

Peak Torque as an Indicator of Rapid Torque Production during Screening Examinations

Roger Olen Kollock¹, Nelson Cortes², Eric Greska³ and James Oñate⁴

1. Department of Kinesiology and Rehabilitative Sciences, The University of Tulsa, Tulsa, OK, 74104, U.S.A.

2. Division of Health & Human Performance, George Mason University, Manassas, VA, 22030, U.S.A.

3. Department of Exercise Science & Community Health, University of West Florida, Pensacola, FL, 32514, U.S.A.

4. School of Health and Rehabilitation Sciences, The Ohio State University, Columbus, OH, 43210, U.S.A.

Abstract: Although the ability to produce force rapidly is an indispensable characteristic of optimal health and performance, screening for this very critical parameter of strength is difficult because of clinician time constraints. The purpose this study was to investigate relationships between peak torque (PT) and rate of torque development (RTD) at 0-30, 0-50, 0-100, and 0-200 ms in female collegiate soccer athletes. Seventeen female collegiate soccer athletes were recruited. Isometric PT and RTD were collected at the hip abductors (AB), hip adductors (AD), knee extensors (KE) and knee flexors (KF). The coefficients of determination were calculated to evaluate the association between PT and RTD. Normalized AB, AD and KF PT were significantly correlated to RTD at 0-30, 0-50, 0-100 and 0-200 ms, while KE PT was only significantly correlated to RTD at 0-100 and 0-200 ms. The results of this study indicate that PT is a viable, indirect indicator of early late phase RTD at separate time intervals at the AB, AD and KF. However, it is likely that other physiological factors coupled with PT are required to provide information on the rapid force production capabilities of the KFs and KEs based on the percent of common variance observed.

Key words: Maximum strength, hip strength, preparticipation examination, rate of force development.

1. Introduction

Strength is a critical component to both sports performance [1] and activities of daily living [2, 3]. Operationally, strength is the ability of the skeletal muscle to create force through active tension [4]. Practitioners frequently use the term strength to refer to either maximum strength or endurance strength. In clinical practice (e.g. Athletic Training), these qualities can be evaluated relatively easily during pre-season screening examinations using portable isometric dynamometers or tasks of functional performance. However, a number of studies [2, 3, 5-9] have observed that an individual's ability to produce force rapidly is also an important indicator of performance and injury susceptibility. This quality of strength is termed rate of

torque (or force) development (RTD) and within the clinical setting provides practitioners an effective metric for evaluating the quick responding qualities of the neuromuscular system [10-14] for both non-athletic and athletic patients.

Studies indicate that RTD may have important implications for daily activities characterized by a limited time to generate force such as stair descent [2], fast walking [3], or preventing a fall after sudden postural perturbation [7]. From a sports injury prevention perspective, the ability for an individual to produce force rapidly may be critical for tasks such as cutting, landing from a jump [9] and other tasks which allow a limited time for muscular action [15, 16]. In previous literature, researchers using visual inspection analysis of videos of anterior cruciate ligament injury situations found that the time of injury ranged from 17 to 50 ms after initial ground contact [15, 16]. This narrow window of time until injury places a higher

Corresponding author: Roger Olen Kollock, Jr., Ph.D., ATC, CSCS, assistant professor, research fields: identification of musculoskeletal injury risk factors associated to task performance in athletic populations.

importance on the neuromuscular systems quick responding characteristics (i.e. RTD).

Tasks that only provide for shortened contraction time (e.g. catching ones balance to prevent a fall) may not allow for the production of maximal levels of strength. Theoretically, high RTD in the initial 0-100 ms of a contraction hip frontal and transverse plane musculature is desirable because it allows an individual to reach a higher level of muscle force prior to the completion of the task, helping to prevent aberrant lower limb movement patterns during performance. Researchers have proposed that strength at the proximal musculature (trunk, hip and thigh) of the lower limb may play a critical role in preventing excessive femoral adduction and internal rotation during cutting and landing tasks [17, 18]. Thus, the ability to screen for this characteristic of muscular strength during preparticipation physical examinations may help provide clinicians with additional insight on an athlete's readiness to participate.

Due to the limitations in technologies, assessing this component of strength may not be feasible within the context of large-scale screening exams in which clinicians would have to evaluate a large number of athletes in succession. This is because direct collection of RTD often requires offline signal analysis and processing and experience in writing program code to reduce and output pertinent data. Although performing offline analyses and developing program codes may appear to be trivial to most in the scientific community, the average clinician is unfamiliar with this type of technology. In addition, the clinician's primary responsibility is patient care, rendering the time spent analyzing and reducing data as a distraction from their primary responsibilities.

However, it may not be necessary to measure RTD directly during preparticipation examination. Findings within the literature indicate that physiological muscle characteristics such as maximum strength, relative proportion of slow and fast twitch muscle fibers [19], area percentage of type IIX fibers [20], viscoelastic

properties of the muscle-tendon complex [21] and efferent neural drive to the muscle fibers [13] influence this property of muscular strength. Arguably, of these physiological parameters, maximal strength is the easiest to collect within the context of large-scale screening examinations. Clinicians can easily collect measures on maximal strength (i.e. peak torque (PT)) through hand-held or portable fixed dynamometry. Investigators have reported a relationship between PT and RTD [22-24], particularly at the late phases of RTD (greater than 90 ms) at the knee extensors [22] of mainly sedentary males. To our knowledge, there is no research demonstrating this relationship at the frontal plane hip musculature (i.e. abductors and adductors) or in more active populations such as female collegiate soccer athletes. If PT is indicative of RTD at other muscle groups, this information could help minimize the time required to obtain information on an athlete's ability to rapidly produce force.

Therefore, the purpose of this study was to investigate relationships between PT and RTD at four separate time intervals (0-30, 0-50, 0-100, and 0-200 ms) in female collegiate soccer athletes. Our first hypothesis was that PT will demonstrate a significant correlation to late-phase RTD. We further hypothesized that PT will display its strongest relationships to RFD at the 0-200 ms interval. Based on the earlier literature [13, 20, 22], early phase RTD were defined as time intervals less than 90 ms (i.e. 0-30 and 0-50 ms), while late phase RTD represented time intervals greater than 90 ms (i.e. 0-100 and 0-200 ms).

2. Materials and Methods

2.1 Participants

Seventeen Division I female collegiate soccer athletes (19.4 ± 0.9 years, 166.9 ± 4.9 cm, and 62.9 ± 5.8 kg), were recruited. Individuals were excluded if they had suffered a lower extremity injury within the last six months. Subjects reported to the sports medicine research laboratory in athletic attire for one testing session. Anthropometric measures were obtained

for mass, height, lower leg length, and total leg length. Following anthropometric measures the subjects were instructed to perform a 10-minute warm-up on an exercise bike. Prior to participation in this experiment, all participants read and signed a consent form that was approved by the institutional review board.

2.2 Materials and Procedures

Isometric strength data were collected using a commercial load cell (Model: LCR, OmegaDyne, Inc., Stamford, CT). The data were sampled at 1000 Hz (PT and RTD) using a 1 MHz, 24 bit USB data acquisition module (Model: NI-DAQ 9237, National Instruments Corporation, Austin, TX) and logged using LabVIEW Signal Express (National Instruments Corporation, Austin, TX) [25]. The logged data were stored on a laptop computer for offline processing and analysis. We filtered the data post-log using a digital fourth order Butterworth filter within LabVIEW Signal Express [25]. A power spectrum density analysis was performed using a custom Matlab program (The MathWorks Inc., Natick, MA) to determine the optimum filter cut-off frequency of 50 Hz. The load cell was calibrated within 1% of a known weight (178 N) daily [25]. In lab ICC_{3,1} reliability values ranged 0.78 to 0.91 for PT and 0.74 to 0.97 for RTD [25].

For the isometric strength parameters of maximum strength (i.e. PT) and RTD, the participants performed 3 test trials of 5 seconds in duration with a 60 seconds rest period between each trial. Subjects were instructed to contract as hard and fast as possible. All measures were collected on the dominant limb. Limb dominance was determined by asking the subject which leg they would use to kick a soccer ball, using their maximal force effort. Isometric PT and RTD for the hip abductor (AB), hip adductor (AD), knee flexors (KF), and knee extensors (KE) were evaluated. AB and AD were assessed in a standing position. The participants stood with their feet shoulder width apart. The load cell was attached to the lower leg above the medial malleolus via an ankle cinch strap (Fig. 1) [26].

KE and KF were performed in an upright-seated position. The hip and knee of the test extremity was positioned in 90° of flexion so that the tibia of the test extremity is perpendicular to the floor. The load cell was attached to the lower leg proximal to the medial malleolus via an ankle cinch strap. Knee positioning was verified via goniometric measure prior to the first test trial (Fig. 2) [26]. The muscle groups were assessed in counterbalanced order. The main outcome measures included normalized PT and RTD at four separate time intervals (0-30, 0-50, 0-100, and 0-200 ms).



Fig. 1 Standing hip abduction.



Fig. 2 Seated knee flexion.

2.3 Data Reduction and Normalization

Torque was calculated through the following equation: torque = moment arm (m) \times force (N). The measure of total leg length and lower leg length were used as the moment arm for AB/AD and KE/KF, respectively, to calculate torque. The highest PT value of the three isometric attempts was used to determine RTD. The initial 200 milliseconds (ms) after the onset of the contraction were used to calculate the RTD (Nms^{-1}) across four separate time-periods (0-30, 0-50, 0-100, and 0-200 ms) [13, 27]. The time point at which the torque is 7.5 Nm greater than the baseline value was defined as the onset of the muscle contraction [13]. PT and RTD were normalized using an allometric scaling process for females [28]: PT (Nm)/body mass (kg)^{0.482} and RTD (Nms^{-1})/body mass (kg)^{0.482}. The allometric scaling process is a body-size independent normalization technique recommended for athletic female populations, which uses a sex-specific b-value (female scalar of 0.482) for torque (or force). The technique was found to be appropriate for removing body-size dependence in athletic, homogeneous populations [28]. The data were normalized to avoid the opinion that the strength of the correlations merely reflected the anthropometric differences between

subjects [22].

2.4 Statistical Analysis

Separate Pearson product-moment correlations were used to evaluate the association between PT and RTD. The alpha level was set *a priori* at $P \leq 0.05$. The scale set forth by Hopkins [29] was used to interpret all correlation coefficients: trivial (0.0), small (0.1), moderate (0.3), strong (0.5), very strong (0.7), nearly perfect (0.9), and perfect (1.0). For correlation analysis, PT and RTD were normalized relative to weight and height. All coefficient correlations (r -values) were squared to calculate the coefficient of determination (r^2) in order to evaluate the percent of common variance between any two variables. The estimated power of this study was 0.80. The power analysis was performed post-hoc using GPower version 3.1.3 (Franz Faul, Universität Kiel, Germany). PASW Statistics 18 (IBM, SPSS Inc.) was used to analyze all data.

3. Results and Analysis

The means and standard deviation of the normalized strength measures are summarized in Table 1. All correlations are summarized in Table 2. Normalized AB PT was significantly correlated ($P \leq 0.001$) to AB RTD, accounting for 92.7% to 99.6% of the variance

Table 1 Strength means and standard deviations.

Measure	N PT		N RTD							
			30 ms		50 ms		100 ms		200 ms	
	M	SD	M	SD	M	SD	M	SD	M	SD
AB	16.75	3.20	460.48	90.24	279.16	55.23	139.63	28.24	69.74	14.54
AD	17.21	2.79	456.14	76.20	277.30	46.60	139.13	24.54	70.25	12.74
KE	15.97	4.11	363.80	102.63	222.31	62.87	112.34	31.03	56.67	15.19
KF	10.47	2.23	243.58	71.23	148.58	42.79	75.53	21.13	38.73	10.33

N PT = normalized peak torque; N RTD = normalized rate of force development; ms = milliseconds.

Table 2 Normalized strength coefficient of determination (r^2).

N PT measure	N RTD			
	30 ms	50 ms	100 ms	200 ms
AB	0.996	0.990	0.964	0.927
AD	0.712	0.699	0.724	0.581
KE	0.036	0.045	0.068	0.110
KF	0.304	0.342	0.410	0.569

N PT = normalized peak torque; N RTD = normalized rate of torque development; ms = milliseconds.

in normalized RTD at each time interval periods. Normalized AD PT was significantly correlated to RTD at 0-30, 0-50 and 0-100 periods, accounting for 69.9% to 72.4%. In addition, normalized AD PT was significantly correlated ($P \leq 0.01$) to RTD at the 0-200 period, accounting for 58.1% of the variance. Normalized KF accounted for 30.4% to 41.0% at 0-30, 0-50, and 0-100 periods ($P \leq 0.01$), while accounting for 56.9% of the variance in RTD at 0-200 ms ($P \leq 0.001$). KE PT was not significantly ($P > 0.05$) correlated to RTD at any period.

4. Discussion

In the present study, we investigated relationships between PT and RTD at four separate time intervals (0-30, 0-50, 0-100, and 0-200 ms). The main finding of this study is that normalized PT demonstrated a strong to nearly perfect association to both early and late phase normalized RTD at the ABs, accounting for 92.7%-99.6% of the variance. This partially supports the hypotheses of the present study. Although, the present study observed significant correlations between PT and RTD, the strongest relationship did not always occur at the 0-200 ms time interval (Table 2).

The results of the relationship between KE PT and

RTD of the present study are lower than an earlier report [22], which observed that early phase RTD, demonstrated a moderate correlation to PT. That earlier study [22] reported that PT assessed at the KE accounted for approximately 19% to 24% of the variance at time periods less than or equal to 50 ms. The results of the presented study indicated that KE PT accounted for approximately 4% of the variance in KE RTD at similar time frames. Our results indicate that KE PT alone is not viable as an indirect measure of early or late phase RTD in female collegiate soccer athletes, with as much as 96% of the variance unaccounted for by PT measure. KF PT demonstrated stronger relationships to RTD, but also did not account for as much of 65.8% to 69.6% of the variance in early phase RTD. This is in contrast to our observations at the ABs and ADs. The weaker correlations observed at the KEs and KFs as compared to the ABs and ADs indicate that other physiological factors such as stiffness of the muscle-tendon complex [21], muscle fiber characteristics [5, 20, 30], and neural drive to the muscle [13] may also play a role in RTD at both the early and late phases at the KEs and KFs [5, 13, 21, 30].

The present study did also observe that at the KEs and KFs, the strength relationship between PT and

RTD increased as the interval of time increased as in previous reports (2006). ABs and ADs however, did not demonstrate this trend. It should however be mentioned that in the present study; overall the correlation coefficient increased or decreased modestly across the separate time intervals (Table 2).

Clinically, the ability to collect indirect information about the early phase RTD may be a critical component to injury-free sports participation, particularly during maneuvers or tasks executed over brief periods of time (less than 90 ms). Based on the findings, it appears that PT is a very strong indicator of RTD at the ABs and ADs. In addition, we observed that this relationship is not only true for late phase RTD (0-100 ms and 0-200 ms), as reported in previous literature [22], but also in the early phases of RTD (0-30 ms and 0-50 ms) in female collegiate soccer athletes. This is an important clinical finding given the narrow time window between initial ground contact and injury occurrences reported in previous studies [15, 16, 31], with some estimates placing this window of time ≤ 50 ms [15, 16]. This window of time does not allow for the production of maximal strength levels. This places a higher importance on the neuromuscular systems quick responding characteristics (i.e. RTD); thus, screening for this very critical parameter to performance may be critical to helping reduce injury or re-injury risk. The results of the present study suggest that PT may provide clinicians an indirect measure of an athlete's ability to produce force rapidly (RTD) at the ABs and ADs within the context of large-scale screening. This does not appear to be the case for the KEs and KFs.

The author(s) believe the following considerations are warranted in the interpretation of these results. First, the results of the present study reflect single joint isometric data with no electromyography (EMG) information evaluating muscle activity, so the findings may not fully reflect the ability of an athlete to generate force rapidly during a multi-joint dynamic task. Second, it is also important to highlight that the present study used a protocol in which PT and RTD were collected

simultaneously so participants had to contract as hard and as fast as possible on each trial. Traditionally, clinicians instruct patients to contract as hard as possible, but not as fast as possible. This results in a slower ramp up time (2-3 seconds) for achieving PT during a five-second test trial, which may be ideal in certain testing instances. In the protocol of the present study, participants achieved PT in a much faster time. Therefore, the results of this study may not reflect the relationship between PT and RTD when using a traditional methodological approach to evaluating PT. The protocol used in the present study is preferable in collegiate soccer athletes given the nature of their sport where fast and short lasting movements allow for minimal time for the initiation and completion of the appropriate neuromuscular response [14, 32].

Third, these findings are based on a cross sectional study with a relatively small homogeneous sample; thus these results may not be generalizable to those other than collegiate female soccer athletes at the division one level. Fourth, the present study only explored the association between these variables and although the results provide insight into the area, they do not address questions of cause and effect. Future studies powered to use predictive models are required.

Finally, researchers should seek to include other parameters of muscular strength such as the total contractile impulse. Graphically, the total contractile impulse is represented as the area under the force-time curve [33] and is identical to the kinetic impulse or momentum reached under dynamic conditions [13]. The inclusion of other parameters of muscular strength, such as contractile impulse parameter, could provide greater insight into developing effective low-cost and time-efficient muscular strength test batteries for use in preseason screening examinations.

4.1 Practical Application

RTD is a critical component to both health and performance; thus the ability to directly or indirectly evaluate this component will help practitioners to

identify deficits rapid force production capabilities prior to play or activity. The results suggest that practitioners can use PT measures obtained from simple portable isometric devices during large scale-screening examinations to make evidence-based decisions about a female athlete's ability to rapidly produce force at the ABs and ADs. The results of this study reflect a protocol that instructs the athletes to contract as hard and fast as possible; thus athletes need to be instructed to perform repetitions in this manner. Practitioners can use this information to develop post-screening corrective exercise (focusing on rapid force production) that can be integrated into already existing in-season training programs with strength and conditioning staff to reduce injury risk and increase performance.

5. Conclusion

The results of this study indicate that PT is a viable indirect indicator of early and late phase RTD at separate time intervals at the ABs and ADs. However, it is likely that other physiological factors coupled with PT are required to provide information on the rapid force production capabilities of the KEs and KFs.

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