

Practical assessment of heart rate response to exercise under field conditions

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Research Paper

Abstract

Regular monitoring of the heart rate (HR):speed relationship may help evaluate response to training and aid in the early detection of problems. This relationship is normally determined using a treadmill or via a ridden test conducted outside on a track. Simple practical alternative methods to obtain this relationship without access to a treadmill or a track could be of value in the field. To evaluate whether the HR:speed relationship could be determined via an indoor ridden test or a lunge test, HR was monitored on two occasions at least 3 h apart, in 12 adult horses (mixed breed) in a familiar environment during a 5 or 7 m radius circle lunge (unridden) test (5LT or 7LT) and an incremental (ridden) test (RT) on the same day. The RT comprised two ridden laps of the perimeter of a 60 × 40 m indoor school at walk, three laps at trot, three at medium canter and four at fast canter (all on the right rein). The speed of each lap was recorded. The LT comprised lunging for 2 min on each rein at walk, trot and canter. Speed was determined from the number of laps completed and measurement of the distance travelled. HR and speed were highly correlated in both lunge and ridden tests (both $r = 0.99 \pm 0.01$). V_{140} on the ridden test ($5.2 \pm 0.6 \text{ m s}^{-1}$) was significantly greater than on the pooled lunge test data (4.4 ± 0.6 ; $P < 0.0001$). There was a negative correlation between recovery HR at 2 min following either the LT or RT and V_{140} ($P < 0.05$). The slope of the HR versus speed relationship and V_{140} were not different between RT and 7LT, but were significantly different from those of the 5LT ($P < 0.05$). V_{140} was always lower on the lunge tests compared with the ridden test. This suggests that, in this study, lunging without a rider increased the metabolic demand above that for being ridden at a similar speed. V_{140} determined by the 7LT gave the closest approximation to the V_{140} determined by the RT. The HR:speed relationship can be obtained either from riding an incremental test in an indoor school or from an unridden lunge test.

Keywords: heart rate; V_{140} ; field testing; lunging; exercise testing

Introduction

Heart rate (HR) increases linearly with workload (equivalent to speed) up to c. 90% of maximal HR¹. The slope of the HR:speed relationship varies between breeds and between individuals within a breed, which may be related to athletic ability². Within an individual, the HR:speed relationship changes with training and fitness level, but can also be affected by certain clinical conditions, such as lameness, respiratory disease and infection as well as the level of excitement³. Regular monitoring of horses can help in evaluating

responses to training and in the early detection of certain problems⁴. Assessment of the relationship between HR and speed on treadmill under standardized conditions is commonly used and is a relatively simple procedure. However, these facilities are not universally available and require a degree of familiarization of the horse with the treadmill. Treadmill evaluation is also not a practical approach for most veterinary practitioners to assess horses or for ordinary horse owners or trainers to carry out routine and frequent monitoring.

There is, therefore, a need for a simple and accessible approach to monitoring horses under field conditions. A number of field-based tests have been described, but they often rely on the availability of measured tracks and large, open spaces. In addition the results, as well as being influenced by the rider, can be influenced by the terrain⁵ and other environmental factors⁶, particularly if the test used is not of short duration. The present study was undertaken to evaluate two simple and practical methods of obtaining the relationship between HR and workload (taken to be equivalent to speed) using minimal equipment and facilities – a lunge (unridden) test and an incremental (ridden) test carried out indoors.

Materials and methods

Animals

Twelve horses maintained at the Equine Centre, Nottingham Trent University (Brackenhurst, Southwell, Nottinghamshire, UK) for student equitation courses were studied (Table 1). Horses were exercised for *c.* 2 h per day, 5 days per week, in a variety of activities, including lunging, flatwork, jumping and hacking. All horses were housed in individual stables and bedded on straw, shavings or paper. The horses were fed a wide variety of diets to maintain body weight for the type and volume of work in which they were engaged. All horses had water provided by automatic drinkers.

General

All studies were undertaken in a 60 × 40 m indoor school with a fibresand surface. At the start of each series of exercise tests, the school was watered by a fixed roof sprinkler system. Before each individual ridden or lunge test, the surface was harrowed to attempt to provide standardized conditions. Cones were used to mark the inside of the ridden track to try and ensure that the distance covered was as

consistent as possible. A cone was placed to mark the position in the school from where the handler lunged the horses.

Three experienced handlers lunged and rode the horses. Each horse was always ridden and lunged by the same handler. HR measurements during the lunging and ridden tests undertaken in year 1 were made using a Polar PEH200 HR monitor (Polar Electro, Finland) with a cotton saddle cloth holding two steel plate electrodes in cloth pouches. In the tests in year 2, the HR measurements were made with a Polar Sport Tester (equivalent to the Polar XL model) and Polar Horse Trainer electrode system (Tyler Animal Systems, Hough-on-the-Hill, Lincolnshire, UK). A comparison of the HR data obtained with each system from three horses exercising on a treadmill, and also against an ECG, all showed good agreement (Marlin, Davidson and Harris, unpublished data). Electrodes were positioned on the upper left thorax (positive electrode) and to the right of the ventral midline (negative electrode). The skin under the electrodes was soaked with tap water to assist contact. All HR data were recorded using the 5 s averaging mode. In order to identify the HR data corresponding to the different phases of each test, the inbuilt stopwatch function of the HR monitor was synchronized with a second stopwatch.

Protocols

Ridden tests

With the rider mounted, the horse was stood quietly for at least 1 min. The rider was then instructed to ride the horse at walk on to the marked track and pass the start cone, from which all lap timings were recorded. The rider rode two laps at walk, three laps at trot, three laps at slow-medium canter and four laps at fast canter, all on the right rein. The rider was instructed to attempt to maintain a constant pace around the track at each speed. At the end of the test, the rider was instructed to ride the horse in walk for 2 min. The actual path the horse travelled around the school was measured following the completion of the test with a measuring wheel (Trumeter, Manchester, UK).

Lunge tests

The handler led the horse to the centre of the lunge area and the horse stood for 1 min. The horse was then lunged for 2 min at walk on the left rein, 2 min walk on the right rein, 2 min trot on the right rein, 2 min trot on the left rein, 2 min canter on the left rein and 2 min canter on the right rein. The horse then walked for a further 2 min on the right rein. The number of laps from a fixed point on the circle (marked by the cone) was recorded for each stage of the test (gait and direction).

Table 1 Details of the horses used in the study

Horse	Age at year 1 (years)	Sex	Breed	Weight (kg)
A	14	m	Wx	570
Bg	16	g	Old	564
D ^a	8	g	IP	570
F	16	g	7/8 TB	504
G	14	m	Han	550
Ha ^a	6	g	I × TB	552
He ^a	13	g	ID × TB	592
Li	11	m	I × WB	584
N	9	g	ID × TB	600
R	6	m	IP	495
T	15	g	Cob × Conn	500
W	5	m	I × TB	566

^a Denotes horses used in both years 1 and 2 studies. W, Welsh; Old, Oldenburg; IP, Irish pony; TB, Thoroughbred; Han, Hanoverian; ID, Irish Draught; WB, Warmblood; Conn, Connemara.

In the first series of tests (year 1), the lunge line was marked at 5 m (radius), thus producing a circle c. 31 m in circumference (provided the handler stood directly by the cone) and, in the second series of tests (year 2), the lunge line was marked at 7 m (radius), producing a circle c. 44 m in circumference. The handlers were instructed to maintain the marked length between themselves and the horse and to stand as close to the cone as possible. The distance of the path actually travelled by each individual horse was measured as described previously. In year 1, the horses performed two lunge tests (L1 and L2) at the same time of day 24 h apart. On each occasion following the test, the horses were allowed to stand in their own boxes for 3–4 h and then they undertook the ridden test (R1 and R2). The horses did not undertake any other exercise on the test days. In year 2, the horses performed the lunge test twice on the same day with 1–2 h break between them, followed by a single ridden test 3–4 h later. Three horses were used in both years 1 and 2.

Statistics

The relationship between HR and speed for the lunge and ridden tests was determined using correlation and linear regression. A nested ANOVA was used to investigate the effect of speed, rein and test (first versus second) on HR and V_{140} . Significance was taken as $P < 0.05$ for the ANOVA. Unpaired *post hoc t*-tests with a Bonferroni correction were used when the ANOVA was significant. Comparison between the first and second ridden or lunge tests was undertaken using a paired *t*-test.

Results

Reproducibility

The actual lunge radius measured in year 1 (nominal 5 m radius) was 5.0 ± 0.1 m (range 4.8–5.3 m), whilst in year 2 (nominal 7 m radius) it was 6.7 ± 0.2 (range 6.3–7.1 m). There was no significant overall difference between HR and speed in L1 or L2 for rest, walk, trot or canter on the 5 or 7 m radius. There was no significant difference between HR and speed on left or right rein for pooled data (LT1 and LT2) for 5 or 7 m radius ($P > 0.05$). There was no significant difference between the 5 or 7 m radius circles for HR or speed (Fig. 1). There was no significant difference between HR and speed for the first or second ridden tests performed 24 h apart (Fig. 2). V_{140} determined in test 2 was significantly higher than that in test 1 for the 7 m radius lunge test ($P < 0.05$) but not different for the 5 m radius lunge test (Table 2; Fig. 3a). There was no significant difference between the V_{140} determined in the RT1 and RT2 (Fig. 4a).

Heart rate:speed relationship

Correlation coefficients (r) for the relationship between HR and speed for the lunge tests ranged from 0.961 to 0.999 (mean 0.989 ± 0.009) and were all significant at $P < 0.05$ or greater. Correlation coefficients (r) for the relationship between HR and speed for the ridden tests ranged from 0.981 to 0.999 (mean 0.994 ± 0.005) and were all significant at $P < 0.05$ or greater.

There were no significant differences in the slope or intercept of the HR versus speed relationship, V_{140} or 2 min recovery HR between the 5 and 7 m radius lunge tests (Table 2). There was a significant negative correlation between recovery HR at 2 min after

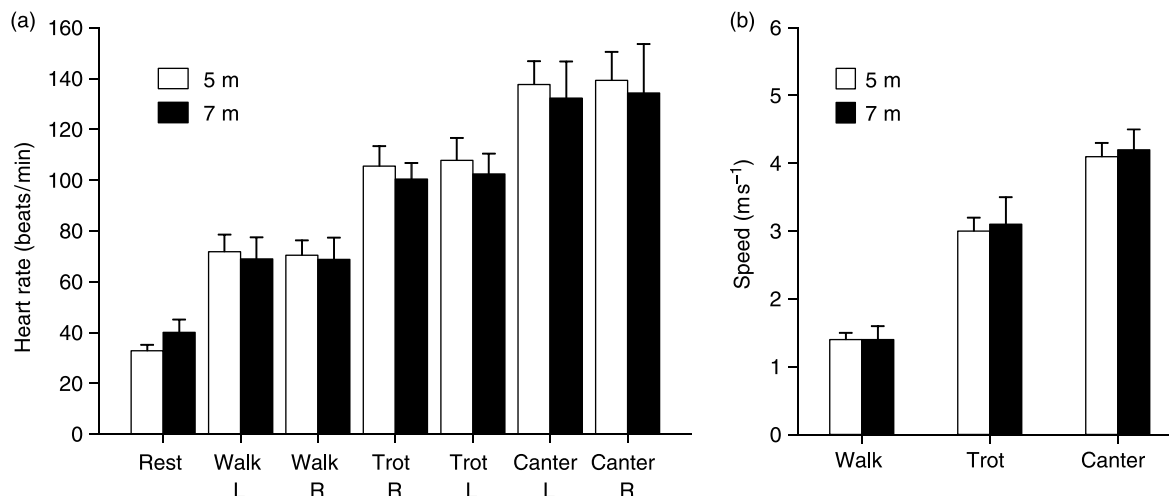


Fig. 1 (a) Mean ($\pm$ SD) heart rate for horses undertaking a lunge test on either a 5 or 7 m radius circle; 5 metre radius $n = 8$; 7 m radius $n = 7$. Each horse performed two lunge tests. R and L indicate right and left rein, respectively. Three horses were used for both the 5 and 7 m tests. (b) Mean ($\pm$ SD) speed for horses undertaking a lunge test on either a 5 or 7 m radius circle; 5 m radius $n = 8$; 7 m radius $n = 7$. Each horse performed two lunge tests. Three horses were used for both the 5 and 7 m tests

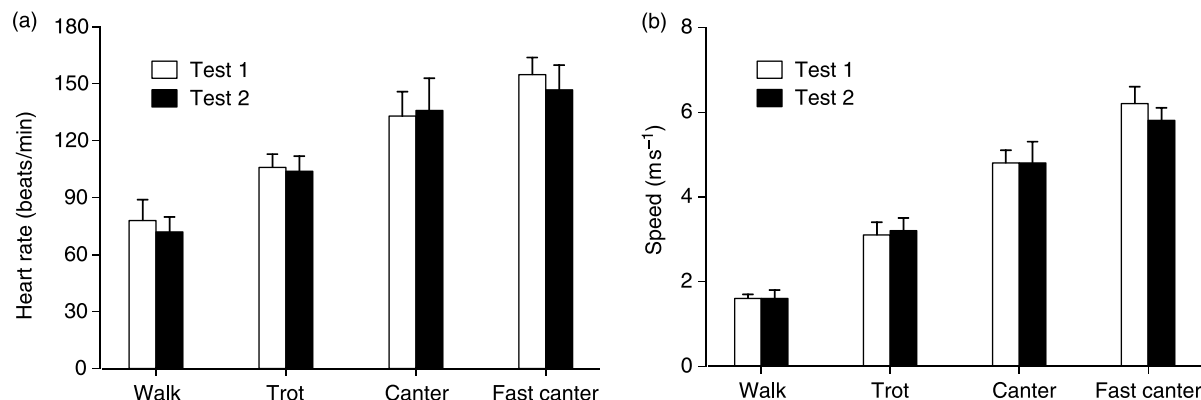


FIG. 2 (a) Mean ($\pm$ SD) heart rate for horses undertaking the ridden test on two separate occasions. (b) Mean ($\pm$ SD) speed for horses undertaking the ridden test on two separate occasions

completion of the lunge test (5 and 7 m radius data pooled) and V_{140} (Fig. 3b).

There were no significant differences in slope, intercept, V_{140} or 2 min recovery HR between the ridden tests (Table 2). There was a significant negative correlation between recovery HR at 2 min after completion of the ridden tests (undertaken in conjunction with either the 5 or 7 m radius lunge test) and V_{140} (Fig. 4b).

Lunge versus ridden

The slope of the relationship between HR and speed and V_{140} for the 5 m lunge test was significantly different from those obtained in the ridden test on the same day (Table 2; Fig. 5). There was no difference between slope, intercept or V_{140} for the ridden and 7 m lunge tests. Recovery HR at 2 min was not different between ridden and lunge tests. When horses were ranked according to their V_{140} on ridden and lunge tests (Fig. 6) for the 7 m lunge test, the rankings were always within 1–2 of the ridden test. However, for

the 5 m lunge test for two horses, the difference in rank between the two tests was 3 and 5.

Discussion

The correlations between HR and speed as determined in either the lunge or ridden tests, which were the basis for calculation of V_{140} , were better than had been anticipated, particularly when taking into account the fact that only four values (rest and mean of each rein at walk, trot and canter) for HR and speed were used from each horse in each lunge test and five (rest and one value for each step at walk, trot, canter and fast canter) from each ridden test.

The values obtained for V_{140} for the ridden tests (range 4.1–6.0 m s^{-1}) are within the ranges for V_{140} , which have been published or extrapolated from published data, for ridden field tests: 4–6 m s^{-1} for Standardbred and Dutch Warmbloods ridden on a sand track⁷, 5–8 m s^{-1} for Quarter Horses ridden on a

Table 2 Slope and intercept of the relationship between heart rate (HR) and speed, V_{140} and 2 min recovery HR for lunge (5 m year 1 and 7 m year 2) and ridden tests (years 1 and 2). Pooled data are based on the mean of each set of animal data for tests 1 and 2

		Test 1	Test 2	Pooled data
Slope (beats/min $\text{m}^{-1} \text{s}^{-1}$)	Lunge 5 m (year 1)	24.4 $\pm$ 2.9	26.5 $\pm$ 2.1 ^a	25.5 $\pm$ 2.3
	Lunge 7 m (year 2)	22.6 $\pm$ 4.7	21.0 $\pm$ 4.8	21.8 $\pm$ 3.7
	Ridden (year 1)	19.1 $\pm$ 2.2	19.8 $\pm$ 2.7	19.5 $\pm$ 2.4****
	Ridden (year 2)	19.6 $\pm$ 3.2	nd	19.6 $\pm$ 3.2
Intercept (beats/min)	Lunge 5 m (year 1)	36 $\pm$ 7	30 $\pm$ 3	33 $\pm$ 5
	Lunge 7 m (year 2)	37 $\pm$ 6	40 $\pm$ 7	38 $\pm$ 5
	Ridden (year 1)	41 $\pm$ 7	37 $\pm$ 3	39 $\pm$ 4***
	Ridden (year 2)	38 $\pm$ 4	nd	38 $\pm$ 8
V_{140} (m s^{-1})	Lunge 5 m (year 1)	4.3 $\pm$ 0.5	4.1 $\pm$ 0.3	4.2 $\pm$ 0.4
	Lunge 7 m (year 2)	4.6 $\pm$ 0.7	4.8 $\pm$ 0.6 ^a	4.7 $\pm$ 0.7
	Ridden (year 1)	5.2 $\pm$ 0.4	5.2 $\pm$ 0.6	5.2 $\pm$ 0.5****
	Ridden (year 2)	5.3 $\pm$ 0.7	nd	5.3 $\pm$ 0.7
Two min recovery heart rate (beats/min)	Lunge 5 m (year 1)	84 $\pm$ 9	84 $\pm$ 8	84 $\pm$ 7
	Lunge 7 m (year 2)	86 $\pm$ 10	83 $\pm$ 11	85 $\pm$ 10
	Ridden (year 1)	88 $\pm$ 6	84 $\pm$ 6 ^a	86 $\pm$ 5
	Ridden (year 2)	86 $\pm$ 7	nd	86 $\pm$ 7

nd, not determined; ridden test (year 1) significantly different from 5 m lunge test (year 1) or ridden test (year 2) significantly different from 7 m lunge test (year 2): *** $P < 0.001$; **** $P < 0.0001$. ^aTest 2 significantly different from test 1 at $P < 0.05$.

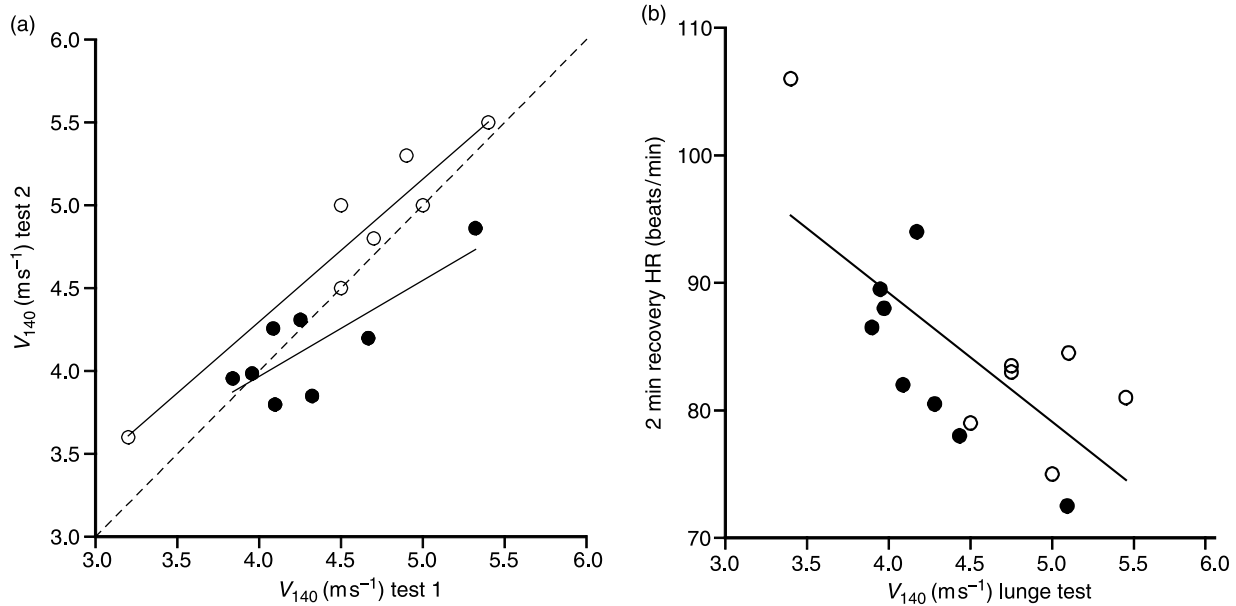


FIG. 3 (a) Regression of V_{140} (ms⁻¹) determined in test 2 as a function of V_{140} determined in test 1 for 5 m radius (●) and 7 m radius (○) lunge tests. (--- line of identity). ● 5 m radius: $y = 0.79(\pm 0.42)x + 1.65(\pm 1.84)$; $r = 0.806$ ($P < 0.02$); ○ 7 m radius: $y = 0.86(\pm 0.31)x + 0.85(\pm 1.45)$; $r = 0.954$ ($P < 0.001$). (b) Two min recovery heart rate (beats/min) as a function of V_{140} (ms⁻¹) for 5 m radius (●) and 6 m radius (○) lunge tests. Regression and correlation performed on combined data sets: $y = -10.12(\pm 2.81)x + 129.7(\pm 12.6)$; $r = 0.694$ ($P < 0.01$)

half-mile dirt track⁴, 3.7–5.8 m s⁻¹ for horses (unspecified breed) ridden on an indoor school (82 m) and outdoor sand track (165 m)⁸ and 6.8–7 m s⁻¹ (V_{150}) for untrained Thoroughbreds and Anglo-Hunters ridden on a 1500 m sandy track⁹.

There was considerable variation in age (5–16 years), breed and sex of the horses used in this

study. The structure of the data obtained does not suggest that older horses behaved differently between ridden and lunge tests. However, it is conceivable that older horses could have a lower V_{140} than younger horses due to the age-associated decrease in exercise capacity previously identified¹⁰, although this would be expected to have had a similar influence on the

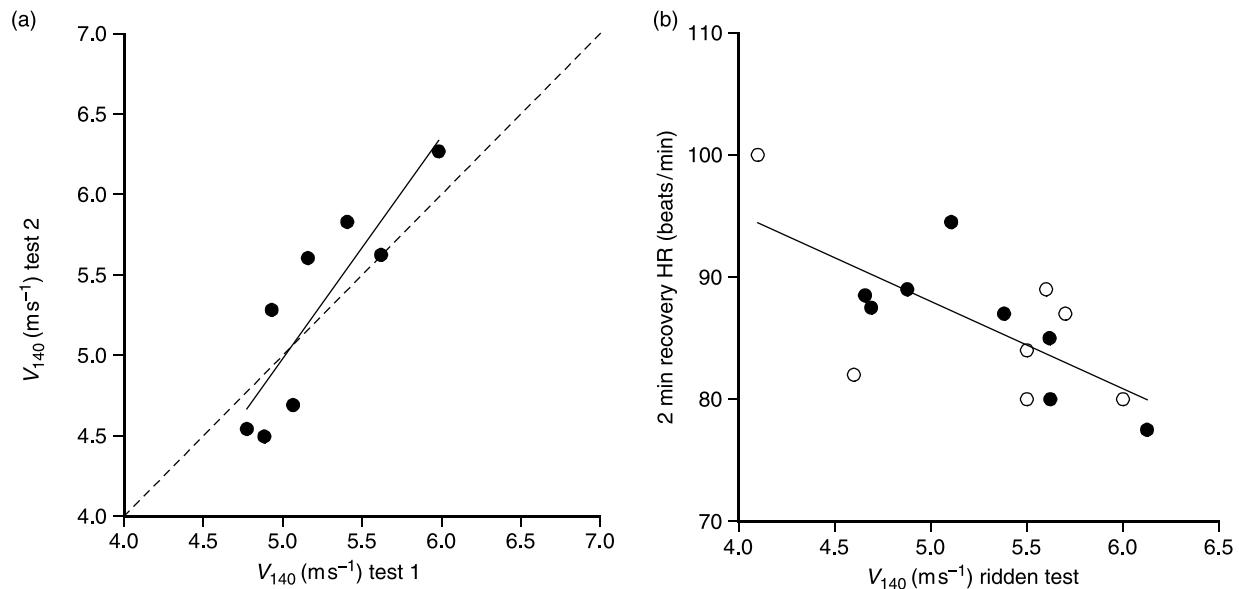


FIG. 4 (a) Regression of V_{140} (ms⁻¹) determined in test 2 as a function of V_{140} determined in test 1 for ridden test (determined in conjunction with 5 m radius lunge test). (--- line of identity). $y = 1.38(\pm 0.77)x - 1.93(\pm 4.06)$; $r = 0.872$ ($P < 0.01$). (b) Two min recovery heart rate (beats/min) as a function of V_{140} (ms⁻¹) for ridden tests (carried out in conjunction with 5 m radius (●) and 6 m radius (○) lunge tests). Regression and correlation performed on combined data sets: $y = -7.14(\pm 2.08)x + 123.7(\pm 11.0)$; $r = 0.689$ ($P < 0.01$)

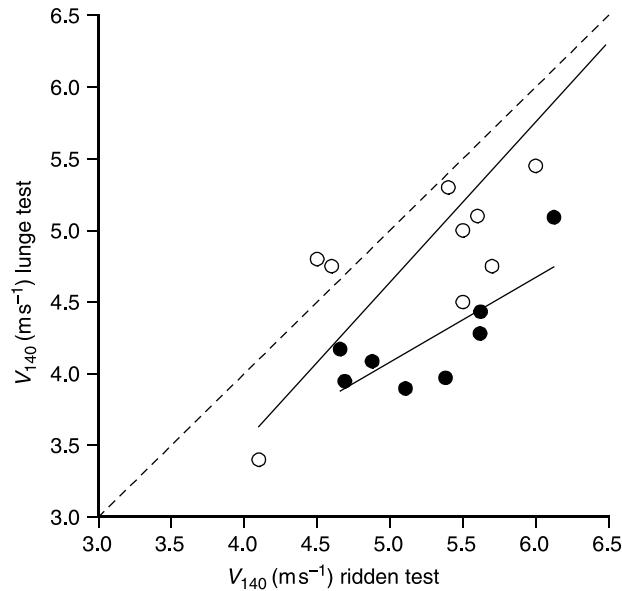


Fig. 5 V_{140} (ms^{-1}) determined by the lunge test on either a 5 m radius (●) or 7 m radius (○) circle as a function of V_{140} determined in the corresponding ridden test

response to both ridden and lunging tests. The only possible explanation for a differential response to ridden and lunge tests would be in older horses with orthopaedic disease, as this would probably be exacerbated by exercising on a circle and thus lowering V_{140} through a pain response.

Erickson *et al.*⁴, found that track conditions, perhaps not surprisingly, affected the performance of the horses, in that poor conditions such as a muddy track reduced the horses' V_{140} by $1\text{--}2\text{ ms}^{-1}$. This underlines the importance of taking environmental, and particularly ground, conditions into consideration when using such tests. Although the present studies were carried out on separate occasions, the

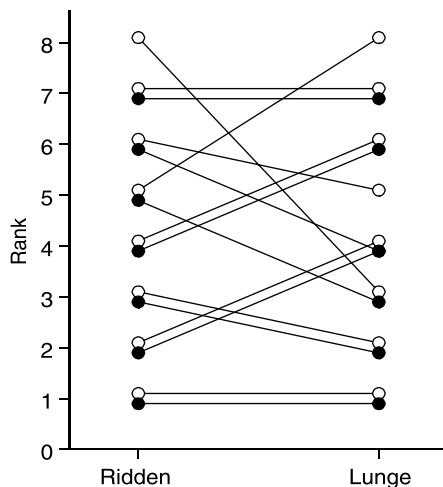


Fig. 6 Rank V_{140} in ridden and lunge tests (open circle = 5 m, solid circle = 7 m)

environmental conditions inside the indoor school, as well as the surface of the arena, were similar on both occasions.

Mean exercising HRs on both lunge tests ranged only from 68 to 140 b.p.m. and on the ridden tests from 73 to 155 b.p.m. Excitement can cause elevations in HR, particularly within this low range, above those induced simply by physical exertion. The horses in the present study were studied in a familiar environment in which they exercised frequently (often up to 5 days per week) and were handled and ridden by the regular full-time staff. This would have reduced the risk of excitement influencing the HR³. Care was also taken to ensure that no other activities were taking place within or around the indoor school that could have caused distraction or excitement. Thus, to a large extent, the present study could be considered to have been conducted in field conditions as close as possible to ideal.

Despite the ridden test involving an increased load due to the presence of the rider (Sloet van Olderenborgh-Oosterbaan *et al.*, 1999), the horses had lower V_{140} during the lunge tests, suggesting that they found the lunge tests to be harder than the ridden test. The lunge tests were carried out before the ridden tests, so this is unlikely to be a reflection of fatigue. However, although all horses were clinically healthy with no clinical signs of lameness, it is possible that the presence of mild subclinical limb problems, which may have been more exacerbated by the lunging than the riding around the arena, could explain why they apparently found the lunge tests slightly more difficult. Certainly, during the first series of lunge tests carried out on 5 m radius circles, it was more difficult to keep the horses exercising at a steady pace, particularly at trot and canter. We, therefore, considered that the 5 m radius circle may have been too small for some of the larger horses and, therefore, a second series of lunge tests was also carried out using a 7 m radius circle. However, although there was a trend for V_{140} to be lower in the 5 m radius lunge test (than the 7 m), this was not significant. The ranking of the horses based on the ridden and lunge tests was not the same. However, for the 7 m circle lunge, the rankings were closer to the ridden ranking than on the 5 m lunge.

A further possibility to consider is that horses move differently on a circle compared with in a straight line. Unfortunately, kinematic measurements were not made in this study, but stride length for a given speed is likely to be lower on a circle than when the horses were exercising predominantly in straight lines when being ridden. Thus, exercise on a circle may have forced the horse to adopt a less efficient combination of stride frequency and stride length compared with exercise in a straight line at a similar speed. Most kinematic research in horses has focused

on straight line exercise, and only one kinematic study¹¹ has evaluated the effects of turning a corner on the distal joint motions. Horses turning in a sharp (1.5 m diameter) left circle demonstrated a shortening in stride length but an increase in stance duration. This work also showed that the lower leg and foot rotate as the weight of the horse moves over the limb.

In the present study, the range in size of horses was quite narrow and limb lengths were not recorded. However, it is also conceivable that, if turning exercise does alter gait, that this effect may be greatest on horses with longer limb lengths. Certainly, in show-jumping, it is recognized that whilst larger horses have the advantage in the height of fences they can negotiate, smaller horses usually find turning easier.

There have been few published papers on lunging exercise and HR, and none with which we could directly compare our data. However, Maier-Bock and Ehrlein⁸ showed data that indicated the slope of the regression of HR against speed was less for larger circumferences on the same surface, suggesting that the metabolic demand was less for horses travelling around larger circumferences; this supports the slight differences we found between the 5 and 7 m lunge circles.

The methodology we used in the present study appeared to provide reproducible HR-speed relationships without the use of complex exercise protocols or facilities. This means that such tests may be acceptable for use in training yards, veterinary practices or by individual owners, as the speeds required by the horses were similar to those routinely experienced by horses in such training centres. These type of investigations should also become simpler with the availability of GPS systems for recording speed.

However, there are a number of potential limitations associated with this study. In particular, the HRs were below 160 b.p.m. and, therefore, there is an increased potential for excitability to influence the results. In this particular study, the correlations between HR and speed were very good, suggesting that excitement was not a major factor. In addition, some authors have raised doubt over the use of submaximal exercise tests specifically due to the issue of excitement¹².

Conclusion

The HR:speed relationship can be obtained either from riding an incremental exercise test in an indoor school or from an unridden lunge test. A larger (7 m) lunge

circle may provide the closest approximation to the relationship determined by the ridden test.

References

- 1 Persson SGB (1983). Evaluation of exercise tolerance and fitness in the performance horse. In: Snow DH, Persson SGB and Rose RJ (eds) *Equine Exercise Physiology*. Cambridge: Granta editions, pp. 441–457.
- 2 Courouge A (1999). Field exercise testing for assessing fitness in French standardbred trotters. *The Veterinary Journal* **157**: 112–122.
- 3 Kobayashi M, Kuribara K and Amada A (1999). Application of V_{200} values for evaluation of training effects in the young thoroughbred under field conditions. *Equine Veterinary Journal Supplement* (30): 159–162.
- 4 Erickson BK, Erickson HH, Sexton WL and Coffman JR (1987). Performance evaluation and detection of injury during exercise training in the quarter horse using a heart rate computer. In: Gillespie JR and Robinson NE (eds) *Equine Exercise Physiology II*. California: ICEEP Publications, Davis, pp. 92–101.
- 5 Schroter RC and Marlin DJ (2002). Modelling the oxygen cost of transport in competitions over ground of variable slope. *Equine Veterinary Journal Supplement* (34): 397–401.
- 6 Marlin DJ, Scott CM, Schroter RC, Mills PC, Harris RC, Harris PA, Orme CE, Roberts CA, Marr C, Dyson S and Barrelet F (1996). Physiological responses in non heat-acclimated horses performing treadmill exercise in cool (20°C/40%rh), hot dry (30°C/40%rh) and hot humid (30°C/80%rh) conditions. *Equine Veterinary Journal Supplement* (22): 70–84.
- 7 Sloet van Oldruitenborgh-Oosterbaan M, Wensing T and Breukink HJ (1987). Standardized exercise test on a track to evaluate fitness and training of saddle horses. In: Gillespie J and Robinson NE (eds) *Equine Exercise Physiology II*. San Diego, California: ICEEP Publications, pp. 68–76.
- 8 Maier-Bock H and Ehrlein HJ (1978). Heart rate during a defined exercise test in horses with heart and lung disease. *Equine Veterinary Journal* **10**: 235–242.
- 9 Munoz A, Riber C, Santisteban R, Vivo R, Agüera S and Castejon F (1998). Investigation of standardized exercise tests according to fitness level of three-day event horses. *Journal of Equine Science* **9**: 1–7.
- 10 Betros CL, McKeever KH, Kearns CF and Malinowski K (2002). Effects of ageing and training on maximal heart rate and VO_{2max} . *Equine Veterinary Journal Supplement* (34): 100–105.
- 11 Chateau H, Degueurce C and Denoix J-M (2005). Three-dimensional kinematics of the equine distal forelimb: Effects of a sharp turn at the walk. *Equine Veterinary Journal* **37**(1): 12–18.
- 12 Rose RJ and Christley RM (1995). How useful are submaximal exercise tests to forecast performance. *Equine Veterinary Journal Supplement* (18): 471–479.
- 13 Sloet van Oldruitenborgh-Oosterbaan MM, Barneveld A and Schamhardt HC (1995). Effects of weight and riding on workload and locomotion during treadmill exercise. *Equine Veterinary Journal Supplement* (18): 413.