Reflections pertaining to exercise physiology and sports medicine.

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Why are horses high-performance athletes?

It is pure fascination to watch the field of steaming Thoroughbreds thundering in full racing speed past the tightly packed stands of spectators in the marvelous mountain arena on the snow-covered lake of St. Moritz! A horse is able to accelerate from 0 to 60 km/h in only a few seconds, the heart rate speeding up to 200 bpm. Per minute, over 300 liters of blood are pumped through the body and about 2000 liters of air are pulled into the lungs. The horse does not need any EPO-doping or high-altitude training to increase its haematocrit (Hct, or the packed cell volume (PCV)), which is the decisive factor defining oxygen transport capacity: The PCV may easily be double depending upon the intensity of work. Everything in a horse is geared towards speed and endurance—starting shortly after its birth.

Speed and endurance at birth

Through century-long breeding selection the horse developed from a herd- and flight animal into a highly specialized high performance athlete, equipped with an extraordinary athletic capacity. Speed, strength, endurance and high-precision locomotor skills are well developed at birth. Furthermore, it is astonishing to note that these athletic abilities developed differently in the various breeds. The locomotor muscles best reflect the breed-specific differentiation of the athletic abilities: There are some breeds, such as Thoroughbreds, with a high percentage of anaerobic and aerobic fast-twitch fibers, which are especially used for high-speed racing competitions, whereas Arabian horses are equipped with a high percentage of aerobic slow-twitch fibers and therefore are predestined for endurance races.

Accordingly, horses are able to perform at exceptionally high levels in racing and jumping: Over sprint distances of up to 400 meters, American Quarter Horses reach speeds of up to 1200 m/min (72 km/h). In flat races (1000-1400 m), Thoroughbreds run at speeds of 1100 m/min (65 km/h), and over the classic distances (up to 4000 m), barely under 1000 m/min (57 km/h). The mile record for Standardbreds (trotters or pacers) lies at 1'42", which results in a mean speed of about 950 m/min. The best endurance horses nowadays finish a 100-mile race cross country in less than 8 hours with an average speed of 22 km/h. The high jump record (Puissance) is 2.47 m. In phase D, the cross-country phase of a 4-star 3-Day Eventing, horses jump over 45 obstacles of up to 1.20 m in height and 3.00 m in width, spaced out over a course distance of 6 to 7.5 km.

It is interesting to notice that contrary to human athletic disciplines, new records are rarely broken in equestrian sports. The fastest time for the world-famous 1.25-mile Kentucky Derby was set in 1973 by the legendary Secretariat. All the acquired knowledge from the last 20 years on how to raise, feed, train and keep sound an equine athlete seems not to have resulted in faster-running or higher-jumping horses. For this reason there is good evidence that all the body systems contributing to performance capacity are highly tuned to an "end-stage" of differentiation.

Fig 1 White Turf International Horse Racing on snow at St. Moritz, Switzerland

Enormous aerobic capacity

The above-mentioned impressive athletic accomplishments result in mechanic and metabolic peak loads on the entire body. The bones, joints, ligaments and tendons, especially of the lower limbs, are exposed to extremely high external peak loads. Already at a trot, a 500 kg horse loads each limb with more than its body weight. The loads encountered on the forelimbs during landing after jumping over an obstacle of 1.3 m in height amounts to nearly one ton. During a racing gallop, the forelimbs are loaded with 2.5 times the body weight at each step! In addition, the flexor tendons and the suspensory ligament are exposed to extreme tensional forces. The very strong suspensory apparatus, positioned palmarly/plantarly to the cannon bone (McIII/MtIII) prevents over-extension of the meatcarpo-/ metatasophalangeal joint during loading, exhibits shock-absorbing characteristics, and may store and return mechanical energy.

A healthy tendon has a unique tensional resistance: The superficial digital flexor tendon with a cross sectional area of 1.5 cm^2 withstands tensional loads of up to 1.5 tons before rupturing. The fact that during training or a race a tendon may fully or partially rupture allows an estimation of the dimension of the tensional forces these structures are exposed to during the stance phase.

Another outstanding quality of the equine athlete is its enormous aerobic capacity, the basis for all equestrian disciplines. The oxidative metabolism, meaning the transport and consumption of oxygen for energy production, is the key to endurance competence. Along the oxygen chain from the lungs to the skeletal muscles, every organ or organ-system involved is structurally and functionally optimized and exceptionally well developed. The lung of a horse contains an enormous surface (equivalent to the surface of 7 tennis fields), which guarantees the high diffusion capacity for respiration gases; the heart impresses through its size and pumping capacity; and erythrocytes can be ejected from the spleen into the circulation in no time, to significantly increase oxygen transport capacity (**Tab 1**). Finally the skeletal musculature contains exceptional biochemical tools to trans-

	During rest	under maximal work load
Heart rate [l/min]	24–32	220–240
Cardiac output [l/min]	29	310
PCV [%]	32–46	60–65
Respiration rate [l/min]	12–16	120–135
Minute ventilation [l/min]	80–95	1600–1900
Peak flow [l/s]	4–6	85–100

Tab 1 **Functional plasticity of key parameters determining aerobic capacity.**

Fig 2 Three-Day Eventing, the summit of equestrian sports disciplines. (photo courtesy B. Mühlebach)

Fig 3 Exercise spirometry used to quantify upper airway resistance.

form nutrients into ATP. The resulting VO_2max, the maximal oxygen uptake capacity, in horses reaches 180–200 mlO_2/kg/min compared to its endurance-trained human counterpart, which reaches 105 mlO_2/kg/min; untrained persons attain just 30–45 mlO_2/kg/min.

Internal and external factors determine potential

The athletic potential depends upon different internal and external factors. Internal factors are inherited physical and mental capacities. The most important external factors include training, nutrition, boarding facilities, recovery time and most importantly the horse's physical and mental health. From the sports medicine point of view, the health status of and ability to train the athlete are the most important key factors to manage. It is therefore a central aspect in the philosophy of equine sports medicine to get to know in detail the physical and mental strengths and weaknesses of an equine athlete in order to be able to address minor health problems at an early stage and to implement individual training in a careful and efficient manner.

Stagnant improvements in training and declining competition results in any athlete have to be taken seriously, even if there are no apparent symptoms or disease to explain it. In most cases poor performance is an unspecific manifestation of simultaneously apparent, complex interrelated problems, which should neither be approached emotionally nor purely scientifically. An open cooperation between horse owner, rider, trainer and the clinician is essential. This accounts not only for problem-solving strategies, but also for an optimal fine-tuning of the various prerequisites for a successful athletic career. Only fit and mentally well-balanced horses with a superb health status can reach their full athletic potential.

For detection of subclinical diseases, it is imperative that the affected horses be assessed at work in order to test the function of the body systems involved in exertion. Ideally, this is done on a high-speed treadmill with the horse hooked up to various modern diagnostic tools. Poor performance evaluation normally focuses on the locomotor, respiratory and cardiovascular system first. Routine tests include the following: exercise testing, exercise ECG and post-exercise echocardiography for evaluation of cardiac function; exercise endoscopy and spirometry for evaluation of the upper respiratory tract (**Fig 3**); and evaluation on the treadmill of the patient's gait at different gaits up to racing speeds.

More than half of racehorses experience lameness

Musculoskeletal injuries are the main reason for wastage in the horse industry worldwide. Epidemiologic studies revealed that more than 50% of racehorses experienced some period of lameness in their sporting career and in 20% of those cases the lameness is sufficient to prevent the individuals from racing after the injury. Furthermore, it is estimated that three-quarters of

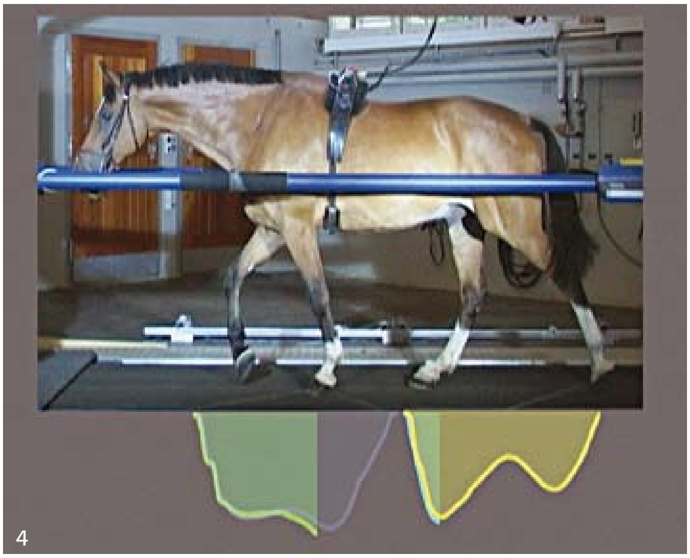


Fig 4 "TiF", a treadmill-integrated force measuring system able to record the vertical ground reaction forces of all four limbs simultaneously, here at the walk.

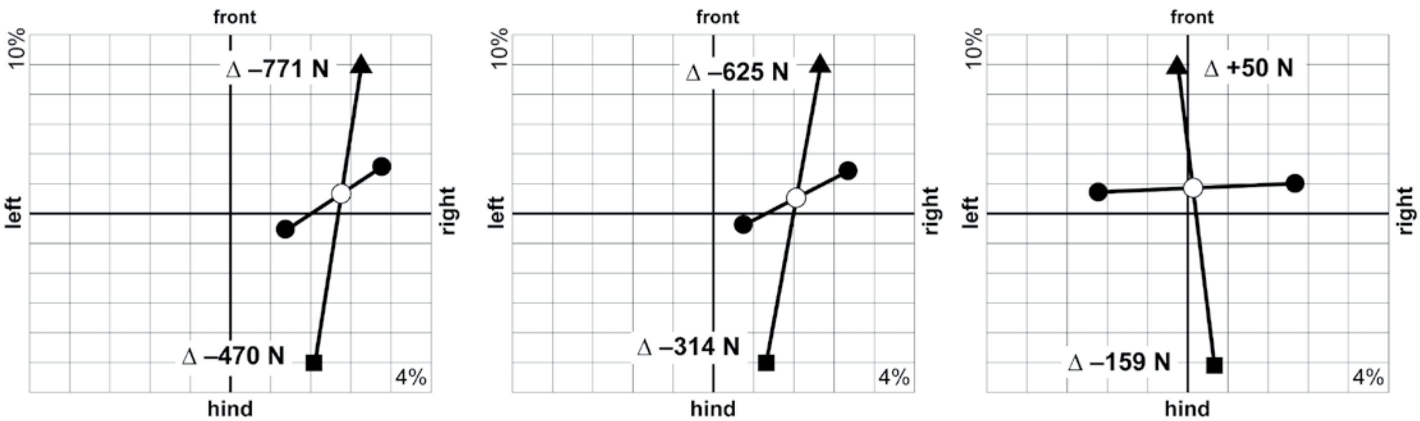
poorly performing horses suffer from subclinical disorders of the locomotor system. The expenses ensuing from veterinary treatment and the costs of all lameness-related loss-of-use are estimated to exceed USD 1 billion per year in the US alone.

Conformation, management factors such as training methods, level of schooling and performance, time intervals between starts, type of ground surface in training and competition, and quality of horseshoeing and saddle fitting can all contribute to injury that may affect the ability to compete successfully. Therefore, prevention and early identification of locomotor deficiencies have a high priority in equine sports medicine and animal welfare. Visual assessment of gait abnormalities and lameness is based on subjective assessments and therefore relies strongly on the expertise of the orthopedic clinician. The measurement of ground reaction forces proved to be a very reliable technique for detecting subclinical lameness. The development of an instrumented treadmill at the Equine Performance Centre of the Equine Department at the University of Zurich was an important step forward to assess lameness objectively in a clinical setup [1]. The force measuring system is able to record the vertical ground reaction forces of all four limbs simultaneously over multiple strides and to provide the clinician with the results of weight-bearing instantaneously (**Fig 4**).

Studies on load redistribution in lame horses revealed that horses apply strategies that do not necessarily induce an overload situation in another limb [2-3]. The gait analysis with the treadmill integrated force measuring system is especially useful in combination with diagnostic nerve blocks to assess instantaneously and reliably changes in weight bearing (**Fig 5**).

Fitness tests help prevent over-training

The athletic potential is a combination of different parameters, which can be roughly divided into endurance, speed, strength, agility, and coordination. These parameters are adjusted through training for each equestrian discipline specifically. It is obvious that some of these abilities, such as strength or coordination are difficult to assess and quantify in the horse. However, the assessment of aerobic capacity is relatively easy to perform with the help of an exercise test. A fitness test, which is preferably conducted on a treadmill under standardized conditions, involves working the horse during intervals of 90 seconds at progressively higher intensities. The heart rate is determined continually and during each work level a blood sample is taken for the determination of the blood lactate concentration: The lower the heart rate and the lower the lactate concentration for a defined workload, the fitter the horse. The results of a fitness test should never be interpreted on their own, separated from competitive results or the impressions of the trainer. With repetitive fitness tests during a training period, the effect of the training can be objectified and the training stimuli can be fine tuned, over-training can be prevented and health issues recognized at an early stage.



5a 5b 5c

Fig 5a–c Graphical presentation of the asymmetry index of peak vertical force (ASI Fz_{peak}) in a horse with proximal suspensory desmitis. The triangle represents the ASI Fz_{peak} of the forelimbs, and the square the ASI Fz_{peak} of the hindlimbs.

a initial lameness clinically scored as grade 2/5 weight-bearing left forelimb (FL) lameness and grade 2/5 weight-bearing left hindlimb (HL) lameness.

b lameness after a low palmar nerve block on the FL; lameness score grade 2/5 FL and grade 1-2/5 HL.

c lameness after perineural analgesia of the palmar metacarpal nerves on the FL; lameness score grade 1/5 right forelimb and grade 1-2/5 HL.

The application of knowledge pertaining to sports medicine does not aim to increase the speed of the horse or allow it to jump higher, but to keep the athlete sound, prepare it optimally for a specific event, and to recognize detrimental influences early in order to avoid an untimely end to an athletic career.

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