THE RELATIONSHIP OF THE REACTIVE STRENGTH INDEX-MODIFIED AND MEASURES OF FORCE DEVELOPMENT IN THE ISOMETRIC MID-THIGH PULL

George K. Beckham, Timothy J. Suchomel, Christopher A. Bailey, Christopher J. Sole, and Jacob L. Grazer

East Tennessee State University, Johnson City, TN, USA

Reactive strength index-modified (RSImod) may be an important variable to measure in the performance testing and monitoring of athletes, and very little work has examined this particular variable. One hundred six Division-I collegiate athletes performed countermovement jumps and the isometric mid-thigh pull. The relationship between the RSImod and variables from the isometric mid-thigh pull representative of explosive performance were evaluated with Pearson's *r*. Relationships between RSImod and variables related to explosiveness ranged from moderate to large. Maximum and relative maximum strength had the strongest correlations to RSImod. RSImod appears to be a measure of explosiveness. Furthermore, an athlete's isometric strength may be an indicator of their reactive strength.

KEYWORDS: Explosiveness, Rate of Force Development, Maximum strength, performance testing

INTRODUCTION: Evaluation of an athlete's performance is a vital part of the comprehensive training process. Without assessment of progress, it is difficult to determine if an athlete is actually improving. Likewise, performance markers can provide a measure of progress relative to other athletes in a given sport, position, etc. However, the variables that a coach or sport scientist uses to evaluate an athlete's progress must be specific to the performance demands of the sport.

The reactive strength index is a measure designed to provide an indication of an athlete's reactive, explosive ability (McClymont, 2005; Young, 1995). Originally, the reactive strength index was measured during the depth jump and was calculated by dividing jump height by ground contact time. Recently, the reactive strength index-modified (RSImod) was introduced as an alternative to the RSI (Ebben, Flanagan, & Jensen, 2009; Ebben & Petushek, 2010). RSImod is a similar calculation to the reactive strength index: jump height divided by time to take-off (Ebben & Petushek, 2010). However, RSImod can be calculated form various jumping movements other than the depth jump such as the countermovement jump (CMJ). It is possible that RSImod measured during the CMJ is more useful than the depth jump, given the ease of administration and common use of CMJs in performance testing. A paucity of research exists that has examined RSImod with CMJs, and no study has evaluated the relationship of RSImod with other variables.

Previous research has described the isometric mid-thigh pull (IMTP) in detail (Beckham et al., 2013; Kraska et al., 2009; Nuzzo, McBride, Cormie, & McCaulley, 2008; Sato et al., 2012). This particular performance test has been used to evaluate performance in a variety of athletes, including track and field, tennis, soccer, softball, volleyball and weightlifters (Beckham et al., 2013; Kraska et al., 2009; Sato et al., 2012). A number of performance variables of interest have been identified such as rate of force development (RFD), peak force, and impulse. Both Kraska et al. (2009) and Nuzzo et al. (2008) found that a number of IMTP measures had at least moderate relationships to CMJ height. Nuzzo et al. (2008) also found at least moderate relationships between IMTP variables and a number of other jump variables, although did not evaluate RSImod. Due to the limited amount of research evaluating RSImod, and the high amount of literature using variables of the IMTP, the purpose of this study was to evaluate the relationship of RSImod with variables obtained from the IMTP.

METHODS: One hundred six Division-I collegiate male and female athletes from a U.S. institution participated in this study (height: 175.6±9.1cm, body mass 76.1±12.7kg). The performance tests used in this study were part of an ongoing athlete monitoring program, and the variables of interest were calculated from data obtained during this monitoring program. This retrospective study was approved by the East Tennessee State University Institutional Review Board.

Athletes began the warm-up by completing 25 jumping jacks, followed by one set of five repetitions of mid-thigh pulls with a 20 kg barbell, and then 3 sets of 5 mid-thigh pulls with either 40 kg (women) or 60 kg (men). For the CMJs, athletes performed warm-up jumps at 50% and 75% of their perceived maximum effort. Athletes then performed two maximum effort CMJs holding a PVC pipe of negligible load (<1kg) behind their neck and across their shoulders. Each attempt was separated by 30 s. Athletes performed all CMJs on a force plate (91 cm x 91 cm, Rice Lake, WI, USA) sampling at 1000 Hz. Data were filtered using a digital low-pass Butterworth filter with a cutoff frequency of 10Hz. All data were collected and analyzed using a custom program in Labview 2010 (National Instruments Co., Austin Texas, USA). RSImod was calculated by dividing jump height by time to take off (Ebben & Petushek, 2010).

The procedures of the IMTP have been described previously (Beckham et al., 2013; Kraska et al., 2009). Briefly, athletes entered a custom adjustable power rack that allows fixation of a horizontal bar at any height. The bar was adjusted to a height that allowed the athlete to assume a position that closely approximates the beginning of the second pull of the clean while standing on a dual force plate set up (2 separate 45.5 cm x 91 cm; RoughDeck HP; Rice Lake, WI, USA) underneath the rack (goniometer verified knee angle of 125±5°). Each athlete used straps to ensure grip was not a limiting factor in their performance, and their hands were secured using athletic tape. Prior to the maximal effort pulls, each athlete performed two warm-up pulls, at an athlete-estimated 50% and 75% effort. For the maximal effort pulls, the athlete was instructed to pull as "fast and hard as you can", in order to encourage high RFD and peak force (PF). The athlete received a countdown, at which point the athlete exerted a maximal effort for 4 to 5 seconds. Two IMTPs were performed by each subject and the average measures were used for analysis. If the athlete performed a countermovement prior to the pull, an additional pull was performed. Athletes were allowed one minute of rest between each pull.

Force-time variables calculated from the IMTPs were PF, PF allometrically scaled (PFa; peak force · body mass$^{(0.67)}$), force at 200ms (F200), allometrically scaled force at 200ms (F200a), average RFD from 0-200ms (RFD200), and impulse 0-200ms (I200). Variables were deemed reliable due to acceptable ICCs, typical error values (TE%, expressed relative to the mean as a percent), and paired t-tests between trials (ICC, TE%, *p*-value: PF: 0.98, 4.1% *p*=0.01; PFa: 0.97, 4.1%, *p*=0.01; F200: 0.94, 9.4%, *p*=0.88; F200a: 0.90, 9.3%, *p*=0.79; RFD200: 0.90, 16.9%, *p*=0.75, IMP200: 0.93, 8.4%, *p*=0.22). While there were statistically significant differences between PF measurements, in light of the acceptable ICC and TE% values, the variables were kept for analysis. The 200ms time length was chosen as it corresponds to the approximate length of time that the net positive impulse is generated that ultimately results in vertical propulsion (Mizuguchi, 2012). The length of this phase of the CMJ in the athletes tested was 203.0± 50.2ms, agreeing with a previous study (Mizuguchi, 2012).

To evaluate the relationships between RSImod and IMTP performance variables, Pearson zero-order, product-moment correlations were calculated. Statistical significance was designated at *p*≤0.05. All statistical analyses were conducted in SPSS 21 (IBM, New York, NY, USA), while reliability analysis was calculated in a custom Excel spreadsheet (Microsoft Corporation, Redmond, WA) modified from Hopkins (2014). Correlation values of 0.0-0.1, 0.1-0.3, 0.3-0.5, 0.5-0.7, 0.7-0.9, and 0.9-1.0 were interpreted as trivial, small, moderate, large, very large, and nearly perfect according to Hopkins (2014).

RESULTS: RSImod for the group was 0.36±0.10. PF was 3802±1053N. PFa was 209.7±45.9. F200 was 2348±885N. F200a was 65.3±18.8. RFD200 was 6544±3427N·s^{-1}. IMP200 was 331±118N·s. Correlations between RSImod and each IMTP variable is shown in Table 1.

Table 1: Correlations between RSImod and IMTP Variables

Variable	*r*
Peak Force allometrically scaled	0.537*
Peak Force	0.509*
Force at 200ms	0.449*
Average rate of force development 0-200ms	0.442*
Impulse 0-200ms	0.425*
Force at 200ms allometrically scaled	0.342*

Note: *Statistically significant at $p<0.05$

DISCUSSION: RSImod has been described as a measure of explosive strength (Ebben & Petushek, 2010). This appears to be the first study to have evaluated the relationships of RSImod to other markers of explosiveness, and found data to support the previous notion. The moderate to large relationships between the markers of explosiveness (RFD200, F200, F200a, IMP200) and RSImod show that RSImod shares common ground with isometric explosiveness.

In order to exhibit a high RSImod, an athlete must both jump high and spend little time on the ground. In order to do this, substantial force must be generated rapidly and sustained during the eccentric and concentric phase (Cormie, McGuigan, & Newton, 2010b; Dowling & Vamos, 1993). High forces combined with short eccentric and amortization phases result in efficient use of stored elastic energy and maximizes the benefits of the myototic reflex (Cormie et al., 2010b). Increased or maintained high forces during propulsion ensure a large impulse and jump height (Mizuguchi, 2012). The ability to rapidly generate eccentric forces and generate high concentric forces is therefore vastly important to RSImod. While the strength, RFD, and impulse measurements were obtained during a multi-joint isometric activity in this study, the abilities expressed in the IMTP provide some general idea of rapid force generation capability. The relationships elucidated between RSImod and explosiveness characteristics in this study support the notion that knowledge of general isometric force output characteristics can glean some information about RSImod. Future analysis should examine similar variables (e.g. RFD, impulse) in dynamic activities, such as the dynamic mid-thigh pull or loaded jump, to further understand RSImod and how other performance characteristics specifically influence RSImod.

The relationship between maximal strength and increased explosive performance has been investigated thoroughly, and it is clear that maximal strength in the IMTP has strong ties to a variety of performance measures related to explosiveness (Beckham et al., 2013; Kraska et al., 2009; Stone et al., 2003). The findings of this study indicate that maximum strength during the IMTP has a substantial relationship to reactive strength ability. However, it is not clear exactly how increased maximum strength might influence RSImod. The athlete must be able to generate forces quickly in the eccentric portion of the CMJ, but being able to maintain high forces during the concentric phase is critical. Higher jumps are largely due to the impulse generated during the jump, so to maximize impulse, an athlete must generate very high forces, very quickly. Maximum strength exhibited is likely to reflect the peak forces obtained during the jump (Nuzzo et al., 2008). Furthermore, because increasing maximum strength through strength training positively affects jumping ability and various force-time characteristics of the CMJ (Cormie, McGuigan, & Newton, 2010a; Cormie et al., 2010b), it is likely that strength training will also improve RSImod. Further study is necessary to examine this.

One potential area of further study is to examine the forces that an athlete is able to generate in the IMTP over the period of time of their propulsive phase. This study used the approximate group average of 200ms. However, future research may consider evaluating each individual athlete based on their own propulsive phase length. The length of the propulsive phase is certainly a major factor in impulse generation during the jump, as is the force generated during that time (which then affects RSImod). Thus, evaluation of the force production ability in the IMTP may reveal further information about RSImod in individual athletes. It seems likely that this might better represent the relationship between the various force development variables and RSImod, but this should be tested in further research.

CONCLUSION: RSImod appears to be a measure of explosive ability. Strong correlations between force generation in early time periods in the IMTP and RSImod show cross-over of ability between the two. Similarly, maximal strength, especially relative to body mass, appears to have a very strong relationship with RSImod, indicating that stronger athletes tend to have better reactive strength. How maximal strength affects RSImod is not clear however, and further research is needed.

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