

New perspective for field measurement of cardiorespiratory parameters in exercising horses

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Summary

This study aimed at testing the feasibility of using the Cosmed K4 b²[®] portable telemetric gas analysis system to record metabolic parameters in ridden exercising horses. Adaptation of the Cosmed K4 b²[®] to horses' specificities included the design of an airtight face-mask (Equimask[®]) adapted to a hackamore bridle to allow riding the horse. The portable system enables the recording of tidal volume (VT), respiratory rate (RR), minute expired volume (VE), pulmonary oxygen uptake (VO₂), carbon dioxide delivery (VCO₂), heart rate (HR) and speed. Four saddle horses equipped with the system completed 3 treadmill tests (TT1 to TT3) and 1 field test (FT) consisting of galloping phases at incremental speeds. Horses were sampled for blood lactate (LA) during the tests. The successive treadmill tests showed the influence of stress on measurements: with horses becoming accustomed to treadmill, LA and HR were reduced between TT1 and TT3. As VO₂ is related to cardiovascular function, influence of stress resulted in higher VO₂ in TT1 vs. TT3. The VO₂ reached at maximal speed during treadmill tests was lower than the expected maximal aerobic power (VO_{2max}) for trained saddle horses. During FT, the VO₂ reached at the final gallop was lower than the VO₂ recorded during any of the treadmill tests thus reflecting the increasing difficulty to reach VO_{2max} with ridden horses in field conditions. This study demonstrated that cardiorespiratory parameters may be obtained in ridden horses during a field trial and opens new perspectives in the follow-up of sport horses in real field conditions.

Keywords: horse, exercise, pulmonary oxygen uptake, field testing, portable metabolic system, Cosmed K4 b²

Neue Perspektiven zur Feldmessung kardiorespiratorischer Parameter beim arbeitenden Pferd

Die maximale aerobe Kapazität oder VO_{2max} stellt einen wichtigen Wert zur Bestimmung der Fitness dar. Bis heute sind Messungen zur pulmonalen Sauerstoffaufnahme (VO₂) und VO_{2max} am arbeitenden Pferd nur unter Laborbedingungen möglich. Seit kurzem steht Cosmed K4 b²[®], ein portables telemetrisches Gasanalysesystem für den Einsatz am arbeitenden Pferd zur Verfügung. Ziel der Studie war die Prüfung dessen Einsatzfähigkeit für metabolische Messungen am Pferd unter dem Reiter. Zur Anpassung von Cosmed K4 b²[®] an die spezifischen Bedingungen beim Pferd wurde eine luftdicht abschließende Atemmaske entwickelt (Equimask[®]) und diese mit einem Hackamore-Halfter verbunden. Zwei Öffnungen innerhalb der Maske erlauben den Durchfluss der Atemluft durch 2 Turbinen, über die Messungen des Atemzugvolumens (VT), der Atemfrequenz (RR) und des Expirationsminutenvolumens (VE) möglich sind. Proben der Expirationsgase werden an einer der Turbinen entnommen und in der portablen Cosmed K4 b²[®]-Messeinheit, die an der Brustwand des Pferdes fixiert wird, auf den Gehalt an O₂ and CO₂ analysiert. Die tragbare Einheit zeichnet metabolische Parameter ebenso wie die Herzfrequenz (HR) und Geschwindigkeit auf. Vier gesunde und trainierte Military-Pferde, ausgerüstet mit dem portablen Messsystem, absolvierten innerhalb von 3 Wochen 3 Laufband-Stufentests (TT1 to TT3) und einen Feldtest (FT). Der Laufbandtest bestand aus einer Aufwärmphase gefolgt von 2 Minuten Galopp bei 7, 8 m/sec (TT1) und 9 m/sec (TT2 and TT3). Beim Feldtest wurden die Pferde nach einem Warmup zweimal in einem Reitpaddock galoppiert. Bei allen Test wurden den Pferden jeweils unmittelbar nach den Galoppphasen Blut für den Laktatnachweis (LA) entnommen. Der Zeitverlauf der kardiorespiratorischen Parameter während des Stufentests auf dem Laufband zeigte den Einfluss des Stresses auf die Messungen: Im Verlauf der Gewöhnung der Pferde an das Laufband zwischen TT1 und TT3 sanken LA and HR. Da VO₂ von allen Systemen zur O₂-Versorgung und damit von der kardiovaskulären Funktion abhängig ist, resultiert der Stresseinfluss in einem höheren VO₂ bei TT1 im Vergleich mit TT3. VO₂ war bei maximaler Geschwindigkeit auf dem Laufband geringer als das erwartete VO_{2max} der Pferde unter dem Sattel. Beim Feldtest war VO₂ beim letzten Galopp niedriger als jeder beim Laufbandtest gemessene VO₂-Wert. Dies zeigt wieder die Schwierigkeit auf, beim Pferd unter dem Reiter unter Feldbedingungen VO_{2max} zu erreichen. Der errechnete Respirationsquotient (RQ) war bei jeder Geschwindigkeit mit den physiologischen Werten inkompatibel, was darauf hinweist, dass das System die CO₂-Versorgung beim arbeitenden Pferd nicht exakt messen kann. Die Ergebnisse der Untersuchung zeigen, dass beim Pferd unter dem Reiter unter Feldbedingungen kardiorespiratorische Parameter gemessen werden können. Die Ergebnisse zeigen auch die Notwendigkeit, 1. zur Stressreduzierung die Pferde an die Testbedingungen zu gewöhnen, 2. hoch standardisierte Test zu verwenden, um VO₂ in Abwesenheit von VO_{2max} verlässlich interpretieren zu können und 3. zur Beurteilung der Kondition von Pferden unter dem Reiter unter Feldbedingungen auf einen anderen physiologischen Parameter als VO_{2max} auszuweichen. Die Studie eröffnet bei der Verlaufsuntersuchung von Pferden neue Perspektiven bezüglich der Bewertung der Anpassung an Training und Kondition unter Feldbedingungen.

Schlüsselwörter: Leistung, Sauerstoffaufnahme, pulmonal, Feldtest, portables Messsystem, Cosmed K4 b²

Introduction

In the exercising horse, the oxygen delivery to the muscle enables the regeneration of high-energy phosphates (ATP) which are necessary for sustaining an effort and for subsequent

recovery. For a fixed and constant level of submaximal exercise, the pulmonary oxygen uptake (VO₂) reflects a balance between the energy required by the working muscles and ATP production via the aerobic metabolism. In horses performing

high-intensity maximal exercise, it is, in fine, the cells of the locomotory muscles that determine the demand in oxygen because over 90 % of the energy spent is dedicated to muscle cells (Hoppeler and Weibel 1998). The point at which VO_2 plateaus and shows no further increase with additional workload corresponds to the maximal aerobic power, or $\text{VO}_{2\text{max}}$. The $\text{VO}_{2\text{max}}$ is an important variable that sets the upper limit for submaximal performance and thus correlates to athletic performance in horses (Harkins et al. 1993, Gauvreau et al. 1995). Study of the metabolic response to exercise has proved to be of great value to determine fitness as well as to study the effects of training or detraining in sport horses (Seeherman and Morris 1990, Art and Lekeux 1993, Betros et al. 2002, Ohmura et al. 2002). To the authors' knowledge, up to now, VO_2 and $\text{VO}_{2\text{max}}$ measurements in exercising horses have been limited to treadmill tests because the gas analyzer used to measure VO_2 and carbon dioxide delivery (VCO_2) required a heavy stationary apparatus. Therefore, field testing of sport horses has usually been based on heart rate (HR) and blood lactate (LA) determination without any direct evaluation of respiratory components (Kobayashi et al. 1999, Courouce et al. 2002, Davie et al. 2002). In human sport medicine, metabolic parameters during field testing may be evaluated using the commercially available Cosmed K4 b2[®],1 portable telemetric gas analysis system (Laconi et al. 1998, Doyon et al. 2001, Thomas et al. 2005) which has been validated in human (Duffield et al. 2004). Recently, the system has been adapted to horses and the validity of the measured parameters has been controlled (Art et al. 2006). The purpose of this study was to examine the feasibility of metabolic measurement to record physiologically significant parameters in ridden exercising horses.

Materials and methods

The portable metabolic measurement system

Adaptation of the K4 b2[®],1 to horses' specificities included the design of an airtight face-mask (Equimask[®],2; Figure 1). The Equimask[®],2 is a lightweight preformed plastic mask that contains internal pieces of foam to allow a snug fitting over the horse's muzzle. A silicone rubber gasket ensures an airtight seal and can be fastened with external straps. The Equimask[®],2 is adapted to a hackamore bridle that allows riding the horse whilst maintaining the mask airtight. The dead space in the mask is around 0.5 L (Art et al. 2006). Two openings in the mask, facing each nostril, direct the transit of respiratory airflow through 2 bidirectional turbines (internal diameter: 60 mm). Rotation of the turbines with airflow is measured by an opto-electronic reader that counts the revolutions/sec. The K4 b2[®],1 portable unit integrates this information to calculate the tidal volume (VT), respiratory rate (RR) and minute expired volume (VE). Lung volumes and flows are given in BTPS conditions. The expired gases are sampled at the level of one of the turbines and collected in the portable unit strapped to the horse's chest wall via a sampling line (Nafion[®],3 tubing). The collected gases are analysed for O_2 and CO_2 content. The oxygen-polarographic zirconium cell-analyser (range 7-24%; accuracy: $\pm 0.02\%$) and the infrared non-dispersive thermostatically controlled carbon dioxide analyser (range 0.0-8.0%; accuracy: $\pm 0.01\%$) measure the end tidal O_2 (FETO₂) and CO_2 (FETCO₂) fractions, respectively. The

portable unit, powered by a rechargeable battery, records metabolic parameters as well as HR (Heart rate Polar Equine Transmitter[®],4) and speed owing to a GPS system (GPS AutolocateTM,5; horizontal accuracy: < 15 meters).

Before each use, the O_2 and CO_2 analysers were calibrated with ambient air (assuming O_2 and CO_2 fractional contents of 20.9 % and 0.03 %, respectively) and a O_2 - CO_2 mixture with definite concentrations (O_2 and CO_2 fractional contents of 15 % and 5 %, respectively). The delay between airflow and gas signal was measured using the sampling line utilized



Fig 1 Photograph of a horse wearing the Equimask[®]. This mask especially designed for horses is a lightweight preformed plastic mask adapted to a hackamore bridle that allows riding the horse whilst maintaining the system airtight. Two bidirectional turbines facing each nostril enable measurement of respiratory parameters. Expired gases are sampled at the level of one of the turbines to be analysed for O_2 and CO_2 in a portable unit strapped to the horse's chest wall.

Pferd mit Equimask[®]. Die Maske wurde speziell für Pferde entwickelt, eine leichte Kunststoffmaske, adaptiert an ein Hackemore-Halfter, was die Messung unter dem Reiter ermöglicht. Zwei gegenläufige Turbinen über jeder Nüster ermöglichen die Messung respiratorischer Parameter. Proben der Expirationsgase werden im Bereich einer der Turbinen entnommen und in der portablen Messeinheit, die an der Brustwand des Pferdes fixiert ist, auf O_2 und CO_2 analysiert.

during the test protocol. According to the manufacturer, no volume calibration is required prior to the test. The accuracy of volume measurement is regularly checked by the manufacturer during routine maintenance of the system (at least twice a year). However, it must be specified that this check is performed using 3, 5 and 7 L-syringes of air sent at 20 and 40 pulses per minute to the system.

Experimental protocol

Four healthy trained military horses (weight = 546.3 ± 51.8 kg, age = 6.4 ± 0.1 yr; [means \pm SD]; 2 geldings and 2 females) were used. Each horse was equipped with the adapted portable system and completed 3 incremental treadmill tests (TT1 to TT3) and 1 field test (FT) within 3 weeks. The treadmill tests

consisted of a warm-up period (5-min walk [1.5 m/sec] and 5-min trot [4 m/sec]) followed by galloping for 2 min at 7 and 8 m/sec during TT1 and for 2 min at 7, 8 and 9 m/sec during TT2 and TT3. For FT, ridden horses were galloped twice for 2 min in a large riding paddock (80 x 60 m) after a warm-up period (Figure 2). The speed of the second gallop corresponded to the maximum speed that could be subjectively and reasonably attained by the rider with each horse in these specific field conditions (i.e. wearing a facemask and galloping in a paddock). The speeds attained during FT were calculated by the GPS system and checked by manual chronometry.



Fig 2 Photograph of a horse galloping with Equimask® und Cosmed K4 b²® during the field test.
Pferd mit Equimask® und Cosmed K4 b²® während des Feldtests

Cardiorespiratory measurements were collected continuously throughout the tests. Horses' blood was sampled within 15 sec following each gallop for determination of LA using a portable lactate analyzer (Accutrend®⁶).

Data analysis

The respiratory coefficient (RQ) was calculated by dividing VCO_2 by VO_2 on a breath-by-breath basis. Results of the breath-by-breath data, HR and running speed (during FT) collected during the last minute of each step were averaged. This study did not aim to compare the acquired parameters under different experimental conditions (e.g. treadmill tests vs. FT) but to challenge the feasibility of using the described technology to field testing. Therefore, no statistical analysis was applied to the data. In addition, the small number of subjects ($n = 4$) impedes valid statistical analysis.

Results

Time-course of breath-by-breath values for VO_2 and HR are shown graphically for a representative FT of one horse in Figure 3. Mean (\pm SD) running speeds, LA and HR recorded during the treadmill tests and FT are presented in Table 1. Mean (\pm SD) breath-by-breath values for RR, VT, VE VO_2 , VCO_2 and RQ are presented in Tables 2 and 3.

All horses completed the treadmill tests and FT satisfactorily. Time-course of cardiorespiratory parameters during the successive treadmill tests showed reduced LA and HR at 8 and 9 m/sec galloping speeds whereas higher VO_2 and VCO_2 were found in TT1 vs. TT3. During FT, the mean (\pm SD) galloping speeds attained were 5.7 ± 0.3 m/sec (1st gallop) and 6.2 ± 0.4 m/sec (2nd gallop) with maximal peak of 7.2 ± 0.5 m/sec. The speeds given by the GPS system were slightly lower than the ones calculated by chronometry (data not shown). The VO_2 reached at the final gallop was lower than the VO_2 recorded during any of the treadmill tests. The cal-

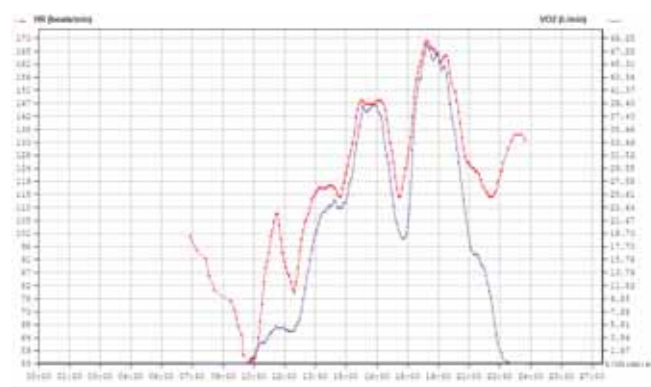


Fig 3 Heart rate and pulmonary oxygen uptake (VO_2) recorded over time (t) during a field test with one representative horse. The VO_2 is expressed in L/min without taking into account the weight of the horse as opposed to the data in Table 3 where VO_2 is expressed in ml/kg/min.
Herzfrequenz (HR) und pulmonale Sauerstoffaufnahme (VO_2) über die Zeit (t) während eines Feldtests bei einem repräsentativen Pferd. VO_2 ist in l/min ausgedrückt ohne Berücksichtigung des Pferdegewichts im Gegensatz zu den Werten in Tabelle 3, die in ml/kg/min ausgedrückt sind.

culated RQ at any speed (except during walk; data not shown) was incompatible with physiologic data.

Discussion

Reliability of the system

The bi-annual calibration of the volume performed by the K4 b²®,¹ manufacturer mimics a maximal VE of 280 L/min which is far below the 1,500 L/min that may be reached during high-intensity exercise in horses (Art et al. 1990, Art and Lekeux 1995). However, the K4 b²® has proven to reliably measure VE even at high workloads (Art et al. 2006). The consistency of metabolic measurements has been confirmed for all the parameters described in our study except for measurement of VCO_2 which tended to be underestimated most probably because the response-time of the infra-red analyser that measures FETCO₂ was too slow at high RR (Art et al. 2006). In our study, the calculated RQ (from 0.4 to 0.6) were too low as compared to physiological data thus confirming the unreliability of the VCO_2 measurement with the K4 b²® in exercising horses.

The GPS system tended to underestimate the speeds of horses during FT. This is most probably explained by the accuracy of the system which would prevent precise determination of the speed in horses moving in a small area.

Table 1 Mean \pm SD ($n = 4$) speed, lactatemia (LA) and heart rate (HR) recorded during 3 incremental treadmill tests (TT1 to TT3) and 1 field test (FT). *Mittlere \pm SD ($n = 4$) Geschwindigkeit, Blutlaktat (LA) und Herzfrequenz (HR) während 3 Laufband-Stufentests (TT1 to TT3) und 1 Feldtest (FT).*

Gait	Speed (m/sec)				LA (mmol/L)				HR (beats/min)			
	TT1	TT2	TT3	FT	TT1	TT2	TT3	FT	TT1	TT2	TT3	FT
T	4.0 ± 0.0	4.0 ± 0.0	4.0 ± 0.0	3.5 ± 0.5	---	---	---	---	137.4 ± 23.3	132.9 ± 35.1	77.8 ± 28.6	141.3 ± 21
G1	7.0 ± 0.0	7.0 ± 0.0	7.0 ± 0.0	5.7 ± 0.3	4.4 ± 2.6	2.3 ± 0.7	3.1 ± 1.4	1.9 ± 0.3	181.3 ± 21.3	148.9 ± 20.3	153.3 ± 8.6	163.2 ± 14.5
G2	8.0 ± 0.0	8.0 ± 0.0	8.0 ± 0.0	6.2 ± 0.4	3.9 ± 1.7	2.3 ± 0.4	2.0 ± 0.5	2.4 ± 0.6	172.4 ± 27.5	151.0 ± 26	131.1 ± 34.4	167.1 ± 6.1
G3	---	9.0 ± 0.0	9.0 ± 0.0	---	---	2.8 ± 0.3	2.5 ± 0.5	---	---	165.0 ± 7.7	162.9 ± 5.2	---

T: trot; G1: 1st gallop; G2: 2nd gallop and G3: 3rd gallop.

Table 2 Mean \pm SD ($n = 4$) respiratory rate (RR), tidal volume (VT) and minute expired volume (VE) recorded during 3 incremental treadmill tests (TT1 to TT3) and 1 Field test (FT).

Mittlere \pm SD ($n = 4$) Respirationsrate (RR), Atemzugsvolumen (VT) und expiratorisches Minutenvolumen (VE) während 3 Laufband-Stufentests (TT1 to TT3) und 1 Feldtest (FT).

Gait	RR (breaths/min)				V _T (L)				V _E (L/min)			
	TT1	TT2	TT3	FT	TT1	TT2	TT3	FT	TT1	TT2	TT3	FT
T	71.4 ± 27.2	68.1 ± 13.3	62.9 ± 11.4	87.6 ± 7.2	11.8 ± 2.1	11.5 ± 1.4	11.4 ± 0.8	10.9 ± 1.0	771.3 ± 82.1	761.1 ± 118.6	702.4 ± 64.9	899.0 ± 80.2
G1	99.6 ± 14.4	107.8 ± 5.3	105.9 ± 6	106.1 ± 2.7	14.6 ± 2.1	11.9 ± 1.3	12.7 ± 1.6	12.9 ± 0.4	1394.7 ± 143.1	1264.6 ± 118.2	1326.8 ± 200.7	1359.8 ± 10.5
G2	110.8 ± 4.1	111.0 ± 3.6	108.2 ± 4.5	109.3 ± 4.2	12.9 ± 1.7	12.6 ± 1.5	12.8 ± 1.5	13.7 ± 0.9	1417.2 ± 151.5	1395.1 ± 136.2	1375.6 ± 105.4	1498.8 ± 41.3
G3	---	110.6 ± 3.0	110.7 ± 5.0	---	---	13.7 ± 0.9	12.7 ± 1.7	---	---	1501.7 ± 78.4	1393.3 ± 166.2	---

T: trot; G1: 1st gallop; G2: 2nd gallop and G3: 3rd gallop.

Table 3 Mean \pm SD ($n = 4$) pulmonary oxygen uptake (VO₂) and carbon dioxide delivery (VCO₂) measured during 3 incremental treadmill tests (TT1 to TT3) and 1 field test (FT) and the calculated respiratory quotient (RQ) for each test.

Mittlere \pm SD ($n = 4$) pulmonale Sauerstoffaufnahme (VO₂) und Kohlendioxidabgabe (VCO₂) während 3 Laufband-Stufentests (TT1 to TT3) und 1 Feldtest (FT) und der errechnete Respirationsquotient (RQ) für jeden Test.

Gait	VO ₂ (ml/kg/min)				VCO ₂ (ml/kg/min)				RQ			
	TT1	TT2	TT3	FT	TT1	TT2	TT3	FT	TT1	TT2	TT3	FT
T	44.5 ± 10.1	37.8 ± 2.0	41.5 ± 8.2	40.2 ± 7.0	29.3 ± 13.9	21.7 ± 4.8	24.8 ± 6.6	21.2 ± 5.4	0.6 ± 0.2	0.6 ± 0.1	0.6 ± 0.1	0.5 ± 0.2
G1	99.1 ± 21.4	77.4 ± 18.6	91.1 ± 29.4	67.0 ± 9.4	65.0 ± 29.1	36.9 ± 16.2	45.9 ± 17.5	38.6 ± 15.3	0.6 ± 0.2	0.5 ± 0.1	0.5 ± 0.1	0.6 ± 0.2
G2	90.5 ± 17.8	81.6 ± 14.2	76.6 ± 2.4	75.8 ± 16.2	52.7 ± 23.8	36.2 ± 15.1	34.7 ± 3.6	41.3 ± 12.9	0.6 ± 0.2	0.4 ± 0.1	0.5 ± 0.1	0.6 ± 0.3
G3	---	81.6 ± 11.7	81.3 ± 3.8	---	---	31.5 ± 12	34.4 ± 4.3	---	---	0.4 ± 0.1	0.4 ± 0.1	---

T: trot; G1: 1st gallop; G2: 2nd gallop and G3: 3rd gallop.

Influence of stress

Time course of cardiorespiratory parameters during the successive treadmill tests showed the influence of stress on mea-

surements: with horses becoming accustomed to treadmill, LA and HR were significantly reduced between TT1 and TT3 at each galloping speed. As VO₂ is related to all systems involved in O₂ supply and thus to cardiac output (Jones and Lind-

stedt 1993, Hoppeler and Weibel 1998), influence of stress resulted in higher VO_2 in TT1 vs. TT3 at each gallop. This observation highlights the necessity to acclimatize horses to the face mask and test procedures in order to reduce the influence of stress on the measured parameters.

Reaching $\text{VO}_{2\text{max}}$ with saddle horses

Oxidative metabolism is the principal means of the organism to generate energy. The $\text{VO}_{2\text{max}}$ is the best parameter to estimate aerobic capacity because at $\text{VO}_{2\text{max}}$, the oxygen cascade (from respiratory system to mitochondria, see further) is saturated at one or several steps (the strongest determinant of $\text{VO}_{2\text{max}}$ being the capacity of the cardiovascular system to transport oxygen; Poole 2004). Therefore, $\text{VO}_{2\text{max}}$ measurement demonstrates a better reproducibility as compared to other estimates of maximal aerobic capacity (e.g. maximal HR [HRmax], velocity at a HR of 200 beats/min [V_{200}], VO_2 at a HR of 200 beats/min [VO_{2-200}], VO_2 at HR_{max} [$\text{VO}_{2-\text{HRmax}}$], work rate at a HR of 200 beats/min [W_{200}], work rate at HRmax [$W-\text{HRmax}$], LA threshold [i.e. the point at which an accelerated increase in LA concentration is noted] ...) which were found to be less precise (Evans and Rose 1988). At the highest level of treadmill exercise (9 m/s) the VO_2 reached (81.5 ± 7.8 ml/min/kg; mean \pm SD for TT2 and TT3) was lower than the expected $\text{VO}_{2\text{max}}$ (above 100 ml/min/kg) for trained sport horses (Evans and Rose 1988). During FT, the mean run speeds at gallop were below the lowest galloping speed of the treadmill tests. Therefore, the VO_2 reached at the final gallop (75.8 ± 16.2 ml/min/kg; mean \pm SD) was lower than any of the values obtained at gallop during the treadmill tests thus reflecting the increasing difficulty to reach $\text{VO}_{2\text{max}}$ with ridden horses in field conditions.

Measuring VO_2

In the absence of $\text{VO}_{2\text{max}}$ determination, assessment of fitness in sport horses must rely on other cardiorespiratory parameters. Aerobic capacity depends both on the availability of oxygen and the ability of muscle tissue to use that oxygen for energy. At $\text{VO}_{2\text{max}}$, the oxygen uptake may be considered as allotted to locomotory muscle cells (Hoppeler and Weibel 1998). On the other hand, the physiological significance of VO_2 under the level of maximal and a fortiori submaximal exercise must be interpreted with caution. The VO_2 is intimately linked to the systems required for supply (respiratory tract and lungs, RR, VT, alveolar-capillary membrane ...), transport (haemoglobin concentration ...), delivery (blood volume, cardiac output, peripheral blood flow, muscle capillarization, diffusive capacity at the capillary-myocyte interface ...) and utilisation (mitochondrial density, aerobic metabolism, ...) of oxygen. Therefore, external factors that interfere with one of the component of the respiratory cascade influence VO_2 especially when these factors act on the cardiovascular system. Stress and anxiety acting on the cardiac function are an example and the variation in HR observed during the successive treadmill tests performed in this study are a good illustration of the impact of these factors. Other examples of external factors may be found in the literature such as the effect of body incline on cardiac output (McDonough et al. 2002a) and VO_2 (Eaton et al. 1995, McDonough et al. 2002b) or such as the effect of hot and humid conditions on

aerobic metabolism (Art et al. 1995). Carefully controlled conditions and adequate preparation of the horse to test procedures are a prerequisite to correct interpretation of VO_2 data.

In addition, the VO_2 kinetics (the rate at which VO_2 adjusts to meet the new energy demand at the transition from one metabolic rate to another, Poole et al. 2004) imposes that VO_2 measurements in field trials are performed under controlled timing, ideally after attainment of an equilibrium corresponding to a constant load of exercise. The equine pulmonary VO_2 response following the onset of exercise has been characterised (Langsetmo et al. 1997). The VO_2 response to an exercise at constant work-rate depends on its intensity: at moderate levels of exercise (below LA threshold), the VO_2 steady state is achieved within 60 sec whereas at heavy exercise levels (above the LA threshold), the initial VO_2 fast response is markedly slowed down and followed by a secondary slow component of VO_2 which prevents attainment of a VO_2 plateau. This slow component is initiated within 2.5 min after exercise transition and is superimposed on the initial response. This slow component elevates VO_2 above that predicted from exercise below LA threshold or from the VO_2 -speed relationship determined during incremental exercise. Thus, accurate interpretation of VO_2 measurement is dependent on determination of level of exercise (i.e. using LA determination) and precise timing of VO_2 data acquisition. In field trials where $\text{VO}_{2\text{max}}$ may not be achieved, constant moderate exercise level might be a good alternative to define aerobic capacity under specific conditions.

New perspectives for exercise testing in the field

The portable metabolic system opens new perspectives for studying cardiorespiratory dynamics in horses as they carry out exercise in genuine field conditions. This system might be used to study the metabolic changes and energy cost induced by equestrian equipment/ harnessing (e.g. tension of the girth strap, draw or running reins, Gogue, Chambon ...), rider intervention (e.g. imposed attitude ["rassemblé", stooping, ...], gait used for a specific speed ...), horse's locomotory patterns (e.g. stride close to the ground vs. springy stride, extended vs. shortened paces ...) and/or environmental factors (e.g. quality of the track, outdoor vs. indoor exercise ...). More fundamental approaches include the study of the dynamic control of breath-by-breath VE and VO_2 in relation to HR, speed and gait (e.g. cardiorespiratory modifications at the transition from warm-up to maximal exercise achieved in field conditions and at the transition from exercise to active recovery [e.g. by trotting for a few minutes] ...). Such studies would probably provide additional key insights into equine sport medicine and would undoubtedly have applications in training management and conduct of competition in sport horses.

Conclusions

This study demonstrated that VO_2 and cardiorespiratory parameters may be obtained in ridden saddle horses during a field trial. It also highlighted the necessity (1) to acclimatize horses to the face mask and test procedures to reduce influence of stress on the measured parameters, (2) to perform highly

standardized tests, even in the field, to be able to interpret VO_2 in the absence of $\text{VO}_{2\text{max}}$ attainment and (3) to resort to other physiological parameters than the $\text{VO}_{2\text{max}}$ to predict the athletic capacity of ridden horses under field conditions. This study opens new perspectives in the follow-up of sport horses especially in the evaluation of adaptations to training and athletic capacities in real field conditions.

Acknowledgements

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Manufacturer's addresses

- ¹ K4 b²®, Cosmed SRL, Rome, Italy
- ² Equimask®, Cosmed SRL, Rome, Italy
- ³ Nafion® tubing, Perma Pure INC, New Jersey, USA
- ⁴ Polar Equine Transmitter®, Polar Electro Europe BV, Fleurier, Switzerland
- ⁵ GPS Autolocate™, Garmin International INC, Kansas City, USA
- ⁶ Accutrend® Lactate, Roche, Basel, Switzerland

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