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1 **6-Year Follow-Up of a World Record Breaking Master Marathon Runner**

2
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5
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27 **ABSTRACT**

28 Endurance performance declines with advancing age. Of the three main physiological
29 factors that determine endurance running performance (maximal oxygen consumption
30 [$\dot{V}O_2\text{max}$], lactate threshold, and running economy [RE]), $\dot{V}O_2\text{max}$ appears to be most
31 affected by age. While endurance performance declines with age, recently, endurance
32 performance has rapidly improved in master athletes as the number of master athletes
33 competing in endurance events has increased. Master athletes represent an intriguing
34 model to study healthy aging. In this case study, we reassessed the physiological profile
35 of a 76-year-old distance runner who broke the marathon world record for men over 70
36 years of age in 2018. This runner was tested a few months before breaking the world
37 record and retested in 2024. Between 2018 and 2024, his marathon running velocity
38 decreased significantly. Therefore, the purpose of this case study was to determine the
39 physiological changes that explain his performance decline. RE remained similar to
40 2018, and while there was not a clear breakpoint in blood lactate, he still likely runs
41 marathons at a high percentage (~90%) of his $\dot{V}O_2\text{max}$. However, $\dot{V}O_2\text{max}$ declined by
42 15.1%. HRmax declined by 3.2% and maximal O_2 pulse declined by 12.4%, suggesting
43 that maximal stroke volume and/or arteriovenous O_2 difference decreased. Altogether,
44 although this marathoner continues to compete at an elite level, his performance has
45 declined since his record-breaking marathon due to a reduction in $\dot{V}O_2\text{max}$. This is likely
46 caused by reductions in maximal stroke volume and/or arteriovenous O_2 difference. We
47 speculate that these changes reflect primarily age-related processes.

48 **NEW & NOTEWORTHY**

49 We performed six-year follow up testing on a world-record breaking master marathon
50 runner. We determined that his performance declined since his record-breaking
51 marathon in 2018 primarily due to a reduction in $\dot{V}O_2$ max. His max HR changed
52 minimally, but his peak O_2 pulse decreased, suggesting that his maximal stroke volume
53 and/or arteriovenous O_2 difference decreased. These changes likely reflect primarily
54 age-related effects in the absence of an overt pathological disease process.

55

56 **Keywords:** aging, running, master athlete, oxygen consumption, case study

57 INTRODUCTION

58 Cardiorespiratory fitness and endurance performance decline with age (1–7).
59 Specifically, peak endurance performance declines in a curvilinear pattern, decreasing
60 modestly from the age of ~35 years to 50-60 years with more notable declines after the
61 age of 60 years (6, 7). Three main physiological parameters determine endurance
62 running performance: maximal oxygen consumption ($\dot{V}O_{2\max}$), lactate threshold, and
63 efficiency (running economy, RE) (8). Of these three factors, $\dot{V}O_{2\max}$ appears to be
64 most affected by the aging process (5, 6), since $\dot{V}O_{2\max}$ decreases by ~5-10% per
65 decade of life after the age of 30 (1–5). Lactate threshold, when expressed as an
66 absolute running velocity, decreases with advancing age; however, when expressed as
67 a percentage of $\dot{V}O_{2\max}$, lactate threshold does not decline with age (6). Rather,
68 master athletes may achieve their lactate threshold at a higher percentage of their
69 $\dot{V}O_{2\max}$ (9). The effects of age on RE are mixed since some studies indicate that age
70 does not affect RE (9), while other studies suggest that RE declines with advancing age
71 (10, 11). Thus, while likely to a lesser extent, it is possible that declines in lactate
72 threshold and RE may also contribute to the age-related decline in endurance running
73 performance (5).

74

75 While endurance performance appears to inevitably decline with advancing age (6, 7),
76 recently, endurance performance of the best master athletes has improved more rapidly
77 than that of younger athletes (5). This is associated with improved training strategies
78 and the growth of the number of master athletes competing in endurance events, some
79 of whom may be lifelong endurance athletes (5, 6). Master athletes represent an

80 intriguing model of healthy aging (6), providing a population to investigate how to
81 maintain cardiorespiratory fitness into old age. Thus, several case studies have been
82 performed on elite master athletes to determine the physiological parameters that
83 enable them to continue competing at a high level (12–16).

84

85 In this case study, we reassessed the physiological profile of a 76-year-old distance
86 runner who broke the marathon world record for men over 70 years of age in the 2018
87 Jacksonville Marathon (2:54:23, 14.5 km/h). This runner was tested in our laboratory in
88 2018 a few months before breaking the world record (12). This athlete has continued
89 competing at an elite level, and he was retested in our laboratory in April 2024. Within
90 ~7 months of his testing in 2024 he ran several marathons, including the Berlin
91 Marathon (3:18:23, 12.8 km/h, 12.1% decline in running velocity from Jacksonville
92 Marathon in 2018), the Chicago Marathon (3:17:01, 12.9 km/h, 11.5% decline from
93 2018), the Kiawah Marathon (3:25:51, 12.3 km/h, 15.3% decline from 2018), and the
94 Boston Marathon (3:28:43, 12.1 km/h, 16.4% decline from 2018; ~10 days prior to
95 testing). His Boston Marathon time is about 12 minutes slower than his Boston
96 Marathon time from 2018 (3:16:20, 12.9 km/h, 5.9% decline in running velocity between
97 Boston Marathons). Thus, this athlete's marathon running velocity has significantly
98 declined since his world-record-breaking marathon in 2018. Therefore, the purpose of
99 this case study was to recharacterize the physiological profile of this world-record-
100 breaking master athlete and determine the physiological changes that account for his
101 performance decline.

102

103 **MATERIALS AND METHODS**

104 ***Human Subjects Approvals and Medical Screening***

105 The Institutional Review Board at the University of Delaware approved all experimental
106 procedures, and the testing complies with the principles defined by the Declaration of
107 Helsinki. Verbal and written consent were obtained prior to testing.

108

109 In March 2024, the participant underwent an initial medical screening. He was asked to
110 avoid caffeine, alcohol, and moderate-to-vigorous exercise for the 24-hours preceding
111 the visit and fast for at least eight hours before his arrival. During this screening, resting
112 blood pressure, height, and weight were measured. The participant also had a venous
113 blood draw (for a lipid panel, complete blood count, and comprehensive metabolic
114 panel). Body composition was assessed using dual energy x-ray absorptiometry
115 (DEXA). The participant was also asked to provide information about his training and a
116 training log, which was used to calculate average weekly training volume for the 6-
117 months and 1-year preceding his performance testing visits in 2018 and 2024. Following
118 the medical screening, the participant completed a brief treadmill familiarization session
119 in which he ran for a few minutes at several pre-selected velocities, including at 10, 11,
120 and 12 km/h (corresponding to the initial speeds used for the steady state testing during
121 the performance testing visit).

122

123 ***Performance Testing***

124 Performance testing occurred in April 2024. The participant was instructed to refrain
125 from caffeine, alcohol, and moderate-to-vigorous exercise for at least 24 hours prior to

126 the visit. He was told that he could eat a typical “pre-race” meal prior to this visit. The
127 athlete was tested in his normal training shoes (i.e., shoes without a carbon fiber plate)
128 to match his footwear in 2018.

129
130 Prior to exercise, a registered nurse placed an intravenous (IV) catheter in one of the
131 participant’s antecubital veins. The IV was used to draw blood samples immediately
132 following the $\dot{V}O_2$ max test and each steady state running stage. Blood lactate was
133 measured using a Lactate Plus Meter (Nova Biomedical; Waltham, MA). Gas exchange
134 was recorded continuously using indirect calorimetry (ParvoMedics TrueOne 2400
135 metabolic measurement system; Sandy, UT) and averaged in 15-second intervals.
136 Heart rate (HR) was measured continuously using a Polar chest heart rate monitor.
137 Prior to testing, flow and gas calibrations were performed on the gas analyzer; the
138 accuracy of the treadmill velocity was verified according to manufacturer
139 recommendations; and quality controls were run on the Lactate Plus Meter to confirm
140 accuracy.

141
142 Performance testing took place following a brief warm-up at a self-selected easy
143 intensity. We assessed $\dot{V}O_2$ max, lactate threshold, and RE, the three main predictors of
144 endurance running performance. We defined RE as the steady-state $\dot{V}O_2$ associated
145 with a given running velocity, such that a lower $\dot{V}O_2$ at a given velocity indicates better
146 efficiency (8). To assess RE and lactate threshold, the master athlete ran at 4 velocities
147 (~10, 11, 12, and 13 km/h) at 0% grade for 5 minutes each, except for the fourth velocity
148 (13 km/h), at which he was only able to complete a little over 4 minutes due to fatigue.

149 The velocities were selected based on his previous testing to provide overlap at 12 km/h
150 and 13 km/h and allow for direct comparison of his $\dot{V}O_2$ at each velocity. Each stage
151 was separated by a few minutes of slow walking followed by 5 minutes of seated rest.

152

153 After a short break, the master athlete completed the $\dot{V}O_{2\max}$ test. He started running
154 at 7.5 mph (about 12 km/h) at 0% grade, which was equivalent to a rating of perceived
155 exertion (RPE) of 14 during the steady-state testing. Velocity was held constant, and
156 grade increased by 2% every 2 minutes until volitional exhaustion. The $\dot{V}O_{2\max}$ test
157 protocol is identical to the protocol used in 2018, except for a slower starting velocity.
158 $\dot{V}O_{2\max}$ was defined as the 30-second interval (i.e., the average of two adjacent 15-
159 second intervals) with the highest $\dot{V}O_2$. This was calculated during the $\dot{V}O_{2\max}$ test and
160 the final stage of the steady-state testing (13 km/h). Additionally, maximal O_2 pulse was
161 calculated as $\dot{V}O_{2\max}$ divided by HRmax (17).

162

163 **RESULTS**

164 ***Screening Results***

165 The marathoner's body composition and metabolic health remained similar between
166 2018 and 2024 (**Table 1**). However, he has been diagnosed with hypertension and
167 essential thrombocythemia takes amlodipine and hydroxyurea for these conditions.

168

169 The athlete self-reported that his training volume has been "about the same" since 2018
170 (12). However, he races more frequently now, meaning he has more racing miles and
171 fewer training miles currently compared to in 2018. His self-reported training volume

172 was verified using his training log. His average weekly training volume was similar for
173 the 6 months preceding his testing in 2018 and 2024 (2018: 70 km/week vs 2024: 68
174 km/week). However, his average weekly training volume over the year prior to testing
175 was slightly lower in 2024 (64 km/week) compared to 2018 (79 km/week).

176

177 ***Performance Testing Results***

178 Steady-state $\dot{V}O_2$ at several velocities from 2018 and 2024 is presented in **Figure 1B**.

179 Notably, $\dot{V}O_2$ was similar at the overlapping velocities (12 and 13 km/h), indicating that
180 the athlete's RE is similar between 2018 and 2024.

181

182 There was not a clear breakpoint in blood lactate in 2024 as blood lactate increased
183 incrementally following each stage (**Fig 1C**). However, at 12 km/h (close to his average
184 2024 Boston marathon running velocity of 12.1 km/h), he achieved ~90% of his
185 $\dot{V}O_{2max}$, suggesting that his marathon running velocity may be ~90% of his $\dot{V}O_{2max}$.

186

187 The athlete also completed a $\dot{V}O_{2max}$ test. The highest $\dot{V}O_2$ recorded during this
188 graded exercise test was 38.4 ml/kg/min (**Fig 1A**). This corresponded to a max HR of
189 153 bpm, a peak RPE of 19-20, and a peak respiratory exchange ratio of 1.03 during
190 the $\dot{V}O_{2max}$ test. However, the highest 30-second-average $\dot{V}O_2$ recorded during this
191 test was slightly lower than the highest 30-second-average $\dot{V}O_2$ recorded at 13 km/h
192 during the steady-state testing (39.8 ml/kg/min). Using the highest $\dot{V}O_2$ during the
193 steady-state testing, the athlete's $\dot{V}O_{2max}$ declined by 15.1% since 2018 (~2.5% per
194 year; 46.9 ml/kg/min vs 39.8 ml/kg/min). This corresponds to a 3.2% decline in the

195 athlete's HRmax (158 bpm vs 153 bpm) and a 12.4% decline in the athlete's maximal
196 O₂ pulse (0.30 ml/kg/beat vs 0.26 ml/kg/beat).

197

198 **DISCUSSION**

199 In this case study, we reassessed the physiological profile of a 76-year-old elite master
200 distance runner who broke the marathon world record for men over 70 years of age in
201 2018. We sought to determine the physiological factors that account for his performance
202 decline from 2018 to 2024. We demonstrate that the athlete's RE is similar between
203 2018 and 2024, and he still races marathons at a high percentage (~90%) of his
204 $\dot{V}O_2$ max. However, his $\dot{V}O_2$ max declined by 15.1% since 2018, indicating that the
205 athlete's performance decline is primarily due to a reduction in $\dot{V}O_2$ max. His HRmax
206 declined by only 3.2%; however, maximal O₂ pulse declined by 12.4%, suggesting that
207 his decline in $\dot{V}O_2$ max can be explained by reductions in maximal stroke volume and/or
208 arteriovenous O₂ difference.

209

210 We demonstrate that the athlete's $\dot{V}O_2$ max declined by 15.1% since 2018 (46.9
211 ml/kg/min vs 39.8 ml/kg/min). This corresponds to a reduction of ~2.5% per year, which
212 is much larger than the expected ~5-10% reduction in $\dot{V}O_2$ max per decade (~0.5-1%
213 per year) (1–4). Despite this large change, his $\dot{V}O_2$ max remains well above average for
214 males of his age (3). While age-associated reductions in $\dot{V}O_2$ max have been associated
215 with a lower HRmax (1, 2), this athlete's HRmax declined by only 3.2% (158 bpm vs 153
216 bpm), suggesting that changes in the other components of $\dot{V}O_2$ max, maximal stroke

217 volume and/or arteriovenous O₂ difference, may explain his decline in $\dot{V}O_{2\max}$. Indeed,
218 maximal O₂ pulse declined by 12.4%.

219

220 There was not a clear breakpoint in blood lactate during the steady-state testing upon
221 reassessment in 2024, so we were not able to determine lactate threshold. However, we
222 suggest that this athlete maintained his ability to sustain a high percentage of his
223 $\dot{V}O_{2\max}$ during competition. At 12 km/h, he achieved ~90% of his $\dot{V}O_{2\max}$. Since he
224 averaged 12.1 km/h for the 2024 Boston marathon, and he ran at least three other
225 marathons with an average velocity faster than 12 km/h within the past ~7 months
226 (Berlin Marathon: 12.8 km/h, Chicago Marathon: 12.9 km/h, and Kiawah Marathon: 12.3
227 km/h), he likely still races marathons at a high percentage (~90% or greater) of his
228 $\dot{V}O_{2\max}$ (12). This also suggests that changes in lactate threshold are unlikely to
229 explain this athlete's performance decline. Interestingly, other master athletes (59-71
230 years) also run marathons at a high percentage of their $\dot{V}O_{2\max}$ (15, 16, 18),
231 suggesting that this may be a universal phenomenon which enables master athletes to
232 compete at an elite level.

233

234 The master athlete's RE also appears to be similar between 2018 and 2024. RE data
235 was compared to reference values published by Barnes and Kilding (19) and regression
236 equations relating running velocity and $\dot{V}O_2$ produced by Joyner (20). This athlete's $\dot{V}O_2$
237 at 12 km/h (which is close to his 2024 Boston Marathon running velocity) was lower
238 (i.e., better) than average for recreational and moderately trained runners as
239 summarized by Barnes and Kilding (19), suggesting that he is more economical than

240 these runners. Comparing his RE results to the regression equations from Joyner (20)
241 based on data from highly trained distance runners (21), in 2024, the athlete's RE was
242 close to average at 12 km/h. In 2018, the athlete's RE was between low and average at
243 12 km/h, close to average at 14 km/h, and between high and average at 15 km/h,
244 suggesting that his RE may have also been about average at his world record breaking
245 marathon running velocity in 2018 (14.5 km/h). Collectively, these results are consistent
246 with the understanding that a reduction in $\dot{V}O_2\text{max}$ is the primary factor that limits
247 endurance running performance with advancing age as lactate threshold and RE
248 appear to be similar between 2018 and 2024 (5, 6).

249

250 While the athlete's training volume declined modestly since 2018, we speculate that the
251 changes reported in this athlete reflect primarily age-related processes. Interestingly,
252 findings from other studies suggest that endurance performance begins to decline more
253 rapidly starting between the ages of 70 and 80 years (22–24), consistent with the
254 findings in this master athlete, suggesting that part of this athlete's decline may be
255 associated with the normal aging process. However, this athlete has been diagnosed
256 with hypertension and essential thrombocythemia and takes amlodipine and
257 hydroxyurea for these conditions. Thus, it is possible that disease processes may have
258 also contributed to his more rapid decline in $\dot{V}O_2\text{max}$ and performance.

259

260 While we believe this unique case study advances our understanding of endurance
261 performance and aging, we recognize a few limitations. First, we were unable to directly
262 identify the athlete's lactate threshold since there was not a clear breakpoint in blood

263 lactate with increasing velocity. However, his marathon running velocity is at a high
264 percentage (~90%) of his $\dot{V}O_2\text{max}$ in both 2018 and 2024. Second, the results of this
265 study could be impacted by the athlete competing in the Boston Marathon ~10 days
266 prior to testing and a potential detraining effect while he recovered. However, the athlete
267 resumed training after only a few days off running. His training between the Boston
268 Marathon and the testing in our laboratory included a 4.4 km run, an 8.1 km race with a
269 4.1 km warm-up, a 7.5 km run, and a 5 km run. This athlete also competes in races
270 frequently, so the timing of this testing mimics the short recovery time with which the
271 athlete is used to competing. Third, while we think matching the athlete's footwear (i.e.,
272 non-carbon fiber plated shoes) for his performance testing in 2018 and 2024 is a
273 strength of this case study, we recognize that this may limit comparability to some of his
274 marathon races, in which he wore carbon plates shoes. Since these advanced running
275 shoes improve running economy and performance (25, 26), the athlete's running
276 economy is likely even better during competition.

277

278 In conclusion, although this master athlete continues to compete at an elite level, his
279 performance has declined since his world record-breaking marathon in 2018 due to a
280 reduction in $\dot{V}O_2\text{max}$. RE is similar and he still competes at a high percentage of his
281 $\dot{V}O_2\text{max}$, suggesting that RE and lactate threshold can be mostly maintained into older
282 age with continued training. HRmax changed minimally but peak O_2 pulse declined,
283 suggesting that maximal stroke volume and/or arteriovenous O_2 difference decreased.
284 We propose that these changes are largely age-related in the absence of an overt

285 pathological disease process. We encourage additional longitudinal studies to confirm
286 these findings in other elite master athletes.

287

288 **DATA AVAILABILITY**

289 Data will be made available upon reasonable request.

290

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293

294 **GRANTS**

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297

298 **DISCLOSURES**

299 No conflicts of interest, financial or otherwise, are declared by the authors.

300

301 **AUTHOR CONTRIBUTIONS**

302 All authors conceived and designed research; N.T.R., J.M.S., R.K.M., M.L.O., and
303 W.B.F. performed experiments; N.T.R., J.M.S., and M.L.O. analyzed data; all authors
304 interpreted results of experiments; N.T.R. prepared figures; N.T.R. drafted manuscript;
305 all authors edited and revised manuscript; and all authors approved final version of
306 manuscript.

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418 **FIGURE LEGEND**

419 Figure 1. Performance testing results as a 70-year-old (2018) and 76-year-old (2024).
420 $\dot{V}O_2$ was continuously recorded during $\dot{V}O_{2\max}$ testing (A). Steady-state $\dot{V}O_2$ was
421 determined while the athlete ran at constant velocities (B) and blood lactate was
422 measured immediately following each steady-state stage (C). The vertical lines in
423 panels B and C reflect the running velocity associated with his world record time of
424 2:54:23 (~6:39 min/mi or ~14.5 km/h) and his 2024 Boston marathon time of 3:28:43
425 (~7:58 min/mi or ~12.1 km/h). Triangles and dashed lines represent results as a 76-
426 year-old. Squares and solid lines represent results as a 70-year-old. $\dot{V}O_2$: oxygen
427 consumption.

428 **TABLE**

429

430 **Table 1. Body Composition and Cardiometabolic Health**

	2018	2024
Body Mass (kg)	64.2	64.9
Body Fat (%)	19.1	20.6
SBP (mmHg)	122	121
DBP (mmHg)	75	71
Hematocrit (%)	44.9	43.5
Hemoglobin (g/dL)	15.0	15.1
Total Cholesterol (mg/dL)	173	176
LDL Cholesterol (mg/dL)	84	102
HDL Cholesterol (mg/dL)	66	58
Triglycerides (mg/dL)	135	74
Blood Glucose (mg/dL)	86	90

431 DBP = diastolic blood pressure; HDL = high-density lipoprotein; LDL = low-density

432 lipoprotein; SBP = systolic blood pressure

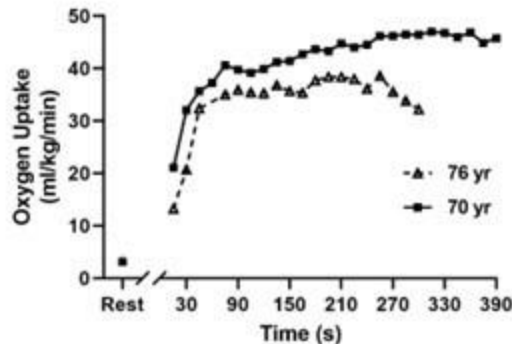
World record breaking master marathon runner: 6-year follow-up

METHODS

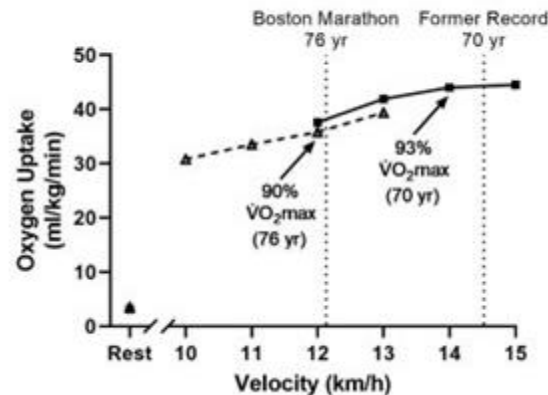
- We reassessed the physiological profile of a 76-year-old distance runner who broke the marathon world record for men over 70 years of age in 2018.
- This runner was tested a few months before breaking the world record and retested in 2024.

OUTCOME

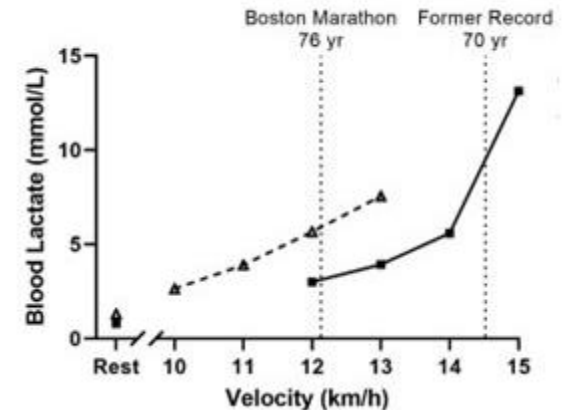
A. Maximum Oxygen Uptake



B. Running Economy

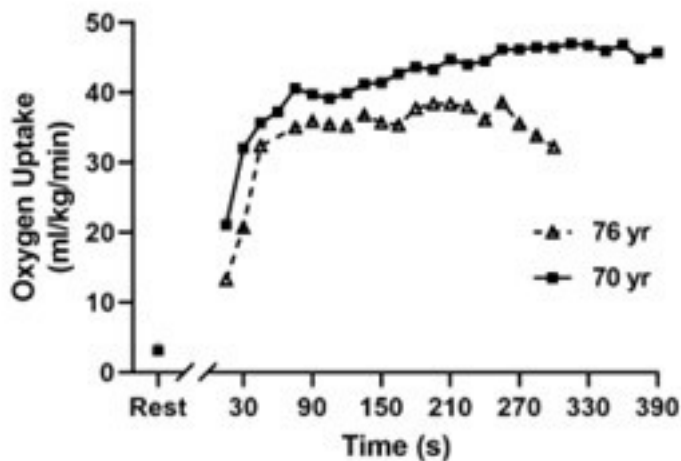


C. Blood Lactate Concentrations

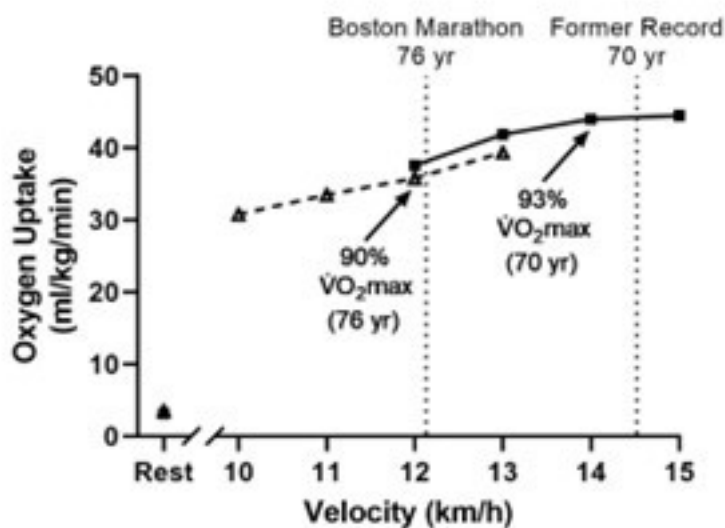


CONCLUSION This marathoner's performance has declined since his record-breaking marathon in 2018 primarily due to a reduction in $\dot{V}O_2$ max. His max HR changed minimally, but his peak O_2 pulse decreased, suggesting that his maximal stroke volume and/or arteriovenous O_2 difference decreased. These changes likely reflect primarily age-related effects.

A. Maximum Oxygen Uptake



B. Running Economy



C. Blood Lactate Concentrations

