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The effect of overtraining on plasma cortisol concentrations at rest and in response to exercise and administration of synthetic adrenocorticotropin in Standardbred racehorses

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Summary

The potential role of the hypothalamic-pituitary-adrenocortical axis in the aetiopathogenesis of overtraining was investigated in a longitudinal training study. Plasma cortisol concentration was measured in Standardbred geldings before and after high-intensity training (control group) or overtraining (treatment group) at rest, in response to an incremental exercise test, and after ACTH administration. Resting cortisol concentration and peak concentration after ACTH administration did not change throughout the study. Area under the curve (AUC) for cortisol concentration versus time over 2 hours post-ACTH injection decreased significantly for all horses over the study period, while the net rise (peak corrected for pre-injection concentration) decreased significantly for the C group only ($P<0.05$). Peak cortisol concentration, AUC and mean concentration over 2 hours after exercise decreased significantly with overtraining ($P<0.05$). Further work may help to elucidate the potential value of the cortisol response to exercise in predicting the onset and monitoring recovery from overtraining.

Keywords: cortisol, exercise, overtraining, training, ACTH

Der Einfluß von Übertraining auf die Kortisolkonzentration im Plasma in Ruhe, nach Belastung und nach Gabe von synthetischem Adrenokortokotropin bei Trabrennpferden

In einer Langzeit-Trainingsstudie wurde die mögliche Rolle der Achse Hypothalamus-Hypophyse-Nebennierenrinde bei der Ätiopathogenese des Übertrainings untersucht. Bei Traberwallachen wurde die Plasma-Kortisolkonzentration vor und nach intensivem Training (Kontrollgruppe) oder Übertraining (Versuchsgruppe) in Ruhe, als Antwort auf einen stufenförmigen Belastungstest und nach Gabe von ACTH gemessen. Die Ruhekonzentration des Kortisols und die maximale Kortisolkonzentration nach Gabe von ACTH blieben während des Versuches unverändert. Über zwei Stunden nach Injektion von ACTH nahm die Fläche unter der Kurve (area under the curve, AUC) der Kortisolkonzentration versus Zeit bei allen Pferden im Verlauf der Studie signifikant ab, während der Nettoanstieg (maximale Konzentration korrigiert um die Konzentration vor der Injektion) nur in der Kontrollgruppe signifikant abnahm ($p<0,05$). Die maximale Kortisolkonzentration, AUC und mittlere Konzentration über zwei Stunden nach Belastung nahm mit dem Übertraining signifikant ab ($p<0,05$). Weitere Studien können helfen, den möglichen Nutzen der Reaktion von Kortisol auf Belastung bei der Vorhersage des Beginns und bei der Überwachung der Erholung von Übertraining zu erhellen.

Schlüsselwörter: Kortisol, Belastung, Übertraining, Training, ACTH

Introduction

Overtraining is described as a state of prolonged fatigue caused primarily by an imbalance between training and recovery (*Kuipers* and *Keizer,* 1988; *Fry* et al., 1991). The principles of overload training are to provide a gradually increasing workload, or stimulus for adaptation, with periods of active recovery separating the increments in training load. Continued heavy training with inadequate regeneration time can result in overtraining, which manifests as chronically depressed performance accompanied by a range of clinical signs. In horses these commonly include loss of body weight and appetite, reluctance to exercise, and increased injury rates.

As yet no specific biological markers have been identified to help predict the onset of overtraining. There have been reports of both decreased (*Persson* et al., 1980) and increased (*Bruin* et al., 1994) adrenocortical responsiveness to ACTH administration in overtrained horses. Similarly, studies in human athletes have failed to demonstrate consistent effects of overtraining on the hypothalamic-pituitary-adrenocortical axis.

Aims

In view of the lack of consistent information currently available, this study was undertaken to investigate the effects of prolonged training and overtraining on plasma cortisol concentration in horses (i) at rest; (ii) in response to a standardised, incremental exercise test; and (iii) after administration of synthetic adrenocorticotropin (ACTH).

Materials and methods

Twelve clinically normal Standardbred geldings were conditioned on a treadmill (Mustang™ 2000, Kagra AG, Switzerland) exercising at low intensities for 7 weeks prior to commencement of testing procedures in week 8. Experiments were conducted on separate days in the same week. Experiment 1: Blood samples were collected from resting horses via indwelling jugular catheters every 20 minutes from 15.00–19.00 h. Plasma was harvested immediately and stored at –20°C. Experiment 2: Each horse performed an exercise test between 08.30–10.30 h, comprising 2 mi-

nute increments at speeds corresponding to 30, 50, 70 and 100% of maximum oxygen uptake ($\dot{V}O_{2max}$). Blood samples were collected prior to exercise (2 samples 15 minutes apart); during the last 15 seconds of exercise at 70% and 100% $\dot{V}O_{2max}$; then 5 min, 15 min, 30 min, 1 h, 1½ h and 2 h after exercise. Experiment 3: Commencing at 07.30 h, blood samples were collected immediately prior to and 1, 2, 3, and 4 hours after intravenous injection of 25 IU synthetic ACTH (Synacthen® 0.25 mg/ml, Ciba-Geigy Australia Ltd).

The horses were then trained at higher intensities (60–100% $\dot{V}O_{2max}$) during weeks 8–16 before being randomly allocated to control (C) (n=6) or overload training (OT) (n=6) groups in week 17. From week 17, the volume of training increased at a faster rate for the OT group, and these horses also performed a greater proportion of high-intensity exercise than the C group. Training ceased when overtraining was diagnosed in week 32, on the basis of a significant reduction in performance capacity for the OT group (determined from total run time during standardised $\dot{V}O_{2max}$ tests) accompanied by a significant reduction in body weight, (P<0.05). Experiments 1, 2 and 3 were then repeated.

Total plasma cortisol concentration was measured in duplicate using a commercially available radioimmunoassay kit (Coat-A-Count® cortisol RIA kit, Diagnostic Products Corporation, Biomediq DPC® Pty. Ltd., Doncaster, Victoria, Australia). In experiment 1, mean plasma cortisol concentration over 4 hours and area under the curve (AUC) of cortisol concentration versus time were calculated. The plasma cortisol response to exercise in experiment 2 was assessed in the following terms: mean pre-exercise cortisol concentration; the absolute peak plasma concentration achieved during or after the exercise test; absolute peak corrected for the pre-exercise mean concentration; and AUC and mean concentration of cortisol over 2 hours after exercise. In experiment 3, pre-injection cortisol concentration; absolute peak concentration after ACTH injection; absolute peak corrected for the pre-injection concentration (ie. net rise in cortisol concentration in response to ACTH administration); and AUC over 2 hours after ACTH administration were calculated.

Effects of group and week of training were analysed by two-way repeated measures analysis of variance and Student-Newman-Keuls post-hoc tests.

Results

Results are presented in the table as mean ± s.e. In experiment 1, there was no change in mean plasma cortisol concentration (93.1 ± 5.22 nmol l^{-1}) or AUC (22.3 ± 1.3 μmol min l^{-1}) over the 4-hour afternoon resting sampling period.

In experiment 2, the absolute peak, AUC and mean concentration over 2 hours after exercise were significantly lower in overtrained horses (P< 0.05). There were no significant effects of group or week of training on pre-exercise concentration (215.4 ± 9.2 nmol l^{-1}), although the p value for the interaction between the effects of group and week was 0.068. Absolute peak corrected for pre-exercise mean concentration decreased (P< 0.05) for all horses over time (98.5 ± 9.2 nmol l^{-1}, 77.2 ± 11.4; n=10).

In experiment 3, pre-injection cortisol concentration was significantly lower in the OT group overall, however there was no interaction with time (C: 217.5 ± 15.0 nmol l^{-1} ; OT: 182.5 ± 14.9 nmol l^{-1}). AUC over 2 hours post-ACTH administration decreased for all horses over time (1240 ± 64.2 nmol min l^{-1}; 1099 ± 63.6; n=10), (P< 0.05). There were no significant effects of group or week of training on the absolute peak cortisol concentration after ACTH administration (365.4 ± 12.5 nmol l^{-1}). The absolute peak corrected for the pre-injection concentration (or net rise in cortisol concentration in response to ACTH administration) decreased for the C group only (P< 0.05).

Discussion

This is the first longitudinal study of experimentally-induced overtraining in horses in which an objective measurement of perfor-

Tab.1: Plasma cortisol results

Cortisol results	Units	Week 8	Week 33	Week 8	Week 33
Experiment 2: Exercise test		*C group (n=5)*		*OT group (n=5)*	
Pre-ex [cortisol]	nmol l^{-1}	209.5 ± 16.8	226.4 ± 14.1	235.1 ± 17.4	190.8 ± 23.5
$Peak_{abs}$ $[cortisol]_{ex}$	nmol l^{-1}	321 ± 20.5^{ab}	326 ± 11.2^{ab}	320 ± 15.6^{a}	245 ± 17.0^{b}
Mean $[cortisol]_{post-ex}$	nmol l^{-1}	250 ± 16.7^{ab}	252 ± 17.4^{a}	258 ± 11.7^{a}	192 ± 16.6^{b}
$AUC_{post-ex}$	μmol min l^{-1}	28.1 ± 1.9^{ab}	28.4 ± 2.1^{a}	29.0 ± 1.2^{a}	21.4 ± 1.9^{b}
Experiment 3: ACTH Response test		*C group (n=5)*		*OT group (n=5)*	
Pre-injection [cortisol]	nmol l^{-1}	209.5 ± 25.7	225.5 ± 17.7	206.4 ± 19.7	158.6 ± 18.0
$Peak_{corr}$ $[cortisol]_{post-ACTH}$	nmol l^{-1}	188.1 ± 16.6^{a}	135.8 ± 15.1^{b}	158.0 ± 32.4^{ab}	181.6 ± 19.3^{ab}

Key: a, b – Means sharing the same superscript are not significantly different (P< 0.05)
Pre-ex [cortisol] – mean pre-exercise cortisol concentration (nmol l^{-1})
$Peak_{abs}$ $[cortisol]_{ex}$ – absolute peak concentration during or after exercise (nmol l^{-1})
$AUC_{post-ex}$ – area under the curve (μmol min l^{-1}) over 2 hours after exercise
Mean $[cortisol]_{post-ex}$ – mean concentration (nmol l^{-1}) over 2 hours after exercise
Pre-injection [cortisol] – pre-injection cortisol concentration (nmol l^{-1})
$Peak_{corr}$ $[cortisol]_{post-ACTH}$ – absolute peak corrected for the pre-injection concentration (nmol l^{-1})

mance capacity was used to diagnose the condition. Overtrained horses showed a significant decline in performance which persisted after 11 days of reduced activity, and a significant loss of body weight.

Intense exercise is associated with an elevation in plasma glucocorticoids in a number of species, and the magnitude of this response depends on the intensity of exercise performed, as well as the state of training (*Foss* et al., 1971; *Winder* et al., 1982; *Luger* et al., 1987; *Tabata* et al., 1990). In this study, overtrained horses showed a diminished adrenocortical response to equivalent exercise challenges (with respect to $\dot{V}O_{2max}$), however basal levels and the response to ACTH stimulation were unchanged. These findings suggest there may be some dysfunction of the hypothalamic-pituitary-adrenocortical axis in overtraining, but that the defect is unlikely to be at the level of the adrenal cortex. An earlier study of overtraining in humans suggests that adrenocortical stimulation from higher centres is depressed in overtraining (*Barron* et al., 1985). Perhaps this is part of some centrally-mediated general defence reaction aimed at preventing fatal depletion of the resources of the organism (*Viru* and *Äkke,* 1969).

Conclusions

Overtraining occurs in horses subjected to prolonged high-intensity training with insufficient recovery periods. In this study the syndrome was characterised by decreased performance capacity and loss of body weight, as well as behavioural changes including a reluctance to exercise. In addition, overtraining was associated with a decrease in magnitude of the plasma cortisol response to exercise at equivalent relative intensities. Resting plasma cortisol concentration and response to ACTH administration were not useful indicators of overtraining. Further work is required to determine whether the reduction in cortisol response to exercise precedes or occurs with the decrement in performance, and thus its potential value in predicting the onset and monitoring recovery from overtraining.

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