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Angular Kinematics and Critical Power of Younger and Older Cyclists during the 3-Min All-Out Test

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Abstract: This study aimed to determine differences in angular kinematics and critical power between younger and older cyclists during the 3-min all-out test. Younger (n = 15, 21.8 ± 2.4y) and Older (n = 15, 53.3 ± 6.6 y) Category 1 or 2 riders completed maximal aerobic testing and a 3-min all-out test on separate days using their own road bicycle on a cycle ergometer. Eight retroreflective markers determined right side sagittal plane angular kinematics during the 3-min all-out test. Younger cyclists displayed higher $\dot{V}O2$max, $\dot{V}O2$ @ VEbp, HRmax, Power@$\dot{V}O2$max and Critical Power ($p < 0.05$) than older cyclists. Cadence decreased over time for the combined group (time 1 (T1) = 87.3 ± 4.5 rpm, time 2 (T2) = 83.7 ± 4.6 rpm, and time 3 (T3) = 83.6 ± 5.0 rpm) where T1 was significantly higher than T2 and T3 ($p < 0.001$), but there were no differences between age groups. Ankle (T1 > T2 > T3, $p < 0.026$) and foot ranges of motion (T1, T2 > T3, $p < 0.01$) decreased over time for both age groups. Additionally, Younger cyclists had larger ankle and foot ranges of motion (ROM) compared to Older cyclists (23.2 ± 5.9° vs. 19.3 ± 5.6°; $p = 0.036$ and 49.8 ± 6.6° vs. 44.8 ± 6.5°; $p = 0.032$, respectively). Age related differences in physiological measures occurred as expected, although the skill level of the cyclists may explain their similar cadence. Smaller ankle and foot ROM may be strategies to assist force and power generation, particularly in older cyclists as they attempt to overcome aging related physiological declines. With smaller ROM, Older cyclists may aim to strengthen ankle musculature and deemphasize high cadence to maintain force generation and critical power.

Keywords: work; $\dot{V}O_2$; range of motion, steady state cycling

1. Introduction

Critical Power (CP) has been defined as a theoretical maximum workload that could be sustained for "a very long time" without fatigue (Monod & Scherrer, 1965). This parameter is thought to lay on the boundary between heavy and severe exercise (Hill & Smith, 1999; Poole, Ward, Gardner, & Whipp, 1988) and is considered more consistent with high-intensity exercise performance (Poole, Ward, & Whipp, 1990). Originally, CP was determined in the lab via protocols consisting of multiple Time to Exhaustion (TTE) tests at various workloads over the course of several days (Moritani, Nagata, & DeVries, 1981). More recently, a 3-min all-out test has been adopted as a more easily recorded estimate of CP and W' (work done above CP) during a single bout of exercise (Burnley, Doust, & Vanhatalo, 2006; Vanhatalo, Doust, & Burnley, 2007).

Early studies validated the 3-min all out test to determine CP with various equipment (Burnley et al., 2006; Francis, Quinn, Amann, & Laroche, 2010; Vanhatalo et al., 2007). Studies using the 3-min all-out test to determine CP have enrolled participants of varying competition levels, but who are generally younger. Burnley et al. (2006) determined CP for recreationally active participants with mean age 27 y. Other studies enrolled participants of mixed competition levels whose mean age were ~33 y (Vanhatalo et al., 2007; Wright, Bruce-Low, & Jobson, 2017). Francis et al. (2010), Karsten, Jobson, Hopker, Passfield, and Beedie (2014), and McClave, LeBlanc, and Hawkins (2011) studied CP in competitive cyclists with mean ages of 32.4 y, 33 y and 40.5 y, respectively. The latter also determined the sustainability of CP for competitive cyclists. There is a lack of literature investigating CP in elite cyclists both younger and older than these studies

Lower extremity kinematics and kinetics have been frequently studied during cycling in a diverse set of conditions for younger age groups. The influence of fatigue, brought on by different protocols, has been studied with various participants during cycling (Abt, Lephart, & Fu, 2007; Bini & Diefenthaeler, 2010; Bini, Diefenthaeler, & Mota, 2010a; Dingwell, Joubert, Diefenthaeler, & Trinity, 2008; Sanderson & Black, 2003). The influence of workload (Bini & Diefenthaeler, 2010), cadence (Bini et al., 2010b; Chapman, Vincenzino, Blanch, Hodges, & Dowlan, 2006; Chapman, Vincenzino, Blanch, & Hodges, 2009), and preferred saddle height (Millour et al., 2020) on cycling kinematics and kinetics has also been investigated. However, none of these studies used the 3-min all-out test as their protocol.

In general, older cyclists have been the focus of little research. Early work investigated the contributions of age, sex and body weight to energy expenditure while cycling (Adams, 1967). Peiffer, Abiss, Chapman, Laursen, and Parker (2008) studied the physiological characteristics of masters-level cyclists (ages 35 and older). Lastly, Sacchetti, Lenti, di Palumbo, and de Vito (2010) compared the effect of cadence on cycling efficiency in young (mean age 24.3 y) and older (mean age 65.6 y) cyclists. Yet none of these studies considered CP or the lower limb angular kinematics in an older population.

The literature does not provide knowledge of how the cycling kinematics relate to the decrease in power over time during a 3-min all-out CP test, or particularly during the last 30s when CP is established. It is also unknown whether the kinematics during the last 30s are indicative of a steady state which coincides with the maximal sustainable workload (CP). Furthermore, it is not known if differences exist in CP, the corresponding W' and kinematics between cyclists of differing ages, but similar skill levels. Therefore, the purpose of this study was to determine if there were differences in CP and kinematics using the 3-min all-out test between younger and older elite cyclists. We hypothesize that there will be differences between the young and older CP values that reflect the expected physiological differences associated with normal aging. Additionally, we hypothesize that because the participants are elite cyclists and that CP represents a sustainable power, the two groups will exhibit similar kinematics during the test, in particular during the phase that defines CP.

2. Materials and Methods

Participants

Two groups of elite road and mountain cyclists were recruited from the surrounding cycling community. The Younger Group consisted of 15 cyclists who were between 18-30 y old and the Older Group consisted of 15 cyclists who were between 45-70 y old. All cyclists were either Category 1 or 2 riders. Prior to participation in the study, participants read and signed an informed consent that was approved by the Institutional Review Board at California Lutheran University in accordance with the Declaration of Helsinki. Height and body mass were measured using balance scale and stadiometer (Health O Meter, McCook, IL).

Testing took place over two visits to the Human Performance Laboratory with a minimum of 24 hours of rest between visits. Tests were performed at the same time of day for each participant. Participants were asked to maintain consistent nutritional and fluid intake prior to tests, and to abstain from alcohol and maintain typical caffeine intake for 12 hours prior to each test. The average self-reported caffeine intake was equivalent to 1-2 cups of coffee in a 12 hour time period.

Maximal Aerobic Power Test

At the first visit participants performed a $\dot{V}O_2$max test on their road bicycle mounted to a CompuTrainer lab ergometer (RacerMate Inc, Seattle WA). The device uses a locking rear mount stand and electronic load generator that can apply up to 1500 W of resistance with an accuracy of ± 2.5%. Tire pressure was standardized at 827.4 kPa and the trainer was calibrated to 17.8 N of press on force (RacerMate Inc, Seattle WA). Participants performed a 10 minute warm-up on their bicycle prior to testing and identified a preferred cadence to the researcher. Subjects began cycling at a 100 W workload and every two minutes the workload was increased by 50 W until volitional exhaustion or pedaling cadence dropped 10 revolutions per minute (rpm) below target cadence for more than 10 seconds. This protocol was consistent with that used by Smith, Dangelmaier, and Hill (1999). Expired gases were collected in a mixing chamber with samples taken every 15s; minute averages were analyzed via a Parvo-Medics: True One 2400 Metabolic System (Sandy, Utah) with $\dot{V}O_2$max being identified as the highest by minute $\dot{V}O_2$ value obtained. HR was determined by telemetry via a Polar T31 transmitter and receiver (Lake Success, New York). VEbp was determined by plotting subjects' ventilation against time; the point at which the subjects' ventilation shifted from a linear to exponential increase was identified as VEbp. Additionally, VE/$\dot{V}O_2$ vs. VE/CO2 was also used to determine the anaerobic threshold. Both methodologies identified the same value so the former method was used as a representative of the threshold. A single investigator performed all analyses of anaerobic threshold.

Three Minute All-Out Test

At the second visit participants performed a 3-min all-out test on their road bicycle mounted to a CompuTrainer lab ergometer in order to determine CP (Burnley et al., 2006; Poole et al., 1988; Smith et al., 1999). The power output identified at the midpoint between VEbp and $\dot{V}O_2$max from the $\dot{V}O_2$max test determined the fixed resistance value for the 3-min all-out test (Burnley et al., 2006; Vanhatalo et al., 2007). Subjects performed a 10 minute warm-up on their bicycle prior to testing. Following the warm-up subjects slowly ramped up their cadence up to approximately 120 rpm without any resistance from the electromagnetic brake on the ergometer. Participants were given a countdown and then the fixed resistance was immediately added. Subjects were instructed to give an all-out un-paced effort for 3 minutes; strong verbal encouragement was given to ensure a maximal effort, with no time feedback. Expired gases were collected in a mixing chamber with samples taken every 15s; 30s averages were analyzed via a Parvo-Medics: True One 2400 Metabolic System, and HR determined by telemetry via a Polar T31 transmitter and receiver. CP was determined by averaging the power outputs measured every 15s from the final 30s of the 3-min all-out test.

Kinematics Data Collection

Prior to their Critical Power test, 8 reflective markers (14 mm diameter) were affixed to body landmarks on the right side of the body including the acromion process, elbow, wrist, trochanter, lateral femoral condyle, lateral malleolus, heel, and metatarsal IV. Marker location was collected using six Vicon MX-40 (Centennial, CO) cameras collecting at 120 Hz. Motus 9.2 software (Centennial, CO) was used to determine three-dimensional coordinate data which was filtered using a low pass fourth-order Butterworth filter with zero lag with a cut-off frequency of 6 Hz. Coordinate data was represented using a fixed reference frame with the X-direction pointing to the cyclist's right, Y-direction pointing forward and Z-direction pointing upward.

For each subject, motion analysis data was collected for three seconds during four different time intervals. The first time interval was immediately after the fixed resistance had been implemented (T0). The other three time intervals corresponded to the first, second and third minutes of the CP test (T1, T2 and T3, respectively). Cadence was determined by the motion analysis data.

Segment angles for the trunk, thigh, shank and foot were computed using the coordinate data (see Figure 1). The trunk segment angle was defined as the angle created by the trunk (as defined by the trochanter and acromion process markers) projected onto the YZ plane and a line pointing in the positive Y direction from the trochanter. The other segment angles were defined as the angle between the segment projected onto the YZ plane and a line pointing in the positive Y-direction from the segment's proximal endpoint. The joint angles (hip, knee and ankle) were created by the angle in the YZ plane between the trunk and thigh, thigh and shank, and shank and foot, respectively. Within each revolution, the range of motion (ROM) for each angle was computed by subtracting the smallest value of that angle from the largest value of that angle. Then the ROM values were averaged over revolutions to obtain the ROM for that time interval. At least three revolutions were used for each time interval.

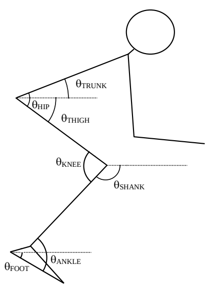

Figure 1. Diagram of sagittal plane definitions for the trunk, hip, thigh, knee, shank, ankle, and foot angles.

Statistical Analysis

Data were analyzed using SPSS v25 software (IBM, Chicago, IL). Independent t-tests were used to determine differences between the two group's physiological data and to compare cadence and ROM values at the final time interval (T3). The normality of the distributions and the equality of the variances were tested using Kolmogorov-Smirnov and Levene tests, respectively. Two factor repeated measures ANOVA was performed to determine the main effect of group and time for the cadence and ROM values for the trunk, hip, thigh, knee, shank, ankle, and foot. If the assumption of sphericity was violated, a Greenhouse-Geisser correction was performed. When significant differences were found, post-hoc testing was performed using Fisher's Least Significant Difference. Effect sizes were determined by Cohen's d for t-tests and by eta squared (η^2) for factorial ANOVA. Significance was pre-determined as $p < 0.05$.

3. Results

The Younger group consisted of 15 cyclists whose age was 21.8 ± 2.4 y and the Older group consisted of 15 cyclists whose age was 53.3 ± 6.6 y. The Younger group's height and mass were 177.5 ± 3.3 cm and 69.5 ± 7.2 kg, respectively while the Older group's height and mass were 174.7 ± 5.1 cm and 74.2 ± 6.9 kg, respectively. There was no statistical difference between the two groups' height and mass.

Physiological data obtained from the incremental ramp $\dot{V}O_2$max test and CP test are displayed in Table 1. There was a significant difference between the two groups in their maximum $\dot{V}O_2$ value ($p < 0.0001$, Cohen's d = 1.43), as well as the $\dot{V}O_2$ value at VE_{bp} ($p = 0.044$, Cohen's d = 0.77). There was a difference in the maximum heart rate between the two groups ($p < 0.0001$. Cohen's d = 2.54), but no difference in their preferred cadence. Power differences existed between the two groups at $\dot{V}O_2$max ($p = 0.016$, Cohen's d = 0.93) and there was a trend towards a difference at VE_{bp} ($p = 0.053$).

Figure 2 illustrates the group means and standard deviation power values during the 3-minute all-out test. The mean CP value for each group is shown with a dashed line. The area under the curve, but above the CP line indicates the work done above CP (W′). While the CP values differed statistically ($p = 0.018$, Cohen's d = 0.93), the W′ values did not. (See Table 1).

Table 1. Physiological data for the Younger and Older Groups. Mean (SD values) for physiological values measured during the maximum aerobic capacity test and critical power and work above the critical power value (W′) during the 3 min all-out test. $\dot{V}O_2$ values are given in ml·kg^{-1}min^{-1}, heart rate values are given in beats/minute cadence values are given in revolutions/minute, power values are given in Watts, and work values are given in kiloJoules.

Measure	Younger	Older
$\dot{V}O_2$max*	67.2 (5.8)	56.6 (8.7)
$\dot{V}O_2$@VE$_{bp}$*	54.3 (6.2)	48.7 (8.2)
HRmax*	193 (8)	170 (10)
Preferred cadence	90.3 (3.5)	90.3 (4.0)
Power @ $\dot{V}O_2$max*	400 (33)	360 (51)
Power @ VE$_{bp}$	323 (26)	297 (44)
CP*	320 (36)	283 (43)
W'	13.8 (4.1)	11.6 (3.4)

* denotes differences between the groups ($p < 0.05$)

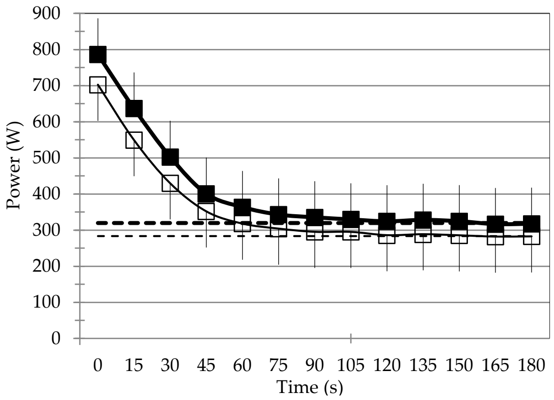

Figure 2. Power output during the 3-min all-out test for the Younger and Older Groups. Mean ± SD values for Power (W) over time for the Younger Group (solid squares and thicker line) and the Older Group (open squares and thinner line). Mean critical power value for each group are shown with the dashed lines with corresponding thickness.

The two-factor ANOVA revealed a main effect for time for the cadence values ($p < 0.001$, $\eta^2 = 0.54$), but no main effect for age. In particular, the cadence values for the three time periods were 87.3 ± 4.5 rpm, 83.7 ± 4.6 rpm, and 83.6 ± 5.0 rpm, respectively. Post hoc testing showed that the cadence at T1 differed from both T2 ($p < 0.001$) and T3 ($p < 0.001$). There was no difference in the cadence between the two groups at T3.

Figure 3 provides ROM data for the trunk, hip and thigh for the two groups over time. There was a main effect for time for the trunk ROM (T1: 5.4 ± 1.4°, T2: 5.0 ± 1.5°, T3: 5.1 ± 1.2°, $p = 0.007$, $\eta^2 = 0.17$) with the values at T1 differing from values at both T2 ($p = 0.002$) and T3 ($p = 0.029$). There was also a main effect for age for the trunk ROM (Younger: 4.5 ± 1.1°, Older: 5.8 ± 1.3°, $p = 0.004$, $\eta^2 = 0.28$). There was no main effect for time for the hip or thigh ROM. However, there was a trend towards a main effect for age for the hip ROM (Younger: 47.5 ± 2.9°, Older: 49.3 ± 2.0°, $p = 0.064$). An independent t-test identified a difference in the trunk ROM values at T3 (Younger: 4.6 ± 1.2°, Older: 5.5 ± 0.9°, $p = 0.038$, Cohen's d = 0.85).

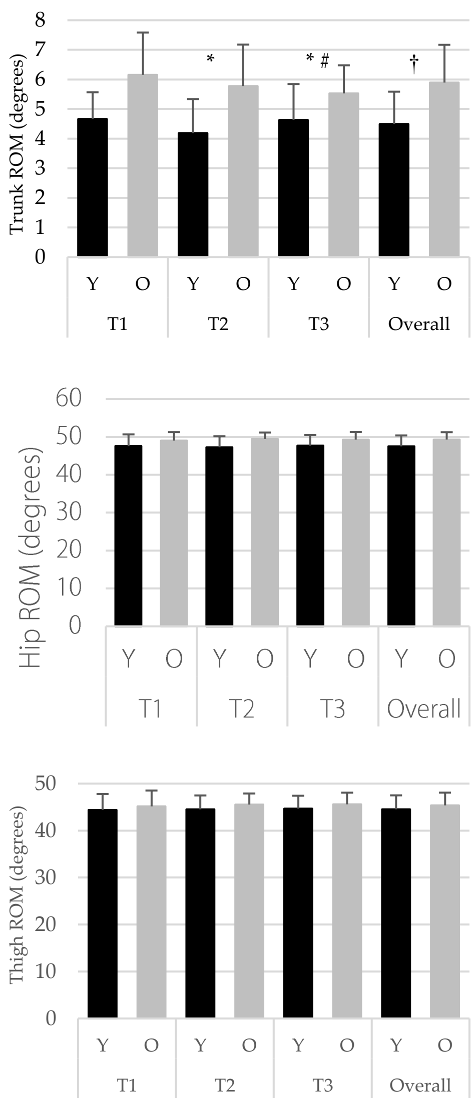

Figure 3. Mean range of motion for the Trunk (top), Hip (middle) and Thigh (bottom) for the Younger group (Y) and the Older group (O). Error bars represent standard deviation values. * indicates values that differ from T1 ($p < 0.05$), # indicates that the two groups differ at T3 ($p < 0.05$), and † indicates overall group differences ($p < 0.05$).

Investigation at the knee showed that there was no main effect for time or age for the knee ROM. The knee ROM values collapsed over ages were 75.0 ± 4.7°, 75.5 ± 4.2°, and 75.2 ± 3.9° for T1, T2 and T3, respectively. There was no difference in the knee ROM between the two groups at T3.

Figure 4 provides ROM values for each group over time for the shank, ankle and foot. There was a main effect for time for both the ankle ROM (T1: 23.3 ± 6.7°, T2: 20.9 ± 5.8°, T3: 19.5 ± 4.9°, $p = 0.001$, $\eta^2 = 0.26$) and the foot ROM (T1: 48.7 ± 7.4°, T2: 47.2 ± 6.9°, T3: 46.0 ± 6.5°, $p = 0.024$, $\eta^2 = 0.15$). At the ankle, ROM values at all times differed from one another ($p < 0.026$ for each pairwise comparison). At the foot, ROM values at T3 differed from both T1 ($p = 0.010$) and T2 ($p = 0.008$). Additionally, there was a main effect for age for both the ankle ROM (Younger: 23.2 ± 5.9°, Older: 19.3 ± 5.6°, $p = 0.036$, $\eta^2 = 0.15$) and the foot ROM (Younger: 49.8 ± 6.6°, Older: 44.8 ± 6.5°, $p = 0.032$, $\eta^2 = 0.15$). The comparison between the groups at T3 showed only a trend towards a difference in the foot ROM ($p = 0.073$).

4. Discussion

The aim of this paper was to investigate if there were differences between younger and older cyclists as they relate to the 3-min all-out critical power test. In particular, if kinematic differences existed at CP (T3), over time or between groups during the 3-min all-out test was investigated. Other than differences in the trunk ROM between the two groups, the hypothesis that there would be no difference in the kinematics between the groups at CP was supported by the data. The Older group's trunk ROM was statistically greater than the Younger group's trunk ROM. However, the actual difference was quite small (less than a degree) and so likely not functionally significant.

Across the duration of the CP test, there were differences in the cyclists' ROM values over time and between groups for the trunk, ankle and foot. Similar to the difference identified at CP for the trunk ROM, the statistically significant difference over the test for the trunk ROM was likely not functionally meaningful as it is so small (less than 0.5 degree). However, the differences found at the ankle and foot do merit attention. The ankle and foot ROM became progressively smaller over the three minutes of the test. Additionally, the Older group had smaller ROM values than the Younger group at the ankle and foot. There were no differences in the shank ROM over time or between groups so the ankle differences can be explained by the foot differences.

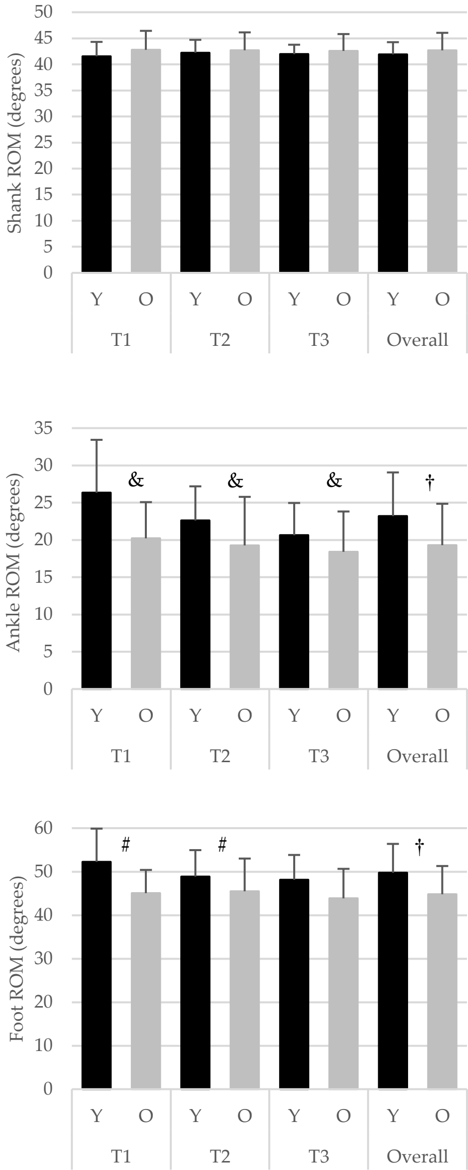

Figure 4. Mean range of motion for the Shank (top), the Ankle (middle) and the Foot (bottom) for the Younger group (Y) and the Older group (O). Error bars represent standard deviation values. # indicates times that differ from T3 ($p < 0.05$), & indicates times that differ from all other times, and † indicates overall group differences ($p < 0.05$).

In the current study, the differences seen in ankle and foot ROM over time would support that the cyclists changed their ankle ROM to assist in force generation. Other studies have noted ankle ROM decreases when power output decreases (Bini and Diefenthaeler, 2010; Bini, Senger, Lanferdini, & Lopes, 2012). The smaller ankle ROM used by the Older cyclists may be taking advantage of shorter muscle lengths and slower shortening velocities. There has been speculation that a decreased ankle ROM may be advantageous in keeping the gastrocnemius and soleus in a more favorable length in the length-tension curve for generating force (Sanderson, Martin, Honeyman, & Keefer, 2006). A decreased ankle ROM would indicate slower concentric muscle contractions, which also puts the muscles in an advantageous position to generate more force as determined by the force-velocity curve (Alcazar, Csapo, Ara & Alegre, 2019). It has been reported that aging creates a larger decrease in concentric force production so the Older group would benefit more by a shift to slower conditions than the Younger group (Hortobagyi et al., 1995). Other factors that may explain the decreased ankle ROM include the desire to simplify the task due to central and peripheral fatigue (Lepers, Maffiuletti, Rochette, Brugniaux, & Millet, 2002), greater efficiency of plantarflexor muscles (Zajac, 2002), and/or the importance of ankle stiffness to effectively transmit force to the pedal and crank (Mornieux, Guenette, Sheel, & Sanderson, 2007).

Consistent with previous research, there were no differences between the two groups or over time in knee ROM (Bini and Diefenthaeler, 2010; Bini et al, 2010a; Bini et al., 2010b; Pouliquen, Nicolas, Bideau, & Bideau, 2021) or hip ROM (Bini et al., 2010b; Bini et al., 2012). However, Bini and Diefenthaeler (2010) reported much smaller knee ROM values. Previous research has shown that knee ROM decreases with larger cadences while hip ROM was not affected (Bini et al., 2010b). It should be noted that in many studies, the hip angle reported was equivalent to the thigh angle in the current study (see Figure 1).

The cadence values used by the cyclists were different at T1 than the other times, but did not differ between the two groups. Previous work with older cyclists reported lower freely chosen cadence (FCC) values at all levels of intensity during an incremental test (Sacchetti et al., 2010) which differs than the findings in the current study. This difference may be due to the higher skill level of the cyclists in the current study who may use a more efficient value. The cadence for both groups during T3 was below their FCC (approximately 90 rpm determined during their $\dot{V}O_2$max test) which was expected as other studies have reported a lower (approximately 80 rpm) cadence to be most efficient for elite cyclists at workloads of 350 W (Foss & Hallén, 2004; Foss & Hallén, 2005).

Age related differences in most of the values obtained during the $\dot{V}O_2$max test were as expected. These data are consistent with those found in the literature (Sacchetti et al., 2010; Sanderson & Black, 2003; Peiffer et al., 2008). The $\dot{V}O_2$ @ VE_{bp} for the Younger group was 80.8% of their $\dot{V}O_2$max while for the Older group it was 86.1% of their $\dot{V}O_2$max. This agrees with previous work reporting that aging leads to a higher breakpoint (Allen, Seals, Hurley, Ehsani, & Hagberg, 1985), and may help explain the high performance capacity of middle-aged and older athletes despite declining $\dot{V}O_2$max (Coggan et al., 1990).

The data obtained during the 3-min all-out test resulted in a greater CP for the Younger group than the older group. To our knowledge, no previous work has investigated the influence of age on CP, but it was not surprising that aging was associated with reduced physiologic capacity. Our CP values for the Younger group were consistent with previous research from our laboratory (305 ±32 W) (McClave et al., 2011), but was higher than studies using the same protocol but different equipment (Burnley et al., 2006; Francis et al., 2010). The former reported CP at 273 ± 52 W, while the latter, in the seminal research on the 3-min all-out protocol, reported CP at 257 ± 49 W. In addition to equipment differences, Burnley et al. (2006) did not use elite level cyclists as subjects but rather habitually active. These two differences could explain the higher CP noted in this work. While CP was different, W' did not appear to be, with our values of 13.8 ± 4.1 kJ for Y similar to Burnley et al.'s (2006) reported values of 14.2 ± 4.7 kJ.

5. Practical Applications

The careful analysis of both the physiological and mechanical aspects of the CP test for two age groups is unique. The results of this study may explain how experienced Older cyclists use strategies that help them overcome the expected physiological decline associated with aging. In particular, the diminished ability to generate force and power appears to be mitigated by the use of a lower cadence that is optimal for generating power (Foss & Hallén, 2004; Foss & Hallén, 2005) and is the same as the Younger cyclists. Additionally, using a smaller ROM at the ankle across time during the CP test positions the older cyclists to generate more force than a larger ankle ROM would enable. It is reasonable to expect that the older cyclists would still generate less force on the pedals, given their lower power output and equivalent cadence. From a practical standpoint, strengthening of the musculature controlling ankle movement would particularly benefit older cyclists as they seek to maintain CP with a smaller ROM. Older cyclists could also place less concern on high cadence as this may not benefit them in terms of generating force and CP. Additionally, as others have reported that saddle height adjustments can increase muscle power by 9%, these cyclists may consider altering their bike setup to enhance their power generation (Millour et al., 2020).

Future studies should perform a 3D kinematic analysis to determine if there are differences between the two groups in other planes. This 3D study could also include a more continuous temporal analysis instead of looking at the three discrete times, as this study did. Future studies should include the use of pedal force transducers to determine the magnitude and direction of these forces because they contribute to power generation. If both pedals were instrumented and markers were also added to the left side of the body, symmetry could investigated, as well as musculoskeletal modeling of the movement. It would also be useful to investigate if the cyclists maintain the kinematics identified at CP during a sustained session at CP. Finally, the results of this study are specific to male cyclists at a particular skill level and age. It is not known if the patterns identified would also be obtained by cyclists of different ages, sexes, or levels.

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Conflicts of Interest: The authors declare no conflict of interest.

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