

Average stride length and stride rate of Thoroughbreds and Quarter Horses during ‘Sprint’ and ‘Classic’ races

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8 **Abstract**

9 The main factors influencing speed in athletes are stride length (SL) and stride rate (SR).
10 However, conflict remains whether SL or SR is the key determinant of higher speeds. Quarter Horses
11 (QH) generally reach higher speeds in their races than do Thoroughbreds (TB). However, the influence
12 of SL and SR on this greater speed is unclear. Therefore, the main objective of this study was to
13 compare SL and SR in QH and TB raced in short (sprint) and long (classic) distances. We hypothesized
14 that QH have a higher SR in comparison to TB, and SR decreases as distance increases. Two race
15 distances were analyzed for each breed: QH races of 100.6 and 402.3 m, and TB races of 1,207.0 m
16 and 2,011.7 m. Data from twenty horses were obtained, consisting of five horses from each race
17 distance (10 QH and 10 TB). Five individuals watched recordings of each race three times counting
18 the number of strides taken by each winning horse. The SR was calculated using the average number
19 of strides over a given race duration, and SL was determined by calculating the total number of strides

20 over the distance covered. Speed was calculated dividing the distance by the time of the winning horse.
21 The PROC Mixed Procedure was used to identify statistical differences between breeds, and between
22 distances within the same breed. Results showed that although the SL of the TB was longer in
23 comparison with the QH ($P < 0.001$), the average SR in QH was higher than in TB (2.88 vs 2.34 ± 0.03
24 strides/s; $P < 0.001$). Further, QH classic distance demonstrated a faster speed than TB at either distance
25 ($P < 0.001$). In conclusion, QH achieve a higher SR in comparison to TB (between 14-20% more than
26 TB), confirming the importance of SR in achieving high racing speeds.

27 **Introduction**

28 Whether it is a human sprinter, a marathoner, or a racehorse, speed is critical to performance. It
29 is a common belief among sports enthusiasts that a greater stride length (SL) will result in a faster
30 individual. While many have been focusing only on SL, velocity is dictated by SL and SR [1]. Daniels
31 [2] identified that elite human athletes maximize their performance by reaching an average step rate of
32 180 steps/min (90 strides/min) or more in racing distances of 800 m or more. Some believe that SL and
33 SR may have an inverse relationship [3]. In horses, it is currently unknown whether SL or SR is most
34 influential in racing speed. Determining the importance of SL or SR on racing speed could have far
35 reaching implications on horse selection.

36 Similarly, horse enthusiasts often believe that SL is the most important factor influencing speed.
37 For instance, the outstanding racehorses Man O' War, Secretariat, and Justify have SL reported to be
38 8.5, 7.6, and 7.5 m respectively [4]. These stride lengths are often quoted, leading to the potential
39 misconception that speed in horses is most strongly influenced by SL. Thoroughbreds (TB) are the
40 world's most widely distributed racehorse and are well-known for their speed [5]. Triple crown winners
41 have achieved peak speeds of 61.2 km/h [6]. However, this is not the fastest horse breed. Quarter
42 Horses (QH), developed in the United States, are the fastest horse to run a quarter of a mile (403.3 m)

43 [7], reaching top speeds of 87.5 to 92.6 km/h [7, 8]. QH and TB typically race different distances. For
44 instance, QH most often run distances between 91-796 m, and TB usually run between 1,006-3,219 m
45 (5-16 furlongs) [9].

46 Previous studies investigating the effect of SL and SR on racing speed have conflicting results.
47 An early study showed that SL was responsible for the increase in speed, up to 8.3 m/s [10]. However,
48 at higher speeds (11.7 m/s), increasing SR resulted in faster speeds [10]. Another study using three TB
49 at six different speeds reported that, as the speed increases, both SL and SR increased nearly linearly.
50 Yet, the fastest TB from the study had the shortest SL and highest SR at maximum speed indicating
51 that, at higher speeds, SL may decrease as SR increases [11]. In another study using nine TB, it was
52 observed that the SR increased linearly without signs of a plateau [12].

53 The objective of the current study was two-fold. The first objective was to evaluate the average
54 SL and SR in both QH and TB breeds within their breed-specific races. The second objective was to
55 determine if SL and SR are influenced by the distance raced. Therefore, it was hypothesized that QH
56 have a greater average SR than TB, and that SR will decrease as running distance increases. Finally, it
57 was hypothesized that SL would decrease as the SR increases.

58 **Material and Methods**

59 To examine differences between breeds and between short and long race distances, “sprint” races
60 and “classic” races were analyzed for both QH and TB from 2008 through 2012. The QH sprint race
61 analyzed was the Texas Twister Stakes, 100.6 m (110 yards), held at Sam Houston Race Park
62 (www.shrp.com), and the QH classic race was the Champion of Champions, 402.3 m (440 yards), held
63 at Los Alamitos Race Course (www.losalamitos.com). For the TB races, the Breeders’ Cup Sprint,
64 1,207.0 m (6 furlongs), and Breeders’ Cup Classic, 2,011.7 m (10 furlongs), were analyzed. The

65 Breeders' Cup races were held at Santa Anita Park (www.santaanita.com) in 2008, 2009, and 2012,
66 and at Churchill Downs (www.churchilldowns.com) in 2010 and 2011 [13]. This resulted in a total of
67 20 horses being analyzed (5 QH sprint, 5 QH classic, 5 TB sprint, 5 TB classic). Five individuals
68 watched recordings of each race three times (in slow motion when necessary) and counted the strides
69 of the winning horse. If, during periods of a race, the winning horse was not in camera view, the horse
70 in the lead was chosen as a surrogate horse for which to count strides until the winning horse was back
71 in the camera view. From the 15 viewings of each race (five individuals viewed each race three times),
72 the average number of strides for the winning horse was calculated.

73 For the QH races, the stride count began when the starting gates opened, signifying the official
74 start to the race. For TB races, the stride count began after the horses left the starting gates, had
75 completed the "run-up" (passed the 'flagman' or 'tripped the beam'), and the race officially started.
76 The average SL was determined by dividing the length of the race by the average number of strides
77 taken during the race. The SR was computed by dividing the number of strides by the race time in
78 seconds. Further, the average speed and standard error of each type of race was calculated using the
79 distance of each race and then divided by time for each winning horse.

80 Data were analyzed with SAS (version 9.4, Cary, NC, USA). Using the average number of strides
81 of each winning horse, the PROC Mixed Procedure was used to evaluate differences in SR and SL
82 between QH and TB, along with differences between distances within each breed. Differences were
83 considered significant at $P \leq 0.05$.

84 **Results**

85 Overall, QH averaged a half of stride more per second than did TB (2.88 vs 2.34 ± 0.03
86 strides/sec; $P < 0.001$). Furthermore, SR decreased ($P < 0.001$) as race distance increased, regardless of

87 the breed, with the highest SR being 2.96 ± 0.04 strides/s during the 101-m QH race and the lowest SR
 88 (2.23 ± 0.04 strides/sec) in the 2,011.7-m Breeders' Cup Classic (Table 1).

TABLE 1. Average stride rate (strides/sec) for Quarter Horses and Thoroughbreds.

	Breed				SEM
	Quarter Horse (n = 10)		Thoroughbred (n = 10)		
Stride rate	2.88 ^a		2.34 ^b		0.03
	Race length (meters)				SEM
	100.6 (n = 5)	402.3 (n = 5)	1,207.0 (n = 5)	2,011.7 (n = 5)	
Stride rate	2.96 ^a	2.81 ^b	2.45 ^c	2.23 ^d	0.04

^{abcd}Values within a row not sharing the same superscript differ ($P < 0.001$). SEM corresponds to the standard error of the mean.

89 Average values for SL are presented in Table 2. A greater SL was observed in TB compared to
 90 QH at all distances ($P < 0.001$). Further, QH had the shortest SL in the 100.6-m race, with it increasing
 91 in the 402.3-m race. TB stride length did not differ significantly between distances.

TABLE 2. Average stride length (meters) for Quarter Horses and Thoroughbreds.

	Breed				SEM
	Quarter Horse (n = 10)		Thoroughbred (n = 10)		
Stride length	5.9 ^a		7.4 ^b		0.11
	Race length (meters)				SEM
	100.6 (n = 5)	402.3 (n = 5)	1,207.0 (n = 5)	2,011.7 (n = 5)	
Stride length	5.0 ^a	6.8 ^b	7.3 ^c	7.5 ^c	0.04

^{abc}Values within a row not sharing the same superscript statistically differ ($P < 0.001$). SEM corresponds to the standard error of the mean.

92 The average speeds for each breed and each race are presented in Table 3. The average speed for
 93 QH and TB did not differ when calculating the speed during the official races (which involves a
 94 standing start for QH and a running start with TB), although the average speed for each distance varied

95 with QH racing the classic distance having the fastest average speed ($P < 0.001$). On the other hand, TB
 96 showed a significantly faster speed in sprint versus classic distances ($P < 0.001$).

TABLE 3. Average speed (m/s), time and SEM for Quarter Horses (QH) and Thoroughbreds (TB) calculated from when the race officially started for each breed; from a standing start when the starting gates open for QH and from a running start when TB completed the “run-up”.

	Breed				SEM
	Quarter Horse (n = 10)		Thoroughbred (n = 10)		
Speed	16.87		17.11		0.03
	Race length (meters)				
	100.6 (n = 5)	402.3 (n = 5)	1,207.0 (n = 5)	2,011.7 (n = 5)	
Speed	14.76 ^a	18.99 ^b	17.68 ^c	16.54 ^d	0.04
Time	6.82 ^a	21.19 ^b	68.28 ^c	121.66 ^d	0.20

^{abcd}Values within a row not sharing the same superscript statistically differ ($P < 0.001$). SEM corresponds to the standard error of the mean.

97 Discussion

98 Results from the study support the hypothesis that the average SR was greatest in the racing QH
 99 and SR decreases as race distance increases (Table 1). In terms of SL, the study data suggest QH have
 100 a shorter SL than TB. In addition, as hypothesized, the shortest races with the highest SR have the
 101 shortest average SL. Similarly, as also hypothesized, as the distance of the race increased, the SL also
 102 increased, but only up to the point at which the TB race distances were reached as no differences were
 103 seen between TB racing at the sprint or classic distances (Table 2).

104 Though it is recognized that QH are faster than TB [8, 14], the results obtained from the
 105 calculations used in this study to determine average speed (distance divided by time) would appear to
 106 lack support for this. Despite differences in speed at every race distance, the overall average speed by
 107 both breeds were not different – thereby providing temptation to conclude that QH and TB race at

108 similar speeds. Likewise, if one compares the world speed records at the same distance (402 m), they
109 appear somewhat similar. Currently, the QH record is held by 'First Moonflash', with 20.27 seconds
110 [15], and the TB record is held by 'Winning Brew', with 20.57 seconds [16]. In reality, while accurate,
111 calculating the speed using the time of the race and distance fails to take into consideration that QH
112 races are timed from when the starting gates begin to open and the horse is standing still while TB
113 races are timed after horses have already started running [7] and have traversed the “run-up” which is
114 highly variable [17]. While TB tend to be relatively constant in their speed throughout a race and the
115 peak speed reached often is somewhat similar to their average speed, this is not true for QH. The
116 average speed for a QH takes into account the period in which they are standing still and have not yet
117 begun running. Pratt [8] has estimated it can be 0.6 sec before a QH has taken a step away from the
118 starting gates. Using that estimate, roughly 9% of the race time for the QH sprint races is spent on the
119 very first step away from the starting gate. While constituting only 3% of the race time for the QH
120 classic races, it still represents a period during the race when the speed of the horse is at or near 0 m/s.
121 Even after that, QH are accelerating during the initial portion of the race whereas TB had that period
122 of acceleration during the “run-up” before the official timing of the race began. Although QH racing
123 at the classic distance demonstrated the fastest speed, higher peak speeds could have been achieved
124 during the sprint races. However, peak speed measurements were not within the scope of this study.

125 While the general public tends to believe that a long stride is correlated strongly with greater
126 speed, this study indicates that performance is dependent on both SL and SR. That stated, a difference
127 in stride rate within breeds at different distances is noteworthy. At the classic distances for each breed,
128 the average QH speed over the entire race was 2.5 m/s faster than the TB speed (even with the QH
129 timed from a standing start). With QH racing at higher speeds than TB, it is clear that the SR plays a
130 greater role in reaching peak speeds in short distances. This findings go in agreement with the study
131 by Hay [18] that stated, at maximum speeds, the SL remained constant or decreased slightly, contrary

132 to the SR that was increased with the increase in speed. In fact, the fastest horse analyzed showed the
133 highest SR but the lowest SL, showing the important role of both factors and not only SL. Moreover,
134 the findings of another study, showed that both variables (SR and SL) increased linearly, although SL
135 showed a tendency to decrease [11]. Of note, with the average SR being 2.96 ± 0.04 strides/s during
136 the sprint QH races, some of the horses had over 3 strides per second – a truly amazing physical feat.

137 In the case of human athletes, they reach maximum speeds and performance using different
138 strategies, Elite human sprinters have been shown to possess individual preference, whether it is a
139 higher SR or SL [3]. Yet, Hunter *et al.* [19] concluded that SR may be the most significant factor
140 influencing speed in short distances. They examined 28 human athletes performing repeated sprint
141 trials. Results indicate the best individual results were obtained when they had a higher SR. In fact, a
142 negative correlation was found between SR and SL ($r = -0.70$). Acknowledging that there are distance
143 differences between and within the breeds, the differences in SR and SL average between breeds can
144 be an adjustment in racing strategy according to race distance. In other words, if trained and raced like
145 a QH, a TB running for distances of 402 m or less may have a similar recorded time as a QH racing
146 the same distance. For example, QH are often not ridden every day, usually being galloped only a few
147 days per week at most [7]. This is in contrast with the TB training in which it is common practice to
148 gallop the horses on most days and for longer distances during each ride, developing more endurance
149 ability required for longer races in comparison with the typical distances in QH [9]. Interestingly, in
150 the study of Ferrari *et al.* [20], the SR was increased after six months of training mature TB.

151 The difference in muscle mass between QH and TB is also a likely factor in the speed difference.
152 It is reported that more than 75% of fiber muscles are Type-II in TB [21]. However, QH have a greater
153 proportion of muscle fibers II-X when compared to TB which, in combination with their increased
154 muscle mass compared to TB, may explain their increased speed [7, 22, 23]. Moreover, having this
155 larger II-X fiber proportion in QH could provide a higher muscle glycolytic power and a higher

156 maximum speed when raced short distances. While differences in muscle fiber composition are likely
157 to be heavily influenced by genetics, differences in training techniques may also have an influence.

158 The current study had some limitations. In the QH races, the distance horses ran was likely very
159 similar to the official distance of the race as QH typically run in a straight line. In contrast, the TB
160 races were run on an oval. Often winning horses traveled greater distances than the official race
161 distance unless they happened to be on the rail for the entire race, thus decreasing the precision in the
162 calculation of the average SL. In truth, the average TB SL is likely slightly greater than what is reported
163 in this study due to that variation. This does not negate the breed differences in SL, but it is
164 acknowledged that the difference between breeds could be even greater.

165 Another limitation was the difficulty of counting the short steps of QH at the beginning of the
166 races. As mentioned previously, QH races begin as the starting gates open [14] and acceleration is
167 dramatic. There is a short period in a QH race when the horse is standing still and has not left the gate.
168 During that rapid acceleration, QH take several short strides [8]. However, by having 15 views of each
169 race, the challenge associated with counting those first few strides should have been ameliorated. By
170 contrast, TB races begin when the first horse crosses in front of the flagman or electronic beam – a
171 short distance in front of the starting gates [7]. While the TB races officially start while the horses are
172 already running and, hence, are taking full strides (an advantage to being able to count strides), there
173 is some degree of uncertainty in terms of being to determine exactly when the horse crossed that line.
174 With repeated viewing of each race by five individuals, this uncertainty was likely minimized and a
175 meter or so difference in starting point would have only a minor impact on the number of strides taken
176 over the longer distance of the TB races. This difference in the start and how it is timed (running versus
177 standing start) makes comparing SR and SL during different segments of the race challenging,
178 especially at the start of the race. It was determined that only average differences in SR and SL over
179 the entire race could be performed accurately, as opposed to, for instance, comparing SR and SL in the

180 last 100 m of the race (which would represent the entire race for the QH sprint races). As a result of
181 these differences in the type of racing, comparing TB and QH over the same distance could lead to
182 inaccurate conclusions. Therefore, it is also acknowledged that differences between breeds are
183 confounded with distance.

184 Besides the novelty of reporting the amazingly high SR seen in racing QH (especially at the
185 shorter distance), this study illustrates other considerations as it relates to other physiological systems
186 within the racing QH. First, the study raises some potential questions regarding how an increasing SR
187 may affect the respiratory system. A locomotor-respiratory coupling system has been described in
188 horses cantering and galloping [24, 25]. If this coupling system remains true at high speeds, the average
189 respiratory rate may reach 134 to 147 breaths/min in the TB and 169 to 178 breaths/min in the QH with
190 some QH individuals in the sprint races likely taking over 3 breaths/s. This respiratory rate is between
191 14-20% higher in the QH than the 148 breaths/min previously reported for TB racehorses [25, 26].
192 Although clarifying the deeper mechanisms and effects on respiratory system are beyond the scope of
193 this study, further studies are needed to determine the potential impact on this system due to the high
194 SR, especially for QH.

195 Beyond the respiratory system, the average SR findings also have possible implications for the
196 dynamics of the equine lower limb and hoof. During each stride, the hoof momentarily comes to a halt
197 during the stance phase of the stride (other than minor rotations or sliding of the hoof on the ground).
198 For racing QH taking three strides per second, this suggests that three times during each second the
199 hoof experiences rapid deceleration as the hoof comes to a stop and then experiences rapid acceleration
200 as the hoof leaves the ground during the swing phase. For horses previously reported to reach speeds
201 of around 89 km/h [8, 14], it suggests that the hoof on these QH may have to reach double that speed
202 or greater (nearly 180 km/h) at some point in the swing phase. While not the point of this project, with

203 enhanced technology being developed, it would be interesting to determine peak speeds the hooves of
204 racing QH achieve and determine the forces associated with such rapid acceleration and deceleration.

205 In conclusion, despite some limitations in methodology, differences between breeds and within
206 breeds support that a higher average SR contributes to the higher speeds previously reported for QH.
207 Therefore, the analysis of an equine athlete must consider both SR and SL as determinants of potential
208 performance in speed competitions. Future work could explore how the increased respiration rates
209 affect the integrity of the respiratory system in animals with high SR, especially in the short QH races.

210 **Author Contributions**

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227 **References**

228 1. Clayton HM. Horse species symposium: Biomechanics of the exercising horse. *Journal of animal*
229 *science*. 2016;94(10):4076-86. doi:10.2527/jas2015-9990

230 2. Daniels J. *Daniels' Running Formula*. Champaign, IL: Human Kinetics.

231 3. Salo AI, Bezodis IN, Batterham AM, Kerwin DG. Elite sprinting: are athletes individually step-
232 frequency or step-length reliant. *Med Sci Sports Exerc*. 2011;43(6):1055-62.

233 doi:10.1249/MSS.0b013e318201f6f8

234 4. von Hippel P. Why the one horse who ran faster than Justify in the Preakness was only third.

235 *Thoroughbred racing commentary*. 2019 May 17 [Cited 2021 March 16]. Available from:

236 [https://www.thoroughbredracing.com/articles/why-one-horse-who-ran-faster-justify-preakness-only-](https://www.thoroughbredracing.com/articles/why-one-horse-who-ran-faster-justify-preakness-only-came-third/)
237 [came-third/](https://www.thoroughbredracing.com/articles/why-one-horse-who-ran-faster-justify-preakness-only-came-third/)

238 5. Bower MA, McGivney BA, Campana MG, Gu J, Andersson LS, Barrett E, et al. The genetic

239 origin and history of speed in the Thoroughbred racehorse. *Nature communications*. 2012;3(1):1-8.

240 doi:10.1038/ncomms1644

241 6. Denny MW. Limits to running speed in dogs, horses and humans. *Journal of Experimental*

242 *Biology*. 2008;211(24):3836-49. doi:10.1242/jeb.052886

243 7. Nielsen BD. Training the racing Quarterhorse. In: Hodgson DR, McKeever KH, McGowan CM,

244 editors. *The athletic horse: principles and practice of equine sport medicine*. 2nd ed. St. Louis:

245 Elsevier; 2014. pp. 354-360.

- 246 8. Pratt GW. Clocking the fastest horses on earth. *The Quarter Racing Journal*. 1991;4:36-40.
- 247 9. Hodgson DR. Training the Thoroughbred Racehorse. In: Hodgson DR, McKeever KH, McGowan
248 CM, editors. *The athletic horse: principles and practice of equine sport medicine*. 2nd ed. St. Louis:
249 Elsevier; 2014. pp. 302-304.
- 250 10. Dušek J, Ehrlein HJ, Engelhardt WV, Hörnicke H. Beziehungen zwischen Trittlänge,
251 Trittfrequenz und Geschwindigkeit bei Pferden 1. *Zeitschrift für Tierzüchtung und*
252 *Züchtungsbiologie*. 1970;87(1-4):177-88. doi:10.1111/j.1439-0388.1970.tb01333.x
- 253 11. Yamanobe A, Hiraga A, Kubo K. Relationships between stride frequency, stride length, step
254 length and velocity with asymmetric gaits in the Thoroughbred horse. *Japanese Journal of Equine*
255 *Science*. 1993;3(2):143-8. doi:10.1294/jes1990.3.143
- 256 12. Witte TH, Hirst CV, Wilson AM. Effect of speed on stride parameters in racehorses at gallop in
257 field conditions. *Journal of Experimental Biology*. 2006;209(21):4389-97. doi:10.1242/jeb.02518
- 258 13. Breeders' Cup. Races. 2020 [Cited 2021 March 16] available from:
259 <https://www.breederscup.com/races>
- 260 14. Nielsen BD, Turner KK, Ventura BA, Woodward AD, O'Connor CI. Racing speeds of quarter
261 horses, thoroughbreds and Arabians. *Equine Veterinary Journal*. 2006;38(S36):128-32.
262 doi:10.1111/j.2042-3306.2006.tb05528.x
- 263 15. Equibase. 2020a. Sunland Park Track Records. [Cited 2021 March 17] available from:
264 <https://www.equibase.com/premium/eqbTrackRecords.cfm?trk=SUN&cy=USA>
- 265 16. Equibase. 2020b. Sunland Park Track Records. [Cited 2021 March 17] available from:
266 <http://www.equibase.com/premium/eqbTrackRecords.cfm?trk=PEN&cy=USA>

- 267 17. Thoroughbred Idea Foundation. Run-ups cause inaccuracies that are ‘an affront to integrity’.
268 2020 Nov 11 [Cited 2021 May 13] available from: [https://www.paulickreport.com/horseplayers-
category/thoroughbred-idea-foundation-run-ups-cause-inaccuracies-that-are-an-affront-to-integrity/](https://www.paulickreport.com/horseplayers-
269 category/thoroughbred-idea-foundation-run-ups-cause-inaccuracies-that-are-an-affront-to-integrity/)
- 270 18. Hay JG. Cycle rate, length, and speed of progression in human locomotion. *Journal of applied
271 Biomechanics*. 2002;18(3):257-70. doi:10.1123/jab.18.3.257
- 272 19. Hunter JP, Marshall RN, McNair PJ. Interaction of step length and step rate during sprint
273 running. *Medicine & Science in Sports & Exercise*. 2004;36(2):261-71.
274 doi:10.1249/01.MSS.0000113664.15777.53
- 275 20. Ferrari M, Pfau T, Wilson AM, Weller R. The effect of training on stride parameters in a cohort
276 of National Hunt racing Thoroughbreds: A preliminary study. *Equine veterinary journal*.
277 2009;41(5):493-7. doi:10.2746/042516409X374591
- 278 21. Kawai M, Minami Y, Sayama Y, Kuwano A, Hiraga A, Miyata H. Muscle fiber population and
279 biochemical properties of whole body muscles in Thoroughbred horses. *The Anatomical Record:
280 Advances in Integrative Anatomy and Evolutionary Biology: Advances in Integrative Anatomy and
281 Evolutionary Biology*. 2009;292(10):1663-9. doi:10.1002/ar.20961
- 282 22. Stull CL, Albert WW. Comparison of muscle fiber types from 2-year-old fillies of the belgian,
283 standardbred, thoroughbred, quarter horse and welsh breeds. *Journal of Animal Science*.
284 1980;51(2):340-3. doi:10.2527/jas1980.512340x
- 285 23. Valberg SJ. Muscle Anatomy, Physiology, and Adaptations to Exercise and Training. In:
286 Hodgson DR, McKeever KH, McGowan CM, editors. *The athletic horse: principles and practice of
287 equine sport medicine*. 2nd ed. St. Louis: Elsevier; 2014. pp. 174–201.

- 288 24. Franklin SH, Van Erck-Westergren E, Bayly WM. Respiratory responses to exercise in the horse.
289 Equine Veterinary Journal. 2012;44(6):726-32. doi:10.1111/j.2042-3306.2012.00666.x
- 290 25. Lekeux P, Art T, Hodgson DR. The respiratory system: anatomy, physiology, and adaptations to
291 exercise and training. In: Hodgson DR, McKeever KH, McGowan CM, editors. The athletic horse:
292 principles and practice of equine sport medicine. 2nd ed. St. Louis: Elsevier; 2014. Pp 125-154.
- 293 26. Hörnicke H, Weber M, Schweiker W. Pulmonary ventilation in Thoroughbred horses at
294 maximum performance. Equine exercise physiology. 1987;2:216-24.