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Age-Related Changes in Maximal Power and Maximal Heart Rate Recorded During a Ramped Test in 114 Cyclists Age 15–73 Years

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This study assessed age-related changes in power and heart rate in 114 competitive male cyclists age 15–73 years. Participants completed a maximal Kingcycle™ ergometer test with maximal ramped minute power (RMP_{max}, W) recorded as the highest average power during any 60 s and maximal heart rate (HR_{max}, beats/min) as the highest value during the test. From age 15 to 29 ($n = 38$) RMP_{max} increased by 7.2 W/year ($r = .53$, SE 49 W, $p < .05$). From age 30 to 73 ($n = 78$) RMP_{max} declined by 2.4 W/year ($r = –.49$, SE 49 W, $p < .05$). Heart rate decreased across the full age range by 0.66 beats · min^{-1} · year^{-1} ($r = –.75$, SE 9 beats/min, $p < .05$). Age accounted for only 25% of the variance in RMP_{max} but 56% in HR_{max}. RMP_{max} was shown to peak at age 30, then decline with age, whereas HR_{max} declined across the full age range.

Key Words: aging, competitive, Kingcycle™, maximal ramp minute power

Power output recorded during a maximal progressive incremental test to volitional exhaustion is a strong correlate of indoor (Weston et al., 1997) and outdoor (Balmer, Davison, & Bird, 2000; Hawley & Noakes, 1992) endurance-cycling performance. Terms and definitions used to describe this predominantly "aerobic" measure of power include *maximal power* (Hopkins, Hawley, & Burke, 1999; Stepto, Hawley, Dennis, & Hopkins, 1999; Westgarth-Taylor et al., 1997), *maximal ramped minute power* (Smith, Balmer, Coleman, Bird, & Davison, 2002), *peak power output* (Hawley & Noakes), and *maximal sustained power output* (Weston et al.). This measure of power should not be confused with maximal "anaerobic" power commonly recorded during a 30-s Wingate test (Vandewalle, Peres, & Monod, 1987) or even *maximal aerobic power*, which is commonly used to describe maximal oxygen consumption (Thoden, 1991). Maximal power values reported for male competitive cyclists have ranged from ≈380 to 420 W for trained

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(El-Sayed, Balmer, & Rattu, 1997; Jeukendrup, Saris, Brouns, & Kester, 1996) to above 440 W for elite/highly trained (Wilber, Zawadzki, Kearney, Shannon, & Disalvo, 1997) and over 480 W for professional cyclists (Lucia, Pardo, Durántez, Hoyos, & Chicharro, 1998). Several studies (Aminoff, Smolander, Korhonen, & Louhevaara, 1996; Hagberg et al., 1998; Kavanagh & Shephard, 1990; Massé-Biron, Mercier, Collomp, Hardy, & Préfaut, 1992; Overend, Cunningham, Paterson, & Smith, 1992; Préfaut, Anselme, Caillaud, & Massé-Biron, 1994; Proctor et al., 1998) have reported lower values for maximal aerobic power in older age groups (>50 years) than in younger athletes (<30 years), and this difference has been attributed to a decrease in VO_{2max} (Aminoff et al.) and decline in muscle function (Sargeant, 1994). Little information is available concerning the maximal power of master cyclists, with reported values of 200 W (Massé-Biron et al.) to 240 W (Préfaut et al.) in cyclists with a mean age of 65 years.

Physical performance increases during childhood, peaks in adulthood, and declines with increasing age (Joyner, 1993). Age-related changes in performance appear to be sport specific (Bird, Balmer, Olds, & Davison, 2001), and the age at which maximal power starts to decline in trained cyclists has not been reported. The rate of decline in maximal power with age (W/year), however, can be estimated from mean values reported for younger and master-age groups. Cross-sectional data indicate an absolute rate of decline of ≈1.5 W/year for healthy/active participants (Aminoff et al., 1996; Overend et al., 1992), ≈3 W/year for master athletes (Kavanagh & Shephard, 1990; Proctor et al., 1998), and 1.3 W/year (Massé-Biron et al., 1992) and 2.5 W/year (Préfaut et al., 1994) for master cyclists. Studies of master cyclists, however, have made comparisons involving physical education students (Massé-Biron et al.) and triathletes (Préfaut et al.), not younger cyclists. To our knowledge no study has assessed the cross-sectional rate of change in maximal power in a group of trained cyclists that covers a wide range of age.

A key contributor to the age-related decline in VO_{2max} and maximal power is a reduction in maximal cardiac output resulting from a decrease in maximal heart rate (for a review see Spina, 1999). The decline in maximal heart rate with age has been extensively studied in master runners (Kasch et al., 1995; Pollock et al., 1997) and sedentary populations (Londeree & Moeschberger, 1982; Maritz, Morrison, Peter, Strydom, & Wyndham, 1961; Tzankoff & Norris, 1979). The rate of decline in heart rate with age, however, has not been investigated in competitive cyclists. Several algorithms have been calculated to predict maximal heart-rate value relative to age (Londeree & Moeschberger; Maritz et al.), but their application to a specific group of athletes has been questioned (Bird, George, Theakston, Balmer, & Davison, 2003; Bird, Theakston, Owen, & Nevill, 2003). The most suitable algorithm to predict maximal heart rate with age in competitive cyclists is unknown and requires further investigation.

Laboratory-based physiological tests are frequently used to assess the performance ability of cyclists (for a review see Paton & Hopkins, 2001), yet few studies have used these tests to assess master cyclists (Massé-Biron et al., 1992; Préfaut et al., 1994). Information concerning age-related changes in maximal values for power and heart rate would be useful when comparisons are made within and between competitors to evaluate cycling-performance ability. Data concerning maximal power relative to age would also provide useful information for the study of changes in cycling performance. The aim of this study was to investigate relationships between age and maximal values for power and heart rate in trained cyclists across a wide age range.

Methods

This study was approved by a college research-ethics committee. An information sheet was provided at each testing session, and immediately before his involvement, each participant signed a consent form.

Participants

All of the participants were endurance-trained male cyclists with extensive experience of competitive cycling. They included county, national, and international champions across the range of ages. $M \pm SD$ and ranges ($N = 114$) for the participants' age, height, and body mass were 38 ± 15 and 15–73 years, 1.78 ± 0.07 and 1.57–1.93 m, and 73.5 ± 7.2 and 55.8–90.0 kg, respectively.

Laboratory conditions were maintained throughout testing (ambient temperature 18–22 °C, relative humidity 45–55%), and before testing all participants completed a full habituation session with normal training and dietary pattern maintained and no strenuous exercise for 24 hr before the test. When a participant arrived at the laboratory, bicycle rear-tire pressure was standardized, and the participant's own racing bicycle was attached to a Kingcycle™ air-braked cycle ergometer (EDS Portaprompt Ltd., High Wycombe, UK). The rig was calibrated according to the manufacturer's recommended procedure. The calibration procedure and technical aspects of the Kingcycle system have been previously described by Palmer, Dennis, Noakes, and Hawley (1996). During all tests, power (W) was calculated continuously using Kingcycle version 5.5 computer software, and heart rate (beats/min) was recorded at 5-s intervals using a short-range telemetry system (Polar, Electro Oy, Kempele, Finland).

The Kingcycle ramped test started immediately after completion of 5 min of cycling at 50% maximal ramped minute power (RMP_{max}) calculated from the habituation test. During the ramped test, work rate was increased by 20 W/min. Starting power was calculated for participants to reach volitional exhaustion at between 8 and 12 min. During the test, gear ratios and pedal cadence (revolutions/min) were self-selected. Participants were given verbal encouragement but no feedback concerning power or heart rate. RMP_{max} was calculated as the highest average power recorded during any 60-s period of the test. Maximal heart rate (HR_{max}, beats/min) was the highest value recorded during the test.

To assess the potential confounding factor of training status on age-related changes in maximal performance, 20 younger (35 ± 6 years) and 20 veteran (57

± 6 years) cyclists from the main study group completed a training questionnaire. Frequency and intensity of training and racing were assessed during a 9-month period. This ascertained the number of races completed in one season and the type, frequency, and intensity of cycle training or racing performed during the first week of June, September, December, and March. During this period, cyclists maintained an activity diary and used a heart-rate monitor (Polar, Kempele, Finland) during training and racing. Each subject performed a Kingcycle maximal-aerobic-power test to determine RMP_{max} and HR_{max}. Intensity of training or racing was based on four levels of heart-rate response: Level 1, below 75% HR_{max}; Low Level 2, 75–80% HR_{max}; High Level 2, 80–85% HR_{max}; and Level 3, above 85% HR_{max}.

Statistical Analysis

Correlations assessed using Pearson product–moment correlation coefficients and regression analysis were completed using Microsoft® Excel (Bellevue, WA). Differences in training status were tested using a mixed-model ANOVA. Statistical significance was set at $p < .05$, and values in the text are $M \pm SD$ unless otherwise stated.

Results

Data from the training questionnaire revealed no difference ($p > .05$) between groups for the number of races completed, overall time spent cycling, and the amount of training during the first week of June, September, December, and March (Table 1). Training volume increased ($p > .05$) in the veteran group between the first week of December and March. Training intensity was similar between groups ($p > .05$).

The $M \pm SD$ for RMP_{max} was 382 ± 64 W with a range of 226–550 W. Individual RMP_{max} versus age for the entire group (N = 114) is depicted in Figure 1. Visual inspection of the plot of age against power suggested that a two-segment linear model would fit the data well (see Figure 1). To determine the best fit for this model (i.e., to determine the breakpoint), an approach similar to that of Bird

Table 1 Amount of Time (*M* ± *SD*) Veteran (*n* = 20) and Younger (*n* = 20) Cyclists Trained During First Week of June, September, December, and March

	June (h:min)	September (h:min)	December (h:min)	March (h:min)
Younger	6:56 ± 3:21	7:24 ± 2:44	7:47 ± 3:40	9:09 ± 3:19
Veterans	7:32 ± 3:57	7:23 ± 3:28	6:35 ± 3:17	9:05 ± 3:46[a]

[a]Significantly higher ($p < .05$) than 1st week of December in veteran cyclists.

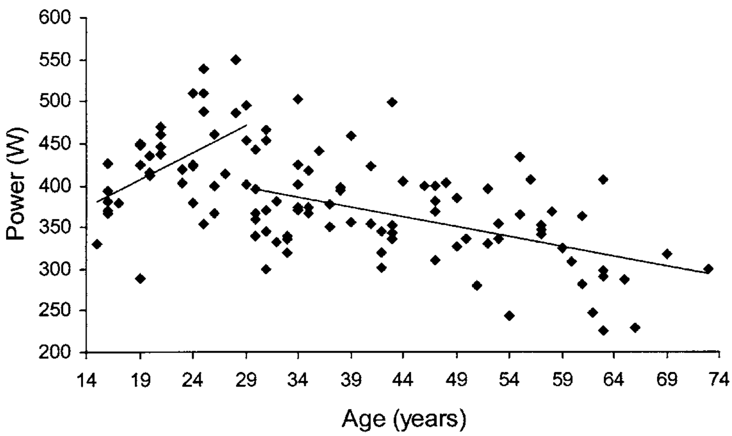

Figure 1. The regression of maximal ramped minute power (W) as a function of age (years) in 114 trained male cyclists. Data fitted with a two-segment linear model.

et al. (2001) was adopted. An iterative procedure was used that involved taking the second of the N data points in each data set as the breakpoint. Each time, the sum of squared residuals for the two-segment model was calculated. This procedure was then repeated using the third, fourth, and so on data points as breakpoints. The combination of the segments that yielded the lowest combined sum of squared residuals was retained as the best fit.

The results of the fit are shown in Figure 1. The breakpoint occurred after the age 29 years. For clarity of the description, the portion of the graphical plot before the breakpoint is referred to as Part 1 (age 15–29 years, $n = 38$), and the decline after the breakpoint is designated as Part 2 (age 30–73 years, $n = 76$).

For Part 1, a moderate correlation was found between RMP_{max} and age ($r = .53$, 95%CI = .34 to .67, $p < .001$). The absolute and percentage (relative) increases in RMP_{max} with age were 7.2 W/year and ≈1.68%/year, respectively. The regression of RMP_{max} on age for Part 1 was RMP_{max} (W) = 270 + [7.2 × age (years)], $r^2 = .28$, SE 49 W (95%CI = 4–64 W) or 12% (95%CI = 10–14%).

For Part 2, a moderate correlation was found between RMP_{max} and age ($r = -.49$, 95%CI = –0.30 to –0.65, $p < .001$). The absolute and percentage (relative) declines in RMP_{max} with age were 2.4 W/year and ≈0.70%/year, respectively. The regression of RMP_{max} on age for Part 2 was RMP_{max} (W) = 467 – [2.4 × age (years)], $r^2 = .24$, SE 49 W (95%CI = 40–64) or 15% (95%CI = 13–18%).

The $M \pm SD$ for HR_{max} was 185 ± 13 beats/min, with a range of 150–214 beats/min. Figure 2 depicts individual HR_{max} versus age for the group ($N = 114$). Visual inspection of the plot of age against power suggested that a single linear model would describe the data well (see Figure 2). A strong correlation was found between HR_{max} and age ($r = -.75$, 95%CI = –0.66 to –0.82, $p < .01$). The absolute

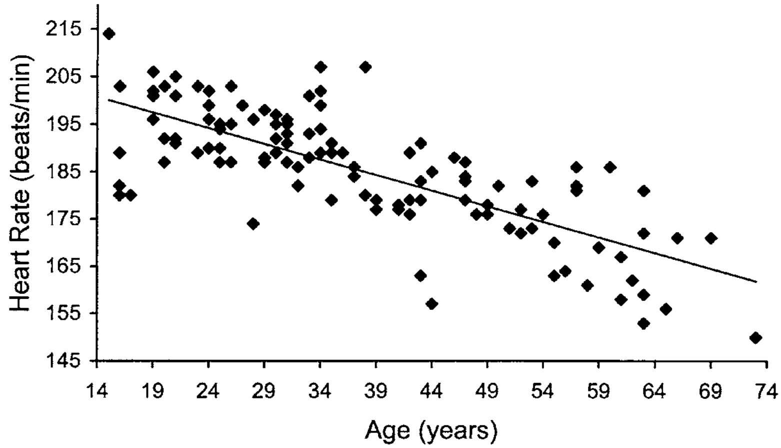

Figure 2. The regression of maximal heart rate (beats/min) on age for 114 men age 15–73 years. Data fitted with a linear model.

and percentage declines in HR_{max} with age were calculated as 0.66 beats · min^{-1} · $year^{-1}$ and ≈0.36%/year. The regression of HR_{max} on age for $N = 114$ was HR_{max} (beats/min) = 210 – [0.66 × age (years)], $r^2 = .56$, SE 9 beats/min, 95%CI = 8–10 beats/min.

No relationship was found between RMP_{max} and HR_{max} for Part 1 ($r = .09$, 95%CI = –0.24 to 0.40, $p = .61$). A weak relationship was found between RMP_{max} and HR_{max} for Part 2 ($r = .32$, 95%CI = 0.10–0.51, $p < .01$). The regression of RMP_{max} on HR_{max} for Part 2 was RMP_{max} (W) = 101 + [1.4 × HR_{max} (beats/min)], $r^2 = .10$, SE 54 W (95%CI = 47–64).

Discussion

The main finding of this cross-sectional study was that in a group of male, competitive, trained cyclists the changes in RMP_{max} with age were best described by a two-segment linear model. RMP_{max} increased from age 15 to 29 years at a rate of 7.2 W/year and declined at a rate of 2.4 W/year beyond age 30. The coefficient of determination (r^2) indicated that aging, per se, accounted for only 25% of the variance in power. Therefore, 75% of the variance might be attributed to factors such as training status (Lucia et al., 1998), biomechanical adaptations in the pedal stroke (Lucia et al.), testing protocol (Davis et al., 1982), and glycogen depletion (Heigenhauser, Sutton, & Jones, 1983). Underlying mechanisms responsible for changes in maximal power in response to training are unclear. Increases in power output have been attributed to peripheral adaptations in skeletal-muscle fiber type, power-output distribution among individual muscle fibers, muscle-capillary density, and oxidative enzyme activity, as well as central changes in maximal cardiac output and total blood volume (Coyle, 1995). It should be noted that analysis of the training questionnaires from a subset of participants in this study showed no difference in training status with age, suggesting that other factors are responsible for the relationship between RMP_{max} and age found in this study.

Hawley and Noakes (1992) found that maximal power in endurance-trained cyclists is strongly related to VO_{2max} (r = .98) and 20-km time-trial performance time (r = –.91). Similarly, Balmer et al. (2000) reported a very strong relationship between RMP_{max} and outdoor 16.1-km cycling-time-trial power (r = .99) in young and master cyclists. Notably, the mean age of the participants (N = 16) in the study by Balmer et al. was 43 years, with a range of 25–63 years. That investigation showed that maximal power could be used as a valid predictor of cycling endurance performance regardless of age.

Although several studies have reported values for maximal power in older age groups (Aminoff et al., 1996; Hagberg et al., 1998; Kavanagh & Shephard, 1990; Massé-Biron et al., 1992; Overend et al., 1992; Préfaut et al., 1994; Proctor et al., 1998), few studies have assessed the maximal power of master cyclists (Massé-Biron et al.; Préfaut et al.). Data from the present study revealed that the age-related decline in power of 2.4 W/year matched the value of 2.5 W/year of Préfaut et al. (1994) but was markedly higher than the 1.3 W/year based on the work of Massé-Biron et al. The present study assessed the rate of decline using linear-regression analysis of individual data that incorporated cyclists across a broad range of ages and not mean values of selected age groups. Notably, the rates of decline calculated by Préfaut et al. and Massé-Biron et al. are based on group mean values of physical education students (Massé-Biron et al.) and triathletes (Préfaut et al.) compared with master cyclists. Therefore, the present study provides new information concerning age-related changes in maximal power in a specific group of trained cyclists.

Figure 1 shows that maximal power peaked at about 30 years of age, a finding that concurs with studies that have assessed the cross-sectional age-related decline in endurance performance in various sports (Grogan, Wilson, & Camm, 1991; Joyner, 1993; Moore, 1975; Salthouse, 1976). Using the algorithm for power versus age of 467 – (age × 2.4) calculated in the present study, it is possible to compare mean maximal power values reported for selected age groups. For instance, mean maximal power reported by Balmer et al. (2000) for a group of cyclists with a mean age of 43 years was 390 W. The predicted maximal power relative to age 43 using the above algorithm is 364 W. Therefore, the maximal power of that group (Balmer et al.) was above average for their mean age. A similar method could also be applied to evaluate changes in maximal power during longitudinal work to account for aging.

Data from the present study revealed a cross-sectional decline in HR_{max} with age of 0.66 beats $\cdot$ min^{-1} $\cdot$ $year^{-1}$. This value is similar to the decline in HR_{max} reported by Kasch et al. (1995) and Maritz et al. (1961). The underlying mechanism(s) responsible for the structural and functional changes in the older heart is/are unclear, but the decline in HR_{max} appears to be mediated by factors that control muscle contraction, such as a down-regulation of beta-adrenergic receptors that decrease the heart's sensitivity to catecholamine stimulation (Seals, Taylor, Ng, & Esler, 1994) and changes in the volume of the sinoatrial node and the number of pacemaker cells (Shiraishi, Takamatsu, Minamikawa, Onouchi, & Fujita, 1992).

Londeree and Moeschberger (1982) estimated that age accounts for 70–75% of the interindividual variability in HR_{max}. In the present study, age accounted for about 56% of the variance in HR_{max}. Therefore, 44% of the variance can be attributed to other factors such as mode of exercise, testing protocol, and interindividual differences in motivation (Londeree & Moeschberger). In addition, HR_{max} can be subdued during periods of heavy training (Gaesser & Poole, 1986; Maassen & Busse, 1989) but return to normal levels after a period of rest (Lambert, Mbambo, & St. Clair Gibson, 1998).

The relationship between chronic exercise and HR_{max} is unclear. Using data from longitudinal studies, it is possible to calculate that the average rate of decline in HR_{max} with age in endurance athletes is about 0.73 beats · min^{-1} · $year^{-1}$ (Kasch et al., 1995; Pollock et al., 1997; Trappe, Costill, Vukovich, Jones, & Melham, 1996). Similarly, data from cross-sectional studies (Fuchi, Iwaoka, Higuchi, & Kobayashi, 1989; Proctor & Joyner, 1997) indicate a decline of 0.60–0.70 beats · min^{-1} · $year^{-1}$, regardless of activity status and previous history of training. In contrast to this, a large-scale cross-sectional assessment completed by Tzankoff and Norris (1979) reported an average rate of decline of 0.91 beats · min^{-1} · $year^{-1}$. This value is closer to the commonly used 1 beat · min^{-1} · $year^{-1}$ calculated from the general population tested by Londeree and Moeschberger (1982). A review of cross-sectional studies by Fitzgerald, Tanaka, Tran, and Seals (1997), however, revealed no difference (p >.05) in the average decline in HR_{max} in regularly exercising endurance-trained athletes when compared with sedentary participants (0.70 vs. 0.79 beats · min^{-1} · $year^{-1}$).

Estimations of the rate of decline in HR_{max} with age in longitudinal and cross-sectional work have been based on HR_{max} values achieved by endurance runners during a running test (Bird, Theakston, et al., 2003; Pollock et al., 1997; Trappe et al., 1996) and sedentary and trained individuals during a cycle-ergometer test (Babcock, Paterson, & Cunningham, 1992; Overend et al., 1992; Proctor et al., 1998). The present study provides unique data in relation to the age-related change of HR_{max} in a group of cyclists and raises issues concerning the appropriate use of nonspecific algorithms to predict heart-rate values in cyclists.

In the present study a weak but significant relationship was found between maximal power and heart rate beyond age 29 years, and heart rate accounted for 10% of the variance in maximal power. This contrasts with the studies that have shown that declines in HR_{max} with aging are highly correlated with changes in VO_{2max} across all age groups (Hagberg et al., 1985; Rivera et al., 1989). Bird, Theakston, et al. (2003), however, argued against the importance of a high maximum heart rate for attaining a high VO_{2max} in younger endurance runners, and the finding in the current study that maximal power was not related to heart rate from age 15 to 29 years agrees with this supposition. In older cyclists, however, the decline in maximal power is related to HR_{max}, and the importance of HR_{max} for attaining a high VO_{2max} and/or maximal power appears to coincide with the age-related decline of performance in the selected sport. Consequently, HR_{max} is an important predictor of endurance performance in older athletes.

In summary, this study found that maximal power increased with age from 15 to 29 years and decreased with age from 30 to 73 years, with a breakpoint at age 29. Age accounted for only a quarter of the change in maximal power, but maximal heart rate declined throughout the life span, and age accounted for over half the variance in values. Data provided a model for predicting maximal values for power and heart rate in trained cyclists across a broad span of ages.

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