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Physiological Performance Characteristics of Male and Female Division I Cross-Country Runners

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Abstract

Aim: This study was aimed to understand the physiological performance characteristics of cross-country runners and differences in performance variables between sexes.
Methods: Twelve male and ten female cross-country runners performed a Maximal Oxygen Consumption test, Dual-Energy X-Ray Absorptiometry and Ultrasound measurements of their lower limb.
Results: Males had significantly higher value levels of VO_{2Peak} (73.3±7.5 vs 62.3±4.7 ml/kg/min), Ventilation (159.0±16.3 vs 120.8±12.5 L/min), Lactate Threshold (318±13.8 vs 259±7.8 m/sec), and Lean Mass (55.5±7.32 vs 42.34±3.81 kg). Females had higher values for Echo Intensity, Body Fat Percentage (7.42±2.60 vs 14.71±2.77 %) and Body Fat (4.76±1.94 vs 7.71±1.70 kg). All other variables were similar between male and female cross-country runners.
Conclusion: The difference in physiological characteristics between males and females may help explain why males have more favorable performance outcomes.

Keywords
Cross Sectional Area,
Muscle Quality,
VO_{2Peack},
Muscle Architecture,

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INTRODUCTION

Physiological characteristics of distance runners have been primarily evaluated using oxygen analysis to determine VO_{2Peak}, oxygen uptake at different thresholds, and running economy (Rabadán et al., 2011). It is generally accepted that runners with a higher VO_{2Peak} and better running economy will perform better in running events. Traditionally these measurements are performed on a treadmill in a lab. These values have been used to generate prediction models of performance (Rabadán, et al., 2011) and have determined that different elite runners have different adaptation depending on the total distance run. Traditionally oxygen analysis is the focal point of performance with runners, however there are many underlying mechanisms that may lead to improvements in performance. To help further understand running performance, research has addressed biomechanical principals like stride rate, flight time, contact time and moment arms in running analysis (Barnes & Kilding, 2015; Barnes, Mcguigan, & Kilding, 2014). Research (Barnes & Kilding, 2015) has indicated that not one biomechanical measurement or even a combination such measurements can actually model performance. Studies have also taken into consideration muscle characteristics and suggested that fiber type (Horowitz, Sidossis, & Coyle, 1994), protein content (Mogensen, Bagger, Pedersen, Fernström, & Sahlin, 2006) and Mitochondria density (Saunders, Pyne, Telford, & Hawley, 2004) may influence running economy. A recent study by Lundly et al (2017) found that these muscle characteristics did not influence performance and that body mass was the only measure that repeatedly predicted performance. Further research into body mass determined that body fat is a good predictor of running performance (Lundby, et al., 2017; Maciejczyk et al., 2014; Salinero et al., 2016) as well as a predictor of injury (Nattiv, 2000; Roelofs et al., 2015). In general, lower body mass and body fat percentage have higher performance values (VO2 max, faster race time) and have a reduced risk of injury.

Recent work has looked at Ultrasound measurements in runners to evaluate performance and injury risk (Roelofs, et al., 2015). Common Ultrasound measurements are: Echo Intensity (EI), Muscle size thickness and Cross-Sectional Area (CSA), and fascicle pennation angle and length (Aagaard et al., 2001). EI is an application that uses a grey scale analysis with 0 being a pure black pixel and 255 being a pure white pixel (Pillen et al., 2009). It is generally accepted that the darker the pixels (low

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echogenicity) the better the quality is, as low frequency beams penetrate further into soft tissue rather than reflect connective and adipose tissue (high echogenicity) (Mayans, Cartwright, & Walker, 2012). EI values have been correlated with fibrous tissue (Pillen, et al., 2009), intramuscular adiposity (Reimers, Reimers, Wagner, Paetzke, & Pongratz, 1993; Young, Jenkins, Zhao, & Mccully, 2015), glycogen stores (Hill & Millan, 2014) and an increase in water content (Sarvazyan, Tatarinov, & Sarvazyan, 2005). Thickness and CSA are measures of muscle size are taken from either a still image or panoramic image of the muscle. Fascicle pennation angle and length are architectural measurements that give an idea into functionality of the muscle (Timmins, Shield, Williams, Lorenzen, & Opar, 2016). Research has evaluated how Ultrasound measurements change and adapt to stimulus with the most common adaptation including increases in muscle size (Aagaard, et al., 2001) with resistance training. Pennation angle and length have demonstrated the ability to get increase (Aagaard, et al., 2001; Alegre, Jiménez, Gonzalo-Orden, Martín-Acero, & Aguado, 2006) or decrease depending on the exercise intervention (Abe, Kumagai, & Brechue, 2000; Blazevich, Gill, Bronks, & Newton, 2003; Murach, Greever, & Luden, 2015). In general, distance runners have smaller muscles with larger pennation angles and shorter fascicle lengths when compared to sprinters (Abe, et al., 2000). There has not been a study evaluating Ultrasound-derived measurements on cross-country runners and what their specific adaptations.

Understanding the physiological characteristics of cross-country runners will be a useful tool for researchers and practitioners working with athletes. Obtaining data on Division I cross-country runners would allow for comparisons between athletic populations to determine similarities and difference in adaptations to specific training. Very little research has examined the differences between male and female runners outside of VO2 and body composition (Roelofs, et al., 2015) measurements. Understanding the underlying mechanisms that may be different from males and females would be beneficial to coaches and researchers. Therefore, the primary purpose of this study was to analyse and measure Division I cross-country runners' physiological characteristics. The secondary purpose was to identify any physiological difference between male and female cross-country runners. We hypothesize that male runners would have better performance variables and larger and more beneficial physiological characteristics when compared to their female counterpart.

METHOD

Participants

Twelve male and ten female collegiate cross-country runners volunteered for this study (Table 1). Prior to any testing, subjects read and signed an informed consent and a health history questionnaire. All subjects were free of any neurological disease or musculoskeletal injuries. This study was approved by the Institutional Review Board for protection of human subjects (FUIRB#0724817).

Table 1. Demographics (means±SD)

	Males (n=12)	Females (n=10)	*ES*
Height (cm)	179.5 ± 6.8	168.1 ± 7.8	1.56*
Mass (kg)	65.2 ± 6.6	54.5 ± 4.8	1.86*
Age (years)	20.8 ± 1.7	19.3 ± 1.3	0.97*

*Males significantly greater then females, *ES*= Cohen's *d* Effect size

Protocol

Each subject visited the lab on multiple occasions. Prior to all testing, height and mass were measured. Participants performed all of the following: Ultrasound assessment on right leg, ramped VO2 test on a treadmill, and Dual-Energy X-Ray Absorptiometry scan.

Ultrasound Assessment

Ultrasound images were taken with a portable B-mode imaging device (GE Logiq e BT12, GE Healthcare, Milwaukee, WI, USA) and a multi-frequency linear-array probe (12 L-RS, 5–13 MHz, 38.4-mm field of view, GE Healthcare, Milwaukee, WI, USA). The panoramic function was used to obtain all images. All images were taken on the right side and transverse images were used for CSA, EI, and Sagittal images for muscle thickness and pennation angle. For the Rectus Femoris (RF) and Vastus

Lateralis (VL) images were taken at half and two-thirds of the distance between the anterior superior iliac spine and the superior border of the patella. Quadriceps tendon length was measured from patella to musculotendinous junction of the quadriceps. For medial and lateral gastrocnemius muscles panoramic images were taken at one-third the length of the lower limb at the visual bulge of the medial gastrocnemius. For Achilles tendon length, a longitudinal image was taken from the calcaneal insertion to the musculotendinous junction of the gastrocnemius (Tweedell et al., 2016).

A high-density foam pad was secured around the right thigh and calf with an adjustable Velcro strap to ensure probe movement in the transverse plane. The same foam pad was used as a guide when performing the longitude assessments for tendon lengths. Ultrasound settings (Frequency: 10 MHz, Gain: 45 dB, Dynamic Range: 72) were kept consistent across participants. To ensure optimal image clarity, scanning depth was individualized for each participant between 3.5–6.0 cm. A generous amount of water-soluble transmission gel (Aquasonic 100 ultrasound transmission gel, Parker Laboratories, Inc., Fairfield, NJ, USA) was applied to the skin such that it immersed the probe surface during testing to enhance acoustic coupling. Consistent with the work of Young et al. (2015), three images were taken for each participant, and the mean values have been reported herein. The ultrasound images were digitized and examined with ImageJ software (version 1.46, National Institutes of Health, Bethesda, MD, USA). The polygon function was used to outline the border of the muscle to measure CSA and EI. EI was assessed by a computer-aided gray-scale analysis using the histogram function. The EI values were determined as the corresponding index of muscle quality ranging between 0 and 255 A.U. (black = zero, white = 255). Pennation angle was measured using the angle function and thickness/length using the line function. Corrected EI was calculated as uncorrected EI + (subcutaneous fat thickness [cm] × 40.5278) (Stock et al., 2018).

VO_{2Peak} Assessment

Prior to coming to the lab participants supplied their current 5k (females) and 8k (males) running times. From these running times an estimated lacted threshold was calculated. The intial stage was 0.54 m/s slower then predicted lactate threshold speed so that there would be 3 stages prior to reaching lactate thrsoold. Each stage lasted three minutes with one-minute rest between stages. Each stage increased 0.18 m/s. After each stage, a drop of blood was supplied via finger prick and was measured using Lactate Plus Nova Biomedical (Waltham MA, USA). Once a two-mmol jump in lactate was observed, speed was held constant and incline was increased one percent every minute until volitional fatigue. Participant's oxygen consumption, ventilations and heart rate were measured with a metabolic cart (Cosemed Quark CPET Rome, Italy) and a heart rate strap (Polar Electro Oy, Kempele, Finland). VO_{2Peak}, ventilation, and heart rate were recorded and running economy was calculated at the highest sub-lactate threshold speed, reported in table 2.

Dual-Energy X-Ray Absorptiometry (DEXA)

Scans were complete on a separate day than max testing to ensure the participants were in a rested state. Each participant had a full body DEXA scan (Lunar Prodigy, GE Healthcare, Milwaukee, WI, USA) administered by a licensed and train professional. All participants removed all metal, thick clothing, and plastics to avoid x-ray interference. Age, height, and mass were measured and imputed into the computer software. The procedure for scanning followed standard guidelines for DEXA scans (Roelofs, et al., 2015). Bone Mineral Content (BMC), Bone Mineral Density (BMD), fat mass, lean mass, body fat % and both left and right leg lean mass were determined using GE enCORE V13.2 software.

Statistical Analysis

An independent sample T-Test was run to compare males to females on all variables. Significance was set at P=0.05). Effect size was calculated using Cohen's *d.* All statistical analyses were performed using Statistical Package for Social Science (IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY).

RESULTS

There was a significant difference for basic demographics (Table 1) of height (P=0.002) and mass (P<0.001). For performance variables (Table 2): There was significant difference in VO_{2Peak} (P=0.001), Max Ventilation (P<0.001), Lactate Threshold (P<0.001), but not Running Economy, and Max Heart Rate.

For Quadriceps measurements (Table 3): There was a significant difference in subcutaneous fat thickness at both locations (P≤ 0.003) with males being smaller. Corrected EI for the RF and VL and both locations were significantly different (P≤ 0.004) with males being lower. The only other significant difference was CSA and Muscle thickness VL at Mid-thigh with males being larger (P≤ 0.006). For all other variables, there was no significant difference (P>0.05).

Table 2. Performance Variables (means±SD)

	Males	Females	*ES*
Running Economy (ml/kg/km)	201.1 ± 16.4	209.1 ± 17.3	0.47
VO2 Max (ml/kg/min)	73.3 ± 7.5	62.3 ± 4.7	1.76*
Max HR (bpm)	191.9 ± 12.4	190.1 ± 9.4	0.16
Max Ventilation (L/min)	159.0 ± 16.3	120.8 ± 12.5	2.63*
Race Times# (mm: ss)	24:46 ± 00:53	19:09 ± 02:35	
Lactate Threshold (m/sec)	5.275 ± 0.23	4.31 ± 0.13	5.15*

#males 8km distance, females 5km distance,
*Significant difference between males and females, *ES*= Cohen's d Effect size

Table 3. Quadriceps Measurements (means±SD)

Variables	Males	Females	*ES*
Quadriceps Tendon			
Length (cm)	8.68 ± 0.89	8.82 ± 0.80	0.16
Thinness (cm)	0.57 ± 0.08	0.59 ± 0.09	0.20
Mid-Thigh Measures			
Subcutaneous Thickness (cm)	0.34 ± 0.16	0.66 ± 0.28	1.41*
Rectus Femoris			
Echo intensity (au)	27.24 ± 5.94	29.78 ± 8.80	0.34
Corrected Echo Intensity (au)	40.90 ± 10.94	56.48 ± 12.82	1.31*
CSA (cm^2)	6.02 ± 1.29	5.57 ± 1.31	0.34
Vastus Lateralis			
Echo Intensity (au)	28.85 ± 5.48	30.45 ± 6.98	0.26
Corrected Echo Intensity (au)	42.50 ± 9.37	57.15 ± 11.96	1.36*
CSA (cm^2)	22.33 ± 3.88	18.71 ± 3.26	1.01
Pennation Angle (^{0})	16.47 ± 2.66	15.15 ± 2.48	0.51
Thickness (cm)	1.95 ± 0.26	1.63 ± 0.21	1.37*
Fascicle Length (cm)	7.34 ± 1.67	6.62 ± 0.96	0.53
2/3 Distal Thigh Measures			
Subcutaneous Thickness (cm)	0.31 ± 0.06	0.52 ± 0.19	1.54*
Rectus Femoris			
Echo intensity (au)	35.72 ± 7.59	39.08 ± 11.65	0.34
Corrected Echo Intensity (au)	48.21 ± 8.22	60.24 ± 15.15	0.99*
CSA (cm^2)	1.70 ± 1.08	1.92 ± 0.77	0.24
Vastus Lateralis			
Echo intensity (au)	31.74 ± 6.30	34.44 ± 6.51	0.42
Corrected Echo Intensity (au)	44.23 ± 7.13	55.59 ± 10.98	1.23*
CSA (cm^2)	14.44 ± 5.17	12.41 ± 3.86	0.44
Pennation Angle (^{0})	13.62 ± 3.42	13.17 ± 5.88	0.09
Thickness (cm)	1.82 ± 0.34	1.67 ± 0.32	0.45
Fascicle Length (cm)	5.40 ± 0.81	4.97 ± 0.89	0.50

*Significant difference between males and females, *ES*= Cohen's d Effect size

For Gastrocnemius Measurements (Table 4): There was a significant difference in Achilles tendon Length (P<0.001) with males having longer Achilles tendons. For Subcutaneous fat thickness males had significantly (P<0.001) less. For both EI values for the Medial and Lateral Gastrocnemius, males had significantly (P ≤0.006) lower values. For all other variables, there were no significant difference (P>0.05).

Table 4. Gastrocnemius Measurements (means±SD)

Variables	Males			Females			*ES*
Achilles Tendon							
Length (cm)	25.91	±	0.78	23.39	±	0.75	3.28*
Subcutaneous Thickness (cm)	0.35	±	0.05	0.49	±	0.09	1.84*
Medial Gastrocnemius							
Echo intensity (au)	29.39	±	4.15	35.01	±	6.32	1.05*
Corrected Echo Intensity (au)	43.62	±	5.71	54.70	±	8.88	1.48*
CSA (cm^2)	10.16	±	2.14	9.76	±	2.13	0.19
Pennation Angle (^{0})	24.45	±	2.23	22.50	±	3.77	0.63
Thickness (cm)	1.44	±	0.21	1.46	±	0.24	0.10
Fascicle Length (cm)	3.96	±	4.22	0.50	±	0.37	1.16*
Lateral Gastrocnemius							
Echo intensity (au)	28.92	±	4.48	39.88	±	8.01	1.69*
Corrected Echo Intensity (au)	43.16	±	6.18	59.58	±	9.58	2.04*
CSA (cm^2)	5.59	±	1.41	4.54	±	1.31	0.77

*Significant difference between males and females, *ES*= Cohen's *d* Effect size

For Body Composition Measurements (Table 5): There was significant ($P<0.05$) difference between males and females for BMC, Fat Mass, Lean Mass, Body Fat %, and Left and Right Leg Lean Mass. Males had higher BMC values and more Lean Mass while having a lower Body Fat Percentage and lower total Fat Mass.

Table 5. Body Composition Measurements (means±SD)

	Males	Females	*ES*
BMD (g/cm^2)	1.25± 0.07	1.22± 0.08	0.40
BMC (kg)	2.90± 0.47	2.23± 0.38	1.57*
Fat Mass (kg)	4.76± 1.94	7.71± 1.70	1.62*
Lean Mass (kg)	55.54± 7.32	42.34± 3.81	2.26*
Body Fat %	7.42± 2.60	14.71± 2.77	2.71*
Left leg Lean Mass (kg)	9.68± 1.16	7.64± 0.69	2.13*
Right Leg Lean Mass (kg)	9.98± 1.19	7.99± 0.83	1.94*

*Males significantly greater than females
BMD= Bone Mineral Density, BMC= Bone Mineral Content,
ES= Cohen's d Effect size

Follow up analysis normalized VO_{2Peak} to average lean body and average echo intensity then compared between males and females (Table 6) and found no significant difference ($P>0.05$).

DISCUSSION

This is the first study of its kind to measure and analyze physiological characteristics of Division I cross-country runners. Previous studies have addressed VO_2 and body composition values (Roelofs, et al., 2015), yet none have used Ultrasound measurements to determine if there is difference between male and female runners. The significant findings of this study are that males have a higher VO_2 and Lactate threshold running speeds, higher lean mass and lower body fat values than females. These results, even though they are significant are not new, as previous research (Barnes, et al., 2014; Fleck, 1983; Hirsch, Smith-Ryan, Trexler, & Roelofs, 2016) have reported similar differences. What is unique to this study is that when analyzing the ultrasound measurement, fascicle length, pennation angle, and muscle size were similar between males and females with the differences being EI, Achilles tendon length, and subcutaneous fat thickness. This may indicate that males and females have similar architectural adaptions to the demands of cross-country running. The differences in Achilles tendon length can be contributed to males being on average 10 cm taller than the females, while subcutaneous fat thickness is related to females having higher body fat percentages than the males. The key difference between the two resides in males having lower EI values than females.

The EI difference between male and female college athletes have been reported (Hirsch, et al., 2016), and our results further demonstrate that males have lower EI values on average than females. It is accepted that darker (lower EI value) is indicative of higher quality muscle, yet quality of muscle is not specifically defined. Lower EI scores have been correlated with strength (E. L. Cadore et al., 2012; E. Cadore et al., 2014; Mota & Stock, 2017) but not muscular endurance (Mota & Stock, 2017). It appears that EI is a significant difference between male and female cross-country runners and may influence running performance. Usually EI is an indicator of muscle quality, referencing characteristics within muscle like adipose tissue(Reimers, et al., 1993) or connective tissue(Pillen, et al., 2009) but generally does consider the composition that is beneficial to performance. However, taking into consideration all other measurements of body composition, we may get a better understanding of the overall composition of the muscle and the possible differences between males and females. Body composition values resulted in males having lower body fat content and higher lean mass. Male athletes having lower body fat percentage is commonly reported (Fleck, 1983; Hirsch, et al., 2016), however what is unique to this study is that males had a higher leg lean mass than females, but similar CSA in the lower leg.

Table 6. Normalized VO_2 Values (means ± SD)

	Males			Females		
Lean Mass (ml/kg/min)	85.6	±	9.3	80.2	±	6.3
Average echo intensity (a.u))	21.7	±	7.3	19.8	±	5.5

When considering the similarity in muscle size with differences in lean muscle, this led to the idea that muscle composition might be a valuable tool when analyzing performance. Thus, we ran a follow up analysis comparing VO_2 performance with lean mass, and EI. Follow up analysis yield interesting results presented in Table 6. When VO_{2peak} was controlled for with total lean mass or average EI there was no significant (P>1.24) difference between males and females. When taking into consideration all the variables in this study along with previous research in intermuscular adiposity (Reimers, et al., 1993; Young, et al., 2015), one would conclude that females have more intermuscular fat than males. This is observed with similar muscle size but leaner and lower echo intensity values for males than females. Overall the differences in muscle composition either measured through lean mass or echo intensity indicate that males have higher make up of lean muscle mass which is advantageous to aerobic performance. The idea that aerobic performance may be indicative of your muscle quality with higher levels (lower EI Values) of muscle quality leading to better performance. Echo Intensity is an easy none-invasive way to measure muscle quality and can be easily incorporated into testing program. Ultrasound imaging does have limitations but its ability to measure muscle quality could lead to it being a valuable tool to measure improvements in muscle composition with training.

CONCLUSION

In conclusion, Division 1 male cross-country runners had higher performance values and lean mass, however lower body fat composition and muscle Echo Intensity values. This study is the first of its kind to address muscle architectural characteristics (muscle CSA, Pennation angle, muscle thickness, Achilles tendon and Quadriceps tendon length) of cross-country runners and as a result demonstrated that male and female runners have similar characteristics, which may be a result of the similar training demand. The most significant finding from this study is that it appears the muscle quality of cross-county runners differs between males and females. This difference may play a significant role in performance. However, further research is needed to determine at what extent male and female muscle are different.

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