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A Scientific Background for Skeletal Muscle Conditioning in Equine Practice

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Summary

The main goal of any conditioning programme in athletic horses is to improve performance by inducing physiological changes within the animal's body. Equine skeletal muscles have a considerable potential to adapt during training and these adaptations have important physiological implications that influence stamina, strength and speed. Although there is an extensive specialized literature in this regard, scientific based muscle conditioning methods have not been introduced sufficiently in the equine sport practice. After a brief synopsis of both equine muscle exercise physiology and muscular adaptations to training, including their physiological significance, this review focuses on specific training programmes that induce muscular adaptations in athletic horses. The article addresses the following principal question: what kind of stimuli for what kind of muscular adaptations? The experimental data are discussed separately for racehorses (thoroughbreds, trotters and endurance horses) and sport horses (dressage, show jumpers and carriage). Finally, published results about the influence of relevant training parameters (such as intensity, duration and type of exercise) on muscular responses are discussed, as well as those concerning overtraining and detraining. The article closes with some concluding remarks on importance of their application in practice.

Introduction

Muscle training is essential to increase or maintain the athletic performance of sport horses and to reduce the incidence of exercise-induced injuries in the musculoskeletal system of these athletes. Muscle conditioning is a more restricted term which means improving athletic performance by inducing muscular changes that can be evaluated by using objective and scientific methods (Davie, 2006). In spite the existence of an extensive specialized literature on this subject, scientific based muscle conditioning programmes have not been introduced in the equine sport practice. There are two potential reasons for this. First, because the high degree of controversial and contradictory results found in the literature, and because investigators have been more interested to know how plastic the equine skeletal muscle is rather than developing practical training methods; for example, few studies have been carried out to compare the effects on muscle of different training protocols varying in the type, intensity, duration and frequency of the exercise. And secondly, because people who have the responsibility for equine training in practice (practitioners, trainers and riders) do not have sufficient knowledge about scientific basis for this goal, i.e. muscular responses to exercise and training.

From the extensive literature available, there is now sufficient evidence that equine skeletal muscle has considerable potential to adapt during training and, overall, these adaptations have important physiological implications that influence power generation (strength), resistance to fatigue (stamina) and maximum velocity of shortening (speed). Much of this work is summarized in the excellent review by Snow and Valberg (1994). Overall, most of these earlier studies on muscular responses to training failed to describe accurately the training protocols assayed (i.e. the intensity and duration of exercises carried out), and were based upon the use of very limited laboratory methods to describe training-induced muscular changes. As a consequence, results from many of these studies are of little, if any, application in practice. In recent years, however, a considerable number of experimental studies, with enhanced standards for training protocols and updated methods, have been published in this field (reviewed by Rivero and Piercy, 2004). Although the majority of these papers have been conduced in racehorses (thoroughbreds, standardbreds and endurance horses), there are other minor specific studies about muscular adaptations to training in horses from other disciplines (show jumpers, dressage and carriage). Altogether, these recent studies provide valuable information about two particular aspects: (i) what can be modified in horse muscle by training? and (ii) how can this be obtained? I am sure that answers to these two big questions are of great interest for people involved in equine sport practice. But to reach this goal, a good knowledge of equine muscle exercise physiology is essential. The readers of this article can be referred to a chapter in a recent book by the author covering these aspects (Rivero and Piercy, 2004). Nonetheless, I will begin with some preliminary considerations about equine muscle exercise physiology to provide an appropriate scenario for subsequent discussions on experimental results.

Synopsis of Equine Muscle Exercise Physiology

In contrast to most mammals, more than half of a mature horse's body weight comprises skeletal muscle. Total muscle blood flow in horses exercising at 100% of maximal oxygen uptake (henceforth $\dot{V}O_{2max}$) has been estimated in 78% of total cardiac output. During exercise, skeletal muscle fibres produce energy in the form of ATP which, via the contractile machinery, is converted into mechanical work.

Equine muscle physiology has centred on the use of percutaneous needle biopsy, which provides muscle samples useful for studies *in vivo* and *in vitro* using a range of morphological, biochemical and physiological techniques.

More than 90% of a muscle is made up of myofibres, with the rest consisting of nerves, blood vessels, fat and connective tissue. Functionally, myofibres are organized as motor units. A motor unit consists of an α-motoneuron and the set of skeletal muscle fibres that it innervates. The ability of muscle tissue to perform efficiently in spite of very different types of exercise is enhanced by a muscle's heterogeneity. Equine skeletal muscle is composed of three main fibre types termed I (slow-oxidative), IIA (fast oxidative glycolytic) and IIX (fast glycolytic). All fibres within a single motor unit are of the same histochemical type. In horses, motor units are selectively recruited in a specific pattern that changes according to the intensity and duration of the exercise. For the maintenance of posture only type I motor units are recruited (Snow and Valberg, 1994). As intensity and duration of the exercise increase, further motor units are recruited, in the rank order I $\rightarrow$ IIA $\rightarrow$ IIX. Type IIX motor units are only recruited at near-maximal exercise intensity (sprint and jumping) and/or during extremely prolonged sub-maximal exercise.

The percentage of each muscle fibre type (i.e. fibre type composition) varies from horse to horse, and multiple factors, both myogenic (lineage, breed, age and sex) and non-myogenic (neural input, neuromuscular activity and extra-cellular substances) in nature, regulate this percentage. Much more important is its significance for performance. For example, endurance ability is correlated with high percentages of type I and IIA fibres, whereas speed ability is correlated with high percentages of fast-twitch fibres, and power generation (strength) is proportional to fibre size (Rivero et al., 2001).

Muscle cannot contract without a source of energy provided by the hydrolysis of ATP that occurs at the head of the myosin molecule. As muscle [ATP] is limited and it is metabolized within a few seconds of the exercise, replacement of ATP is mandatory. There are different metabolic pathways for this goal within the muscle during exercise. Within mitochondria, β-oxidation of free fatty acids, the tricarboxylic cycle and oxidative phosphorylation (via the electron transport chain) combine to produce ATP aerobically (aerobic pathways). Two additional anaerobic mechanisms (anaerobic pathways) exist: the high-energy phosphate and glycolysis. Aerobic production of ATP is a relatively slow but efficient process, while anaerobic pathways produce energy rapidly but relatively inefficiently. Although both pathways are active during exercise, the relative contribution depends on the nature, intensity, duration and frequency of the exercise, the muscle's fibre type composition, the availability of oxygen and substrates, and the presence of intermediary metabolites that may potentially activate or inhibit selected enzymes.

In exercise of low or moderate intensities, the main energy provision for muscular functions comes from aerobic pathways. As exercise intensity increases, a greater proportion of the energy is supplied by the anaerobic pathway. At the point where the availability of oxygen becomes a limiting factor in mitochondria, pyruvate from the anaerobic glycolysis cannot be converted into acetyl-CoA (the substrate for the Krebs' cycle), but it is converted to lactate. The point when the increased rate of lactate production can be detected in the plasma is known as the anaerobic threshold. This threshold varies and depends on several factors, including the muscle's fibre type composition and the level of fitness. In practice (and henceforth in this paper), aerobic capacity is defined as the maximum amount of energy provided by aerobic pathways, whereas anaerobic capacity is the maximum amount of energy provided by anaerobic pathways (Hinchcliff et al., 2002).

At the beginning of the sub-maximal exercise ($<85\%$ of $\dot{V}O_{2max}$), muscle glycogenosis is the main mechanism for providing acetyl-CoA from pyruvate. Either intramuscular glycogen or blood glucose is the substrate for this pathway. But as energy demands increase, higher rates of pyruvate oxidation tend to cause a shift towards free fatty acids β-oxidation. The overall effect is that muscle glycogenosis declines over time during sub-maximal exercise, whereas free fatty acids β-oxidation increases. Although lipids are the predominant fuel utilized during prolonged sub-maximal exercise, fatigue occurs by intramuscular glycogen depletion, as the main cause.

During maximal exercise ($>85\%$ of $\dot{V}O_{2max}$), the high functional demands require the recruitments of most motor units. At this time, intramuscular glycogen and blood glucose act as the predominant fuels to replenish ATP through anaerobic glycolysis. Limitations imposed by this high-intensity exercise result in greater amounts of pyruvate being converted to lactate rather than acetyl-CoA. As a consequence, muscle [lactate] increases in a rate proportional to the percentage of type II fibres. Initially, intracellular lactate accumulation is removed from the cell by active transport into the blood, but saturation of this mechanism results in a sudden exponential rise in intracellular lactate accumulation (anaerobic threshold), that generally occurs when the plasma [lactate] reaches about 4 mmol/l. The rise in intracellular lactate results in a significant reduction in cytoplasmic pH, the main cause of fatigue during maximal exercise. Local acidosis leads to impairment of both muscle structure and function. A fall in cytoplasmic pH is partially overcome by a buffering system within myofibres.

From a biochemical point of view, the main goal of muscle conditioning is to increase performance by: (i) increasing aerobic and/or anaerobic capacities or (ii) reducing the major causes of fatigue during sub-maximal (i.e. heavy intramuscular glycogen depletion) or near-maximal (i.e. intramuscular acidosis) exercise or (iii) both situations.

Muscular Responses to Training

What can be modified in skeletal muscle with training?

Equine skeletal muscle has considerable potential to adapt during training, largely mediated by the structural and functional plasticity of muscle fibres. These long-term (weeks to months) adaptations occur independently from the immediate or short-term muscular metabolic responses to either a single bout of sub-maximal or near-maximal exercise. Depending on the basal muscle status (i.e. breed, age, sex, level of fitness and history of the horse training) and characteristics of the stimulus (i.e. nature, intensity, duration, and frequency of exercise bouts and total length of the conditioning programme), the adaptive response to training can take two different forms. First, the quantitative response, when myofibres increase (hypertrophy) in size but otherwise retain their basal structural, physiological and biochemical properties.

And secondly, the qualitative responses or remodelling, where myofibres do not change in size but acquire markedly different enzymatic and structural characteristics (i.e. fibre type transitions). In practice, the most common adaptive response of equine skeletal muscle to training takes a mixed form of remodelling with discrete or substantive hypertrophy, and often accompanied by increases in the number of capillaries.

A list with the main muscular adaptations to training reported in horses is presented in Table 1. To read this information correctly some premises are necessary. While many of these adaptations occur in parallel and in a well coordinated manner, they never occur simultaneously. For example, while a significant increase in muscle (glycogen) can be obtained with only a short-term training of moderate intensity [treadmill exercise at ~55% $\dot{V}O_{2max}$ (4.3–4.6 m/s), 60 min (~13–14 km)/day, for 10 consecutive days (Geor et al., 1999)], a significant type II-to-type I fibre type conversion (i.e. an increase in I:II fibre ratio) needs a much more prolonged low-intensity training programme [riding at ~25–50% $V_{LA}4$, 60–120 min/day, 5 days/week for 8 months (Serrano et al., 2000)]. Moreover, muscular adaptations to training are usually accumulative (progressive) in a longitudinal form, existing a relationship cause-effect. For example, the most common and earliest muscular adaptation to training is an increase in the activity of aerobic metabolism, which is an optimal modification to increase the resistance to fatigue. But if the training stimulus is applied for a long period of time, this metabolic adaptation might well be accompanied by a fibre type transformation in the order IIX → IIA → I, which means an intrinsic reduction in maximal velocity of shortening (Serrano et al., 2000). Nevertheless, there is an upper limit in which further muscular adaptations are not obtained even when the stimulus continues to be applied. In this scenario, heavy prolonged training is not beneficial, but it is a considerable risk to induce overtraining (Tyler et al., 1998; McGowan et al., 2002).

As already commented, muscular adaptations to training have important physiological consequences (Table 1). The main consequence of increased muscle mass due to myofibre hypertrophy in response to training is to produce a muscle with a greater peak force capacity, because force output is proportional to total cross-sectional area of the fibre mass recruited. At low speeds, this adaptation has an impact on gait, causing a marked reduction in both stance and stride duration (Rivero et al., 2001). Additionally, such an adaptation has considerable impact on the performance of show jumpers via enhanced power output from the hindquarters (Rivero and Letelier, 2000). Furthermore, because increased power output results in a greater ability to accelerate and may increase stride length, these training adaptations (strength rather than endurance) may be important for racehorses competing over short distances (Snow and Valberg, 1994). But enhanced power through training comes with the cost of a corresponding theoretical 'decline' in aerobic capacity, because the increased mass of recruited fibres and concomitant rise in ATP utilization, occurs simultaneously with a relative inability of oxygen to diffuse into the larger fibres. In practice, this means that training-induced myofibre hypertrophy might well be a handicap not only for long-distance endurance horses, but also for trotters and gallopers competing over middle or long distances (stayers).

The most common qualitative muscular response to training in the horse (i.e. remodelling of myofibre phenotype) produces a muscle that is much more resistance to fatigue during both sub-maximal and near maximal exercises; but with an intrinsic decreased maximal velocity of shortening. The rise in resistance to fatigue corresponds not only to an increased aerobic capacity but also to a concomitant increase in anaerobic capacity (i.e. ~92% $\dot{V}O_{2max}$, 10 min/day, 4–5 days/week, 10 weeks; Hinchcliff et al., 2002). In general, there is an optimal relationship between some of these peripheral (muscle) adaptations and central adaptations to training in horses. For

Table 1. Summary of main muscular adaptations to training reported in horses and their functional significance for endurance, strength and speed

Muscular adaptations	Physiological trait		
	Stamina	Strength	Speed
Morphological adaptations			
Muscle fibre hypertrophy	–	+ + +	+
Increased number of capillaries	+ + +	nc	nc
Increased mitochondrial volume	+ + +	nc	nc
Increased myonuclear density	nc	+ + +	nc
Metabolic adaptations			
Increased aerobic muscle enzyme activities	+ + +	nc	nc
Increased glucose and fatty acid transport	+ + +	nc	nc
Increased muscle [glycogen] and its sparing during exercise	+ + +	nc	nc
Increased muscle [triglycerides]	+ + +	nc	nc
Decreased post-exercise muscle [lactate]	+ + +	nc	nc
Increased anaerobic muscle enzymes	nc	nc	+ + +
Decreased anaerobic muscle enzymes	nc	nc	– – –
Increased muscle [high energy phosphate]	nc	nc	+ + +
Increased muscle buffering capacity	+	nc	+ + +
Contractile adaptations			
Unidirectional IIX → IIA → I fibre type (MyHC isoform) transition	+	nc	– – –
Bidirectional IIX → IIA ← I fibre type (MyHC isoform) transition	+	nc	– – –
Increase in IIA:IIX fibre type (MyHC isoform) ratio	+	nc	– – –
Increase in I:IIA fibre type (MyHC isoform) ratio	+	nc	– – –
Increase in IIA:I fibre type (MyHC isoform) ratio	–	nc	+ + +

The symbols + + + and – – – indicate primary implication (positive and negative respectively) towards the particular characteristic; + and –, secondary implication (positive and negative respectively); nc, no contribution to the particular characteristic.

instance, in the elegant study by Tyler et al. (1998), an optimal correlation between lineal increases of mitochondrial volume of myofibres and $\dot{V}O_{2max}$ was demonstrated. The training-induced reduction in contractile speed is associated with the switch of fibre types in the direction IIX → IIA → I. This is because the maximal velocity of shortening of myosin isoforms decreases significantly in identical order.

Following endurance training, exercise at sub-maximal intensities elicits optimal delivery of oxygen and blood-borne substrates, and early activation of oxidative metabolism with lower utilization of endogenous carbohydrates, and an increased reliance of fat oxidation as an energy source. Muscle glycogen sparing is underlying the delay in the onset of fatigue during this type of exercise. Furthermore, in the trained status, the speed at which a horse begins to accumulate lactate increases gradually (i.e. there is a delay in the onset of lactate accumulation and ATP depletion). This is accomplished by an enhanced muscle buffering capacity. Hence collectively, endurance may be enhanced by a wide variety of related factors that delay the onset of fatigue during high-intensity exercise.

Specific Training Programmes Inducing Muscular Adaptations in Athletic Horses

Ideally, conditioning programmes in athletic horses should be aimed at the development of muscle properties that optimize equilibrium among strength, stamina and speed. Afterwards, exercise-training for each discipline should be oriented towards the development and maintaining of those muscular traits more directly related to physiological features of each particular discipline. As often there is an upper limit in the range of muscular adaptations to training, the coach and/or practitioner should be able to recognize when signs of overtraining are present, as this situation reduces performance considerably and is pernicious to the horse's health (Tyler et al., 1998). Furthermore, as adaptive training responses of skeletal muscles are reversible (i.e. there is a return of adaptations to pre-training values when the stimulus ceases), knowledge of the maintenance of the trained phenotype during inactivity (i.e. detraining periods) is also mandatory in practice.

Muscle conditioning in racehorses

Thoroughbreds

In earlier studies found in the literature muscle adaptations to training in Thoroughbreds have been studied in horses aged 2 and 3 years. But as training effects differ with age, sex and state of training (Rivero and Piercy, 2004), it is highly probable that these muscular adaptations to training have not been separated from the spontaneous adaptations associated with growth. Thoroughbred does not complete its growth until the age of ~5 years. During the first year, they reach approximately 65% of adult body weight and 90% of adult height. As most racehorses are trained regularly from about age of 18 months, body length and width continue to increase during this state of growth.

Training thoroughbred racehorses is probably more difficult than training endurance horses and trotters. The metabolic demands of thoroughbreds racing over distances of 1000–3600 m are quite different. Earlier reports of the measurement of the anaerobic capacity in thoroughbred racehorses suggest that thoroughbred racing is a much more aerobic activity than previously believed. Conventional training of thoroughbred divide it into three phases: endurance phase (~100% $\dot{V}O_{2max}$), combined aerobic and anaerobic phase (~125–135% $\dot{V}O_{2max}$) and anaerobic phase (~140–165% $\dot{V}O_{2max}$). However, there is no a formal knowledge of the physiological adaptations with this protocol.

Only recently, the importance of training in the early stage of development has been considered in thoroughbreds and differentiate properly by using control groups (Eto et al., 2003; Table 2). Thus, adequate exercise of relatively low intensity during the first year postpartum induces relevant muscular adaptations [i.e. hypertrophy of types I and IIA fibres, and an increase in the oxidative capacity of type IIX fibres (Table 2, Eto et al., 2003)], which cause an improvement in later athletic performance. The importance of age on muscular response to training is again illustrated when comparing results with the same conditioning programme between 2-year-old thoroughbreds (Yamano et al., 2002) and 2- to 3-year-old thoroughbreds (Miyata et al., 1999; see Table 2). The higher range and magnitude of muscular adaptations found in the youngest animals in comparison with the oldest one, clearly demonstrate the superior sensitivity to training stimulus of skeletal muscle during early stages of growth.

In general, practical training of racehorses would appear to involve short distance and low-to-moderate intensity workouts because of serious concern for muscle and tendon damage (Miyata et al., 1999). Relevant muscular adaptations to training (i.e. fibre hypertrophy, and enhanced aerobic and anaerobic capacities) can be obtained in thoroughbreds with exercises of high intensity (~100–165% of $\dot{V}O_{2max}$) over relatively short (1600–3600 m) distances in only 16 weeks (see Table 2; Miyata et al., 1999; Yamano et al., 2002). Similar changes, although less extent, in both aerobic (Sinha et al., 1993) and anaerobic (Eto et al., 2004) capacities can be obtained reducing both the intensity of the exercise at ~80% of $\dot{V}O_{2max}$ and the total length of the conditioning programme to 6 weeks (Sinha et al., 1993) or 12 weeks (Eto et al., 2004). The physiological importance of high-intensity workouts in the thoroughbred is to recruit the fast-glycolytic type IIX fibres Yamano et al. (2006). These fibres represent nearly 50% of fibre type composition of the M. gluteus medius in this breed, and they are considered as a pool of reserve that is only partially recruited during supra-maximal exercises (sprints). An increase in the oxidative capacity of these fibres, without a concomitant change in contractile speed (i.e. IIX-to-IIA fibre type transition) may cause an improvement in performance of these racehorses.

An increase in the aerobic capacity of thoroughbreds can also be induced with exercises of low-intensity (~55% of $\dot{V}O_{2max}$) over long distances (60 min, ~13–14 km) for only 10 consecutive days (Geor et al., 1999). Such an adaptation, however, comes with a parallel decrease in anaerobic capacity [i.e. a reduction in muscle (glucose-6-phosphate) and (creatine) at point of fatigue; see Table 2].

Standardbreds

Since the pioneering study about interval training effects on skeletal muscle by Lindholm and Piehl (1974) 30 years ago, many other training studies have been carried out to gain

Table 2. Conditioning programmes inducing muscular adaptations in Thoroughbred racehorses of different ages

STIMULUS – Intensity	Duration/distance/bout	Frequency	Phase duration	Total duration	RESPONSES – Muscular response
Reference: Eto et al., 2003.					
Subjects: 2-month-old					
Thoroughbred foals ($n = 7$) acclimatized to exercised on a treadmill					
Trotting 2.5 → 3.3 m/s	4 min	5 days/week	10 months	10 months	Hypertrophy I and IIA fibres
Cantering 5 → 11 m/s	15 s (×5)				↑ SDH IIX fibres
Reference: Yamano et al., 2002.					
Subjects: 2-year-old					
Thoroughbred foals ($n = 10$), racetrack exercise					
Reference: Miyata et al., 1999.					
Subjects: 2- to 3-year-old					
Thoroughbreds ($n = 22$), exercised on either a flat or inclined (3°) track					
~100% $\dot{V}O_{2max}$ (10 m/s)	2.66 min (1600 m)	3 days/week	3 weeks	3 weeks	2 years old (Yamano et al., 2002)
~100% $\dot{V}O_{2max}$ (10 m/s)	4–5.33 min (2400–3200 m)	2 days/week			Hypertrophy I (17%) and IIA (12%) fibres
~100–135% $\dot{V}O_{2max}$ (10–13.5 m/s)	2.66–2 min (1600 m)	3 days/week	7 weeks	10 weeks	↑ IIA:IIX fibre ratio (130%)
~100% $\dot{V}O_{2max}$ (10 m/s)	4–5.33 min (2400–3200 m)	2 days/week			↑ IIA:IIX myosin ratio (29%)
					↑ Relative area IIA:IIX fibre ratio (61%)
					↑ SDH muscle activity (37%)
					↑ SDH in IIX fibres (50%)
					↑ PFK muscle activity (17%)
~135–165% $\dot{V}O_{2max}$ (13.5–16.5 m/s)	2–1.66 min (1600 m)	3 days/week	6 weeks	16 weeks	2–3 years old (Miyata et al., 1999)
					Hypertrophy type I fibres (17%)
~100% $\dot{V}O_{2max}$ (10 m/s)	4–5.33 min (2400–3200 m)	2 days/week			↑ IIA:IIX fibre ratio (15%)
					↑ Relative area I (28%) and IIA:IIX (30%)
					↑ SDH muscle activity (35%)
Reference: Eto et al., 2004.					
Subjects. Adult (5–7 years old)					
Thoroughbreds ($n = 6$) exercised in a treadmill					
~80% $\dot{V}O_{2max}$	5 min (×2)	5 days/week	6 weeks	6 weeks	↑ PFK muscle activity
~80% $\dot{V}O_{2max}$	4 min (×2)	5 days/week	6 weeks	12 weeks	
~100% $\dot{V}O_{2max}$	1 min (×2)				
Reference: Geor et al., 1999.					
Subjects. Adult (4–8 years old) exercised in a treadmill 6° slope					
~55% $\dot{V}O_{2max}$ (4.3–4.8 m/s)	60 min (~13–14 km)	10 consecutive days		10 days	↑ $\dot{V}O_{2max}$ (9%)
					↑ Muscle [glycogen] (19%)
					↓ Muscle [lactate] fatigue (22%)
					↓ Muscle [glucose-6-phosphate]
					↑ Muscle [PCr]
					↓ [Creatine] at fatigue
Reference: Eaton et al., 1999.					
Subjects. Lightly trained					
Thoroughbreds ($n = 10$), age?					
Post-exercise [lactate]	1600 m	5 days/week	2 weeks	2 weeks	↑ $\dot{V}O_{2max}$
4–8 mmol/l	2400 m		3 weeks	5 weeks	↑ $V_{LA}4$
	3200 m		2 weeks	7 weeks	↑ CS muscle activity (after 4 weeks)
	4000 m		2 weeks	9 weeks	
Reference: Sinha et al., 1993.					
Subjects. 2–9 years unfit					
Thoroughbreds ($n = 5$) exercised in a treadmill 6° slope					
~80% $\dot{V}O_{2max}$	3 min (1500 m) ×2	6 days/week	6 weeks	6 weeks	↑ IIA:IIB fibre ratio
					↑ Buffering capacity

SDH, succinate dehydrogenase muscle enzyme activity; PFK, phosphofructokinase muscle enzyme activity; PCr, phosphocreatine; CS, citrate synthase muscle enzyme activity.

insight into practical methods in this breed. As in thoroughbreds, the 'art' of training trotters for optimal racing performance depends on refining the factors of speed, stamina and competitiveness in the individual and presenting the horse on race day so that none of them alone will limit performance. In this section, I have selected from the available literature three well-documented studies describing muscular adaptations with training in this type of horses (see Table 3).

In adolescent (2–3 years old) trotters a simultaneous increase in both aerobic and anaerobic capacities can be obtained after only 5 weeks of training by intermingling exercises of high-intensity [~100–140% of the standardized velocity eliciting a blood lactate concentration of 4 mm/l (henceforth, $V_{LA}4$)] during short time (15 min) with prolonged (60–90 min) sub-maximal (~65% of $V_{LA}4$) exercises (Rivero et al., 2002).

In the study by Tyler et al. (1998), 13 young mature (3–5 years old) Standardbreds were trained in a 10° inclined treadmill over a whole period of 32 weeks split into three consecutive phases: endurance (7 weeks), high-intensity (9 weeks) and overload (18 weeks) training (Table 3). The most relevant muscular adaptations (both in nature and in

Table 3. Conditioning programmes inducing muscular adaptations in Standardbred trotters

STIMULUS – Intensity	Duration/distance	Frequency	Phase duration	Total duration	RESPONSES – Muscular response
Reference: Tyler et al., 1998.					
Subjects. 3- to 5-year-old					
Standardbreds (n = 13), treadmill exercise 10° slope					
Endurance training					↑ Capillaries I, IIA, IIX fibres (18%)
~60% $\dot{V}O_{2max}$ (6 m/s)	11.1 min (~4 km)	5 days/week	7 weeks	7 weeks	↑ Mitochondrial volume II fibres (24%)
					↑ $\dot{V}O_{2max}$ (25%)
High-intensity training					↑ Area I (32%) and IIA (25%) fibres
~80% $\dot{V}O_{2max}$ (8 m/s)	6.25 min (~3 km)	3 days/week	9 weeks	16 weeks	↑ Capillaries I, IIA, IIX fibres (65%)
~100% $\dot{V}O_{2max}$ (10 m/s)	6 min (~3.6 km)	2 days/week			↑ IIA:IIX fibre ratio (40%)
					↑ Mitochondrial volume I (50%) and II (106%) fibres
					↑ $\dot{V}O_{2max}$ (29%)
Overload training					↑ Area I (41%) and IIB (28%) fibres
Control group (n = 6)					↑ Capillaries I, IIA, IIX fibres (67%)
~80% $\dot{V}O_{2max}$ (8 m/s)	8.33 min (~4 km)	3 days/week	18 weeks	32 weeks	↑ Mitochondrial volume I (75%) and II (186%) fibres
~100% $\dot{V}O_{2max}$ (10 m/s)	8.33 min (~5 km)	2 days/week			
Overtrained group (n = 7)					↑ $\dot{V}O_{2max}$ (37%)
~80–85% $\dot{V}O_{2max}$	12.5 min (~6 km)	3 days/week	15 weeks	29 weeks	
~100–110% $\dot{V}O_{2max}$	6 min (~9 km)	2 days/week			
Reference: McGowan et al., 2002.					
Subjects. 3- to 5-year-old					
Standardbreds (n = 13), treadmill exercise 10° slope					
~60–80% $\dot{V}O_{2max}$	11.1–6.25 min	3 days/week		32 weeks	↑ Pre-exercise muscle [glycogen]
~100–110% $\dot{V}O_{2max}$	8.33–6 min	2 days/week			↑ Post-exercise muscle [glycogen]
					↑ Rate muscle glycogen utilization during exercise
					↓ Post-exercise muscle [lactate]
					↑ Buffering capacity of muscle
					↑ $\dot{V}O_{2max}$ and run time to fatigue
					↑ CS and HAD muscle enzyme activities
					↓ LDH muscle enzyme activity
Reference: Rivero et al. (2002).					
Subjects. 2-year-old					
Standardbreds (n = 7), treadmill exercise plus 10 g/day oral L-carnitine					
↑ 100–140% VLA4	15 min	Every 2nd day		5 weeks	↓ Area fibre types I (34%)
65% VLA4	60–90 min	Every 2nd day			↑ Percentage of type IIA fibres (35%)
					↑ Capillary density (27%)
					↑ Muscle [glycogen] (11%)
					↑ IIA:I fibre ratio (23%)
					↑ Histochemical GPDH enzyme activity (34%)

HAD, 3-hydroxy-acyl-CoA-dehydrogenase muscle enzyme activity; LDH, lactate dehydrogenase muscle enzyme activity; GPDH, glycerol-3-phosphate dehydrogenase muscle enzyme activity. See Table 2 footnotes for further details of abbreviations.

magnitude) were recorded at the end of the high-intensity training phase (16 weeks), but few additional changes were seen afterwards, even when exercises of high intensity (~80–110%) were chronically applied for a long period of 18 weeks (overload training phase). Overall, these data indicate that: (i) in general, exercise of moderate or low intensity causes more muscular adaptations than high-intensity exercises and (ii) there is an upper limit over time of muscular adaptations to training, because most of these adaptations were obtained after 16 weeks of training and further adaptations were not observed long-time afterward. The exception to this was the lineal increase seen in the mitochondrial volume of both type I and type II fibres throughout the whole training programme. Furthermore, this increase occurred in a coordinated manner with a concomitant improvement in $\dot{V}O_{2max}$. In this training study, there was a decrease in the lactate dehydrogenase muscle enzyme activity after 32 weeks of training (McGowan et al., 2002), indicating that heavy prolonged overload training can induce a decrease in the anaerobic capacity similar to that seen in endurance horses.

In summary, an improvement of strength and aerobic capacity can be induced in skeletal muscles of standardbred trotters with regular exercises of low-to-moderate intensity (~60–80% of $\dot{V}O_{2max}$) and relatively short duration (6–12 min per session) over a whole period of 16 weeks (Tyler et al., 1998). A simultaneous increase in aerobic and anaerobic capacities, but with the cost of a reduction in strength, can be induced with a short-time 5 weeks conditioning programme with daily workouts of high-intensity (~100–140% of VLA4) and short-duration (15 min) exercise, interspersed with daily exercises of low-intensity (~65% of VLA4) and long duration (60–90 min) (Rivero et al., 2002).

Endurance horses

Endurance horses with the best performance records have high percentages of type I and type IIA fibres, fibres with large sizes and high oxidative muscle enzyme activities (Rivero and Piercy, 2004). The muscular response to long-term endurance training programme with exercises of low-intensity and long-duration takes the form of remodelling of fibre types with discrete muscle fibre hypertrophy (Serrano et al., 2000; see Table 4). Andalusian horses exercising at ~25–30% of VLA4,

Table 4. Conditioning programmes inducing relevant muscular changes in endurance-type horses

STIMULUS – Intensity	Duration/distance	Frequency	Phase duration	Total duration	RESPONSES – Muscular response
Reference: Serrano et al., 2000.					
Subjects. Young adult (~4 years old) untrained Andalusian horses ($n = 8$ controls, $n = 16$ endurance-trained). Free exercise in the morning without the rider and riding exercise in the afternoon on ground with different slopes					
Basic training ~25–30% VLA4	45 min morning 60 min afternoon	5 days/week	12 weeks	3 months	↑ Area type IIA fibres (16%) ↑ IIA:IIX fibre type ratio (17%) ↑ IIA:IIX myosin isoforms ratio (12%) ↑ Percentage high-oxidative fibres (4%) ↑ SDH activity IIA (11%) and IIAX fibres (15%) ↑ CS (22%) and HAD (15%) muscle enzyme activities ↑ Muscle [glycogen] (51%) ↓ PFK (glycolytic enzyme) muscle activity (12%)
Specific training ~50–60% VLA4	45 min morning ↑75–120 min afternoon	5 days/week	18 weeks	8 months	↑ VLA4 (30%) ↑ Area type IIA fibres (13%) ↑ IIA:IIX fibre type ratio (23%) ↑ I:II fibre type ratio (35%) ↑ I:II myosin heavy chain isoforms ratio (25%) ↑ Number of high-oxidative fibres (8%) ↑Capillary density (13%) ↑ SDH activity of IIA (31%) and IIAX (33%) fibres ↑ CS (30%) and HAD (15%) muscle enzyme activities ↑ Muscle [glycogen] (65%) ↑ Muscle [triglyceride] (46%) ↓ LDH (20%) and PFK (13%) activities
Reference: D'Angelis et al., 2005.					
Subjects. Adult (8.6 years old on average) untrained Arabians were trained in a treadmill for 12 weeks					
~80% VLA4	50 min (10 km) 60 min (15 km) 80 min (20 km)	3 days/week	4 weeks 4 weeks 4 weeks	4 weeks 8 weeks 12 weeks	↑ Area type I (40%), IIA (52%) and IIX (50%) fibres ↓ Percentage of type IIX fibres (18%)
Farlek training 4 m/s 0° 10 min + 8 m/s 5° 10 min + 2.5 m/s 0° 5 min + 10 m/s 5° 5 min + 2.5 m/s 0° 5 min + 5 m/s 10° 20 min + 12 m/s 0° 3 min + 2 m/s 0° 10 min	68 min	1 day/week	Last 4 weeks	12 weeks	↑ Relative area occupied by types I (60%) and IIA (17%) fibre types ↑ Cross-sectional area of M. longissimus after the first month of training

See Tables 2 and 3 footnotes for further details of abbreviations.

60 min/day, 5 days/week for 3 months resulted in moderate hypertrophy of type IIA fibres (16%), marked IIX-to-IIA fibre type transition, increased aerobic capacity and decreased anaerobic capacity (Table 4). Five additional months of specific training consisting of exercises of moderate-intensity (~50–60% of VLA4) and incremental long-duration (75–120 min) increased the extent of the previous muscular changes, except for type IIA hypertrophy, which remained unchanged. Furthermore, a very significant fast-to-slow fibre type/myosin isoform transitions was observed at the end of this phase (see Table 4). Altogether, these adaptations imply a considerable increase in aerobic capacity, a moderate improvement in muscular strength (minimal hypertrophy) and a reduced anaerobic capacity.

A similar increase in aerobic capacity, together with a much more marked and generalized fibre hypertrophy (~50%), have recently been documented in purebred Arabian horses endurance-trained with exercise of higher intensity (~80% of $\dot{V}O_{2max}$), and similar duration (50–80 min per session), 4 days/week for 12 weeks (D'Angelis et al., 2005).

Muscle conditioning in sport horses

While elite endurance horses are characterized by high percentage of type I and IIA fibres, and active thoroughbred and standardbred racehorses have a very high percentage of fast-twitch fibres, particularly the glycolytic IIX fibres, the most remarkable muscle characteristic of sport horses (i.e. dressage, show jumpers and carriage driving) is a balanced percentage of the three main fibre types. To the best of my knowledge few specific studies about training effects on muscle have been carried out in these types of horses.

Dressage can be classified as a sub-maximal exercise discipline with high physiological demands for strength and power output. Physical training should be aimed to increase both strength and stamina. The training stimulus summarized in Table 5 for horses of this discipline (basic training: ~25% of VLA4 60 min 3 days/week 12 weeks; specific training: ~50% VLA4 ↑70–120 min 3 days/week 20 weeks) induced an hypertrophy of type I (15%) and IIA (10%) fibres, and a 6.5-fold increase in the IIA:IIX fibre ratio. These muscular changes were accomplished with an increase in VLA4 (20%) and modified kinetics of the trot, i.e. increased stride frequency, and decreased stride duration and stance time (Rivero et al., 2001). Overall, these muscular changes with training were associated with an improved performance during locomotion.

The balanced proportion among the three main fibre types found in show jumpers is in agreement with the versatility of movements and exercises that these animals must perform during competition. Another remarkable muscular feature of

Table 5. Different conditioning programme inducing significant muscular adaptations in sport horses from different disciplines (dressage, show jumpers and carriage)

STIMULUS – Intensity	Duration/distance	Frequency	Phase duration	Total duration	RESPONSES – Muscular response
Reference: Rivero et al., 2001. Subjects. Young adult ($\sim$4 years old) untrained Andalusian horses selected for dressage ($n = 5$ controls, $n = 10$ trained). Free exercise in the morning without the rider and riding exercise in the afternoon on ground with different slopes					
Basic training					↑ Diameter type I (15%) and IIA (10%)
$\sim$25% V_{LA4}	45 min morning 60 min afternoon	3 days/week	12 weeks	3 months	↑ IIA:IIX fibre ratio
Specific training					↑ V_{LA4}
$\sim$50% V_{LA4}	45 min morning ↑ 75–90 min afternoon	3 days/week	18 weeks	8 months	↑ Stride rate ↓ Stride duration ↓ Stance phase duration
Reference: Rivero and Letelier 2000. Subjects. Adult cross-breed unfit Thoroughbreds ($n = 10$) were specifically trained for jumping activity with exercises of three different nature for 6 months. *Exercise A*: riding (walk, trot and gallop). *Exercise B*: jumping with the rider over fences 60 → 100 m. *Exercise C*: free jumping over fences 80 → 110 cm					
Morning					↑ Area type IIA fibres (23%)
$\sim$40–65% $\dot{V}O_{2max}$ (4–6.5 m/s)					↑ IIA:IIX fibre ratio
Exercise A	20 min (1st month) → 30 min (6th month)	6 days/week		6 months	↑ Percentage hybrid IIAX fibres
Incremental Exercise B	60 min				↑ Muscle CS activity (60%)
Afternoon					↑ Muscle HAD activity (400%)
Incremental Exercise C	60–90 min	Every 2nd day		6 months	
Reference: Serrano and Rivero, 2000. Subjects. Young adult ($\sim$4 years old) untrained Andalusian horses used for carriage activity ($n = 7$ controls, $n = 7$ trained). Carriage exercise with 75 kg plus driver for 8 months					
$\sim$25–30% V_{LA4} (140–213 m/min)	10–30 min (increasing 5 min each 2 weeks)	5 days/week	3 months	3 months	↑ Area I fibres (26%) (after 3 months)
	60 min		2 months	5 months	↑ V_{LA4} (28%)
	90 min		2 months	7 months	↑ IIA:IIX fibre and myosin ratio
	120 min		1 months	8 months	↑ I:II fibre and myosin ratios
					↑ High-oxidative fibres (9%)
					↑ Capillary density (18%)

See Tables 2 and 3 footnotes for further details of abbreviations.

these animals is the relatively high size of type II fibres. This feature is also in line with the functional demands on these horses, as the explosive nature of the acceleration required for certain activities (e.g. jumping and sprinting) demands the recruitment of the very fast, glycolytic and large cross-sectional type IIX muscle fibres. Skeletal muscle adaptations to a conventional 6 months show jumping training programme are summarized in Table 5. This particular protocol produced a very significant hypertrophy of type IIA fibres (23%) and a nonsignificant hypertrophy of type IIX fibres (8%). Moreover, the IIA-to-IIX fibre ratio and the percentage of hybrid IIAX fibres increased after training, as well as the whole citrate synthase (60%) and 3-hydroxy-acyl-CoA-dehydrogenase (40%) oxidative muscle enzymes. Collectively, these adaptations are compatible with enhanced strength and aerobic capability associated with training.

Draught-exercise is a training method by which all muscle fibres are recruited at a relatively low speed (Serrano and Rivero, 2000). Information about the adaptations of equine skeletal muscle in response to a long-term draught-exercise programme under field conditions, such as those commonly used for competition in carriage driving is presented in Table 5. This constant low-intensity ($\sim$25 of V_{LA4}) and incremental long-duration (60–120 min) prolonged (8 months) training method can induce a significant fibre type transition in the order IIX → IIA → I, an enhanced aerobic capacity, and minimal, if any, fibre hypertrophy.

Comparing muscle conditioning programmes

Studies presented in Tables 2–5 have described various structural and metabolic changes in muscle associated with training. While these studies have provided important descriptive information, little is still known about specific effects of parameters, such as training intensity and duration on muscular responses. Three of the scarce studies about this subject are presented in Table 6.

In the study by Sinha et al. (1993), significant muscular adaptations to training were only seen in the fast group of horses ($\sim$80% $\dot{V}O_{2max}$) exercised over a constant distance (1500 m). The authors of this study concluded that to achieve an optimal training effect, the degree of exercise load at submaximal intensities is not the critical factor, but rather, an increasing exercise intensity may be necessary. More recently, Eaton et al. (1999) concluded, however, that exercise intensity, applied over a constant distance, for 9 weeks does not appear

Table 6. Comparison of the effect on skeletal muscle of various conditioning programmes with different intensity and/or duration of exercise carried out in each bout (per day)

STIMULUS – Intensity	Duration/distance	Frequency	Phase duration	Total duration	RESPONSES – Muscular response
Reference: Eaton et al., 1999.					
Subjects. Lightly trained Thoroughbreds ($n = 10$).					
Focus. Effect of exercise intensity					
Fast group ($n = 5$)		5 days/week			↑ $\dot{V}O_{2max}$ (15%)
Post-exercise [lactate] 4–8 mmol/l	1600 m		2 weeks	2 weeks	↑ VLA4 (31%)
	2400 m		3 weeks	5 weeks	↑ Muscle CS activity (65%)
Slow group ($n = 5$)					↑ VLA4 (31%)
Post-exercise [lactate] < 2 mmol/l	3200 m		2 weeks	7 weeks	↑ Muscle CS activity (21%)
	4000 m		2 weeks	9 weeks	
Reference: Sinha et al., 1993.					
Subjects. Adult (2–9 years old) unfit Thoroughbreds ($n = 10$) exercised in a treadmill 6° slope.					
Focus. Effect of exercise intensity					
Fast group ($n = 5$): 80% $\dot{V}O_{2max}$	3 min (1500 m) (×2)	5 days/week		6 weeks	↑ IIA:IIX fibre ratio ↑ Capillary density ↑ Muscle buffering capacity
Slow group ($n = 5$): 100% $\dot{V}O_{2max}$	6.25 min (1500 m) (×2)				No significant changes
Reference: Gansen et al., 1999.					
Subjects. Young adult (2 years old) unfit Haflinger stallions ($n = 6$) exercised in a treadmill 17° slope.					
Focus. Effect of intensity and duration of exercise					
Protocol A: ~40% VLA4	45 min	Every 2nd day		6 weeks	A: ↑ Muscle [glycogen] (40%)
Protocol B: ~65% VLA4	45 min				B: ↑ Muscle [glycogen] (50%)
Protocol C: ~100% VLA4	25 min				C: No significant changes

See Tables 2 and 3 footnotes for further details of abbreviations.

to have an impact on muscular response to training. To the best of my knowledge, the study by Gansen et al. (1999) is the first and a unique study in horses describing the combined effects of intensity and duration of exercise on muscular response to training. This study concluded that exercises of low-intensities (~40–50% of VLA4) and long duration (45 min) are more effective in inducing an improvement of aerobic capacity [i.e. enhanced muscle (glycogen)] than exercises of high-intensity (~100% VLA4) and moderate (25 min) duration. In a recent study by Rivero et al. (2006), it was concluded that exercise intensity during the specific phase of training in thoroughbreds is a more important factor than exercise duration in determining the degree of IIX-to-IIA myosin heavy chain transformation.

The nature of the exercise during training has also been studied comparatively in the thoroughbred to introduce new practical training methods to reduce the incidence of injuries during training. For example, the horses' aerobic capacity at the muscular level was significantly improved in 2-year-old thoroughbreds by swimming training of 100 m (×3 or 5)/day, 4 days/week for 5 months (Misumi et al., 1995). This swimming training was added to a basic running training consisting of walk, trot, canter and gallop over incremental distances 6 days/week for 5 months. More recently, training has involved running on flat and sloped tracks. In general, horses trained on a sloped (3°) track did not have, more muscle adaptation than horses trained on a flat track (Miyata et al., 1999). Nonetheless, there was a clear no-significant tendency for a higher increase in muscle succinate dehydrogenase activity in horses trained on the sloped track than in horses trained on a flat track. Moreover, electromyographic activity of various locomotory muscles was significantly higher in horses trained in the sloped track than in those exercised on the flat track. These findings may suggest a high degree of recruitment of glycolytic IIX fibres during the exercise in horses trained on a sloped track.

Weightlifting, as a form of progressive resistance exercise training, has been investigated in horse ponies for improving strength, muscle power and muscle size (Heck et al., 1996). In this experimental protocol that simulates the voluntary weightlifting performed by bodybuilders, two adult (3 and 5 years old) ponies underwent 8 weeks of 3 days/week progressive resistance training walking on a level treadmill grade at a constant speed of 1.9 m/s and carrying sheets of lead over their saddle region (wither). They performed a series of progressive sets of weight carrying to fatigue. The ponies carried 44.5 kg for the first set with increases of 22.3 kg per set until fatigue, and a rest period (without weights) of 60–90 s between consecutive steps. This training method resulted in an improved strength (peak weight carried during a workout increased by 260%), which was accompanied by substantial increase in whole forelimb diameter (19%), individual muscle cross-sectional diameters (7–36%), and selective type IIA and type IIX fibre hypertrophy (26%). There were no parallel changes in myosin heavy chain composition (contractile properties).

Overtraining and detraining

Overtraining

Overtraining syndrome has been recognized as a major cause of poor performance in athletic horses (Bruin et al., 1994; Tyler et al., 1998; McGowan et al., 2002). Although there have been fewer investigations in horses than in humans, the syndrome appears to have similar manifestations, with poor performance accompanied by physiological and/or behavioural signs. These signs include chronic fatigue, increased hear rates and blood lactate concentrations during standardized sub-maximal exercise protocols, unwillingness to train, poor appetite, weight loss and gastrointestinal and/or respiratory problems. Overtraining is defined as a significant ($P < 0.05$) decrease in treadmill run time during a standardized exercise test, carried out over the course of a heavy overload and prolonged training (see 'Overload training' in the study by Tyler et al., 1998 presented in Table 3).

In racehorses, clinical signs of overtraining are accompanied by few characteristic changes in skeletal muscle. In the study by Tyler et al. (1998), overtraining was associated with a significant atrophy of type IIA fibres (8%), and a decrease in the IIA:IIX fibre ratio, but also with a further increase in mitochondrial volume of type I (16%) and II (39%) fibres, which was mirrored with an increase in $\dot{V}O_{2max}$ (8%). Metabolic adaptations described in overtraining situation include muscle [ATP] depletion (Bruin et al., 1994) and a reduced rest muscle [glycogen] (McGowan et al., 2002). This reduction in pre-exercise muscle [glycogen] associated with overtraining may be related with the slow post-exercise muscle [glycogen] repletion that occurs spontaneously in the horse (~72 h). However, this finding is unclear because the muscle glycogen utilization rate was not affected by overtraining.

Detraining

As already mentioned, muscular adaptations to training are reversible, i.e. tend to return to pre-training situation when the stimulus ceases (detraining period) (Snow and Valberg, 1994; Serrano et al., 2000; Serrano and Rivero, 2000). In horses, the return to sedentary activity levels following a prolonged period of endurance training results in normalization of fibre type composition via a fibre type transition in the order I → IIA → IIX (Serrano et al., 2000; Serrano and Rivero, 2000). These changes occur in parallel with a reversion of the muscle fibre's size, and metabolic and capillary characteristics to pre-training levels. Thus, fibre sizes decrease, together with a decline in mitochondrial density, aerobic enzyme activities and glycogen content, and the normalization of anaerobic enzyme activities (Serrano et al., 2000; Serrano and Rivero, 2000).

In practice, the maintenance of the trained phenotype during inactivity depends on the range and magnitude of muscular adaptations to training, but usually appears more prolonged in horses than in other athletic species. Thus, the adaptive training response of skeletal muscles is generally maintained through 5–6 weeks of inactivity, but not beyond 12 weeks (Snow and Valberg, 1994; Rivero and Piercy, 2004).

Concluding Remarks

From the extent literature available, it is clear that equine skeletal muscle has considerable potential to adapt during training and, overall, these adaptations have important functional implications that influence power generation (strength), resistance to fatigue (stamina) and velocity of shortening (speed). Ideally, conditioning programmes in athletic horses should be aimed at the development of muscle properties that optimize equilibrium among these three physiological traits (Table 7).

The nature and magnitude of muscular responses to training depends on two critical groups of factors. The first includes factors affecting the basal status of the muscle, i.e. the breed, age, sex, discipline, level of fitness and training history of the horse. And the second, those factors related to the nature and amount of the applied stimulus: type, intensity, duration and frequency of exercises, as well as the total duration (length) of the conditioning programme (Table 7).

Despite that there is a great deal of controversies in the literature, the adaptive response to training can take two basic ways, although they frequently occur simultaneously in practice and are accompanied with changes in the microvasculature. The first one is the quantitative response, which consist frequently of fibre hypertrophy, when myofibres increase in size retaining their basal properties. The main consequence of

Table 7. Physiological implications of muscular adaptations in various training programmes scientifically evaluated in horses

Horses			Conditioning protocol			Functional significance			
Breed	Age	Intensity	Duration (Distance)	Frequency	Length	Stamina	Strength	Speed	Reference
Thoroughbred	4–8 years	~55% $\dot{V}O_{2max}$	60 min (~13–14 km)	Daily	10 days	+	ni	−	Geor et al., 1999
Thoroughbred	2–9 years	~80% $\dot{V}O_{2max}$	3 min (1500 m) ×2	6 days/week	6 weeks	+	ni	−	Sinha et al., 1993
Thoroughbred	5–7 years	~80–100% $\dot{V}O_{2max}$	5 min (×2)	5 days/week	12 weeks	ne	ni	+ +	Eto et al., 2004
Thoroughbred	2–3 years	~100–165% $\dot{V}O_{2max}$	1.6–5.3 min (1600–3200 m)	5 days/week	16 weeks	+ +	+	−	Miyata et al., 1999
Thoroughbred	2 years	~100–165% $\dot{V}O_{2max}$	1.6–5.3 min (1600–3200 m)	5 days/week	16 weeks	+ +	+	+	Yamano et al., 2002
Standardbred	3–5 years	~60–100% $\dot{V}O_{2max}$	6–12.5 min (~3–9 km)	5 days/week	16 weeks	+ +	+ +	ne	Tyler et al., 1998
					32 weeks	+ +	+	−	
Standardbred	2 years	~100–140% VLA4	15 min	2nd day	5 weeks	+	−	+	Rivero et al., 2002
		~65% VLA4	60–90 min	2nd day					
Arab	8.6 years	~80% VLA4	50–80 min (~10–20 km)	3 days/week	12 weeks	+	+ + +	−	D'Angelis et al., 2005
Andalusian	~4 years	~25–30% VLA4	45–60 min	5 days/week	12 weeks	+	+	−	Serrano et al., 2000
		~50–60% VLA4	75–120 min		32 weeks	+ + +	+	−	

Intensity is expressed as a fraction of either $\dot{V}O_{2max}$ (velocity at maximal aerobic capacity) or VLA4 (velocity inducing a blood lactate concentration of 4 mmol/l). The symbols + and − indicate that either the muscular adaptations to training had positive or negative effect, respectively, towards the particular characteristic; the number of symbols is proportional to the magnitude of the adaptation; ne, no effect; ni, not investigated.

this adaptation is an increase in muscle strength. And the second is a qualitative response or remodelling (the most common), in which fibres acquire markedly different metabolic and structural characteristics (i.e. fibre type transitions). This response produces a muscle that is much more resistant to fatigue, but with an intrinsic decreased speed.

Metabolic demands of most of equestrian disciplines are largely aerobic in nature, including thoroughbred racing. In thoroughbred racehorses, exercises of high-intensity (100–165% of $\dot{V}O_{2max}$) over relatively short distances (1600–3600 m) for 16 weeks induce relevant muscular adaptations compatible with improved strength, stamina and speed (Table 7).

An improvement in both strength and aerobic capacity can be obtained in standardbred trotters with exercises of low-to-moderate intensity (60–80% of $\dot{V}O_{2max}$) and relatively short duration (6–12 min) for 16 weeks. Prolonged training beyond this period with exercises of higher intensities (100–110% of $\dot{V}O_{2max}$) does not improve muscle strength, but only aerobic capacity, and reduces anaerobic capacity, increasing at the same time the risk of overtraining and poor performance (Table 7).

Long-term (6–8 months) endurance training programmes with exercises of low intensity (25–50% of VLA4) and long duration (60–120 min) produce a considerable increase in aerobic capacity, a moderate improvement in muscular strength (discrete hypertrophy) and reduced anaerobic capacity. A marked hypertrophy in endurance horses can be achieved with exercises of higher intensity (80% of VLA4) and moderate-to-long-duration (60–80 min) for 12 weeks. However, the benefit of this adaptation to endurance activity is unclear.

An increase in strength and aerobic capacity can be evoked in dressage-type horses by exercises of low intensity (25–50% of VLA4) and middle-to-prolonged duration (70–90 min) 3 days/week for 8 months. These adaptations may improve athletic performance at low speed in these horses. A conventional 6 months training programme for show jumpers (riding and jumping over fences of different height) also increases strength and aerobic capacity significantly (Table 7).

Despite there is a significant lack of studies in the literature about specific comparisons between muscle conditioning programmes, it seems that exercises of low-to-moderate intensity and long duration are more effective for improvement aerobic capacity than exercises of high-intensity and short duration. To develop strength, exercises of higher intensities (~80% of $\dot{V}O_{2max}$) are required. A concomitant increase in strength (fibre hypertrophy), endurance (aerobic capacity) and speed (anaerobic capacity) can be obtained with exercises of supra-maximal intensity (100–165% of $\dot{V}O_{2max}$) over short distances (1600–3600 m).

Overload training, with exercises of high-intensity (>100% of $\dot{V}O_{2max}$) prolonged beyond a basic and specific training of about 16 weeks should be avoided in athletic horses to reduce the risk of overtraining, a syndrome recognized as a major cause of poor performance.

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