

Original Article

Rate of torque development as a discriminator of playing level in collegiate female soccer players

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Objectives: This study aimed to examine the efficacy of isometric knee extension and flexion peak torque and rate of torque development (RTD) variables to distinguish starters from non-starters in collegiate female soccer players. **Methods:** Eleven starters (20±2 years) and 13 non-starters (19±1 years) performed three isometric maximal voluntary contractions of the knee extensors and flexors. Peak torque, peak RTD, and RTD at 0-100 (RTD100) and 0-200 (RTD200) ms were obtained from each contraction. **Results:** The starters produced significantly greater ($P=0.002-0.015$) knee extension and flexion peak RTD, RTD100, and RTD200 values than the non-starters. There were no significant differences ($P>0.050$) between the starters and non-starters for peak torque. Discriminant analysis revealed thresholds of 9.36, 7.98, and 6.97 $\text{Nm}\cdot\text{s}^{-1}\cdot\text{kg}^{-1}$ for knee extension RTD200 and knee flexion peak RTD and RTD100, respectively. These thresholds showed 81.8% sensitivity and 76.9 to 92.3% specificity for identifying playing group membership. **Conclusions:** Our findings indicate that RTD may be a better parameter than peak torque at differentiating between playing level in collegiate female soccer players. The discriminant analysis thresholds for the RTD variables demonstrated good sensitivity and specificity, and therefore, may be used as indices to identify players with a high degree of soccer playing ability.

Keywords: Contraction, Extension, Flexion, Isometric, Talent Identification**Introduction**

The success of most collegiate soccer programs is largely dependent on the ability to identify and recruit players with a high degree of soccer playing potential. During competition, soccer players perform numerous low- and high-intensity activities¹. Although low-intensity activities (i.e., standing, walking, and jogging) are the predominant movement patterns of players in a game, the ability to perform high-intensity activities are more important to a player's success^{1,2}. High intensity activities, which include fast sprints

and quick changes of direction, depend on the physiological characteristics of each player³. Previous studies have assessed the importance of physical characteristics to soccer playing ability by comparing performance-based outcomes between starters and non-starters³⁻⁵. Starters are often considered the best players on the team⁶. These players get more playing time than non-starters⁵ and have been shown to achieve higher performance outcomes on intermittent fitness and squat jump tests^{3,4}. Intermittent fitness and squat jumps are relatively easy tests to administer. However, the performance measures from these tests have been reported to be poor predictors of critical soccer-related tasks (i.e., quick sprinting and accelerating-type actions)^{7,8}. Thus, the prospect of identifying performance measures more closely associated with these activities that can successfully differentiate starters from non-starters may be advantageous in the testing and evaluation of prospective soccer talent.

Concentric and eccentric power, given their importance during sprinting⁹, may be used to differentiate starters from non-starters in collegiate soccer. Strength-based torque characteristics, which are often measured from an isometric maximal voluntary contraction (MVC), have also

Ty B. Palmer co-invented the Dynamo Torque Analyzer. Kazuma Akehi has nothing to disclose.

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Edited by: G. Lyrakis

Accepted 2 April 2022



been shown to be significant predictors of many soccer-related tasks^{10,11}. These characteristics may depend on the physical training and game movements of players according to their position, leadership role, and overall importance to the team¹¹. Such characteristics may also be particularly useful for distinguishing between soccer players of different playing levels (starters vs. non-starters). Isometric peak torque, which is a measure of maximal force, has been shown to be an important parameter for strength-based performances¹² and intermittent running¹¹. However, because peak torque requires greater than 300 ms to be achieved¹³, it may not be as functionally relevant for explosive soccer activities (i.e., sprinting, accelerating, and cutting) that involve movement durations shorter than 250 ms^{14,15}. In contrast, rapid strength variables, which include rate of torque development (RTD), have functional significance in fast and forceful muscle contractions¹⁶ and thus, may be better discriminators of explosive soccer-related performances. Kalkhoven and Watsford¹⁷ presented evidence in support of this hypothesis by demonstrating the superior capacity of RTD versus peak torque to distinguish between male soccer players with different stiffness, agility, and sprint performance abilities. Moreover, Palmer et al.¹⁸ showed that RTD calculated at 0-200 ms (RTD200) was a better variable than peak torque at differentiating between professional status in higher- and lower-level soccer referees. Thus, based on these results and given the importance of rapid strength to quick and forceful movement tasks, isometric RTD assessed over a short time period (≤ 200 ms) may be a highly effective measure at determining the playing level and on-field performance abilities of soccer players and other athletic populations.

Although RTD may be critical to one's success in soccer, it is not the only determinant of a player's performance on the field. Technical, tactical, and mental abilities may also influence playing status¹⁹. The task of selecting which players are starters and non-starters on a team is typically conducted by the coaching staff. Coaches often select players based on their performance level, as top performers would be selected to start games over lower performers²⁰. Such selection may also depend on tactical beliefs or strategies for each specific game played by the team. With that said, there are likely many factors, in addition to RTD, that contribute to a player being selected as a starter or non-starter.

Few studies have compared isometric RTD measurements between starting and non-starting players. Thompson et al.¹⁴ revealed that early-phase (0-30 ms) knee flexion RTD was able to successfully differentiate starters from non-starters in collegiate American football. Although these findings support the capacity of RTD to discriminate between playing level, Thompson et al.¹⁴ found no significant differences between starters and non-starters for other RTD variables, including peak RTD and RTD at 0-100 ms (RTD100). However, it should be noted that these variables were not normalized to body mass. Previous research has emphasized the importance of correcting for body

mass when analyzing RTD measurements²¹. Dividing RTD by body mass removes the influence of body weight²², which may improve the RTD comparisons made between participants. Further research is needed to determine if RTD measurements (i.e., peak RTD, RTD100, and RTD200) normalized to body mass can effectively distinguish starters from non-starters.

Research suggests that the knee extensors and flexors are large contributors to many soccer-related tasks, including sprinting, accelerating, and cutting²³⁻²⁵. Consequently, isometric knee extension and flexion MVCs may be highly relevant tests for examining the maximal and rapid strength characteristics of soccer players. As mentioned above, it may be important to normalize RTD to body mass. Similar to RTD, body mass has been shown to be an important characteristic relevant to sprinting and accelerating²⁶; therefore, it too may be an effective variable at differentiating between starters and non-starters. Previous studies have examined the efficacy of isometric peak torque and RTD as discriminating variables in male athletes^{14,17}. However, limited research has investigated the discriminatory ability of these measurements in female athletes, and in particular, collegiate female soccer players. Measuring peak torque and RTD variables in collegiate female soccer players of different playing levels may yield novel insight regarding the significance of maximal and rapid strength in this population.

Commercial devices, such as isokinetic dynamometers, are commonly used to measure isometric peak torque and RTD characteristics^{14,16,17}. To calculate RTD with these devices, offline analysis of the torque signal using data processing software is required. Because analyzing the torque signal offline can be a time-consuming task, this method of RTD calculation may not be feasible in certain testing situations where rapid data analysis is required for immediate RTD results²⁷. Recently, a novel strength testing device was developed called the Dynamo Torque Analyzer. The Dynamo consists of a load cell that can be affixed to existing equipment found in laboratories and clinics (i.e., isokinetic dynamometer, resistance training machine, treatment table or chair, etc.) and a microcomputer that records torque in newton-meters (Nm). Unlike isokinetic dynamometers, the Dynamo automatically calculates and displays peak torque and RTD measurements immediately after an isometric contraction (no offline analysis is required). The Dynamo has been shown to be a valid and reliable device for quantifying peak torque and RTD²⁸. Given the accuracy and speed with which it can analyze the torque signal, the Dynamo may be an attractive tool for evaluating the muscle strength capacities of athletes. Thus, the purpose of the present study was to investigate the effectiveness of isometric knee extension and flexion peak torque and RTD measurements from the Dynamo to differentiate starters from non-starters in collegiate female soccer players. Based on the results reported by previous authors^{14,17}, we hypothesized that RTD would be a better discriminator of playing level than peak torque.

Methods

Participants

Before data collection, an a priori power analysis was performed for a between-groups design. Using G*Power software (version 3.1.9.2; Heinrich Heine University, Düsseldorf, Germany) and assuming a large effect size, it was determined that a minimum of 24 participants were needed to achieve a statistical power of 0.80 at an alpha level of 0.05. Thus, 26 collegiate female soccer players were recruited to participate in the present study. Players were recruited from a Midwest region NCAA Division II soccer team. Of the 26 soccer players who were recruited, two had suffered injuries to the lower body prior to testing, and thus, their data were excluded from the analyses. All subsequent analyses were performed on the data from the remaining 24 participants. None of these participants reported any current or ongoing neuromuscular diseases or musculoskeletal injuries specific to the lower extremities. Inclusion criteria consisted of participants who were healthy field players (i.e., defenders, midfielders, and forwards) between the ages of 17 and 22 years. Goalkeepers were excluded from this analysis due to the different physiological demands unique to their position²⁹.

All testing was completed during the 2021 preseason training period (before the season started). Each player was instructed to refrain from any vigorous physical activity or exercise within 24 hours of testing. The players were classified as starters or non-starters according to their average number of minutes played per game during the subsequent exhibition season. An average playing time of 40 minutes per game has been reported and used as a cutoff for distinguishing between starters and non-starters in collegiate female soccer⁵. Based on this criterion, of the 24 soccer players in our study, 11 were identified as starters (≥ 40 minutes) and 13 were identified as non-starters (< 40 minutes). The demographic data for these participants are presented in Table 1. Player position was similarly represented between the starters (defenders=3, midfielders=5, forwards=3) and non-starters (defenders=3, midfielders=7, forwards=3). There were no significant differences ($P > 0.050$) in peak torque or RTD between positions (defenders vs. midfielders vs. forwards). At the time of testing, all players were involved in a weekly training program that consisted of 2-3 d·wk⁻¹ of resistance exercise for muscle strength and 3-4 d·wk⁻¹ of conditioning exercise for endurance, speed, agility, and power. In addition to these exercises, soccer-specific training was also performed and consisted of 2-3 d·wk⁻¹ of ball handling and position drills. This study was approved by the university's institutional review board for human subject's research, and each participant signed and completed an informed consent document and health history questionnaire.

Experimental Design

This study used a cross-sectional research design to investigate the efficacy of isometric knee extension and

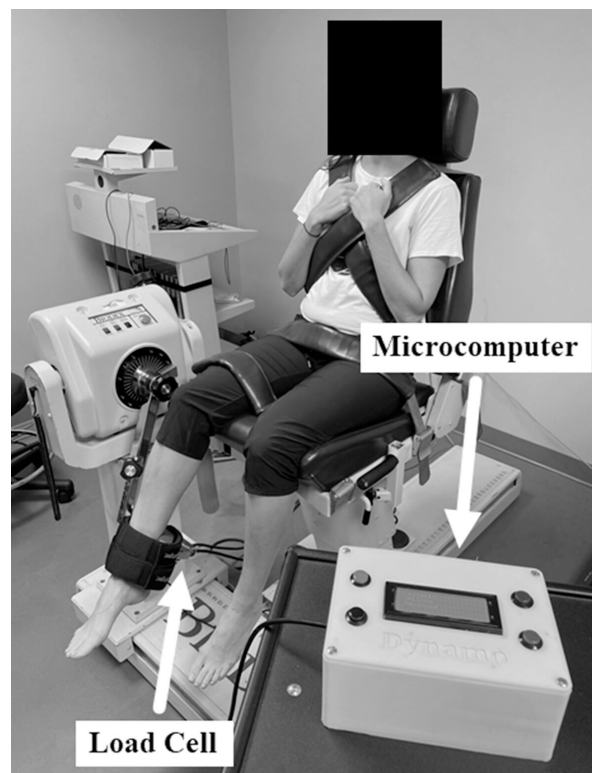


Figure 1. A participant performing an isometric knee extension maximal voluntary contraction using the Dynamo. The Dynamo consists of two functional components: a load cell and a microcomputer.

flexion peak torque and RTD variables to discriminate between starters and non-starters in collegiate female soccer. Each participant visited the laboratory two times, separated by 1-2 days. During the first visit, participants were familiarized with the testing procedures by performing several isometric MVCs of the knee extensors and flexors. During the second visit, participants completed three isometric knee extension and flexion MVC tests.

Isometric Knee Extension and Flexion

Isometric knee extension and flexion MVCs were performed on the right leg using a Dynamo Torque Analyzer, as described previously²⁸. The Dynamo consisted of a microcomputer and a load cell (200 kg capacity) that was attached to the ankle pad of a lever arm fastened around the participant's lower leg (Figure 1). The ankle pad was custom-made. It included two strong Velcro straps. These straps were used to reduce the risk of any changes in joint angle during testing. The lever arm was connected to the input axis of an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems Inc., Shirley, NY) which was aligned with the axis of rotation of the knee joint. For each MVC, participants sat on the dynamometer chair in

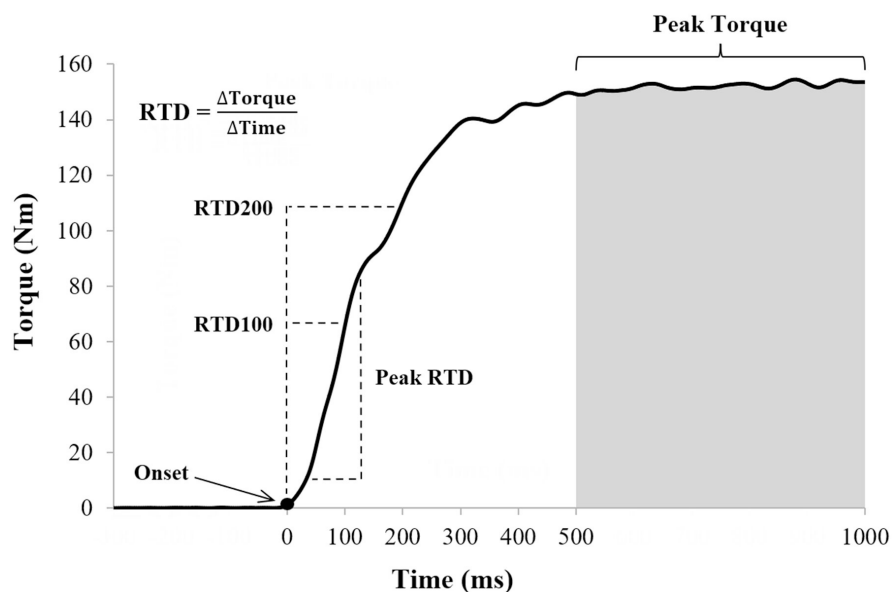


Figure 2. Example of a processed torque signal taken from a typical participant during an isometric knee extension maximal voluntary contraction. The torque signal produced during the contraction was used to measure isometric peak torque and rate of torque development (RTD) characteristics. Isometric peak torque was calculated as the highest mean 500 ms epoch. RTD was calculated as the linear slope of the torque signal at time intervals of 0-100 (RTD100) and 0-200 (RTD200) ms from onset. Peak RTD was calculated as the highest slope value for any 100 ms epoch that occurred over the initial 200 ms of the torque signal.

an upright position with restraining straps placed over the shoulders, waist, and thigh. All MVCs were performed at a knee joint angle of 60° below the horizontal plane (Figure 1). Prior to the MVC assessments, participants performed a standardized warm-up of three submaximal isometric knee extension and flexion joint actions at approximately 75% of their perceived maximal effort²⁸. Following the submaximal contractions, each participant performed three isometric knee extension and flexion MVCs with one minute of recovery between each contraction and three minutes of recovery between joint actions. For all MVCs, participants were verbally instructed to push or pull “as hard and fast as possible” for a total of 3-4 s and strong verbal encouragement was given throughout the duration of the contraction.

Data Processing

During each MVC, the scaled force signal from the load cell was sampled, interpolated to 1000 Hz, and processed automatically by the Dynamo. A torque signal (Nm) was derived by multiplying the force signal (N) from the load cell by the limb length (m) for each participant²⁸. Limb length was measured as the distance from the lateral knee joint to the ankle (positioned over the load cell) and was entered into the Dynamo’s microcomputer prior to the MVC tests. The torque signal was gravity corrected and low-pass filtered with a zero-phase lag, fourth-order Butterworth filter at a cutoff frequency of 20 Hz³⁰. All subsequent analyses were

conducted on the filtered and gravity-corrected torque signal.

Peak torque was calculated as the highest mean 500 ms epoch (Figure 2). RTD100 and RTD200 were calculated as the linear slope of the torque signal ($\Delta\text{torque}/\Delta\text{time}$) at time intervals of 0-100 and 0-200 ms from contraction onset, respectively (Figure 2). Peak RTD was calculated as the highest slope value for any 100 ms epoch that occurred over the initial 200 ms of the torque signal (Figure 2)²⁸. The contraction onset for the Dynamo was set at 1.0 Nm. This automated onset was used to ensure the same threshold value was being selected across all contractions and to allow the early portion of the MVC signal to be captured in the RTD output parameters³¹. Isometric peak torque, peak RTD, RTD100, and RTD200 were calculated and displayed by the Dynamo at the conclusion of each trial and were normalized to body mass.

Unsteady baseline torque resulting from either pre-tension or countermovement can adversely influence RTD³². A unique feature of the Dynamo is its ability to detect unsteady baseline torque. The Dynamo’s microcomputer evaluates unsteady baseline torque by computing the baseline slope prior to contraction onset using methods similar to those described previously³¹. If unsteady baseline torque was detected prior to contraction onset, a warning was displayed by the microcomputer at the end of the trial. Contractions with unsteady baseline torques as indicated by the Dynamo were always discarded, and additional MVCs were performed

Table 1. Means \pm SDs for demographic characteristics and average playing time per game.

Variable	Starters	Non-starters
Age (years)	20.00 \pm 1.67	19.38 \pm 0.87
Height (cm)	163.95 \pm 7.75	164.76 \pm 4.41
Body Mass (kg)	62.19 \pm 6.87*	70.80 \pm 8.37
Limb Length (m)	0.32 \pm 0.03	0.32 \pm 0.02
Playing Time (min/game)	66.09 \pm 16.39*	13.46 \pm 10.29

*Significantly lower body mass and greater playing time for the starters compared to the non-starters ($P \leq 0.050$).

Table 2. Means \pm SDs and Cohen's d effect sizes between groups for isometric knee extension and flexion peak torque and rate of torque development (RTD) variables.

Variable	Knee Extension			Knee Flexion		
	Starters	Non-starters	d	Starters	Non-starters	d
Peak Torque (Nm·kg ⁻¹) [†]	2.26 \pm 0.24	2.21 \pm 0.41	0.15	1.19 \pm 0.12	1.15 \pm 0.16	0.29
Peak RTD (Nm·s ⁻¹ ·kg ⁻¹) ^{*†}	14.62 \pm 2.51	12.87 \pm 1.93	0.75	8.56 \pm 1.21	7.35 \pm 0.95	0.99
RTD100 (Nm·s ⁻¹ ·kg ⁻¹) ^{*†}	13.81 \pm 2.26	11.26 \pm 2.61	0.93	7.72 \pm 1.50	5.70 \pm 1.24	1.20
RTD200 (Nm·s ⁻¹ ·kg ⁻¹) ^{*†}	10.05 \pm 1.47	8.54 \pm 1.28	0.98	5.47 \pm 0.63	4.91 \pm 0.59	0.85

*Significantly greater peak RTD, RTD100, and RTD200 for the starters compared to the non-starters when collapsed across joint action ($P \leq 0.050$). [†]Significantly greater peak torque, peak RTD, RTD100, and RTD200 for knee extension compared to knee flexion when collapsed across group ($P \leq 0.050$).

until three knee extension and flexion contractions presented acceptable data. Of the three MVCs performed, the MVC with the highest peak RTD value for knee extension and flexion was selected for further analysis³³.

Statistical analysis

We inspected data for normality using the Shapiro-Wilk test. Outliers were defined as values that exceeded 2.2 times the interquartile range away from the first and third quartiles³⁴. Independent samples t -tests were used to compare demographic characteristics and playing time between the starting and non-starting groups. Four separate two-way mixed factorial analyses of variance (group [starters vs. non-starters] \times joint action [knee extension vs. knee flexion]) were used to analyze peak torque, peak RTD, RTD100, and RTD200. Cohen's d effect sizes³⁵ were calculated for each between-group comparison. Discriminant analysis using receiver operator characteristics was performed to establish thresholds for peak torque, RTD, and body mass and to determine the sensitivity and specificity of these thresholds for identifying playing group membership (starters vs. non-starters). Multiple regression analysis (stepwise model) was used to determine which variables were the best predictors of playing time. All statistical analyses were performed using IBM SPSS software (version 26.0; SPSS Inc., Chicago, IL), and an alpha level of $P \leq 0.050$ was used to determine statistical significance.

Results

No outliers were identified, and all data were confirmed as being normally distributed. Mean and standard deviation (SD) values for demographic characteristics and playing time are presented in Table 1. There were no significant differences between the starters and non-starters for age ($P=0.260$, $d=0.47$), height ($P=0.750$, $d=0.13$), or limb length ($P=0.760$, $d=0.09$). Body mass was significantly lower ($P=0.012$, $d=0.99$) and playing time was significantly greater ($P<0.001$, $d=1.74$) for the starters compared to the non-starters.

Table 2 shows the means, SDs, and Cohen's d effect sizes between groups for isometric knee extension and flexion peak torque and RTD variables. For peak torque, there was no interaction ($P=0.962$), and there was no main effect for group ($P=0.573$), but there was a main effect for joint action. Knee extension peak torque was significantly greater ($P<0.001$) than knee flexion peak torque when collapsed across group. For the RTD variables, there were no interactions ($P=0.092$ - 0.606), but there were main effects for group and joint action. When collapsed across joint action, the starters exhibited significantly greater peak RTD ($P=0.015$), RTD100 ($P=0.002$), and RTD200 ($P=0.006$) compared to the non-starters. In addition, peak RTD, RTD100, and RTD200 collapsed across group were significantly greater ($P<0.001$) during knee extension than knee flexion.

Discriminant analysis revealed thresholds of 9.36, 7.98, and 6.97 Nm·s⁻¹·kg⁻¹ for knee extension RTD200 and

Table 3. Discriminant analysis statistics for identifying playing group membership.

Variable	Threshold	Sensitivity %	Specificity %
Knee Extension			
Peak Torque (Nm·kg ⁻¹)	2.29	45.5	61.5
Peak RTD (Nm·s ⁻¹ ·kg ⁻¹)	14.07	72.7	76.9
RTD100 (Nm·s ⁻¹ ·kg ⁻¹)	13.06	72.7	76.9
RTD200 (Nm·s ⁻¹ ·kg ⁻¹)	9.36	81.8	76.9
Knee Flexion			
Peak Torque (Nm·kg ⁻¹)	1.14	72.7	53.8
Peak RTD (Nm·s ⁻¹ ·kg ⁻¹)	7.98	81.8	76.9
RTD100 (Nm·s ⁻¹ ·kg ⁻¹)	6.97	81.8	92.3
RTD200 (Nm·s ⁻¹ ·kg ⁻¹)	5.38	63.6	76.9
Body Mass (kg)	67.50	72.7	76.9

Table 4. Stepwise multiple regression analysis for the prediction of playing time.

Model	B	SE _B	β
Constant	-30.286	21.049	
Knee Flexion RTD100	10.238	3.081	0.578*

*B=unstandardized beta; SE_B=standard error for the unstandardized beta; β=standardized beta. *R²=0.334, P=0.003.*

Table 5. List of variables that did not add any unique variance to the stepwise prediction model.

Variables	Partial R	P value
Knee Extension Peak Torque	0.034	0.877
Knee Extension Peak RTD	0.120	0.585
Knee Extension RTD100	0.258	0.234
Knee Extension RTD200	0.214	0.327
Knee Flexion Peak Torque	-0.123	0.577
Knee Flexion Peak RTD	-0.217	0.319
Knee Flexion RTD200	-0.125	0.569

Partial R=the correlation of each variable with playing time after removing the influence of knee flexion RTD100.

knee flexion peak RTD and RTD100, respectively. These thresholds demonstrated the highest sensitivity (81.8%) and specificity ($\geq 76.9\%$) for identifying playing group membership. Discriminant analysis statistics for all isometric torque variables and body mass are shown in Table 3. For the multiple regression analysis, isometric peak torque, peak RTD, RTD100, and RTD200 of the knee extensors and flexors were entered as predictor variables into the stepwise model. The model revealed that knee flexion RTD100 was the single best predictor of playing time ($R^2=0.334$, $P=0.003$, Table 4),

with the other variables explaining no further unique variance (Table 5).

Discussion

In this study, the starters weighed less and produced significantly greater isometric knee extension and flexion RTD values (when collapsed across joint action) than the non-starters (Tables 1 and 2). There were no significant differences between starters and non-starters for peak

torque (Table 2). The thresholds in the discriminant analysis for knee extension RTD200 and knee flexion peak RTD and RTD100 demonstrated the highest sensitivity and specificity for identifying playing group membership (Table 3). Furthermore, multiple regression analysis indicated that knee flexion RTD100 was the single best predictor of playing time (Table 4).

The greater peak RTD, RTD100, and RTD200 observed in the present study for the starters compared to the non-starters demonstrated the efficacy of these measurements at distinguishing between groups based on playing level (Table 2). Previous studies have reported similar findings regarding the efficacy of isometric RTD as a discriminating variable in athletic populations^{14,17,18}. For example, Palmer et al.¹⁸ showed that soccer referees who officiated games at a higher professional level were also able to produce greater isometric RTD values of the hip extensors than lower-level referees. The authors hypothesized that because the higher-level referees exhibited greater RTD values than the lower-level referees, rapid strength may be an effective determinant of soccer refereeing performance¹⁸. For female soccer players, the physiological demands of game participation often require the performance of a relatively large number of sprints and quick changes of direction^{1,2}. These activities (i.e., sprinting, accelerating, and cutting) involve short movement durations (≤ 250 ms) and therefore, may be highly dependent on one's ability to produce torque rapidly^{14,15}. The results of the present study support the importance of rapid strength in regard to playing level (starters vs. non-starters). Starters are often considered the best players on the team⁶ and because the starters in this study exhibited greater RTD values than the non-starters, isometric rapid strength may be an effective parameter at determining the on-field performance abilities of collegiate female soccer players.

Despite the significant differences in RTD values, our findings revealed small, non-significant differences in peak torque between the starters and non-starters (Table 2). These findings are consistent with those of Kalkhoven and Watsford¹⁷ who reported larger differences for knee extension RTD than peak torque between male soccer players of varying stiffness and athletic ability. Collectively, these findings highlight the importance of rapid strength and suggest that RTD may be a better variable than peak torque at differentiating between the playing level and athletic performance abilities of male and female soccer players. Many soccer-related tasks, including sprinting, involve rapid, repetitive muscle actions of the knee extensors and flexors²³. During sprint acceleration, the knee extensors (quadriceps) and flexors (hamstrings) work together in the stance phase to create the ground reaction forces required to propel the body forward at a fast speed^{23,36}. The stance phase of sprinting lasts less than 200 ms³⁷ and because the time required to achieve maximal force is typically greater than 300 ms¹³, rapid strength characteristics (0-200 ms) may be more functionally relevant than isometric peak torque for sprinting and other soccer-related tasks. Thus, the possibility of greater functional relevance between rapid strength

and soccer performance ability may explain why larger differences in RTD variables (collapsed across joint action) were observed between the starters and non-starters in the present study.

Thompson et al.¹⁴ showed that early-phase (0-30 ms) knee flexion RTD was able to successfully distinguish starters from non-starters in collegiate American football players. Although these findings appear to support those of the present study, Thompson et al.¹⁴ found no significant differences between starters and non-starters for other RTD variables, including knee extension and flexion peak RTD and RTD100. Our findings, which revealed significant differences in peak RTD and RTD100 between groups (Table 2), may differ from those of Thompson et al.¹⁴ because of discrepancies in the athletes who were tested (soccer players vs. American football players) and/or the calculation of RTD. Unlike the present study which calculated measurements of RTD normalized to body mass ($\text{Nm}\cdot\text{s}^{-1}\cdot\text{kg}^{-1}$), Thompson et al.¹⁴ calculated non-normalized RTD measurements ($\text{Nm}\cdot\text{s}^{-1}$). Before the RTD measurements in our study were normalized (data not shown), peak RTD and RTD100 were not significantly different ($P>0.050$) between the groups, thus reflecting the same results as Thompson et al.¹⁴. It was only after peak RTD and RTD100 were normalized to body mass that we found significant differences collapsed across joint action between the starters and non-starters. These findings add support to the importance of correcting for body mass when analyzing RTD measurements.

The thresholds in our discriminant analysis for knee extension RTD200 and knee flexion peak RTD and RTD100 showed 81.8% sensitivity (ability to correctly identify those who were starters) and 76.9 to 92.3% specificity (ability to correctly identify those who were non-starters) (Table 3). These sensitivity and specificity statistics were higher than those for isometric peak torque ($\leq 72.7\%$), which supports our previous assertion that the ability to generate torque rapidly may be a better discriminator of playing level than maximal strength in female soccer players. In this study, multiple regression analysis revealed that a significant portion of the variance in playing time ($R^2=0.334$, $P=0.003$) could be explained by knee flexion RTD100 (Table 4). Evidence suggests that RTD is an important characteristic relevant to sprinting and accelerating¹⁰. The ability to sprint and accelerate quickly is critical to one's success in soccer³⁸. Thus, in light of this and given the good sensitivity and specificity observed for the RTD thresholds in our discriminant analysis (Table 3), isometric RTD of the lower-body musculature may be an effective measure at identifying players with a high degree of soccer playing ability.

Rapid strength is influenced by several factors including connective tissue stiffness²¹, type II fiber area³⁹, and muscle activation parameters⁴⁰. These factors may help explain the differences in RTD we observed between the starters and non-starters. Jajtner et al.⁵ examined the effects of playing level on dynamic performance and muscle morphology measurements in collegiate female soccer players. The authors revealed that pennation angle of the vastus lateralis was greater for starters compared to non-starters⁵. Because

pennation angle influences rapid strength⁴¹, such differences may have contributed to the greater knee extension RTD values for the starters compared to the non-starters in the present study.

An interesting finding of this study was that the starters had lower body mass than the non-starters (Table 1). Furthermore, the threshold in our discriminant analysis for body mass showed 72.7% sensitivity and 76.9% specificity for identifying playing group membership (Table 3). Similar to RTD, body mass has been shown to play an important role in sprinting and accelerating²⁶. Consequently, starting soccer players, such as those in the present study, who weigh less and produce greater RTD values, may have an advantage over non-starting players in performing these activities. Miller et al.⁴² reported that collegiate female soccer players who completed 6 weeks of power-based complex training (i.e., Olympic-style exercises, traditional weightlifting, and plyometrics) exhibited significant decreases in body fat percentage and increases in lower-body strength. This type of training may be particularly beneficial for non-starters. If non-starters perform power-based complex training in conjunction with their normal exercise program, they may experience favorable changes in body mass and muscle strength. A decrease in body mass would improve the weight-normalized RTD values of non-starters, which could lead to better on-field performance and more playing time for these athletes.

For the RTD variables in this study, there were no significant interactions, but there were main effects for group. These findings indicate that the magnitude of the differences in RTD values between the starters and non-starters was similar for the knee extensors and flexors. This is somewhat surprising considering the distinct characteristics and roles of these muscles during important soccer-related tasks, such as sprinting²³. The non-significant interactions in this study for the RTD variables may be due to our limited sample size. Another limitation of this study was the examination of NCAA Division II female soccer players. Although this can be viewed as a major strength, the present findings may not be generalizable to other demographic groups. Future studies with larger and more diverse samples are needed to investigate the interactions between soccer playing ability, joint action, and RTD. In addition, it should be noted that our warm-up protocol, which consisted of performing three submaximal isometric knee extension and flexion joint actions, may not have been sufficient for attaining maximal voluntary activation. Previous research has reported that a complex warm-up of jogging, stretching, bounding, and sprinting exercises can improve twitch torque, contraction time, and muscle activation level⁴³. Performing such exercises may also improve RTD; however, further research is needed to test this hypothesis. In this study, we evaluated the strength capacities of the knee extensors and flexors by measuring isometric peak torque and RTD characteristics. Although isometric peak torque and RTD are relatively safe and easy measures to obtain⁴⁴, we do acknowledge that other performance-based measurements, such as concentric and

eccentric power, may be better at differentiating starters from non-starters in collegiate soccer.

In summary, our findings revealed that the starters exhibited greater isometric knee extension and flexion RTD values than the non-starters. No significant differences in isometric peak torque were observed between the groups. Taken together, these findings suggest that RTD may be better than peak torque at differentiating between playing level in collegiate female soccer players. The thresholds in our discriminant analysis for knee extension RTD200 and knee flexion peak RTD and RTD100 demonstrated good sensitivity and specificity, and therefore, may be used as indices to identify players with a high degree of soccer playing ability. Multiple regression analysis indicated that knee flexion RTD100 was the single best predictor of playing time. This finding suggests that rapid torque production of the knee flexors may be an important characteristic relevant to the number of minutes played per game during a competitive season. In this study, the starters had lower body mass than the non-starters. Because body mass and rapid strength are critical to soccer-related tasks, they may be able to predict a player's performance on the field. These findings may have important implications for creating interventions aimed at improving the playing level and on-field performance abilities of female soccer players.

Funding

Funding for this study was provided by the Mid-America Athletic Trainers' Association Research Grants Committee.

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