Oxygen consumption and gait variables of Arabian endurance horses measured during a field exercise test

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Summary

Reasons for performing study: Arabian horses have morphological, muscular and metabolic features designed for endurance races. Their gas exchange and gait variables were therefore measured during a field exercise test. This study presents original respiratory and locomotor data recorded in endurance horses under field conditions.

Hypothesis and objectives: Respiratory gas exchange ratio (RER) of Arabian horses at the speed required to win endurance races (18 km/h for 120–160 km) are <1 and running economy (RE) is also low in order to maintain exercise intensity using aerobic metabolism for long intervals. The purpose of this study was to measure oxygen consumption and gait variables in Arabian endurance horses running in the field in order to estimate RER and RE.

Materials and methods: Five Arabian horses trained for endurance racing were test ridden at increasing speeds on the field. Their speed was recorded and controlled by the rider using a GPS logger. Each horse was equipped with a portable respiratory gas analyser, which measured breath-by-breath respiratory variables and heart rate. The gait variables were recorded using tri-axial accelerometer data loggers and software for gait analysis. Descriptive statistics and linear regressions were used to analyse the speed related changes in each variable with P<0.05 taken as significant.

Results: At a canter speed corresponding to endurance race winning speed (18 km/h), horses presented a VO2 = 42 ± 9 ml/min/kg bwt, RER = 0.96 ± 0.10 and RE (= VO2/speed) = 134 ± 27 l/kg bwt. Linear relationships were observed between speed and VO2, HR and gait variables. Significant correlations were observed between VO2 and gait variables.

Conclusions and potential relevance: The RER of 0.96 at winning endurance speed indicates that Arabian horses mainly use aerobic metabolism based on lipid oxidation and that RER may also be related to a good coordination between running speed, respiratory and gait parameters.

Introduction

Arabian horses have morphological, muscular and metabolic features designed for endurance races being short in height at the withers (150–155 cm), with a high fat free mass and high proportion of muscular fibres of type I compared to type II (Lopez-Rivero et al. 1989). In addition, they have an energetic metabolism particularly suited to endurance exercise. Prince et al. (2002) compared responses to prolonged moderate exercise between Arabian pure-breds and Thoroughbreds. Arabian horses showed a lower respiratory exchange ratio (RER) and higher plasmatic concentration in free fatty acids than in Thoroughbreds. Therefore, Arubians could preferentially use lipids as energetic substrates and have a better adaptation to endurance exercise than Thoroughbreds. Arabian horses frequently win endurance races (90–120 km). Since 1996, 51% of the best ranking endurance races in France (between the first and the fifth rank) are attributed to Arabian horses vs. 9.97% for saddle horses, 9.54% for pure-bred Anglo-Arabian and 6.72% for French saddle horse (SF) (Buffet et al. 2009).

Running economy (RE = VO2/speed) is defined as the amount of oxygen consumed (ml/kg bwt/min) per distance covered (ml/kg bwt/km). Those horses able to consume less oxygen while running at a given velocity are said to have a better running economy. Running economy has already been studied in human marathon runners (Billat et al. 2001) where it has been shown that top class marathon male runners (i.e. performance <2 h 11 min) have a better RE compared to high level marathon male runners (i.e. performance <2 h 16 min). To date, no data have been obtained in horses during exercise in field conditions. However, RE can now be measured in a standardised field exercise test with ambulatory gas exchange (Art et al. 2006; Leprêtre et al. 2009) and gait analysers (Barrey et al. 2001). It is therefore relevant to measure the RE of Arabian horses in field conditions as they show good performance in endurance races.

As the horses that usually win have an average canter speed around 18 km/h (Buffet et al. 2009), the energetic metabolism should be strictly aerobic during most of the race duration in order to avoid rapid fatigue due to lactic acid accumulation. Of course, a short anaerobic boost can occur for a very short time but depth of oxygen recovery will take time and consequently decrease the speed. Therefore, it was hypothesised that the respiratory gas exchange ratio (RER) of Arabian horses at the speed required to win endurance races (18 km/h for 120–160 km) is <1 and the RE is low in order to maintain for a long duration the exercise intensity using aerobic metabolism. The purpose of this study was to measure the oxygen consumption and gait variables in Arabian endurance horses as previously described.

Keywords: horse; endurance race; respiratory exchange ratio; running speed; respiration; heart rate
endurance horses running in field conditions to estimate the RER and RE at the specific endurance competition winning speed.

Materials and methods

Five healthy Arabian horses (age = 8 ± 2 years, weight = 408 ± 27 kg, height = 153 ± 2 cm) trained for endurance racing were tested ridden at increasing speeds in field conditions. The protocol and care of the horses complied with the Declaration of Helsinki. The horses were housed in individual loose boxes during the whole experimental session. Each horse had free access to a drinking trough at a constant level and was fed with a 3 kg hay intake at 10.00 and 16.00 h and with condensed food at 08.00 and 17.30 h. The amount of condensed food fed was based on the weight of the horse at the beginning of the study (Martin-Rosset and Vermorel 1991) and adjusted on a weekly basis as necessary.

The horses were trained 4 times a week under field conditions during a conditioning period of 3 months. The training programme consisted of alternate phases of trotting for 13 km at 3.6 m/s and galloping for 20 km at 4.2 m/s. At the end of the training period, all horses were qualified for a regional level of endurance race (60 km).

During the exercise protocol, horses were ridden by the same experienced endurance rider. The protocol consisted of 6 steps at increasing speeds of 3 min each: trot: 13–15.5 km/h, canter and gallop: 18.7–25.2, 33.5–36 km/h (author to confirm change) and then galloping at increasing speed up to 45 km/h.

The rider could adjust the speed of the gait during exercise. The speed was displayed, recorded and controlled by the rider by a GPS logger (Garmin12) with an accuracy of one knot (± 1.85 km/h). The GPS provided a speed value every 2 s. The mean speed of each step was calculated (Table 1).

| TABLE 1: Mean ± s.d. running speed, oxygen uptake (VO2) and running economy (RE) during different speed stages corresponding to different gaits: trotting (T 1, T2), canter (C, corresponding to the speed in endurance race), galloping (G1, G2, G3, G4, G5, G6) with G5 and G6 only for horses 4 and 5. Data are given for each horse and for the average |
|---|---|---|---|
| Stages | Speed (km/min) | VO2 (ml/min/kg bwt) | RE (l/kg bwt/km) |
| T1 | 0.21 ± 0.01 | 28 ± 3 | 132 ± 19 |
| T2 | 0.26 ± 0.01 | 36 ± 5 | 140 ± 20 |
| C | 0.31 ± 0.01 | 42 ± 9 | 134 ± 27 |
| G1 | 0.42 ± 0.02 | 50 ± 3 | 121 ± 12 |
| G2 | 0.56 ± 0.01 | 60 ± 5 | 108 ± 10 |
| G3 | 0.60 ± 0.00 | 63 ± 5 | 106 ± 8 |
| G4 | 0.66 ± 0.00 | 71 ± 6 | 107 ± 9 |
| G5 | 0.72 ± 0.28 | 85 ± 31 | 118 ± 19 |
| G6 | 0.75 ± 0.27 | 86 ± 28 | 114 ± 18 |

Each horse was equipped with a validated portable respiratory gas analyser, which measured breath-by-breath respiratory variables (K4b2) (Art et al. 2006; Leprêtre et al. 2009) and heart rate (HR, Polar610) (Holopherne et al. 1999; Kingsley et al. 2005). The following respiratory variables were continuously measured: respiratory frequency (RF), tidal volume (Vt), oxygen uptake (VO2) and carbon dioxide production (VCO2). These data allowed calculation of ventilatory flow (VE), and the RER (= VCO2/VO2).

Each horse was equipped with a homemade respiratory mask with a seal for expiratory flow. The horse’s nostril and mouth were entirely enclosed in the mask, which was attached to the snaffle. The volume of the mask was closed by an elastic rubber membrane attached tightly on the nose, just under the zygomatic arch, so that the horse could move its nostrils and lips freely within the mask and all the expired air was able to flow through the 2 turbines. Before the experiment, the horses were accustomed to wearing the mask at rest and exercise.

Before each exercise test the K4b2 was calibrated. According to the manufacturer’s instructions, the O2 and CO2 analysers were calibrated with ambient air containing 20.9% O2 and 0.03% CO2 and calibration gas containing 16.0% O2 and 5.0% CO2 before and after each test. A pretest was used to establish the delay between the airflow and gas signals. The turbine flow meter of the analyser was calibrated with a 3 l syringe, using the sampling line used during the test.

The gait variables (running speed and stride frequency [SF]) were recorded simultaneously using tri-axial accelerometer data logger and gait analysis software (Equimetrix) (Barrey et al. 2001; Leleu et al. 2002). The device recorded accelerations with a sampling frequency of 100 Hz. Therefore, from the recorded VO2 and speed, the RE was calculated as VO2/Speed.

Descriptive statistics (mean ± s.d.) and linear regressions were used to analyse the speed related changes in each variable.

Results

Bioenergetics

Oxygen uptake and RE at different speeds and gaits are given in Table 1. Speed vs. gas exchange components (VO2, VCO2, RER) and heart rate are given in Table 2.

Ventilatory components

Speed vs. ventilatory components (RF, Vt and VE) are given in Table 3.
Gas exchange measures vs. running speed: Oxygen uptake increases linearly when running speed increases \( (r = 0.95, P < 0.001, \text{Fig 1}) \). The same was observed for VCO2 \( (r = 0.92, P < 0.001, \text{Fig 2}) \) and RER \( (r = 0.53, P < 0.001, \text{Fig 3}) \). When running speed equals 18 km/h (endurance race winning speed), the linear regression gives an RER of 0.96 (Fig 3), indicating that the horse’s metabolism was mainly aerobic during most of the race duration.

Heart rate vs. running speed: Heart rate increased linearly when the running speed increased \( (r = 0.75, P < 0.001) \).

Ventilatory components vs. running speed: Respiratory outflow increased linearly when the running speed increased \( (V_E: r = 0.97, P < 0.001, \text{Fig 4}) \). The same was observed for RF \( (r = 0.85, P < 0.001) \) and Vt \( (r = 0.6, P < 0.001) \). In addition, respiratory frequency was correlated linearly with stride frequency when galloping \( (r = 0.68, P < 0.01, \text{Fig 5}) \) whereas it was not during trotting \( (r = 0.18, \text{NS, Fig 5}) \).

Coordination between speed vs. respiratory and gait variables: Strong linear relationships were observed between speed and VO2, HR and gait variables. Significant \( (P < 0.05) \) correlations were observed between VO2 and gait variables.

Gait variables vs. running speed: The stride frequency was correlated linearly with the running speed \( (r = 0.90, P < 0.001) \).

Discussion

The major finding of the study is that Arabian horses are winning endurance races with an RER < 1 (Fig 3), which confirms the hypothesis that energetic metabolism is mainly aerobic based on lipid oxidation during most of the duration of the race. This finding is in accordance with a previous study \( \text{(Prince et al. 2002)} \), which showed that Arabian horses have lower RER and higher plasmatic concentrations of free fatty acids than Thoroughbred horses during prolonged moderate exercise (90 min at 35% VO2MAX). These results indicate that Arabians preferentially use lipids as metabolic substrates during moderate exercise speed corresponding to

### TABLE 3: Mean ± s.d. running speed, heart rate and respiratory components during different speed stages corresponding to different gaits: trotting (T 1, T2), canter (C, corresponding to the speed in endurance race), gallop (G1, G2, G3, G4, G5, G6) with G5 and G6 only for horses 4 and 5. Data are given for each horse and for the average

<table>
<thead>
<tr>
<th>Stages</th>
<th>Speed GPS (km/h)</th>
<th>RF (breaths/min)</th>
<th>Vt (l)</th>
<th>VE (l/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>12.8 ± 0.5</td>
<td>67.6 ± 23.9</td>
<td>9.5 ± 2.7</td>
<td>584.1 ± 114.2</td>
</tr>
<tr>
<td>T2</td>
<td>15.3 ± 0.5</td>
<td>71.8 ± 25.8</td>
<td>11.0 ± 3.1</td>
<td>722.2 ± 140.5</td>
</tr>
<tr>
<td>C</td>
<td>18.8 ± 0.5</td>
<td>97.3 ± 18.1</td>
<td>9.9 ± 1.6</td>
<td>929.3 ± 94.1</td>
</tr>
<tr>
<td>G1</td>
<td>25.0 ± 1.4</td>
<td>113.6 ± 3.2</td>
<td>10.7 ± 0.5</td>
<td>1211.2 ± 63.9</td>
</tr>
<tr>
<td>G2</td>
<td>33.6 ± 0.5</td>
<td>123.5 ± 3.8</td>
<td>11.7 ± 0.4</td>
<td>1450.6 ± 72.4</td>
</tr>
<tr>
<td>G3</td>
<td>36.0 ± 0.0</td>
<td>128.7 ± 6.5</td>
<td>12.3 ± 0.5</td>
<td>1580.0 ± 88.3</td>
</tr>
<tr>
<td>G4</td>
<td>39.6 ± 0.0</td>
<td>133.6 ± 3.8</td>
<td>12.9 ± 0.4</td>
<td>1720.0 ± 69.3</td>
</tr>
<tr>
<td>G5</td>
<td>43.2 ± 16.8</td>
<td>136.1 ± 35.2</td>
<td>13.4 ± 3.0</td>
<td>1818.9 ± 662.4</td>
</tr>
<tr>
<td>G6</td>
<td>45.0 ± 16.3</td>
<td>135.7 ± 33.7</td>
<td>13.2 ± 2.1</td>
<td>1784.7 ± 567.5</td>
</tr>
</tbody>
</table>

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endurance races. Therefore Arabians seem to be particularly well suited for long aerobic exercise using lipid fuel. Moreover, RER was expected to be <1 unless the horses were hyperventilating. During canter at the winning endurance speed (18 km/h), the horses could not hyperventilate because their respiratory frequency was exactly synchronised with the stride frequency in ratio 1:1 as illustrated in Figure 5. The respiratory frequency remained lower than 2 cycles/s.

This study used ambulatory respiratory and gait analysis devices in endurance horses to measure running variables in real field conditions. The use of these devices has allowed RE to be computed in endurance horses at different gaits in the field that are closer to the racing condition than treadmill exercise.

Although the gas exchange device has already been validated during exercise (Art et al. 2006; Leprière et al. 2009), this study again confirmed that the respiratory mask was well accepted by the horses that performed the exercise test on the field. The horses could easily gallop at submaximal speed without any respiratory distress. In this study the horse’s bit was removed and they were driven using only the reins attached around the respiratory mask like a nose band.

Figure 5 shows that the respiratory frequency increases linearly when stride frequency increases when galloping (r = 0.68, P < 0.01); this it is not the case when trotting (r = 0.18, NS). Although the gas exchange device has already been validated during exercise (Art et al. 2006; Leprière et al. 2009), this study again confirmed that the respiratory mask was well accepted by the horses that performed the exercise test on the field. The horses could easily gallop at submaximal speed without any respiratory distress. In this study the horse’s bit was removed and they were driven using only the reins attached around the respiratory mask like a nose band.

Figure 5 shows that the respiratory frequency increases linearly when stride frequency increases when galloping (r = 0.68, P < 0.01). Thus, it seems that there is a strong locomotor-respiratory coupling in Arabian horses when galloping. This study confirmed the results of previous studies (Attenburrow 1982; Butler et al. 1993; Lafortuna et al. 1996). In all these studies, a phase-locked 1:1 coupling between respiratory and stride cycles were observed when galloping. In contrast, Figure 5 shows that the respiratory frequency is not linearly related with the stride frequency during slow trotting around 4 m/s (r = 0.18, NS). This study confirmed the results of previous studies that observed no locomotor-respiratory coupling during trotting when riding saddle horses (Hörnicke et al. 1983) or no steady locomotor-respiratory coupling (Attenburrow 1982, 1983; Bramble and Carrier 1983; Art et al. 1990; Barrey et al. 2000). However, a few studies have reported a strong locomotor-respiratory coupling only during fast trot at speeds...
higher than 8.5 m/s (Barrey et al. 2000; Cotrel et al. 2006). Therefore, to our knowledge, no study has reported a steady locomotor-respiratory coupling during slow trot, at speeds corresponding to those observed in the present study (3.5–4.5 m/s).

The efficient RE of Arabian horses is probably linked to an RER <1 indicating that aerobic metabolism using lipid oxidation is an important energetic pathway used to produce the ATP for muscular contraction. In addition, the smaller withers height and bodyweight of Arabians induces a body surface/mass ratio that favours muscular calorific loss during endurance exercise (Wilmore and Costill 1994). All these characteristics may explain why Arabians can canter at 18 km/h very efficiently for very long distances. In addition, if we compare with the data given in other studies, at the speed required for winning endurance races (18 km/h), under treadmill conditions, with the K4B2 gas-exchange device, the extrapolated VO2 seems lesser in Arabians than in other breeds. Indeed, 42 ml/min/kg bwt was reported in the Arabians of this study vs. 50.1 ml/min/kg bwt for Thoroughbred cross breeds. Indeed, 42 ml/min/kg bwt was reported in the Arabians of this study vs. 50.1 ml/min/kg bwt for Thoroughbred cross breeds. Indeed, 42 ml/min/kg bwt was reported in the Arabians of this study vs. 50.1 ml/min/kg bwt for Thoroughbred cross breeds. Indeed, 42 ml/min/kg bwt was reported in the Arabians of this study vs. 50.1 ml/min/kg bwt for Thoroughbred cross breeds. Indeed, 42 ml/min/kg bwt was reported in the Arabians of this study vs. 50.1 ml/min/kg bwt for Thoroughbred cross breeds. Indeed, 42 ml/min/kg bwt was reported in the Arabians of this study vs. 50.1 ml/min/kg bwt for Thoroughbred cross breeds. Indeed, 42 ml/min/kg bwt was reported in the Arabians of this study vs. 50.1 ml/min/kg bwt for Thoroughbred cross breeds.

Conclusions

To our knowledge, this study presents original respiratory and locomotor data recorded in endurance horses under field conditions. The respiratory gas exchange ratio of 0.96 at winning endurance speed indicates that Arabian horses mainly use aerobic metabolism. Their running economy could also be related to a good coordination between running speed, respiratory and gait parameters. These features of Arabian horses might explain their good performances in endurance racing.

Conflicts of interest

The authors have declared no potential conflicts.

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Manufacturers’ addresses

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References


