

Original Article

Rapid muscle activation changes across a competitive collegiate female soccer season

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Objective: The purpose of this study was to examine the effects of a competitive soccer season on rapid activation properties of the knee extensors and flexors in Division II female soccer players. **Methods:** Eighteen collegiate female soccer players participated in the present study, however, due to injuries during the season a final sample of 16 players were included for study analysis. Participants performed two maximal voluntary isometric contractions (MVICs) of the knee extensors and flexors before, during, and at the end of a competitive college soccer season. Electromyography root mean square (EMG RMS; μV), rate of EMG rise (RER; $\% \text{Peak EMG} \cdot \text{s}^{-1}$), and electromechanical delay (EMD; ms) were examined on both legs for the knee extensors and flexors. **Results:** EMG RMS at early time intervals (0-50, 0-100, and 50-100 ms) and RER at 0-75 ms for the knee extensors and flexors significantly increased from the pre-season to the end of the season ($P \leq 0.010$ - 0.026 , $\eta^2 = 0.36$ - 0.81). EMD of the knee flexors significantly decreased at the mid-season and the end of the season compared to the pre-season ($P < 0.001$, $\eta^2 = 0.95$). **Conclusions:** These findings may have important implications for monitoring improvements on thigh neuromuscular activation and developing lower extremity injury prevention strategies during a competitive collegiate female soccer season.

Keywords: Female Athletes, Motor Control, Neuromuscular Adaptation**Introduction**

A variety of athletic and physically active populations perform plyometric exercises and muscle speed-strength training to facilitate explosive muscle strength development^{1,2}. It is well recognized that explosive strength characteristics such as rate of torque or force development (RTD or RFD) are good indicators of whole muscle contractile speed, which is influenced by motor unit activation²⁻⁵, muscle

fiber type^{6,7}, and sensitivity of myofilaments to Ca^{2+} ⁸. It is suggested that individuals with greater motor unit activation and/or firing rates [i.e. a rate of EMG rise (RER)] can generate greater and more rapid muscle force production (i.e. RTD or RFD) responses during important functionally-related tasks such as running, accelerating, and cutting²⁻⁵. In support of this notion, increases in RER and RFD have been reported following an intervention of heavy-resistance strength training^{5,9,10}. This finding indicates that heavy resistance training induces improvements in RFD that are accompanied by improvements in rapid muscle activation (RER) which may be due to an increase in motoneuron firing frequency⁵.

While resistance training can improve rapid force production capacities, it has been suggested that this type of training can also elicit a decrease in the electromechanical delay (EMD)¹¹. The EMD is the time interval between the onset of electrical activation and the onset of muscle force or torque production. EMD is directly correlated with the stiffness of the series elastic component (SEC) and excitation-contracting

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coupling of the myofilaments¹². Previous research has suggested that a stiffer SEC will result in lower EMD values¹². Although a majority of previous literature has assessed the acute effects of stretching or fatigue interventions on EMD¹³⁻¹⁶, a previous study reported that chronic training using plyometric exercises caused a decrease in the EMD because of an increase in stiffness of the SEC¹⁷. Additionally, it has been reported that a long-term plyometric and heavy-resistance strength training program would improve neural drive in the central and/or peripheral nervous system, which could enhance force or torque production during a rapid voluntary contraction and reduce the risk of injury¹⁷⁻¹⁹.

EMD is directly related to mechanical and neural properties, and has commonly been assessed either at baseline levels, or at specific time points during training to monitor neuromuscular performance changes in recreationally active individuals¹⁷⁻¹⁹. Each team-based sport, and respective position requires different in-game movements and performance demands. To perform such tasks successfully, coaches and training staff have been heavily focused on developing sport-specific plyometric and high-intensity intermittent strength training programs for their athletes in hopes to improve a number of neuromuscular characteristics²⁰⁻²² including firing frequency of motor units²², synchronization²³, and muscle activation²², which would lead to improved rapid force production capacities of the muscles and help achieve the ultimate aim of improved sport performance.

Although previous literature suggests that neuromuscular properties can be affected based upon the mode of exercise (i.e. resistance training, plyometrics or high-intensity intermittent training) performed during a season in a variety of different sports^{2,5,6,21,24-26}, there is still limited research on the neuromuscular activation changes that occur across an entire competitive season for collegiate women's soccer players. Documenting these neuromuscular properties across a season would help elucidate the physiological effects at the neuromuscular level and help provide mechanistic insight regarding training and/or competitive sport participation adaptations. Moreover, previous studies have shown significant differences in maximal and rapid strength between the knee extensors and flexors^{27,28}. Previous research has also established strength differences between the dominant and non-dominant leg²⁹. Because these differences in muscle strength may be due to differences in neural activation characteristics, it may be of great value to analyze the neural properties of both muscles and limbs to determine if such factors play a role in the neural changes that occur across a competitive soccer season. Therefore, the purpose of the current study was to assess muscle activation characteristics including electromyography (EMG), rate of EMG rise (RER), and EMD for the knee flexors and extensors of both legs in collegiate women's soccer players at preseason, midseason, and after the end of a competitive soccer season. We hypothesized that the muscle activation characteristics for the knee flexors and extensors improves from pre-season to the end of the season due to the physical demands of the soccer players' in-season strength training and sport-specific activity.

Table 1. The standardized team training and practice routine.

	Days/week	Exercise
Pre-season (May-August)	2-3	Weight training
	2-3	Cardio exercises
	1-2	Plyometric exercises
In-season (August – November)	1-2	Weight training
	1-2	Mobility and coordination training
	0-1	Aquatic exercise
	3-4	Team practice
	2	Soccer Game (Friday and Sunday)

Methods

Participants

Eighteen female collegiate soccer players (age=20.21±1.01 years, height=167.24±5.36 cm, mass=64.87±7.31 kg) volunteered to participate in the present study. The study was approved by the institutional research board and all subjects signed an informed consent document prior to study participation. All participants completed a health history questionnaire to determine study eligibility. Inclusion criteria consisted of participants who had not experienced any lower-extremity injuries, head trauma (including concussion), or other medical conditions that potentially influences their neuromuscular function within six months prior to the first data collection in August (preseason). During the athletic season, we had two participants who experienced non-contact Grade 3 knee ligamentous injuries. Those participants were removed from the follow-up assessments and analysis. No other participants experienced any lower-body injuries. Therefore, the present study is only reporting on the participants (n=16) who remained healthy and completed all assessment sessions throughout the season. Using G*Power software (version 3.1.9.2; Heinrich Heine University, Düsseldorf, Germany) and assuming a moderate effect size, it was determined that a minimum of 16 participants were needed to achieve adequate statistical power (0.80) at an alpha level of 0.05.

All participants performed the team workouts and training programs through the pre- and in-season that were designed and implemented by the team's strength and conditioning coaching staffs. During the pre- and in-season, each player performed the standardized team training routine (Table 1), which included a weight training program targeting the lower extremities using weightlifting exercises such as the back squat and leg press. The team's strength and conditioning coaches adjusted the volume and intensity of the workout sessions which involved subjects performing 4 sets of 8-10 repetitions at 70-80% of 1RM, every other week. During the season, the intensity was adjusted for each exercise

based on the estimated 1RM. The estimated 1RM was determined using a previously described procedure³⁰ and was measured immediately before the season (preseason) and reassessed each month during the season. In addition to specific strength and conditioning workouts, the team played their regular season soccer games each week on Friday and Sunday, while Monday was typically a day-off. The team also practiced on Tuesday, Wednesday, and Thursday of each week for an hour and half to two hours each day. Each practice consisted of soccer-specific activities including position drills and game-like training using a half- and/or full-soccer-field. Furthermore, the team's soccer coaches closely monitored each subject's practice and play time and strength and conditioning workouts to ensure subjects were not being over-trained. All participants adhered to the aforementioned schedule (i.e., training workouts, practices, and games).

Procedures

To avoid the effects of neuromuscular fatigue on muscle activation characteristics, each participant was instructed to refrain from any vigorous physical activity or exercise 24 hours prior to each testing session. Participants reported to the laboratory on four separate occasions which included: 1) familiarization (48 hours prior to the baseline assessment), 2) baseline measurement (pre-season, prior to the start of the regular season; mid-August), 3) 1st follow-up (mid-season, 4 weeks after the baseline measurement; mid-September), and 4) 2nd follow-up (end of season, 8 weeks after the baseline measurement; mid-October).

During the familiarization session, participants completed the informed consent form and health history questionnaire to ensure their eligibility for the research study. Their demographic information was then collected (i.e., age, height, weight, and dominant leg). The dominant leg was determined as the leg the participants preferred to use when kicking a soccer ball. After collecting demographic information, all participants were familiarized with the testing procedures by performing several submaximal to maximal voluntary isometric contraction (MVIC) trials of the knee extensors and flexors on both legs using the isokinetic dynamometer.

Forty-eight hours after the familiarization session, all participants returned to the laboratory to conduct their baseline testing. Then 1st and 2nd follow-up assessments were performed every 4 weeks after the baseline measurement. During each assessment, participants performed 2 MVICs of the knee extensors and flexors on both legs using an isokinetic dynamometer.

Maximal Voluntary Isometric Contraction Session

Following a 5-minute warm up session of cycling and slow dynamic knee extension and flexion movements, 2 MVICs of the knee extensor and flexor muscles were performed on both legs using a calibrated Biodex System 3 isokinetic dynamometer (Biodex Medical Systems Inc., Shirley, NY). Each participant was seated in an upright position (i.e. the

trunk/hip angle was set at 85 degrees) on the isokinetic dynamometer chair in accordance with the Biodex guidelines for knee extension and flexion testing. The axis of rotation of the dynamometer was set in line with the center of the knee joint. The chest, hip, and leg were then secured with Velcro straps to avoid unwanted movements during the testing. The MVICs were conducted at a knee joint angle of 60 degrees below the horizontal plane for knee extension and 30 degrees below the horizontal plane for knee flexion¹³. During each testing session, participants performed 2 MVICs of the knee extensors and flexors on both legs, with 1 minute of recovery between each MVIC and 3 minutes of recovery between legs and muscle groups. Participants were verbally instructed to "push" or "pull" "as hard and fast as possible" for a total of 3 to 4 seconds during each MVIC. The order of the dominant and non-dominant legs and knee extension and flexion MVICs was randomized for each visit and participant.

Surface Electromyography Recording

Surface electromyography (EMG) was recorded during each MVIC for the knee extensors and flexors using bipolar pre-gelled Ag-AgCl self-adhesive disk electrodes (EL-502; Biopac Systems, Inc., Santa Barbara, CA) with a center-to-center interelectrode distance of 20 mm. The electrodes were placed on the rectus femoris muscle for the knee extensors at 50% of the distance between the anterior superior iliac supine and the superior border of the patella and on the biceps femoris muscle for the knee flexors at 50% of the distance between the ischial tuberosity and the lateral epicondyle of the tibia. The ground electrode was placed on the tibial tuberosity. Prior to electrode placement, an approximate 8 × 8 cm area on each electrode application site was cleaned with an isopropyl alcohol pad.

Signal Processing

During each MVIC, torque and EMG signals were sampled at 2 kHz with a data acquisition unit (MP150; AcqKnowledge v5.0.1; Biopac Systems Inc.) and stored on a laboratory computer for further analysis.

The torque and EMG signals were then processed offline using a custom-written software program (LabView 2016; National Instruments, Austin, TX). Torque signals were scaled to units (Nm) using a regression formula and then filtered with a fourth-order zero phase lag Butterworth filter at a low-pass cutoff frequency of 10 Hz^{13,31,32}. The raw EMG signals were bandpass filtered at 20-400 Hz using a zero-phase fourth-order Butterworth filter and subsequently rectified^{13,31,32}. All subsequent analyses were conducted on the scaled and filtered signals.

Torque onset was determined as the point when the torque signal reached 7.5 Nm for the knee extensors and 4 Nm for the knee flexors^{13,32,33}. EMD was determined as the time difference (ms) between the EMG and torque onsets (Figure 1)¹³. The EMG onset was determined manually by visual inspection where the EMG signal first deflected from

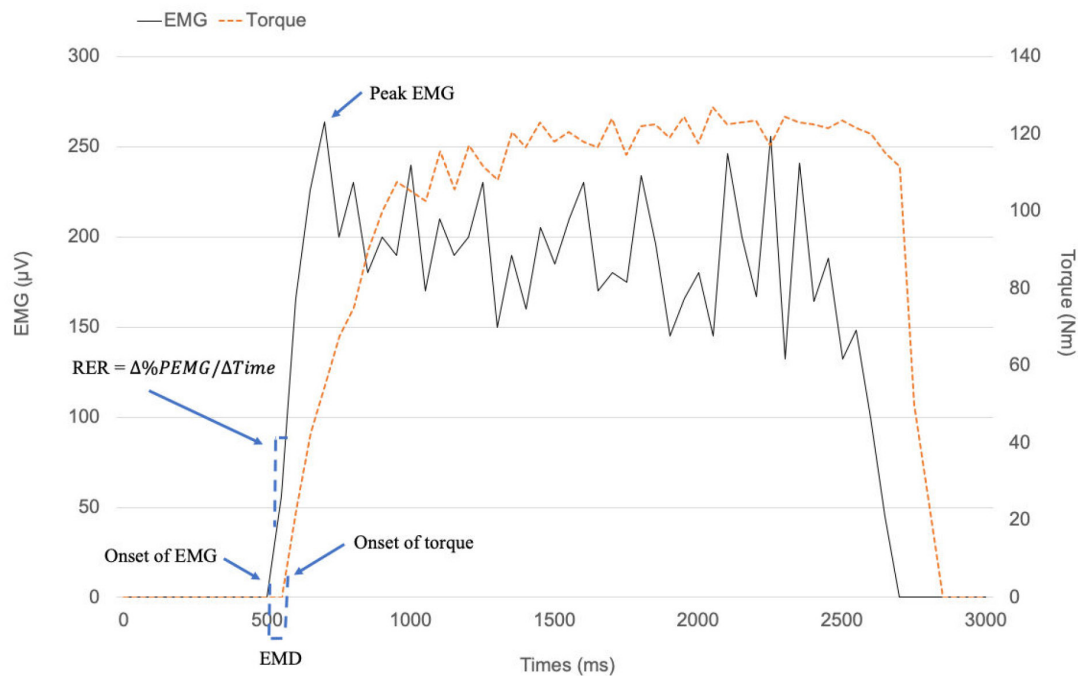


Figure 1. An example of an EMG- and torque-time curve taken from a participant during an isometric maximal voluntary contraction (MVIC) of the knee extensor. EMG= electromyography, RER= rate of EMG rise, EMD= electromechanical delay.

baseline in accordance with our previous procedures¹³.

Peak EMG was determined as the highest EMG amplitude value of the filtered EMG-time curve during each participants' MVIC³¹. EMG RMS was quantified at time intervals of 0-50 ms (RMS_{50}), 0-100 ms (RMS_{100}), 50-100 ms (RMS_{50-100}), and 0-200 ms (RMS_{200}) from EMG onset. RER (% peak $EMG \cdot s^{-1}$; Figure 1) was used to examine the rate of muscle activation and was calculated as the linear slope of the EMG-time curve which was low-pass filtered (using a 10-Hz linear EMG envelope) and normalized to peak EMG at time intervals of 0-30 ms (RER_{30}), 0-50 ms (RER_{50}), and 0-75 ms (RER_{75}) from EMG onset⁵. It has been reported that the EMG signal amplitudes tend to decrease at 80-100 ms following the signal onset⁵; therefore, the current study used the aforementioned time periods (i.e., 30, 50 and 75 ms) to measure RER³¹.

Statistical Analysis

We conducted separate three-way repeated-measures analyses of variance [ANOVA; muscle (knee extensors and flexors) \times limb (dominant and non-dominant limb) \times time (pre-season, mid-season, and end of the season)] to analyze the EMG RMS, RER, and EMD variables. When appropriate, follow-up analysis included one-way repeated measures ANOVAs, Tukey-Kramer multiple comparison post-hoc test and two-factor interaction analysis for either simple main effects (when a significant interaction was present) or main

effects collapsed across the opposing variable (when no significant interaction was present). Eta squared (η^2) effect sizes were reported for each ANOVA using the following formula³⁴:

$$\eta^2 = \text{Sums of Squares}_{\text{Effect}} / \text{Sums of Squares}_{\text{Total}}$$

where 0.02, 0.13, and 0.26 were considered small, medium, and large effect sizes, respectively³⁴. NCSS 2019 Statistical Software (NCSS, LLC, Kaysville, Utah) was used to analyze all data, and an alpha level of $P \leq 0.05$ was used to determine statistical significance.

Results

No significant interactions or main effects for limb were observed for any of the EMG RMS, RER, or EMD variables ($P > 0.05$). There was, however, a main time effect in which significant changes were observed for EMG RMS at 0-50 ms ($F_{2,24} = 4.27, P = 0.026$), 0-100 ms ($F_{2,24} = 5.68, P = 0.01$), and 50-100 ms ($F_{2,24} = 4.99, P = 0.015$) (Table 2). Post-hoc testing showed that the EMG RMS increased at the end of the season compared to the pre-season value. The effect sizes for these differences were large ($\eta^2 = 0.36-0.47$).

We did not observe a significant interaction or main effect for the RER_{30} and RER_{50} variables ($P > 0.05$). However, there was a significant interaction between muscles and time for the RER_{75} ($F_{2,24} = 4.59, P = 0.02$). Post-hoc testing revealed that the knee flexor RER_{75} was significantly greater at the

Table 2. Mean and SEM of electromyography (EMG) root mean square (RMS) for pre-season, mid-season, and end of season by each thigh muscle.

	Pre-season	Mid-season	End of season
Knee extensor EMG RMS (μV)			
0-50 ms	50.24 \pm 9.19	62.81 \pm 9.19	77.05 \pm 10.93
0-100 ms	162.53 \pm 16.31	161.83 \pm 16.31	217.66 \pm 19.41
50-100 ms	222.99 \pm 23.24	247.99 \pm 23.24	294.84 \pm 27.67
0-200 ms	212.26 \pm 30.39	214.42 \pm 30.39	328.62 \pm 36.17
Knee flexor EMG RMS (μV)			
0-50 ms	62.72 \pm 9.19	99.32 \pm 9.33	81.94 \pm 11.17
0-100 ms	171.03 \pm 16.31	246.42 \pm 16.56	232.84 \pm 19.83
50-100 ms	229.08 \pm 23.24	329.86 \pm 23.59	314.98 \pm 28.26
0-200 ms	345.99 \pm 30.39	335.65 \pm 30.85	317.05 \pm 36.95
Mean EMG RMS (μV)			
0-50 ms	56.48 \pm 6.50	81.06 \pm 6.54 ^A	79.49 \pm 7.81 ^A
0-100 ms	166.78 \pm 11.53	204.13 \pm 11.62	225.25 \pm 13.87 ^B
50-100 ms	226.03 \pm 16.44	273.92 \pm 16.56	304.91 \pm 19.77 ^B
0-200 ms	264.12 \pm 21.49	275.03 \pm 21.65	322.84 \pm 25.85

Note. EMG = electromyography, RMS = root mean square, ms = milliseconds ^A indicates a significant change in EMG RMS at 0-50 ms from pre-season to mid-season and end of the season. ^B indicates a significant change in EMG RMS at 0-100 ms and 50-100 ms from pre-season and mid-season to end of the season.

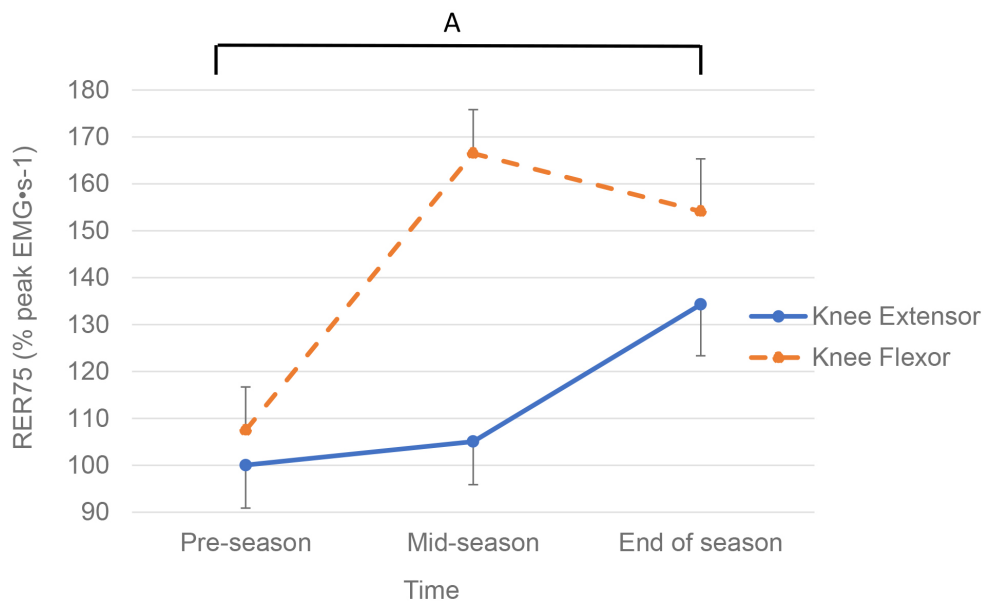


Figure 2. Rate of EMG rise (RER) at 0-75 ms (RER_{75}) values for the knee extensors and flexors across time. ^A indicates a significant difference on the hamstring RER_{75} across time.

mid- and end-season compared to pre-season ($P < 0.01$; Figure 2). Knee extensor RER_{75} did not statistically increase over time ($P > 0.05$). The effect size for this difference was large ($\eta^2 = 0.81$).

Although there was no three-way interaction observed for EMD ($P > 0.05$), a significant interaction between muscles

and time was observed ($F_{2,24} = 6.03$, $P < 0.01$). Post-hoc testing revealed that the EMD significantly decreased at mid-season and at the end of the season compared to pre-season for the knee flexors ($P < 0.001$, Figure 3); however, there were no significant differences in EMD between time points for the knee extensors ($P > 0.05$, Figure 3). EMD was also significantly

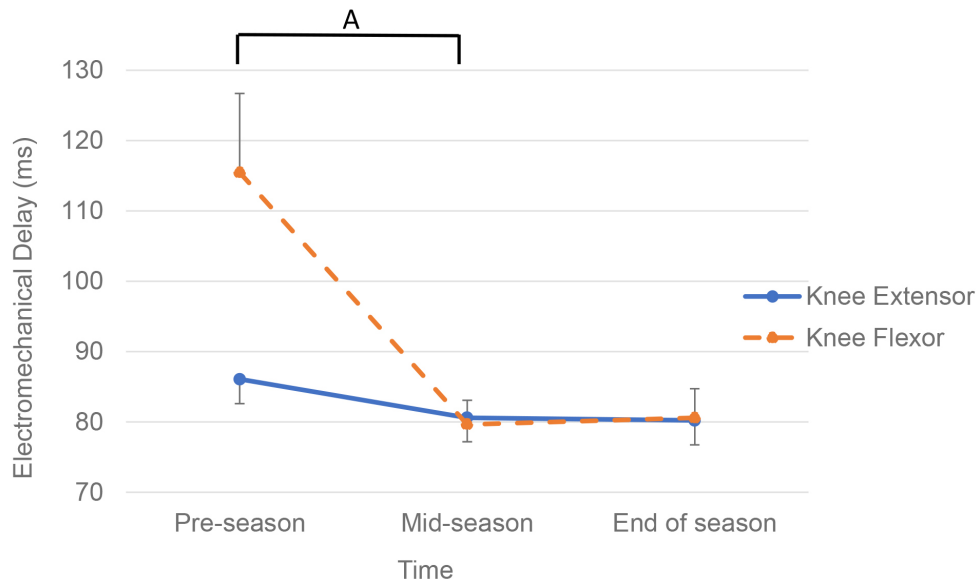


Figure 3. Electromechanical delay (EMD) values of the knee extensors and flexors across time (mean±SEM). ^A indicates a significant difference on knee flexor EMD across time: mid-season and end of the season <pre-season ($P=0.02$).

longer for the knee flexors than the knee extensors at the pre-season time point ($P<0.05$). The effect size for the difference in the knee flexor EMD was large ($\eta^2=0.95$).

Discussion

The purpose of the current study was to examine muscle activation characteristics for the knee extensors and flexors in collegiate women's soccer players before (preseason), during (mid-season), and at the end (end-season) of the competitive soccer season. The primary findings in the current study showed that EMG RER_{75} of the knee flexors and mean EMG RMS collapsed across muscle (0-50, 0-100, and 50-100 ms) were significantly increased at the mid- and/or end-season compared to the preseason. In addition, knee flexor EMD was significantly reduced at the mid-season and remained lower at the end of the season.

The increase in EMG RMS and knee flexor RER_{75} in the current study could be a result of the soccer-specific activity and strength training performed by the soccer players during the competitive season^{5,35}. Previous research has shown that a 14-week heavy-resistance strength training program for non-athletes increased knee extensor RER values by approximately 41-106%⁵. Although the present study did not observe significant knee extensor differences across a competitive soccer season (which could be due to low statistical power), it is interesting to point out that the present study observed significant increases in EMG RER_{75} for the knee flexors. Cutsem et al.³⁵ also reported that average EMG (0-30, 0-50, and 0-100 milliseconds) and RER

(0-30, 0-50, and 0-75 milliseconds) of the ankle dorsiflexors were enhanced after a 12-week lower-leg dynamic strength training program. Similarly, the present study found a ~35-45% improvement in early EMG RMS of the knee extensors and flexors (collapsed together) and knee flexor RER_{75} at the mid and end-season compared to the pre-season (Table 2 and Figure 2). It is interesting to note that the increase in EMG RMS and RER observed in the present study occurred within the 0-100 millisecond time period. This finding, which is in line with the results of previous research⁵ may suggest that the soccer-specific activity and muscle strength training performed by the soccer players in the present study were effective at increasing the neural drive and neuromuscular activity of the leg extensors and flexors during the early phase of muscle activation.

Another notable finding of this study was that EMD of the knee flexor muscles decreased significantly from the pre-season (115.44 ms) to the mid- (79.64 ms) and end-season time points (80.75 ms). We also observed a significantly longer EMD for the knee flexors compared to the knee extensors at pre-season (Figure 3). This is consistent with the findings of Hannah et al.³⁶ who also found longer baseline EMD values for the knee flexors (hamstrings) than the knee extensors (quadriceps) in healthy, college-aged males. It should be noted that although a significant decrease in EMD for the knee flexors was observed in the present study, we did not observe a decrease in EMD for the knee extensors. In contrast, Kubo et al.³⁷ reported a decrease in knee extension EMD values of 18.4% after a 12-week isometric knee extension strength training program in recreationally active college-aged adults. Additionally, Wu et al.¹⁷ showed

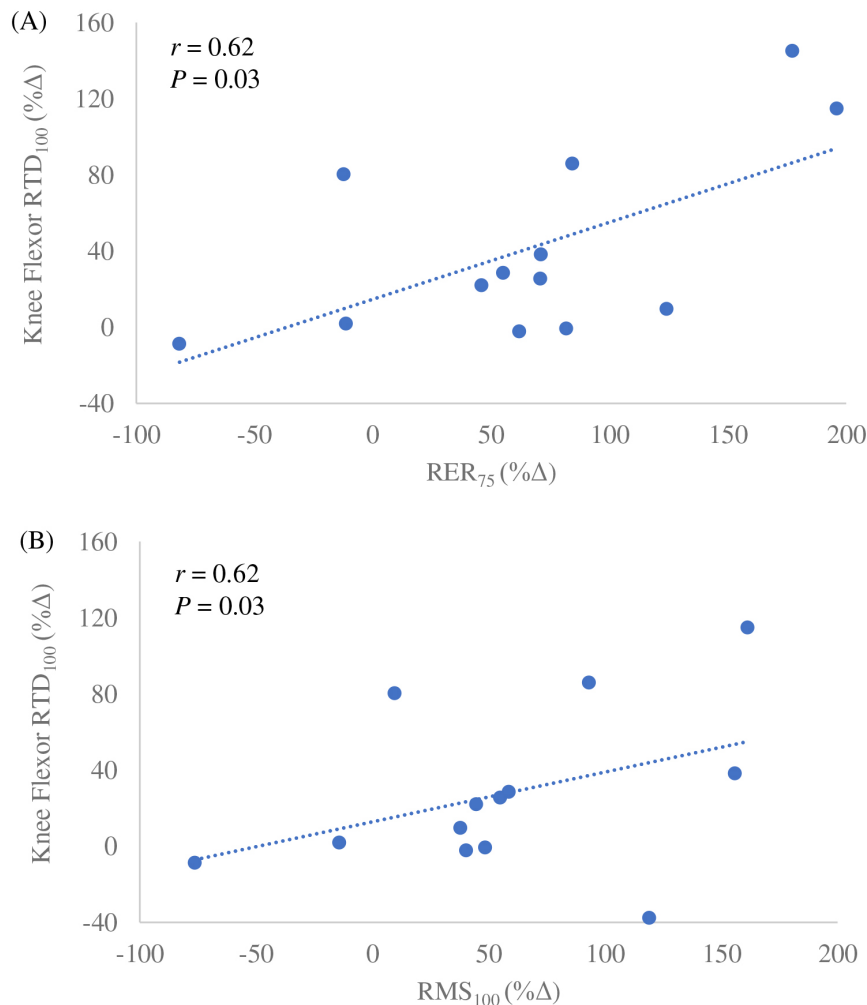


Figure 4. Relationships between the percent change (%Δ from preseason to end-season) in rate of torque development at 0-100 milliseconds (RTD₁₀₀) and (A) rate of EMG rise at 0-75 milliseconds (RER₇₅) and (B) EMG root mean square at 0-100 milliseconds (RMS₁₀₀) for the knee flexors. The RTD data used in the figure were derived from the torque signals produced by the same soccer players in a previously published study by Akehi et al.³².

a knee extension EMD reduction of 12.2.% after 8 weeks of plyometric training (total 16 training sessions) in college-aged males. The discrepancies between these findings and those observed in the present study may be due to differences in the types of training activities performed and/or the athletic status of the participants that were tested. For example, the present study examined highly-trained female athletes that performed both in-season strength training and soccer-specific activity whereas the previous studies examined non-athlete participants that only performed strength or plyometric training. Previous research has reported that decreases in EMD after training may be due to increases in muscle stiffness³⁸. In-season performance training combined with sport-specific activity has been shown to elicit significant increases in stiffness for the hamstrings³⁹ but not for the other muscles and structures

of the lower-body (i.e. leg stiffness)³³. Thus, the possibility of training-induced increases in muscle stiffness specifically for the hamstrings may explain why EMD characteristics of the knee flexors were improved to a greater degree than those of the knee extensors in the present study.

Our findings of a significant increase in EMG RMS and RER and a decrease in knee flexor EMD may contribute to improvements in rapid muscle strength characteristics (i.e., RTD, RTD/PT, etc.)^{5,37}, which could increase soccer-specific performance and reduce the risk of injury. Previous literature has reported increases in relative rapid strength values across a competitive soccer season in female soccer players³², which could be linked to increases in neural activation characteristics, as was reported in the present study (Figure 4). An increase in the amount of force produced within a short time period (<100 milliseconds) during soccer-

specific activity may provide for better knee joint stabilization and a lower risk of knee ligamentous injuries such as non-contact anterior cruciate ligament (ACL) tears⁴⁰. These findings may have important implications for athletes, and in particular female athletes since they are more susceptible to ACL tears and other knee-related injuries^{41,42}. Previous research suggests that a non-contact ACL injury may be due to several different mechanisms including reduced hamstring activation, slower muscle contraction time, decreased knee flexion range of motion, and greater valgus angle at the knee⁴¹. When considering the aforementioned mechanisms for knee ligamentous injuries, an increase in rapid activation of the knee flexors, as was observed in the present study, may be a key component in reducing an athlete's risk of injury during a competitive soccer season. Finally, it should be noted that no significant effects for limb were observed for any of the EMG RMS, RER, or EMD variables measured in this study. These findings suggest the absence of neural activation differences between the dominant and non-dominant legs, which may be an important factor in preventing lower-extremity injury⁴³.

In conclusion, our findings demonstrated increases in EMG RMS of the knee extensors and flexors and knee flexor RER75 and decreases in EMD of the knee flexors across a competitive season in collegiate women's soccer players. These improvements may be attributed to motor unit behavioral enhancements and/or other noncontractile structure changes as a result of the strength training and sports-specific activity performed during the season. These changes may ultimately enhance the muscle contractility and rapid force production capabilities of the athletes when playing soccer. We did not observe any negative changes across the season, which suggests that the in-season strength and soccer-specific activity was not overly extensive or fatiguing. Because the soccer players in this study performed both soccer-specific activity and strength training during the season, it is difficult to attribute one or the other (soccer-specific activity or strength training) as the primary reason for our results. We can only speculate as to why certain variables increased or decreased. In the present study, we had a limited amount of time to test subjects at each point during the season because of strict training schedules, team practice, and games. Thus, we could not control for the menstrual cycle of the subjects in our study. Nevertheless, previous research has shown no significant changes in EMD, force, or rate of force production characteristics across the menstrual cycle in young women⁴⁴. Therefore, based on this research, it is unlikely that variations in the menstrual cycle had a substantial effect on the neuromuscular properties of our subjects. The findings in the present study highlight the need for future research to examine the neuromuscular property changes that occur across other sports seasons, including basketball, baseball, and track and field. Such research may help in the development of in-season strength and sport-specific training programs aimed at improving neuromuscular performance and reducing the risk of musculoskeletal injury in athletes who participate in these sports.

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