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Critical Power Concept: Males vs. Females and the Impact of Muscle Fiber Composition

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ABSTRACT

International Journal of Exercise Science 12(4): 277-286, 2019. CP describes the highest metabolic rate resulting in complete oxidative energy provision (steady state). Between the heavy and severe domain of exercise, CP will be surpassed, and the finite work capacity known as W' will be used up. The purpose of the study is to test CP and W′ and its relationship in males and females, while assessing type I and II muscle fiber distribution in the leg. A 3 MT and isokinetic leg dynamometer muscle fiber typing protocol of 25 consecutive leg extensions were completed. W' for the sample (n = 17) was 8381.64 ± 4556.72 joules [males (n = 9): 12086.22 ± 1851.39 joules; females (n = 8): 4214.00 ± 2459.07 joules]. Type II muscle fiber for the sample was 24.48% ± 12.92% (males: 20.83 ± 13.18%; females: 28.59 ± 12.10%). W' was not significantly correlated to type II muscle fibers (r = -0.070, p = 0.790) but was significantly related when controlling for gender (r = 0.579, p = 0.024). W′ was correlated to Wpeak and BMI in the sample; when controlling for gender, it was correlated to Wpeak, Type I and Type II muscle fiber percentage and CP. Compared to females, males had higher W′ (p < 0.001) and CP (p = 0.004). W′ was not correlated to type II muscle fibers but was when controlling for gender. Males were demonstrated to have significantly higher W′, CP, Wpeak and BMI compared to females suggesting potential muscle cross sectional area influences W′ and CP when comparing genders.

KEY WORDS: Critical Speed, D prime, power-time relationship

INTRODUCTION

The link between fatigue and performance has emerged forming a concept now known as critical power (cycling) or critical speed (running) (CP and CS) (4). CP is considered to represent the highest metabolic rate that results in complete oxidative energy utilization where the body reaches a steady state of pulmonary gas exchange, ventilation, and blood lactate (5). When the body exercises above CP, exercise intolerance occurs quicker. The body experiences an accumulation of blood lactate and an increase breakdown of intramuscular phosphocreatine (PCr); fatigue occurs in the individual within the muscles when the rate of lactate production in active muscle isn't matched by its rate of clearance in muscle and other tissues (4). In transition between the heavy and severe domain of exercise (Figure 1), a subject will surpass their CP, and for the remainder of the exercise test or bout, the subject will be on "borrowed time" as the individual uses up this finite work capacity known as W' (pronounced: W prime) (13). W' has been demonstrated to be dependent on CP and VO_2 slow component amplitude (11,12). Also, CP lies equally between lactate threshold (LT) or gas exchange threshold (GET) and maximal power output reached during incremental exercise (Figure 1). This range can change due to aerobic capacity (10) since LT/GET occurs at 50-65% of VO_2 max and CP occurs at 70-80% of VO_2 max in healthy young subjects (4). The power-time relationship can predict time to intolerance (T lim) for exercise performed above CP (Equation. 1). For example, if a subject's W' is 8900 joules, divided by desire pedaling rate of 300 Watts minus the subjects CP of 250 Watts, the time to intolerance would be 178 seconds, which is when the subject will be unable to sustain the desire pedaling rate any longer and have to slow down (13).

Equation 1: T lim = W' / (P-CP)

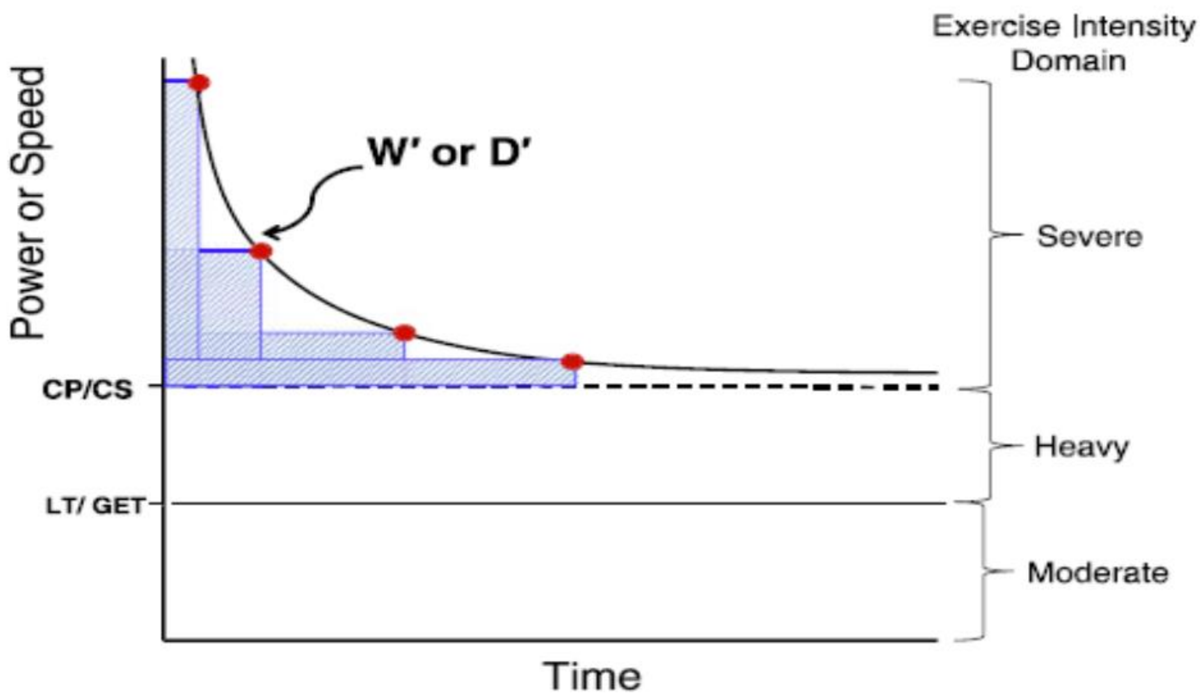

Figure 1. Critical power concept (4).

Muscle fibers are composed of sarcomeres, which are the functional units of muscle fibers. Muscle fibers consist of two proteins: myosin (thick) and actin (thin). Based on their speed of shortening and fatigue resistance, muscle fibers divide into two types: fast-fatigable (type II) or slow-fatigue resistant (type I) (1). These fibers are separated by the morphological differences; white colored fibers express more in fast muscle, and slow muscles appear more red in color. The red color is due to the high amount of myoglobin and capillary content, equating to a better oxidative capacity (1). Type I muscle fibers are beneficial for longer sustained exercise due to the ability to oxidize oxygen, which is "fatigue resistant", whereas type II fibers are nonoxidative, and have a faster shortening speed which are better for short bursts of exercise such as: jumping, sprinting and powerlifting (1).

The VO_2 slow component has been demonstrated to be larger in individuals who have a higher percentage of type II muscle fibers, whereas a high level of endurance fitness is associated with a higher percentage of type I muscle fibers (2, 6). Since the W′ is estimated from a 3 minute all out test which is proportional to the VO_2 slow component amplitude (13), it is possible that W′ may be related to a high percentage of type II muscle fibers while CP may be related to a high percentage of type I muscle fibers. This relationship suggests there is a potential link between the developmental rate of fatigue and skeletal muscle efficiency to W' capacity.

Within the three-minute all out cycling test (3 MT) test against a fixed resistance, peak power output is reached in the first five to 10 seconds and W' is essentially reduced to zero after about two and a half minutes, such that after this time the greatest power output being produced over the final 30 seconds is closely related to the CP value for that specific individual (10). The only study to examine this relationship between CP and W′ to muscle fiber content looked at 11 males (27 ± 8 years; height 1.78 ± 0.07 m; body mass 85.6 ± 15.5 kg) (9). Using the 3 MT and muscle biopsy from the vastus lateralis, CP was found to be positively correlated to type I muscle fibers (r = 0.67, p = 0.05), and inversely related to type II muscle fibers (r = -0.67, p = 0.05). No relationship found between W′ and type II muscle fibers (r = 0.47, $p > 0.05$). Without including a female population in the study, it is unclear if sex, or characteristics associated with gender, impact the relationship of W′ and muscle fiber type. When examining 150 healthy college aged males (n = 95) and females (n = 55), both groups had similar distribution of almost all six types of muscle fibers (I, IC, IIC, IIA, IIAB, and IIB), not including type IC, which were significantly lower in males ($p > 0.05$) (7). When comparing the cross-sectional area measurement, type I, IIA, and IIB fibers were 18.6%, 59.2% and 65.5% larger for males compared to females. Given there was no difference between the sex's fiber type proportions (except for IC) the area made up of each of the major fiber types were different between males and females. The order from largest to smallest for muscle fiber type was IIA > I > IIB for males and I > IIA > IIB for females. This suggests that the slow fibers are found to occupy a greater area in the females, whereas the fast IIA fibers occupied a greater area in the males (7). The understanding of the relationship between CP and W′ in females is unknown and needs to be addressed to determine if there is a difference between males and females CP and W′.

The purpose of this study was to test the theory of the power duration relationship parameters and examine its relationship to muscle fiber distribution in the leg in both males and females. This study aims to add to the understanding of how muscle fiber composition in the leg effects the power duration relationship parameters in males and females.

METHODS

Participants

Seventeen subjects (9 males and 8 females) participated in the study. A 3 MT (12) was completed on the first test day, and the isokinetic leg dynamometer muscle fiber typing protocol (9) was completed on the second test day. Each subject provided informed consent, health history, and demographic information. The subjects were deemed eligible if they met the following criteria: 1) male or female age 18 to 65 years old, and 2) and cleared for vigorous activity (American College of Sports Medicine Risk Stratification). The subjects were instructed to avoid moderate to vigorous exercise 24 hours before the first and second visits. The study was approved by the Institutional Review Board of the researching university (IRBNet#1047102).

Protocol

The 3 MT protocol used an electronically braked cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands). The bike was adjusted to fit each subject comfortably. The subjects were then instructed to keep contact with the handlebars and seat for the duration of the test (3 minutes) and maintain the fastest pedaling rate possible for the duration of the test. The resistance on the pedals during the 3-min effort was set using the linear mode of the ergometer so that the subjects would attain the power output halfway between VO_2 peak (estimated using PA-R, see study by George, 1996 (3) and the GET (i.e., GET + 50% [DELTA], with [DELTA] being the magnitude of the interval between the GET and VO_2peak) on reaching their preferred cadence (linear factor = power/cadence squared) (12). Verbal encouragement was provided throughout the test, although the subjects were not informed of the elapsed time, to prevent pacing (12). To ensure all-out effort, subjects were instructed to maintain their cadence as high as possible at all times throughout the test to reach their peak power output, exhaust their W', and maintain a CP for at least 30 seconds within the 3-minute time frame. W' was calculated using Equation 2, where P_{150s} is the power during the first 150 seconds (4). Wpeak was recorded as the highest power output (Watts) generated by the subject during the 3 MT.

Equation 2: $W' = (P_{150s} - CP)$

On the second visit, the assessment of muscle fiber composition of the quadriceps was completed using Biodex muscle fiber typing protocol. According to previous research, the Biodex measurement of fiber type compared with muscle biopsy showed a high correlation (r = 0.86) between the isokinetic fatigue index and percentage fiber compositions (9). The regression equation generated to predict type II muscle fiber composition in the leg is represented by Equation 3, where the subject completed 25 consecutive leg repetitions at 240 deg/sec, where the first three and last three repetitions were averaged and used in the equation (9). The subject was strapped down to the chair and each subject completed the assessment with their left leg to replicate method design from a previous study by Thorstensson and Karlsson (1976). Subjects with a higher percent of type II fibers were more likely to experience greater torque depreciation in comparison to subject with a higher percent of type I fibers (9).

Equation 3: % type II fibers= 0.9 (x) + 5.2; x = [(Avg. Beginning Torque – Avg. Final Torque) / Avg. Beginning Torque] * 100

Statistical Analysis
All variables were used in Pearson product correlations. Gender difference were compared using two-tailed, paired sample t-tests. The limit set to reject the null hypothesis was $p < 0.05$. All statistical analyses were performed using Statistical Package for the Social Sciences v.23 (SPSS).

RESULTS

Descriptive statistics are presented as means and standard deviations in Table 1. Gender differences are presented in Table 1, using a t-test equality of means between males and females to determine if gender significantly impacted the variables collected. Males were demonstrated to have significantly higher W' and CP compared to females, $p < 0.0001$, and $p < 0.01$ respectfully (Figures 1 and 2). There was also no difference in in Type I and Type II muscle fiber percentage, ($p = 0.492$, and $p = 0.228$).

Table 1. Descriptive statistics and mean differences between males and females.

	Mean (n = 17)	SD	Males (n = 9)	SD	Females (n = 8)	SD	t-test Between Genders
Age	22.82	6.19	21.88	1.69	23.87	9.06	0.527
Height (in.)	68.17	3.35	70.33	2.29	65.75	2.64	0.002*
Weight (lbs.)	160.00	27.31	179.86	18.12	137.66	15.86	0.000***
BMI	24.20	2.63	25.63	2.65	22.59	1.47	0.012*
CP	180.05	41.06	204.77	37.76	152.25	23.58	0.004*
W	8381.64	4556.72	12086.22	1851.39	4214.00	2459.07	0.000***
Type II Percent	24.48	12.92	20.83	13.18	28.59	12.10	0.228
Type I Percent	76.83	14.22	79.16	13.18	74.22	15.78	0.492
Wpeak	525.47	190.72	643.66	174.55	392.50	100.79	0.003*
PAR Score	7.06	1.28	7.22	1.64	6.85	.69	0.592

* Difference is significant at the 0.01 level (2-tailed).

** Difference is significant at the 0.001 level (2-tailed).

*** Difference is significant at the 0.0001 level (2-tailed).

Table 2 displays correlations for the entire sample (n =17). There was no significant correlation between CP and W' (r = 0.408, p = 0.104). Type II muscle fiber percentage was negatively correlated to CP (r = -0.622, p = 0.008) and not correlated to W' (r = -0.70, p = 0.790). Type I muscle fiber percentage was positively correlated to CP (r = 0.514, p = 0.035) and not correlated to W' (r = -0.70, p = 0.791). Table 3 shows the correlation matrix for the test variables when controlling for gender (females = 8; males = 9). There was a negative correlation between CP and W' (r = -0.546, p = 0.035). Type II muscle fiber percentage was significantly correlated to CP and W', (r = -0.594, p = 0.020; r = 0.579, p = 0.024) respectfully. Type I muscle fiber percentage was significantly correlated to CP and W' (r = 0.550, p = 0.034; r = -0.649, p = 0.009) respectfully.

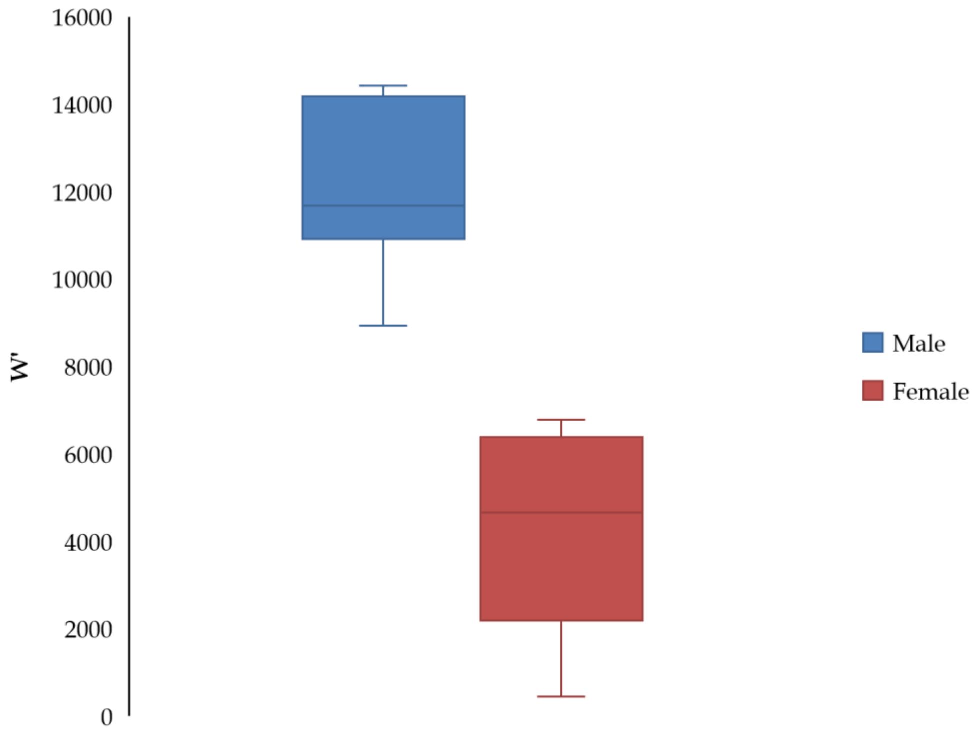

Figure 2. W' scores between genders.

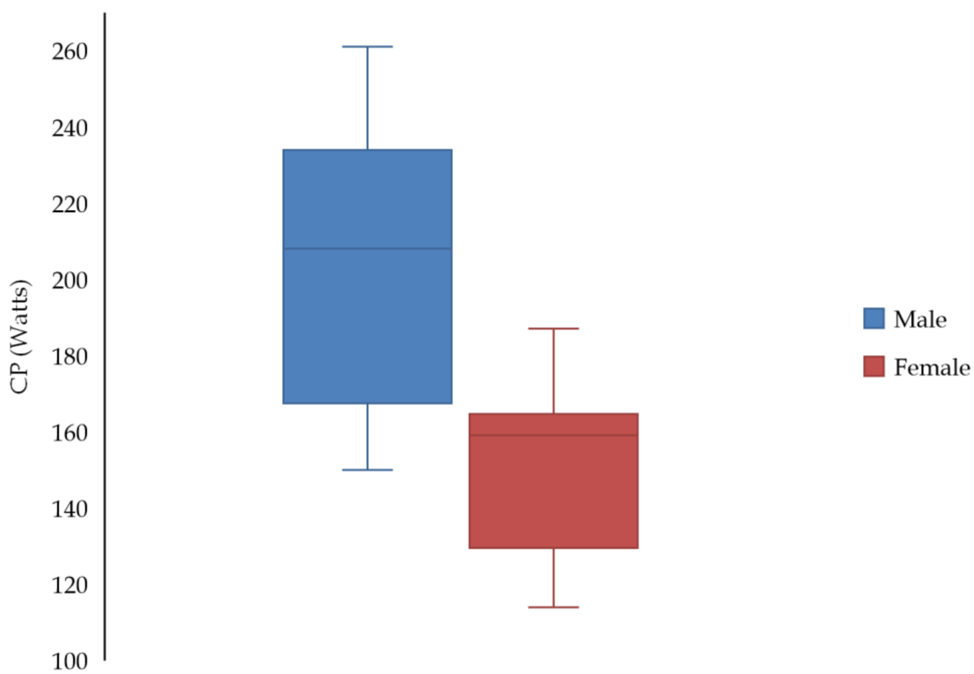

Figure 3. CP score between genders.

Table 2. Correlation matrix of values collected.

		1	2	3	4	5	6	7	8	9	10
1.Age	Pearson Correlation	1									
	Sig. (2-tailed)										
2.Height (in)	Pearson Correlation	-.027	1								
	Sig. (2-tailed)	.918									
3.Weight (lbs.)	Pearson Correlation	-.095	.775**	1							
	Sig. (2-tailed)	.718	.000								
4.BMI	Pearson Correlation	-.161	.262	.810**	1						
	Sig. (2-tailed)	.536	.309	.000							
5.CP	Pearson Correlation	.016	.700**	.745**	.464	1					
	Sig. (2-tailed)	.950	.002	.001	.061						
6.W	Pearson Correlation	-.402	.479	.645**	.586*	.408	1				
	Sig. (2-tailed)	.110	.052	.005	.013	.104					
7.Type II Percent	Pearson Correlation	.015	-.198	-.425	-.438	-.622**	-.070	1			
	Sig. (2-tailed)	.956	.445	.089	.079	.008	.790				
8.Type I Percent	Pearson Correlation	-.026	.234	.408	.383	.514*	-.070	-.924**	1		
	Sig. (2-tailed)	.920	.366	.104	.130	.035	.791	.000			
9. Wpeak	Pearson Correlation	-.191	.487*	.695**	.613**	.497*	.797**	-.074	-.003	1	
	Sig. (2-tailed)	.463	.048	.002	.009	.042	.000	.777	.990		
10.PAR Score	Pearson Correlation	-.193	-.020	-.310	-.441	.089	.134	.069	-.148	-.039	1
	Sig. (2-tailed)	.474	.942	.243	.088	.742	.622	.799	.584	.886	

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 3. Correlation matrix of values collected, controlling for gender.

Control Variable: Gender		1	2	3	4	5	6	7	8	9	10
1. Age	Pearson Correlation	1.000									
	Sig. (2-tailed)	.									
2.Height (in)	Pearson Correlation	.394	1.000								
	Sig. (2-tailed)	.146	.								
3.Weight (lbs.)	Pearson Correlation	.232	.501	1.000							
	Sig. (2-tailed)	.405	.057	.							
4.BMI	Pearson Correlation	-.088	-.271	.692	1.000						
	Sig. (2-tailed)	.755	.328	.004**	.						
5.CP	Pearson Correlation	.377	.443	.487	.125	1.000					
	Sig. (2-tailed)	.166	.098	.066	.656	.					
6.W	Pearson Correlation	-.447	-.497	-.253	.147	-.546	1.000				
	Sig. (2-tailed)	.095	.060	.363	.602	.035*	.				
7.Type II Percent	Pearson Correlation	-.447	.026	-.312	-.329	-.594	.579	1.000			
	Sig. (2-tailed)	.095	.928	.258	.231	.020*	.024*	.			
8.Type I Percent	Pearson Correlation	.478	.159	.450	.345	.550	-.649	-.928	1.000		
	Sig. (2-tailed)	.071	.570	.093	.208	.034*	.009**	.000**	.		
9.Wpeak	Pearson Correlation	-.189	.021	.351	.353	.098	.625	.199	-.181	1.000	
	Sig. (2-tailed)	.501	.940	.200	.197	.727	.013*	.477	.517	.	
10.PAR Score	Pearson Correlation	-.264	-.169	-.691	-.645	-.007	.009	.116	-.172	-.180	1.000
	Sig. (2-tailed)	.342	.548	.004**	.009**	.979	.974	.681	.539	.520	.

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

DISCUSSION

The findings of the study provide insight on the research question which tested the theory of the power duration relationship parameters and muscle fiber distribution in the leg in both males and females. This is based on the previous finding that there is a gender difference in muscle fiber distribution, cross-sectional area (8), VO_2 slow component amplitude relationship to W', and muscular inefficiency (2, 14). Therefore W' is potentially related to type II muscle fibers because of their similarity in fatigability caused by the inability to utilize oxygen to function. CP was seen to be correlated to type I muscle fiber percentage, where W' was not correlated to type II muscle fiber, when looking at 11 males (10). The current study partially supported findings (10) that type II muscle fibers were not significantly correlated to W' when examining the entire sample (Table 2), but was significant when controlling for gender (Table 3), which was not taken in account when comparing 11 males previously. For this study and the study by Vanhatalo et al., (2016), CP had a positive correlation with type I muscle fibers and negative correlation to type II muscle fibers. The current study however, found W' to be related to type II muscle fibers when controlled for gender, which was not compared by Vanhatalo et al., 2016, who only look at males. Given that the current study included males and females, the current results provide a better understanding on the relationship between muscle fiber distribution in the leg for both genders.

The findings that males had significantly higher W' and CP as compared to females has not been demonstrated previously in the literature. When comparing males to females, males were significantly taller, heavier, have higher BMI, and have a higher Wpeak (Table 1) which has not been demonstrated previously in the literature. BMI was shown as being positively correlated to W' and Wpeak, and since physical activity levels (PAR Score) were not significantly different between genders, where the average subject participated in 10 miles to less than 15 miles of running per week or spent 3 hours to less than 6 hours per week in comparable physical activity, so we can infer that the sample group was highly active. Using the self-reported physical activity levels and BMI, researchers can extrapolate that subjects with a higher BMI would have more overall muscle mass, due to the high activity level and muscular adaptation to exercise. Being that males had significantly higher BMI, CP and W', this could be caused by males having a larger cross-sectional area for type I and type II muscle fibers compared to females, which would support previous findings (8). This would explain why there would be a gender difference when looking at CP and W' with equally active males and females (Table 3). Given that there is no current research on this relationship in females and differences between genders, this study adds to the understanding of how muscle fiber distribution effects the critical power concept in males and females (Figure 1 and 2).

Addressing the potential limitations of the current study can potentially assist researchers minimize potential sources of error in future research. First, the sample size was smaller and does not represent the entire male and female populations. Therefore, generalizability is limited with the findings. Based on volunteer subjects, this study best represents male and females between the ages of 19-25 years old who are regularly active. Further examination of the relationship is needed to make claims of different age ranges as an amount of muscle and fiber type distribution may change with age. Second, the Biodex muscle fiber protocol estimates fiber type by a regression equation based on maximal effort given during the test, which can increase the chance of error in the estimation of muscle fibers, compared to muscle biopsy which is not an estimation and is more consistently accurate. However, this test was used based the best available and non-invasive method resources to assess muscle fiber composition in the leg (9). Another limitation is that the effort of the subject is difficult to monitor. Both the 3MT and the Biodex need the subject to perform at a maximal intensity to provide the best results. Given that the majority of the subjects were given verbal encouragement, it is still difficult to produce effort at a high intensity in laboratory settings. Future studies should consider collecting VO_2 max scores and comparing it to the 3 MT to conclusively determine if maximal effort was achieved. Also, not having subjects complete a practice session before completing the visit could have provided less accurate results. The majority of the subjects had never completed a 3 MT or the Biodex assessments before, which can make it difficult for the subjects to complete the test as accurate as needed. Future studies should consider having subjects complete a practice session to help minimize error in the assessments. Lastly, having subjects use self-reported physical activity levels could decrease the accuracy of their true activity level. Using accelerometers, or journals to record activity levels would help increase the accuracy of the measurement of physical activity in the subjects.

The implications for the current study are to help better understand the impact muscle fiber composition has on the critical power concept in males and females. These findings can provide an example of how gender may play a role in the amplitude of CP and W′ (Figure 1 and 2), and how much of an influence muscle fiber distribution has on CP and W′ (Table 3.). Understanding that males have higher CP and W′ provides further evidence of how males and females differ in performance, even if following a similar exercise program. Males will be more likely to experience higher levels of strength and speed performances compared to females due to muscle fiber cross sectional size, and muscle fiber distribution, which stresses the importance of gender specific training programs. Findings from the study help explain more factors that impact performance in males and females at the physiological level.

The data reported in the current study indicate that CP was correlated to type I muscle fibers. W′ was not correlated to type II muscle fibers in the leg but was when controlling for gender. Also, males were seen to have significantly higher W′, CP, BMI, and Wpeak compared to females, even though there wasn't a gender difference between type II and type I muscle fiber percentage in the leg. Wpeak and BMI were seen to be significantly positively correlated to W′, whereas CP and type I muscle fiber percentage was significantly negatively correlated to W′. CP was positively correlated to type I muscle fibers. This current study is the first to address the difference between male and female, CP and W′ and the impact of muscle fiber distribution, while concurrently examining BMI and current physical activity level in their role in contributing to the critical power concept.

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