Pferdeheilkunde 22 (2006) 5 (September/Oktober) 525-530

Equine exercise physiology - Transforming laboratory studies into practical concepts

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Summary

Exercise physiology has brought new insights in equine performance and the basics thereof will be reviewed in this paper. In those disciplines were speed plays an important role in the total performance, post exercise lactate, heart rate and speed monitoring provide suitable parameters to determine training level and condition. Standard protocols so far have not been designed and can not be designed due to the large variation in the conditions of training facilities. Therefore, tailor made protocols must be designed for the individual training yards. All currently available monitoring toys and laboratory tools, however, can not replace clinical skills such as observation of gait abnormalities and of negative changes in behaviour. Therefore, helping trainers to monitor the health and progress of their pupils in training remains a mixture between art and science. The latter can be learned, but being keen observers, most equine clinicians will succeed in managing the art as well.

Keywords: exercise physiology, heart rate monitors, lactate analysers, muscle biopsy, standard exercise test.

Leistungsphysiologie beim Pferd – Die Übertragung wissenschaftlicher Ergebnisse in praktische Konzepte

Die Leistungsphysiologie beim Pferd brachte in den letzten Jahren neue Erkenntnisse und der folgende Beitrag fasst diese zusammen. Hochgeschwindigkeitsstudien spielen in diesem Bereich eine große Rolle. Die Gesamtleistungsfähigkeit, Post exercise-Laktat, Herzfrequenz und Geschwindigkeitskontrolle stellen wichtige Parameter zur Bestimmung von Trainingslevel und Kondition. Standardprotokolle wurde hierbei noch nicht erarbeitet und sie sind wegen der großen Vielfalt unterschiedlicher Trainingsbedingungen auch nicht zu erwarten. Maßgeschneiderte Trainingsprotokolle müssen sich auf den jeweils speziellen Trainingsort beziehen. Alle derzeit zur Verfügung stehenden Labor- und Kontrolltechniken können jedoch klinische Betrachtungen wie die Untersuchung von Gangstörungen oder negative Verhaltensänderungen nicht ersetzen. So betrachtet ist die Unterstützung der Trainer bei der Kontrolle von Gesundheit und Trainingsfortschritt ihrer Pferde eine Mischung auch Kunst und Wissenschaft. Letzteres kann gelernt werden aber der Pferdetierarzt als aufmerksamer Beobachter ist für die erfolgreiche Arbeit ebenso wichtig.

Schlüsselwörter: Leistungsphysiologie, Herzfrequenz, Laktat, Muskelbiopsie, Standard, Leistungstest, Training

Introduction

More than 35 years have passed since *Åstrand* and *Rohdahl* started to study the physiological functions in human athletes during exercise in their Stockholm-based laboratory. Their book, first published in 1970, can be considered the basis of what currently has grown out as sports medicine. Also Stockholm-based in those days was the group around Prof. Sune Persson and Prof. Arne Lindholm, both working at the Swedish Veterinary Faculty. Equipped with a treadmill, they could follow an in concept similar systemic approach as did the team of *Åstrand* and *Rohdahl*. Off cause, numerous earlier researchers, some already from early 1900 and other of the late 1950ies and early 60ies (e.g. *Steel* 1963) had already published facts for better understanding the potentially important parameters of sporting horses, but standardising work load without a treadmill was difficult to attain in those days. Telemetric recording of heart rates and respiratory parameters in the field, as *Hörnicke* et al. (1986) already practised in the late 1970ies was a tedious and technically demanding procedure. However, most researchers were less well equipped and parameters like heart rate or respiratory rate still were determined by auscultation and observation immediately after exercise. Haematology was often performed early in the morning at rest, but often, due to existent excitation by the act of sampling and subsequent splenic contraction, values were sometimes difficult to interpret. *Persson* (1967) therefore considered post exercise haematology to be the better alternative. He came up with the concept of polycytemia (PCV > 0.67 l/l) as a possible sign of overtraining. However, more recently *Tyler-McGowan* (1999) could not find physical markers for overtraining, however, empirical observations revealed that the behaviour of overtrained horses had changed.

With the first conference of Equine Exercise Physiology organised by the ICEEP in Cambridge in 1982 the discipline really set foot and since than a vast majority of information on the exercising horse has been published and still is. In fact, too much to summarize here. At the moment already 6 volumes of ICEEP Proceedings on equine exercise physiology have been published and last year a special journal on equine and comparative exercise physiology has seen the light.

Initially, most research was done on standardbred trotters and thoroughbreds, but later studies with quarter horses eventing horses, long distance horses and saddle horses followed. A special sub-discipline was biomechanics and motion analysis. Nowadays, exercise physiology covers all subjects like cardiopulmonary adaptation, neuro-muscular, hormonal and metabolic response to work, nutritional aspects, transport stress, heat balance and motion analysis (*Marlin* and *Nankervis* 2002). Off course, most studies have been performed under laboratory conditions, however a growing number of researchers following initial attempts such as for instance by *Bayley* et al. (1983) and *van den Hoven* (1983), now try to apply tests under field conditions (*Courouce* et al. 2002, *Davie* et al. 2002, *Evans* et al. 1993, *Evans* et al. 2005, *Kobayashi* et al.1999, *Robert* 2001, *Sloet van Oldruitenborgh-Oosterbaan* et al. 1987, *Trilk* et al. 2002) in order to predict efficacy of training or racing potential.

It is the aim of this paper to summarize the principles of these tests and to indicate elements that could be of help for the equine practitioner in the field when dealing with a problem of disappointing performance or when his opinion is asked on a training schedule.

An excellent review of the basics of exercise physiology in the German language is given by *Krzywanek* (2006), himself being one of the earlier researchers. For the English speaking readers the book by *Marlin* and *Nankervis* (2002) provides a tool to become quickly acquainted with exercise physiology.

Energy metabolism during exercise

A good overview on the costs of locomotion has been given by *McMiken* (1983). When horses move, most of the energy for normal locomotion, in principle, is delivered by the lipid and carbohydrate breakdown. Since there is plenty oxygen in the earth's atmosphere, the aerobic metabolism of these fuels is the most energetically efficient from, however the energy released per unit of time is insufficient to sustain fast locomotion. Rapid delivery of energy is by the anaerobic metabolism of glucose. However, this provides the necessary energy at considerable higher cost. Glucose units from glycogen that are metabolised aerobically generate in total 39 mol ATP per mol, while anaerobically only 3 mol ATP are produced. Why does the horse than use the anaerobic pathways anyway? In order to start running, the animal immediately need plenty energy. Some of this is stored as instantly available phosphocreatine (PCr) and ATP (the total of these energy rich phosphates is also known as phospagen store). Furthermore, some extra energy can be generated when 2 molecules of ADP give one ATP and one AMP. The AMP subsequently is metabolized into ammonia and uric acid. If after 6 to 20 seconds of running these phosphogen resources are exhausted for more than 50%, glucose released from intramuscular glycogen is anaerobically metabolised to supplement the ATP pool. The activated anaerobic glycogenolysis keeps the animal moving at high speeds for about another minute or two at the cost of build up of lactate. At the moment that ATP depletion is threatening again, the cardiopulmonary system must have adapted to the higher oxygen demand of the exercising muscles and if so, the animal can keep its speed. If not it will slow down. Hence, during explosive activities, horses strongly depend on anaerobiosis, while exercise of longer duration at submaximal speed or power depends rather on aerobic metabolism.

The magnitude of aerobic power is determined by the cardiac dimensions, lung function and the ability of the muscle fibres to extract oxygen from the blood. This oxygen uptake can be measured directly in working horses on a treadmill. Oxygen uptake is proportional to speed, only at very high speeds oxygen uptakes levels off and the anaerobic metabolism comes to help sustaining maximal speed for a short period as discussed above. The maximal oxygen uptake per kg body weight is a parameter of the horse's performance level (*Thornthon* et al. 1983). Fit, elite race horses have high maximal oxygen uptake.

Muscles contain a heterogenic pool of muscle fibres. Both type I and IIA fibres have a high capacity to metabolise oxygen. In contrast type IIB fibres rather have a high capacity for anaerobic glycogenolysis. Therefore the latter are also referred to as "sprint fibres". To characterize the work load imposed upon a horse, it is possible to measure oxygen uptake. However, in the field this is difficult. Since oxygen uptake and heart rate are reasonably well correlated, measuring heart rate and expressing this as % of maximal heart frequency gives a good impression whether the work required from the horse is mainly aerobic or anaerobic. Simple validated "on board" heart rate monitors (e.g. Polar® systems) have been available for some decennia (*Physick-Sheard* et al.1983, *Sloet van Oldruitenborgh-Oosterbaan* et al. (1988). These devices have storage functions and the stored information can easily be transferred to a laptop from which time -frequency plots can be printed. The newest trend is speed monitoring by GPS (*Evans* et al. 2005)

Above a heart frequency of 150 beat per minute (bpm) horses start to accumulate lactic acid in their blood due to an increasing contribution of the anaerobic metabolism to the energy output. By taking a post exercise blood sample in which lactate is analysed, an impression can be obtained on the level to which the horse was driven into anaerobiosis. The magnitude in which the ATP pool has been depleted can be estimated by measuring post exercise uric acid or ammonia blood levels. These parameters so far have not been exploited to their limits yet, but could be of help to study work load of sprinters, show jumpers and draft horses.

Quantification of work load of various horse sports disciplines.

In Table I, a quantification of work load for the various disciplines of horse sports has been made based on estimated relative contribution of the energy delivering metabolic pathways.
As can be seen, anaerobic features in decreasing order of importance are to be considered for quarter horses, race horses, trotters, show jumpers and eventers. In jumping, anaerobiosis plays a role for the push off. In other disciplines aerobic energy suppletion plays a major role. Many disciplines such as dressage do not exploit the maximal aerobic power of the horse; therefore poor performance in these horses mostly is not caused by suboptimal maximal aerobic power.
A procedure to test condition in horses is to design a standard exercise test (SET). Heart rate monitors are used to quantify the work load. Furthermore, simply training horses over a set distance and for a set time, followed by taking blood samples for lactate at 3 to 5 minutes after ending the exercise, can provide very useful information on the work load that was

Table 1 Estimated relative contribution of the energy generating pathway to the performance (modified from data by Bayly et al. 1985).
Geschätzte relative Verteilung der Energie-liefernden (modifiziert nach Bayly et al. 1985)

Horse type and exercise	Anaerobic		Aerobic
	Phosfagen	Gycogenolytic	
Quarter Horse 400 m	80%	18%	2%
Thoroughbred 1000 m	25%	70%	5%
Thoroughbred 1600 m	10%	80%	10%
Thoroughbred 2400 m	5%	70%	25%
Thoroughbred 3100 m	5%	55%	40%
Trotter 1600 m	10%	60%	30%
Trotter 2400 m	5%	50%	45%
Show jumper 400-800 m	15%	65%	20%
Eventer 4-6 km	10 %	40%	50%
Endurance >60 km	1%	5%	94%

imposed. However, the interpretation of the results is not straightforward as is explained next. High intensity exercise is associated with production of energy by both aerobic and anaerobic metabolism. Conditioning by repeated exercise increases the maximal rate of aerobic metabolism of horses, but whether the maximal amount of energy provided by anaerobic metabolism can be increased by conditioning of horses is unknown. *Hinchcliff* et al. (2002) therefore, examined the effects of 10 weeks of regular (4-5 days/week) high intensity exercise on accumulated oxygen deficit of 8 standardbred horses that had been confined to box stalls for 12 weeks prior to the experiment. They showed that conditioning with high intensity exercise had induced an increase in both aerobic and anaerobic capacity. Furthermore, the increase in anaerobic capacity was not reflected in the blood lactate concentrations that were measured during intense, exhaustive exercise or during recovery from such exercise. Therefore increased post exercise blood lactate levels concentration will only indicate that aerobic metabolism has been utilized near to its full capacity and that anaerobic metabolism has contributed to the total performance too.

The extent to which ATP pools are recruited might be estimated by post exercise blood ammonia and uric acid concentrations. However guidelines how to interpret elevated concentration for the latter two have still to be developped.

A commonly accepted way to express a horse's work capacity is to calculate its running velocity at a heart frequency of 200/min. This parameter is abbreviated as V_{200} (m/s) and is a hybrid parameter with a main aerobic and a minor anaerobic component. Another speed related parameter is the V_{La4}, the calculated speed that a horse produces at a lactate concentration of 4 mmol/l. This lactate level, a bit arbitrary chosen in analogy with human sport medicine, is believed to represent the aerobic-anaerobic threshold. Work performed below this level is fully aerobic. Work performed beyond this threshold results in a rapid accumulation of blood lactate as a result of intra muscular anaerobic glycogenolysis. Training improves both V_{200} and V_{La4}.

The progress in cardiopulmonary condition normally is quite fast and in practice it is less of a limiting factor than the skeletal system which lags behind in its adaptation to the stress of work. Therefore, monitoring the soundness of the legs should never be neglected. Hence if mild signs of overload are observed, training must be decreased or stopped to let the skeletal system adapt accordingly to the high demands of training. Alas, there are no simple markers yet that indicate overload of tendon tissue, cartilage or bone. Therefore clinical judgement of the gait und the soundness of legs is of utmost important to prevent damage.

Can the athletic performance be predicted by muscle biopsy? By looking at the fibre type % in muscle biopsies of gastronomic muscle, *Åstrand* and *Rohdahl* (1970) could select elite marathon skiers based on their higher % type I fibres. This fact opened perspectives to select elite race horses based on their fibre type composition of the gluteus medius or another hind limb muscles. It all started promising when *Snow* and *Guy* (1980) showed breed differences in muscle fibre composition (Table 2). However the enthusiasm was tempered when *van den Hoven* at al. (1985), *Bruce* and *Turek* (1985) and *Bruce* et al. (1993) showed that within a breed, the inter individual variation was equally large as the intra individual variation. Since horses have been selectively bred for speed already for some hundreds of years, it is logic that the within-breed variation in muscle composition is small. Furthermore, in contrast to man, in whom fibres are randomly distributed within the muscle, the fibres in the horse are more compartmentalized. The more aerobic fibres are located at the inside of the muscle, the more anaerobic fibres more to the outside (*van den Hoven* 1985, *Raub* et al. 1985, *Bruce* and *Turek* 1985 and *Bruce* et al. 1993). Without a rigorous standardisation of the

Table 2 Breed dependent Type I fibres in the gluteus medius muscle (data by *Snow* and *Guy* 1980).
Rasseabhängige Gehalt an Typ 1-Fasern im M. gluteus.

Quarter Horse	9 %
Thoroughbred	11%
Arab	14 %
Standardbred	18 %
Shetland pony	23 %
Donkey	24 %
Heavy hunter	31%

biopsy technique, which is less simple as it looks at first glance due to the various individual shapes of muscles, obtained results are not very useful. However in breeds such as quarter horses, American paints, thoroughbreds and standardbreds a muscle biopsy can be a diagnostic tool for the differentiation of various forms of exercise induced rhabdomyolysis and other myopathies (*van den Hoven* 1987, *Nollet* and *Deprez* 2005).

Monitoring post exercise electrolyte changes

Rose (1983) laid the basis for the parameters of the veterinary checks for long distance rides. Especially horses competing in these races are submitted to large losses of body water and electrolytes (sodium, chloride, calcium and magnesium), mainly by sweating (*Rose* and *Hodgson* 1982). Most problems occurring in this discipline are dehydration and electrolyte imbalance, colic and rhabdomyolysis. The ability of the individual horse to cope with the metabolic and homeostatic stresses of long distance running can be monitored after training by measuring plasma electrolyte levels and glucose concentration and measuring activities of CK and AST. Using heart rate monitors, riders can be taught how to keep their horses in steady state. With handheld blood gas analysers (e.g. i-Statt) even blood pH, pCO_2 and bicarbonate concentrations can be determined; however these devises are quite expensive.

Coping with environmental stress

Prior to the Olympic Games in Atlanta in 1996, *Jeffcott* and *Kohn* (1999) set up an international research programme to study the effects of the weather conditions on performing horses, especially aimed at eventers and driving horses. The primary objective of this effort was to identify strategies for ensuring welfare of horses competing in the heat. Field observations of horses during the endurance test of 3-day events in Europe, Canada, and the USA characterised the work effort of this form of competition; laboratory explored the relationships of thermoregulatory demands to the phases of the competition and documented fluid and electrolyte losses. Estimates of energy expenditure and heat production during the endurance test were made. Strategies for facilitating heat dissipation were also studied in depth. Assessment of the effect of environmental conditions was based upon intensive climate monitoring using a modification of the Wet Bulb Globe Temperature index. Studies on adaptation to thermal stress provided a basis for recommendation of acclimatization times for horses before the Games. The results of all these studies guided the management of equine athletes at the 1996 Olympic Games and significantly advanced knowledge of thermoregulation in competitive horses.

Are there any breed and sport specific tests available yet?

So far an increasing understanding of the working sport horse under laboratory conditions or in the field has been obtained by the various studies. However, except for thoroughbreds and standardbreds, no suitable recognised protocols have been developed. However, if the demands of the sporting activity that the horse has to perform are understood, a monitoring program based on heart rate, blood lactate, speed and distance recording and post exercise biochemistry of plasma samples and electrolyte concentrations can be designed.

Monitoring training induced improvement with standardized exercise test (SET) in the field appeared feasible.

Kobayashi et al. (1999), for example, investigated the usefulness of an incremental exercise test to measure V_{200} for evaluation of training effects in the young thoroughbred. Heart rate and velocity and V_{200} were highly correlated for horses that exercised smoothly during gait changes and had acceleration during the canter in relaxed and non-excitable states. V_{200} appeared a reproducible parameter if all testing conditions could be kept constant. The average V_{200} in 2-year-old thoroughbreds significantly increased from 623 ± 55 m/min to 691 ± 64 m/min after 5 months of training.

Trilk et al. (2002) demonstrated that a lactate-guided conditioning programme at a treadmill could significantly enhance endurance performance over a 6-week time period when the conditioning protocol is adjusted every 2 weeks based on VLa4 improvement. Mean V_{La4} increased 17% (5.8 ± 0.3 to 6.8 ± 0.4 m/s). VLa4 can be determined in the field with some effort.

Courouce et al. (1999) performed SETs at 2 different tracks and on a treadmill during the same week to determine the influence of exercise surface on heart rate, blood lactate concentration, packed cell volume, stride frequency, stride length, gait symmetry and regularity and on different derived physiological variables such as the V_{200}, V_{La4}, VHR_{max}. Five French Trotters, aged 3 years, in training for 3 months prior to the test, performed 3 exercise tests on a training track (Test 1), a racetrack (Test 2) and a treadmill (Test 3). Test 1 utilized 3 steps each of 3 min at speeds of 490, 560 and 630 m/min. Test 2 and 3 utilized the same speeds and a fourth step in which the horse was accelerated for 30 seconds to speed approaching maximal. No significant differences were found for the physiological and locomotor variables between the 2 tracks. In contrast, as could be expected, there was a significant difference for these variables between the tracks and the treadmill. Horses showed lower heart rate and blood lactate response, reduced stride frequency and increased stride length and regularity on the treadmill. The authors concluded that their SET was repeatable on various tracks even when the surface and geometry varied. In contrast, both physiological and locomotor variables were different when comparing the tracks with the treadmill.

By monthly monitoring lactate levels after SETs, a trainer can follow the progress of his pupils and can adapt his training accordingly. Furthermore, it also useful to determine red blood cell parameters immediately after exercise since these are related to aerobic power (*Persson* 1967), although not directly to successful performance. Next, a sample preferably taken 4 hours after work could be analysed for CK and AST activity, in order to detect subclinical rhabdomyolysis. Lactate can be measured directly at the track using e.g. an Accusport® analyser (*Lindner* et al. 1996, *Simmons* et al. 2002), or samples collected in NaF/K-EDTA containing tubes can be sent to a laboratory. Using SET-guided training we were able to successfully race 14 out of 24 yearling trotters brought to training before they had reached the end of their 3rd year. Off cause, each horse was run according to its capacity and a race career was designed accordingly. This also implicated that less talented horse could stop their career earlier, since their owner understood why further training was not beneficial to both horse and himself. Other horses kept racing from 2 till 9 years of age. About one third of these horses competed successfully in classical or highly dotated races.

Munoz et al. (1998) studied 3-day event horses and found that a SET including a warm-up of 5 min walking and 6 min of trotting, followed by galloping at 400 m, 500 m, 600 m and 700 m/min over 1000 m with 5 min walking in between resulted in blood lactate levels of 4 mmol/litre or more. More results were not reported, but these figures could be used as bench marks.

Using the Accusport® equipment to monitor work load of a marathon for driving horses, we were able to show that within one horse pair the same speed represented different work loads. This was traced back to unequal training status or one horse doing all the work, while the other just was pretending.

We also showed the effects of different track conditions in eventing. Horses jumping a course at nearly the same speed, performed this effort totally aerobic (lactate < 4 mmol/l) on a supple tract and moderately anaerobic (lactate 15 mmol/l) the next week on a deep sandy track.

With GPS systems speed monitoring has become a simple procedure (*Evans* et al.2005). GPS monitoring is the new tool around which new SET can be developed. Furthermore GPS will likely replace many judges in the marathon part of driving competition.

Can the athletic performance be predicted by tests?

Conformation and body shape in thoroughbreds, trotters and saddle horse and even pedigree empirically have used to select suitable sporting horses. Furthermore gaits and ability to jump can be judge in free moving horses. In fact this is what most studbooks or individual breeders still apply to select their breeding stock for producing sport horses. Since it is estimated that performance is only determined for about 30% by genetic factors, it must be clear that there are no simple algorithms for selecting the ideal performing horse. Factors like character, so far, were difficult to quantify, but certainly must play an important role for a successful performance horse.

Recently, *Visser* (2003) developed a character test for saddle horse that could predict a substantial part of the show-jumping performance of an individual horse later in life by personality traits earlier in life.

Comparative prediction of aerobic capacity in theory is possible by SET of young horses within one training yard and by echocardiography (*Young* et al. (2002). Some progress has been made to predict success in racing by applying SET test parameters.

Evans et al. (1993) let 26 thoroughbreds gallop over 800 m. Venous blood samples were than collected at 2 and 5 min after exercise. In addition, 14 racehorses were given a strenuous submaximum treadmill exercise test. Heart rates during and after exercise at 10 m/sec on a treadmill inclined at 5° were recorded. There were no significant correlations between any of the measurements taken after the field test and either subsequent race performance or Timeform rating. On the other hand, parameters obtained after treadmill exercise correlated better with racing success. Blood and plasma lactate concentration 2 and 5 min after treadmill exercise were all significantly correlated with Timeform. Plasma ammonia at 2 and 5 min after treadmill exercise was not correlated with performance. So the 800 meter field test for thoroughbreds appears unsuitable for the practice.

Davie et al. (2002) performed a submaximal field exercise test consisting of 2 bouts of pacing for 1600 m, with 5 min rest or walking between runs on Standardbred racehorses at 2 training centres. The results as a whole are a bit disappointing, since no relationship was found between the observed minus the expected lactate levels and performance indices, such as number of race wins, number of race placing, lifetime earnings and average prize money per start. However, in one stable there was a significant association between VLa4 and logarithm of lifetime earnings and logarithm of average earned prize money per start. There were no significant correlations in another stable. A 2-step determination method of VLa4 appeared a possible means for studying limits to performance in pacing Standardbred racehorses.

Alternatives to estimate aerobic capacity.

Young et al. (2002) challenged the empirical theory of the thoroughbred industry that heart size is related to athletic performance. The relationship between peak oxygen consumption (V_{O_2max}) and cardiac size measured by echocardiography, guided M-mode and 2-dimensional echocardiography was determined in 17 conditioned thoroughbreds. Maximal oxygen uptake was measured during a standardised incremental treadmill exercise test to fatigue. This study suggested that there is a strong relationship between V_{O_2max} and measurements of left ventricular size in Thoroughbred horses.

Conclusion

Exercise physiology has brought new insights in equine performance. In the field, simple techniques using blood lactate analyser and heart rate monitors to quantify work load and recording speed and distance travelled by GPS are already successfully used by practitioners and riders. Standard protocols so far have not been designed and can not be designed due to the large variation in the conditions of training facilities. Therefore tailor made protocols must be designed for the individual training yards. In those disciplines were speed plays an important role in the total performance, post exercise lactate, heart rate and speed monitoring will provide suitable parameters to determine training level and condition. For disciplines wherein technical skills both of the horse and the rider, such as dressage and related activities, play an important role, the SET will not be of great help. The monitoring of post exercise electrolyte status and the activity of muscle enzymes is simple to carry out and is helpful in detecting subclinical problems in all sporting horses. However, all currently available monitoring toys and laboratory tools can not replace clinical skills such as observation of gait abnormalities and of negative changes in behaviour. Therefore, helping trainers to monitor the health and progress of their pupils in training, remains a mixture between art and science. The latter can be learned, but being keen observers, most equine clinicians will succeed in managing the art as well.

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