Changes in maximum oxygen uptake during prolonged training, overtraining, and detraining in horses

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The V̇O₂max of horses is at least twice that of humans on a mass-specific basis (9, 28), with a mean value of 154 ml·kg⁻¹·min⁻¹ reported in racing Thoroughbreds (26). However, the response to training in untrained humans, in terms of increases in V̇O₂max, is of a similar magnitude to that in horses, with reported increases in V̇O₂max commonly between 10 and 20% (12, 14, 15, 22, 29, 30, 32).

Detraining is reported to result in a rapid decrease in V̇O₂max in horses, with V̇O₂max returning to pretraining values after 2–3 wk of inactivity (17). Another study reported that a 3-wk period of detraining produced a decline in peak oxygen uptake (V̇O₂) to values close to their pretraining levels (1). The rapid decline in V̇O₂max found in horses appears to be similar to that occurring in human athletes, where V̇O₂max begins to fall within days of the commencement of detraining, despite the length and intensity of training (19, 23). However, another study found no reduction in V̇O₂max in horses detrained for a period of 15 wk (3).

Overtraining syndrome has been recognized as a significant problem for elite athletes for many years (11, 18, 33), and it has also been recognized in racehorses as a major cause of poor performance (2, 24, 25). 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 behavioral signs. These signs include chronic fatigue, increased heart rates and blood lactate concentrations during standardized submaximal exercise protocols, unwillingness to train, poor appetite, weight loss, and gastrointestinal and/or respiratory problems (2, 24, 25). “Overload training” has been used to describe the process of overtraining, whereas “overtraining” is reserved for use in describing the syndrome of poor performance and accompanying signs (11). In the current study, we have used the term “overload training” as the term for the training process involving periods of intense exercise and compensation.

Overtraining syndrome has been shown to affect V̇O₂ max in human athletes. This may be seen as a higher V̇O₂ at submaximal workloads, due to a higher oxygen cost of exercise (18), and may be associated with an unaltered (4) or decreased (16) V̇O₂max.

The aim of the study was to develop a suitable model of overtraining syndrome for the purposes of this study. We hypothesized that prolonged intense training in horses would result in an upper limit to the increase in V̇O₂max, and that signs of overtraining would be associated with a decrease in V̇O₂max. Furthermore, that following prolonged training there would be a slow decrease in V̇O₂max with detraining.

MATERIALS AND METHODS

Thirteen standardbred geldings, 3–5 yr old and weighing 421 ± 10 (SE) kg, were used in a controlled, longitudinally designed training study. The horses presented in the current study were all young racehorses that had been trialed and/or raced with varying athletic ability. While none of the horses were of an elite class of athletes, at the conclusion of training, they all had indexes of exercise capacity comparable to an average standardbred racehorse (27).
Before the commencement of the study, horses were acclimated to exercising on the treadmill and to wearing a respiratory gas-collection mask, after which they were detrained (rested on pasture) for at least 4 mo. All training and exercise tests took place on a high-speed treadmill (Mustang, Kagra, Switzerland) at a 10% slope. Principles of laboratory animal care (the NIH “Guide for the Care and Use of Laboratory Animals,” [DHENV Publication No. (NIH) 86–23, revised 1985, Office of Science and Health Reports, DRR/NIH, Bethesda, MD 20892] were followed, and approval of the University of Sydney Animal Ethics Committee was obtained for the experiment.

Training was divided into four phases. Phase 1, or the endurance phase, consisted of 7 wk of endurance training, 5 days/wk. This consisted of a warm-up of 1,000 m at 4 m/s (4.2 min) followed by exercise at 6 m/s (intensity ~60% VO\(_{2\text{max}}\)) over distances up to 4,000 m (11.1 min) daily. Phase 2, or the high-intensity phase, consisted of 9 wk of moderate-intensity training 3 days/wk and of high-intensity training 2 days/wk. Moderate-intensity training consisted of a warm-up of 1,000 m at 4 m/s followed by training at 8 m/s (intensity ~80% VO\(_{2\text{max}}\)) for a distance of 3,000 m/day (6.25 min). High-intensity training consisted of a warm-up of 1,000 m at 4 m/s followed by 2-min intervals at speeds of ~10 m/s (intensity of 100% VO\(_{2\text{max}}\)) up to a total of 6 min/day (total daily distance of ~3,600 m).

In phase 3, or the overload training phase, the horses were divided into two groups: overload training (OLT) and control (C). The OLT group exercised at higher intensities, more frequently, and for longer durations than group C, with increasing intensities and distances until signs of overtraining were observed, in week 31, or after 15 wk of this phase of training. Overtraining was defined as a significant (P < 0.05) decrease in treadmill run time during a standardized exercise test. Horses continued training for 1 wk after the onset of signs of overtraining to allow completion of the testing procedures and measurements. A further exercise test was then performed 2 wk later, after a relative reduction in workload, and overtraining was confirmed by continued significantly decreased run time, compared with results before signs of overtraining were observed.

The OLT group performed high-intensity training 3 days/wk and moderate-intensity training 3 days/wk, whereas the C group performed high-intensity training 2 days/wk and moderate-intensity training 3 days/wk. Both the OLT and C groups performed a run to fatigue at 110% VO\(_{2\text{max}}\) on one of the high-intensity training days every week throughout the OLT phase. The run time was recorded but was found to be too variable for use in detecting a decrease in run time with overtraining. Instead, the incremental exercise test, which had a lower coefficient of variation, was found to be a better indicator of overtraining.

For the first 11 wk of phase 3, the OLT group performed a rapidly increasing protocol of moderate- and high-intensity training similar to phase 2. Moderate-intensity training consisted of a warm-up of 1,000 m at 4 m/s followed by training at 8 m/s (intensity ~80% VO\(_{2\text{max}}\)) for a distance of up to 6,000 m/day (12.5 min). High-intensity training consisted of a warm-up of 1,000 m at 4 m/s followed by 2-min intervals at speeds of ~10 m/s (intensity of 100% VO\(_{2\text{max}}\)) up to a total of 16 min/day (total daily distance of ~9,600 m). After this period, it was evident that the horses were not showing signs of overtraining, and so the protocol was altered to allow for greater intensity of exercise to be introduced to the OLT group. High-intensity training for the OLT group consisted of a warm-up of 1,000 m at 4 m/s followed by intervals of high-intensity exercise equivalent to 110% VO\(_{2\text{max}}\) until signs of fatigue. Horses exercised for up to ~9,000 m (in intervals of ~800 m). This was equivalent to an average interval time of ~60 s, and ~10–15 intervals were able to be completed by each horse in each training period. Moderate-intensity training for the OLT group also increased in intensity, and the warm-up was followed by training at 9 m/s (~85% VO\(_{2\text{max}}\)) over 6,000 m/day (11.1 min).

The C group continued training as for the high-intensity phase for the same 16-wk period. The amount of exercise was increased slowly in the C group to maintain the training stimulus. High-intensity training included 2-min intervals at 100% VO\(_{2\text{max}}\) that increased from a total of 6 min (average distance ~3,600 m) to 8 min/day (average distance ~5,000 m), and the distances covered during moderate-intensity training (~80% VO\(_{2\text{max}}\)) increased from 3,000 to 4,500 m/day (6.25–9.4 min). During the 2-wk period of reduced workload, the C group performed the same amount of exercise as the OLT group. Phase 4, or the detraining phase, consisted of a period of 12-wk rest, with horses confined to yards.

The VO\(_{2\text{max}}\) was measured every 2–3 wk during the 34 wk of training and at 2, 4, 6, 8, and 12 wk of detraining by using a standard incremental exercise test (8). The test consisted of 2-min warm-up at 4 m/s followed by 1-min increments at increasing speeds (6, 8, 10, 11, 12, 13 m/s) until fatigue. Fatigue was determined as the point at which the horse was unable to keep pace with the treadmill despite encouragement. Total run time for the test was recorded and was used as an objective indicator of overtraining. An open-flow gas-collection system was used for collection of expired gas samples over the last 15 s of each speed increment. Measurements of VO\(_{2}\), carbon dioxide production (VCO\(_{2}\)), and the respiratory exchange ratio (R) during the exercise test were performed as described previously (5). Flow rates of ~7,000 l/m were used during the experiment, and were measured by using the nitrogen dilution technique (10). The gas-collection system had a volume of 218 liters, and at the flow rate used the time delay between the horses’ expiration and the collection of the sample was 1.9 s. VO\(_{2\text{max}}\) was confirmed in all horses by demonstrating no increase in VO\(_{2}\) between the last two steps of the exercise test. Maximal VCO\(_{2}\) and R were defined as the highest values reached during the test. The coefficient of variation for repeated determinations of VO\(_{2\text{max}}\) was 3.5% (5). The coefficient of variation for run time during the incremental exercise test was calculated.

To determine the speeds corresponding to different relative intensities of training exercise, horses were subjected to an additional submaximal incremental exercise test at least 3 h after the VO\(_{2\text{max}}\) test was performed to determine the linear relationship between VO\(_{2}\) and speed at various submaximal exercise speeds (7). With linear regression analysis, using the method of least squares, individual regression values were calculated, and from these values the speeds at which each horse would be exercising at 100 and 110% VO\(_{2\text{max}}\) were determined (21).

Results during training and detraining were compared by using a one-way repeated-measures analysis of variance with time as a repeated-measures factor. Results when overtraining occurred during phase 3 were compared by using a two-way repeated-measures analysis of variance with training group an independent variable and time a repeated-measures factor. Post hoc tests of least significant difference were performed where F-values were significant (P < 0.05). Results are presented as means ± SE.

RESULTS

In both groups, VO\(_{2\text{max}}\) increased throughout training (Fig. 1). From pretraining values of 117 ± 2 ml·kg\(^{-1}\)
There was a significant (P < 0.05) decrease in body weight from 425 ± 10 kg in week 24 to 411 ± 9 kg at the onset of overtraining in week 31 (Fig. 3). In comparison, the C group maintained a body weight of 423 ± 14 kg from week 24 to 423 ± 14 kg in week 31. Although there was no objective measurement of behavior, subjectively, it was noted that horses in the OLT group became more difficult to handle during the period of overtraining than the control group, with signs of irritability and unwillingness to commence and complete training sessions.

**DISCUSSION**

This is the first study to have developed a suitable model of overtraining in horses. A previous study had failed to sufficiently achieve a model, as there was no control group and no statistically significant reduction in performance in a standardized exercise test (2). In the current study, the proof of overtraining is in the combination of a significant reduction in body weight and reduction in performance, which was measured as a reduction in run time during a standardized incremental exercise test. Overtraining was confirmed by continued reduction in performance after a period of reduced workload. The coefficient of variation for run time using this technique was only 4%. Although the overtraining was diagnosed in week 32, based on a significant reduction in run time for the group, retrospectively, it was evident that individual horses had a reduction in run time in week 29 and more in weeks 31 and 32. Thus, while a group effect was evident only in weeks 31 and 32, the onset of signs of overtraining may have occurred earlier in individual horses.

This is the first long-term study of changes in $\dot{V}_\text{O}_{2\max}$ with training in horses, and it was surprising to find that $\dot{V}_\text{O}_{2\max}$ continued to increase throughout training. The total increase was 29% above pretraining values.
Table 1. Values for run time, $\dot{V}_{O_2\text{max}}$, $\dot{V}_{CO_2\text{peak}}$, and $R_{\text{peak}}$ for control and overload training groups during training, (34 wk), and detraining (12 wk).

<table>
<thead>
<tr>
<th>Week of Training</th>
<th>Run Time, s</th>
<th>$\dot{V}_{O_2\text{max}}, \text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$</th>
<th>$\dot{V}_{CO_2\text{max}}, \text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$</th>
<th>$R_{\text{peak}}$</th>
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<tr>
<td></td>
<td>C Time, s</td>
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<td>C</td>
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<tr>
<td>1</td>
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<td>324 ± 5</td>
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Values are means ± SE. C, control (6 horses); OLT, overload training (7 horses) groups. Run times are not included for weeks 1, 8, and 15, since an additional submaximal 1-min increment was included in the rest. $\dot{V}_{O_2\text{max}}$, maximal $O_2$ uptake; $\dot{V}_{CO_2\text{peak}}$, peak $CO_2$ consumption; $R_{\text{peak}}$, peak respiratory exchange ratio.

with about one-half of the increase and the most rapid increase occurring in the first 7 wk of endurance training. The increase in $\dot{V}_{O_2\text{max}}$ was greater than has been previously described in training studies involving horses. Reported increases in $\dot{V}_{O_2\text{max}}$ have ranged from 10% (17) to 23% (8), and peak $V_O_2$ has been reported to increase by 25% (1). However, the present study involved 34 wk of training, compared with 6–12 wk in the previous reports. The training program used in this study was of a longer duration and used higher intensities of training than in other treadmill studies (1, 8, 17).

Horses trained at a constant exercise load for 6 wk, at intensities of either 40 or 80% $\dot{V}_{O_2\text{max}}$ and had a 10% increase in $\dot{V}_{O_2\text{max}}$ at either intensity after 2 wk of training but thereafter there were no further increases (17). While horses trained with an increasing exercise load for 7 wk, they had a 23% increase in $\dot{V}_{O_2\text{max}}$ at the end of training (8). Despite the durations being relatively short compared with studies in human athletes, the training regimen was much more demanding for the horses than would be expected at commercial training establishments where traditional training methods were used (20).

When results of studies in humans and horses are compared, the percent increases due to training in $\dot{V}_{O_2\text{max}}$ of untrained subjects are similar and depend on the level of physical activity before the start of the training program. Saltin and colleagues (29) found a 33% increase in $\dot{V}_{O_2\text{max}}$ in previously sedentary subjects after a 50-day training period but only a 4% increase in subjects who were previously physically active after the same training period. Despite the range of increases in $\dot{V}_{O_2\text{max}}$ with training in humans, most studies have shown a ~10–20% increase in $\dot{V}_{O_2\text{max}}$ with training in previously untrained or detrained people (12, 14, 15, 22, 29, 30, 32).

There have been relatively few studies on the time course of increases in $\dot{V}_{O_2\text{max}}$ in humans. Hickson and colleagues (13) found a linear increase in $\dot{V}_{O_2\text{max}}$ during 10 wk of strenuous endurance training when the training stimulus increased throughout training. Mikesell and Dudley (22), during a similar training program, found that the linear increase in $\dot{V}_{O_2\text{max}}$ was maintained for only 5 wk, with a decline in the 6th wk. However, the latter study had begun with well-conditioned distance runners who may have been closer...
to their limit of increase in $V_{O2max}$ than the untrained subjects in the first study. In a longer study of 36 wk, $V_{O2max}$ increased for the first 24 wk of endurance training but showed no further increase over the final 12 wk of training (32). From the results of these studies, it appears that the time course of changes in $V_{O2max}$ of humans and horses is similar, as there was almost a linear increase in $V_{O2max}$ in the first 10 wk of the current study and no significant increase after 28 wk of training (Fig. 1).

Whether the increase in $V_{O2max}$ occurring in horses in the current study is close to the maximum extent of increase could not be determined from this study. $V_{O2max}$ continued to increase over the final phase of training, but in the last 4 wk this was not significant. However, the power to detect the increase of ~5 ml·kg$^{-1}$·min$^{-1}$ was only 80%. It is possible that training for >34 wk would have led to continued increases in $V_{O2max}$.

Overtraining did not affect $V_{O2max}$ but maximal $V_{CO2}$ and $R$ were both lower in the OLT group at the onset of overtraining, presumably because of the lowered run time in the overtraining group. The cause of the reduction in run time may be due to physiological (metabolic) or psychological causes. The reduced maximal values for $V_{CO2}$ and $R$ in the OLT group at overtraining indicate that it is unlikely that increased lactate accumulation and metabolic acidosis were the cause of the reduced run time. Lactate accumulation has been postulated as a possible physiological factor in overtraining (18, 24). Glycogen depletion has been shown to cause decreases in maximal $V_{CO2}$ and $R$ during exercise in humans (31) and may have been a factor in the overtrained group of horses.

The pathophysiology of overtraining remains unclear, with psychological factors complicating physiological factors. It may well be that overtraining is a largely psychological syndrome, where there is fatigue and poor performance despite little change in $V_{O2max}$, one of the major indexes of exercise capacity.

In a previous study, there was a rapid decrease in $V_{O2max}$ in horses, with values not significantly different from pretraining levels by 2 wk of detraining (17). In the current study, there was no significant reduction in $V_{O2max}$ during the first 4 wk of detraining. While $V_{O2max}$ values after 12 wk of detraining were 8% lower than peak training values, they were still 15% above those before training. This indicates a much slower decrease in $V_{O2max}$ than has been described in human athletes (19, 23) and horses (17) but agrees with the results of Henriksen and Reitman (12), who found that $V_{O2max}$ was not significantly different from the level at the end of training after 6-wk detraining in humans. Butler and colleagues (3) found no significant change in $V_{O2max}$ with 15-wk detraining in horses, despite an apparent decrease in mean $V_{O2max}$ values between fully fit horses and 15-wk detraining of 11%. The reason that the apparent decrease was not significant may have been that there were only four horses in the study. Also, the detraining period was simply described as 15 wk of relative inactivity where horses were walked for 20 min each day, which may have been enough exercise to maintain $V_{O2max}$. Studies on human athletes have found that, once peak fitness has been achieved, even a small amount of exercise during the detraining period would maintain $V_{O2max}$ (14, 23). In our study, horses were confined to yards and only tested every 2 wk for the first 8 wk of detraining and at 12 wk of detraining.

The slow decrease in $V_{O2max}$ after prolonged training has implications for the loss of aerobic fitness and performance in horses in training, which may need a period of rest due to injury or disease. If horses have been in training for a long period, a 4- to 6-wk rest may not have adverse effects on aerobic capacity. Such horses may be able to resume training at a higher training level more rapidly and return more quickly to racing. However, there have been no studies on the effects of detraining on bone density and soft tissues such as tendons.

Conclusion. In this study, $V_{O2max}$ continued to increase during prolonged training. However, the increase in $V_{O2max}$ may be close to the possible limit of increase in $V_{O2max}$ in standardbred horses, as $V_{O2max}$ did not increase over the last 4 wk of this study despite increases in exercise intensity and duration. A suitable model for the development of overtraining syndrome in horses has been developed in this study. Signs of overtraining were not associated with changes in maximal aerobic power, but lower values were noted for maximal values for $V_{CO2}$ and $R$, probably due to a lower run time in the OLT group. After prolonged training, decreases in maximal aerobic power occurred slowly during detraining, and after 12 wk of detraining $V_{O2max}$ values remained 15% above pretraining values.

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