertz (Hz) which was followed by two minutes of rest in preparation for the start of their trials. The participant performed five counter-movement vertical jumps for which data was recorded in a 10 second period for each trial, to provide participants sufficient time to establish the weighing phase prior to each jump for proper jump threshold detection. A recovery period of one minute was performed between each trial upon completion of the platform acquisition period. After the completion of data collection, all five trials collected were visually inspected using the Bioware proprietary software (Bioware, Version 5.4.3.0) and the vertical force numerical data was exported to Microsoft EXCEL (EXCEL, Version 2110) for preparation to be analyzed in RStudio Version 2021.9.1.372 (Team, 2021). Included in this set of data specific to the analysis was the contact time of the unweighting, braking, and propulsion phases, the flight time following the take-off, and the vertical displacement of the center of mass being the jump height. Modified reactive strength indexes and stiffness were calculated using the following formulas presented in Figure 1. Exported data was entered into the Statistical Package for Social Sciences (SPSS) version 28 (Release 28.0.0) for statistical analysis and testing of the hypothesis. The following kinematic variables were defined and calculated as:

<u>Kinematic Variables</u>
The Modified Reactive Strength Index ($RSI_{mod}$) variable was calculated using the exported spreadsheet data using the formula presented in Figure 1, and expressed in meters per second (m/s). Modified Reactive Strength Index ($RSI_{mod}$) is the ratio of the vertical displacement of the center of mass to the contact time in the vertical jump.

$$\mathbf{RSImod} = \frac{\mathbf{Jump\ Height\ (m)}}{\mathbf{Contact\ Time\ (s)}}$$

**Figure 1: Modified Reactive Strength Index ($RSI_{mod}$) calculation**

The leg vertical stiffness ($K_{field}$) is defined as the force needed to resist the displacement of the body's center of mass (CM) after the application of ground reaction forces represented by the field-based equation presented in Figure 2. $K_{field}$ was calculated using the exported spreadsheet data using the following formula:

$$K_{field} = \frac{\pi * (FT + CT)}{CT^2 * \left(\frac{(FT + CT)}{\pi} - \frac{CT}{4}\right)}, \quad \pi = 3.1428 \text{ and expressed as kilonewton meters (kN/m)}$$

**Figure 2: Vertical Stiffness calculations**

The variable of contact time was defined as the amount of time spent on the ground performing the unweighting, braking, and propulsion phases while performing the vertical jump. The durations for the unweighting, braking, and propulsions phases are included within the duration of the contact. Contact time was utilized in both the modified reactive strength index and stiffness calculations. Contact time was measured to the thousandth of a second (0.001 s) prior to data reduction.

The variable of flight time is defined as: the amount of time spent off the ground in the flight phase involved in the vertical jump. Flight time was used in both the modified reactive strength index and stiffness calculations. Flight time was measured to the thousandth of a second (0.001 s) prior to data reduction.

The power variables used for analysis are comprised of the interaction of the temporal variables described above. The braking rate of force development (BrakingRFD), deceleration rate of force development (DecelRFD), and average rate of force development (AvgRFD) of the movement were utilized to examine the interaction between the force produced and velocity at which that force was produced in the CMVJ.

The temporal variables used for analysis were comprised of contact time, flight time, time to peak force, unweighting duration, braking duration, and propulsive duration.

All data was analyzed using the Statistical Package for Social Sciences (SPSS) (version 28; SPSS Inc., Chicago, IL, USA). The average of the five trials collected were utilized for the statistical analyses. Correlations were determined to examine the relationship of stiffness and other variables output from the RStudio vertical jump program including $RSI_{mod}$. A simple linear regression was also performed with $RSI_{mod}$ to predict $K_{field}$. All statistical procedures and analyses were tested at the .05 level for significance.

**RESULTS:** The simple linear regression established that $RSI_{mod}$ had a large effect ($F^2$= .727) that statistically significantly predicted $K_{field}$, $F(1,11) = 9.71$, $p = .01$, with $RSI_{mod}$ accounting for 42.1% of the explained variability in $K_{field}$ (Cohen, 1988). The predictive regression equation was: $\mathbf{K_{field} = 7.254 + 54.047*RSI_{mod}}$ Note: Significance was set at an alpha level of $p \leq .05$.

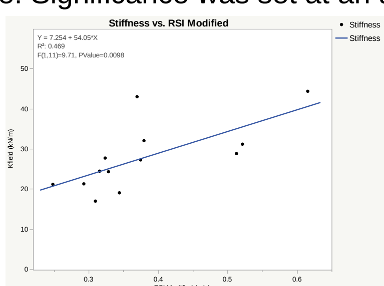


**Figure 3: Relationship of $RSI_{mod}$ and $K_{field}$**

**DISCUSSION:** The purpose of this study was to examine the relationship between $K_{field}$, $RSI_{mod}$, power, and temporal variables used for assessment of the CMJ as it could assist practitioners in the assessment of an individual. A positive linear relationship between the variables was identified.

The modified reactive strength index does significantly predict vertical stiffness, however, some variables utilized in the calculation of $RSI_{mod}$ could have an effect of a confounding variable. As contact time and jump height are utilized for the $RSI_{mod}$ measure, finding that the relationship with flight time was stronger than $K_{field}$ could possibly be due to the jump height measure variability

reflecting similar variability as flight time accounting for performance variation that does not necessarily utilize the SSC. Once the individual has propelled from the ground minimal SSC components will be utilized while the participant is airborne. Vertical stiffness demonstrated a stronger relationship with the temporal variables measured during vertical ground reaction forces generated during the contact time than $RSI_{mod}$, possibly indicating a difference in the sensitivity of the measure. Practitioners should continue further examination of relationships among vertical jump metrics. Importance into variable consideration should be taken as a second predictor could change the relationship due to the interaction among variables.
This study identified a significant regression equation utilizing $RSI_{mod}$ to predict $K_{field}$. To the investigator's knowledge, this is the first study examining the relationship between $RSI_{mod}$ and $K_{field}$ to determine a regression. Until presently, $K_{field}$ measures have been primarily utilized to measure stiffness in hopping. A hop is a frequency variation of a jump, as the frequency of the hopping increases then the contact time decreases while the vertical displacement variables should increase. The variation between hopping and jumping is dependent on frequency (Hobara et al., 2011). Further investigation of the application of $K_{field}$ should be performed to further validate its use, although the variables are linearly related with frequency. The use of $K_{field}$ could be of interest due to its difference in associated variables as compared to $RSI_{mod}$, possibly accounting for more aspects of the motor performance in comparison to $RSI_{mod}$.

**CONCLUSION:** Utilization of valid predictors for performance can aid in practitioners' assessment of training program effectiveness, in that not every practitioner has access to the gold-standard, force plates. With the development of a valid $K_{field}$ regression, a practitioner can predict stiffness utilizing more affordable equipment such as contact timing mats and video analysis to aid in the assessment of LE status. Temporal sequencing for an individual is important as it is an aspect of motor coordination throughout motor performance calling for more sensitive measures to assess components involved in vertical ground reaction force production throughout the movement. As stiffness measures have been utilized to assess rehabilitation progress, its utilization as an assessment metric in performance could aid in fatigue monitoring in a similar fashion $RSI_{mod}$ does, as it possibly could be more sensitive to temporal changes from the findings in this study (Brazier et al., 2019).

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