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Utilization of the time constant calculated from recovery heart rates after exercise for evaluation of autonomic activity in horses

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Introduction

Heart rates just after exercise are mainly attenuated by parasympathetic reactivation. Therefore, the time constant (T) calculated from recovery heart rates just after exercise is thought to be an index of parasympathetic activity in humans. In this study, we investigated whether it is possible to evaluate training-induced parasympathetic alterations by T in horses.

Material and methods

Seven thoroughbred horses were trained on a treadmill at a 10% incline for eleven weeks. Training intensity was gradually increased until week 8 (maximal speed: 12 m/sec) and maintained at 60% VO2max (6.0 ± 0.1 m/sec) in the last three weeks. Heart rates of each horse during standard exercise (8 m/sec for 2.5 min at 10% incline) were measured at intervals of one or two weeks during training and T was calculated from them. During the same week, the incremental exercise tests were performed to measure maximal oxygen uptake (VO2max). Furthermore, in six horses, T with a pharmacological autonomic blockade was measured before and after the whole training period (in week 0 and 12, respectively).

Results

As training progressed, T decreased until week 6 with an increase of VO2max and remained at a lower level thereafter. T was significantly increased by a parasympathetic blockade in week 12, whereas it was not shown in week 0.

Conclusion

These results indicate that T reflects alterations of parasympathetic activity resulting from training in horses. However, T with parasympathetic blockade was significantly lower in week 12 than in week 0. This suggests that T is also affected by factors other than parasympathetic activity.
A retrospective study of predictive variables for maximal heart rate (HRmax) in horses undergoing strenuous treadmill exercise

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Introduction

Work intensity during exercise is commonly expressed as %VO2max or %HRmax (maximal heart rate). HRmax in people is known to be affected by factors such as age, sex, fitness and disease and despite its widespread use in exercise physiology and clinical medicine, it is rarely measured and is more often estimated as HRmax = 220-age. Whilst HRmax has been shown to be reduced in aged horses (Betros et al. 2002, 34: 100-105), the effect of other factors on HRmax in horses is poorly understood.

Material and methods

A total of 328 individual values for HRmax were obtained from 5 different laboratories from horses either referred for clinical exercise testing or from healthy research or client owned horses. HRmax was measured during incremental treadmill exercise tests to fatigue. The following variables were recorded for each horse: age, weight, gender, breed, health, fitness and laboratory. Univariable analysis was followed by multiple linear regression analysis using a backward elimination modelling procedure to relate the observed HRmax values simultaneously with different predictive variables.

Results

Age, fitness, gender, breed and laboratory were all statistically significantly predictive of HRmax and together these variables accounted for 41% of the variance in HRmax. With all other variables at baseline, for each year older than the baseline (2 years old) HRmax decreases by 0.86 bpm/year, unfit horses have an HRmax 21 bpm lower than fit horses, mares have an HRmax 4 bpm higher than geldings and non-racing Thoroughbreds have an HRmax 7 bpm lower than racing Thoroughbreds.

Conclusion

A model is presented which demonstrates that age, gender, breed, and fitness influence HRmax measured in treadmill incremental exercise tests to fatigue.
An echocardiographic study of right ventricular responses to commercial race training in young National Hunt Thoroughbreds

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Introduction

The aim of this study was to investigate the effect of commercial race training on right ventricle (RV) and tricuspid valve function in an untrained group of National Hunt Thoroughbreds (TB).

Material and methods

Cardiac auscultation, guided M-mode and Colour Flow Doppler (CFD) echocardiography of the RV, tricuspid valve and right atrium were performed in 37 TB (age 3-6 years). The horses were examined on at least 3 occasions: i) before commencement of race training, ii) when cantering after approx. 8 weeks of training and iii) at full race fitness. Tricuspid regurgitation (TR) murmurs were graded on a 1-6 scale on auscultation. CFD echocardiography TR signals were graded on a 1-10 scale. RV internal diameter (cm) in diastole and systole (RVIDd and RVIDs) was measured by guided M-mode. Associations between continuous RVID and TR measures and explanatory covariates of weight, age, heart rate, yard and stage of training were examined using general linear mixed models with horse-level random effects.

Results

RVIDd and RVIDs increased on average by 0.4 and 0.3cm, respectively per year increase in age ($P < 0.0001$) and by 0.6 and 0.5cm, respectively between pre-training and race fitness ($P < 0.0001$). TR score increased on average by 0.8 per year increase in age ($P = 0.0004$) and by 1.8 between pre-training and race fitness ($P = 0.0009$). No significant associations were found between any outcomes and weight, heart rate and yard. Due to the high level of co-linearity between age and training (i.e. stage of training increased with age; $P < 0.0001$), multivariable models including both terms were not interpretable.

Conclusion

The current study suggests that the RV adaptive response to race training in older naive Thoroughbreds is similar to, if not greater than, that previously reported for the LV.
Comparison of exercise and pharmacological stress echocardiography in healthy horses

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Introduction
Stress echocardiography is gaining interest in equine sports medicine, since it might help to diagnose cases where exercise induced-myocardial insufficiency is suspected to be the cause of exercise intolerance. The purpose of this study was to compare the cardiac effect of stress echocardiography performed after treadmill exercise and under pharmacological challenge.

Material and methods
Echocardiography was performed in 10 healthy horses, either immediately after maximal treadmill exercise (group EXE, n = 5) or during pharmacological challenge (group DOB, n = 5) of 35µg/kg of atropine, followed by incremental dobutamine infusion rates from 2 to 6µg/kg/min. Left ventricular M-mode parameters were compared in both groups at rest and at heart rates of 80, 100, 110, 120, 130, and 140 bpm, using an ANOVA 2 test.

Results
In two horses of group EXE, echocardiographic measurements were impossible at 130 and 140 bpm, since their heart rates dropped too fast in the immediate post-exercise period. In both groups, the thickness of the inter-ventricular septum (IVS) and of the left ventricular free wall (LVFW) increased, whereas the left ventricular internal diameter (LVID) decreased with increasing heart rates. There were no significant differences in echocardiographic parameters between the two groups at any heart rate except for the systolic IVS, which was significantly higher in group DOB at 110 bpm, the systolic LVFW, which was significantly lower in group DOB at 130 bpm, and the systolic LVID, which was significantly lower in group DOB at heart rate of 100, 110 and 120 bpm.

Conclusion
This pharmacological stress test induced changes in ventricular dimensions that were similar to those induced by exercise and appeared to be technically easier to perform than exercise stress echocardiography.
Cardiac arrhythmias during and after treadmill exercise in poorly performing racehorses

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Introduction

The prevalence and severity of cardiac dysrhythmias during exercise in athletic horses presented for poor performance is not well described. The aim of this retrospective study was to describe the prevalence and severity of ventricular and supraventricular dysrhythmias immediately before, during and immediately after the standardized incremental treadmill exercise test (IET) to fatigue in Thoroughbred horses during investigation of poor performance.

Material and methods

The electrocardiograms (ECG) of 72 thoroughbred racehorses, judged to be free of significant heart disease or arrhythmia at rest, were used. A modified base-apex ECG was recorded throughout an IET to fatigue. Recordings were independently analysed by two observers. Twenty-one horses were diagnosed with dorsal displacement of the soft palate, 20 had varying degrees of soft palate instability and aryepiglottic fold collapse, 7 had other respiratory problems and in 24 cases no definitive diagnosis was reached.

Results

Forty-six horses (64%) had at least one ventricular (VPD) or supraventricular (SPD) depolarisation, 20 (28%) had only VPD, 12 (17%) had only SPD and 14 (19%) had both. Premature depolarisations were predominantly seen during the first minute of recovery from IET. The number of premature beats ranged from 1 to 37 VPD (median 3), and from 1 to 13 SPD (median 1). No significant associations were observed between the occurrence of at least one premature beat and age, sex, race type, diagnosis, peak HR during IET or duration of IET. Development of severe arrhythmias (multiple singles [> 5] or pairs or paroxysms of premature depolarisations during peak exercise or immediately after exercise) was positively associated with peak HR and duration of IET. However, a larger sample size would be required to have greater confidence in these associations.

Conclusion

Isolated VPD and SPD are frequently detected in poor performing racehorses during IET but their clinical relevance remains to be determined.
Measurements of right ventricular size and their relationships to the severity of tricuspid valve regurgitation in National Hunt Thoroughbreds

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Material and methods

To test the hypothesis that right ventricular (RV) chamber size would be positively related to severity of tricuspid regurgitation (TR), an echocardiographic and auscultation study was conducted in 394 race-fit National Hunt Thoroughbreds in four training yards. Horses were aged 6.7 (± 2.0) years and weighed 493 kg (± 29) kg. Auscultation was performed on each horse and audible murmurs of TR were graded using a 1-6 scale. On another occasion, echocardiography was performed and standard short (SA) and long axis (LA) images of the RV were obtained from a right parasternal location. An m-mode image was also recorded from a SA view of the RV just below the level of the tricuspid valve. All images were recorded onto the hard disk of the ultrasound computer for subsequent analysis. Colour flow Doppler (CFD) echocardiography was used to interrogate the tricuspid valve and right atrium. If retrograde flow was visible at the valve during systole, representative recordings were also acquired. Severity of TR by CFD was then graded using a subjective 1–10 scale. Measurements of RV chamber size in systole and diastole were made from archived LA, SA and M-mode images by a single observer unaware of the auscultation and CFD findings. Images from 30 horses were also measured on a second occasion to determine the intra-observer repeatability for RV measurements from different image planes.

Results

Mean grade of TR by auscultation and CFD was 0.95 (± 1.27) and 3.62 (± 1.84) respectively, with an overall prevalence of 47 or 86% dependent on the assessment method. Regression analysis demonstrated positive and significant correlations between the severity of TR by CFD and RV size from each image plane (p value range = 0.05 [LA systole]-0.0002 [SA diastole]). In contrast, there were no significant associations between grade of TR by auscultation and any RV dimension.

Conclusion

These data also showed that only RV measurements derived from M-mode images have acceptable intra-observer repeatability (intraclass correlation coefficient > 0.75).
The effect of heart rate on valvular regurgitation in Standardbred trotters

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Introduction

Valvular regurgitation is frequently observed in racehorses both by auscultation and by the more sensitive method of colour Doppler echocardiography. Until now, all examinations have been performed in resting horses with low heart rates whilst no studies have examined the same valvular regurgitation in horses after a stress test to increase the heart rate. The aim of the study was to describe the effect of tachycardia on valvular regurgitation in trotters examined by colour Doppler echocardiography.

Material and methods

Fifty-eight standardbred trotters (3 to 8 years) with valvular regurgitation present in one or more valves detected by colour Doppler echocardiography on resting examination were included in the study. After the resting echocardiographic examination, all horses were trotted by hand for approximately 50 meters. Immediately after the light exercise, while the heart rate was above 60 beats/minute, the regurgitant valves were re-examined by colour Doppler echocardiography.

Results

The frequency of horses with regurgitation decreased significantly for all four valves (tricuspid, pulmonary, mitral and aortic valves) after light exercise. In addition, the size of the regurgitation decreased significantly. In four horses with tricuspid regurgitation, the severity of the regurgitation increased dramatically after exercise, suggesting that these regurgitations were pathologic.

Conclusion

The results show that most valvular regurgitation in racehorses disappears after light exercise. Worsening of the regurgitation after light exercise suggests a pathologic regurgitation. Thus, light exercise may offer a quick discriminatory test between pathologic and non-pathologic valvular regurgitation in performance horses.
Right ventricular pressure dynamics and stress echocardiography in pharmacologic and exercise stress testing

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Introduction
Pharmacologic stress testing (PST) is used as a substitute for exercise stress testing (EST) in people unable to complete an EST. EST has been used in horses to detect subclinical cardiac disease that may limit performance. These tests require specialized equipment/personnel that are often unavailable, and some horses are unable to complete an adequate test. For these and other reasons, there is interest in using PST to evaluate cardiac function in horses. The purpose of this study was to compare indices of cardiac function and stress echocardiography in horses undergoing PST and EST.

Material and methods
Five horses completed a PST and EST in a randomized crossover design. High fidelity pressure transducers were placed in the right ventricle. Continuous pressure signals were digitally collected and stored. ECG were recorded continuously for 20 hours. Echocardiography (M-mode and stress echocardiography) was performed prior to EST and PST, during and after PST, and immediately post EST. Plasma cTNI was measured pre and 3 hours post stress testing. For PST, 5μg/kg glycopyrrolate IV followed in 10 minutes by 5 μg/kg/min dobutamine infusion over 10 minutes was given. EST consisted of a 2 minute gallop at 110% speed required to elicit VO2max.

Results
Both EST and PST resulted in a significant increase in dP/dt over baseline (3122/s vs 476/s and 2253/s vs. 466/s, respectively; \( P < 0.0001 \)). EST dP/dt were significantly greater than PST dP/dt (\( P < 0.001 \)). Two min post EST and 5 min post PST dP/dt were significantly less than during EST and PST and significantly greater than pre. %FS was higher at end PST vs post EST. cTNI was elevated post PST, and greater than post EST.

Conclusion
PST deserves further evaluation in normal horses and those with cardiac disease, and may be complementary to EST.
Associations between exercise-induced pulmonary haemorrhage, right ventricular dimensions and atroventricular valve regurgitation in conditioned National Hunt racehorses

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Introduction

Exercise-induced pulmonary haemorrhage (EIPH) and tricuspid valve (TR) are both conditions with high prevalence in conditioned Thoroughbreds. Stress failure of pulmonary capillaries, leading to EIPH, is most likely when pulmonary vascular pressure is increased, and so we hypothesised that the right ventricle (RV) of horses known to suffer repeated episodes of EIPH would be subject to higher pulmonary vascular pressures during training and hence increased RV afterload. We deduced that greater increases in right ventricular pressure induced by exercise in severely affected horses should, in turn, provide a greater stimulus for training-induced RV remodelling (dilation and hypertrophy). Pulmonary hypertension, cardiac dilation and secondary stretch of the tricuspid valve annulus all promote tricuspid valve regurgitation (TR) and so we hypothesised that there should be an association between EIPH and TR.

Material and methods

An echocardiographic and auscultation study was conducted in 121 race-fit National Hunt Thoroughbreds in three commercial training yards. The horses were aged 6.2 (± 2.0) years and weighed 497 kg (± 24) kg. Cardiac auscultation and echocardiography were performed. A guided M Modr image of the RV just below the tricuspid valve was obtained from a right parasternal location and colour flow Doppler (CFD) was used to interrogate the tricuspid valve and right atrium. An experienced echocardiographer retrospectively graded the severity of TR by CFD using a 1–10 scale. Binary data on EIPH, based on whether the horse was perceived to have a clinically significant problem, were determined retrospectively for each horse by the horses’ primary care veterinary surgeon from medical and other records. Data were analysed using a standard logistic regression analysis approach.

Results

The prevalence of EIPH in the population was 20.7% (25/121) and that of tricuspid valve regurgitation measured by CFD was 83.5% (101/121) CFD and that of tricuspid murmurs was 40.5% (49/121) TR. The mean size of RV in diastole was 5.72 cm (s.d. 0.90) and that in systole was 4.45 cm (s.d. 0.97). EIPH was significantly and positively associated with the systolic and diastolic dimensions of the RV \((P = 0.017 \& 0.011 \text{ respectively})\) and this association was not sensitive to the effects of age, weight or the presence & severity of tricuspid valve regurgitation or murmur. There were no significant associations between EIPH and TR by auscultation or CFD.

Conclusion

This study was limited by the method used to classify EIPH, but there was no association between EIPH and horse age, or weight in this population of Thoroughbreds. Nevertheless, RV size was greater in the horses severely affected by EIPH, suggesting that factors resulting in EIPH may directly or indirectly affect RV remodelling in athletic horses.
Effects of a specific endothelin-1A antagonist on exercise-induced pulmonary hemorrhage in Thoroughbred horses

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Introduction

During high intensity exercise, the very high pulmonary artery pressure (Ppa) experienced by Thoroughbred horses is considered a major cause of exercise-induced pulmonary hemorrhage (EIPH). Recently, endothelin-1 (ET-1), a potent vasoconstrictive hormone, has been found to increase Ppa in horses at rest when binding to its receptor subtype, ET-1A. In addition, plasma concentrations of ET-1 have been found to be increased in horses after exercise. Therefore, we hypothesized that ET-1 increases Ppa during exercise in the horse, and administration of a specific ET-1A antagonist would decrease Ppa and therefore EIPH.

Material and methods

We administered saline (Control) or an ET-1A receptor antagonist, TBC3214 (3 mg/kg i.v.) to horses 1 hour prior to an incremental exercise-test on a treadmill. Gas exchange measurements were taken on a breath-by-breath basis, and blood samples were collected at each stage to determine cardiac output and several metabolic variables. EIPH was determined via bronchoalveolar lavage (BAL) ~30 min after exercise.

Results

The time to fatigue and gas exchange, cardiovascular, and metabolic variables were similar between groups ($P > 0.05$). Resting (Control: 32 ± 3; Antagonist: 28 ± 4 mmHg) and peak Ppa’s (Control: 81 ± 6; Antagonist: 91 ± 8 mmHg) did not differ between treatments ($P > 0.05$). Most importantly, TBC3214 did not decrease EIPH (Control: 4.1 x 106 ± 1.2 x 106; Antagonist: 1.7 x 107 ± 7.7 x 106 rbc’s/mL BAL fluid: $P > 0.05$).

Conclusion

These data suggest that ET-1 may not play a role in the increased Ppa and therefore, EIPH, in the equine athlete during high intensity exercise. Consequently, treatment with an ET-1A receptor antagonist (TBC3214 at 3 mg/kg) does not appear to be a viable treatment in the prevention of EIPH.
Effect of fatigue during five successive heats (800-m at high velocity) and recovery runs on heart rate variability in Standardbreds

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Introduction
High frequency peak (fHF) detected by heart rate variability (HRV) analysis corresponds to a link between heart rate and breathing frequency. It is hypothesized that modifications induced by fatigue could be detected from fHF. The aim of this study was to find fatigue indexes from HRV in horses during interval training.

Material and methods
RR series of seven trotting horses were recorded during an interval training session. Interval training is made up of 5 successive 800-m high-velocity trotting runs (H1, H2,…H5) spaced by 1 minute recovery bouts at low speed (R1, R2,…R5). A Fast Fourier Transform and Poincaré Plot were applied to the RR series.

Results
Running speed and repetition had significant effects on HRV components during interval training. Despite respective constant velocities during high-speed and recovery, repeated exercise induced a decrease in the RR interval (H1: 295 ± 19 vs. H5: 283 ± 15 ms, P < 0.05) and in the root mean square of successive differences in the RR series (H1: 6.31 ± 1.28 vs. H5: 5.31 ± 1.31 ms, P < 0.05). Conversely, high-speed and recovery repeated exercise induced an increase in fHF (H1: 1.37 ± 0.35 vs. H5: 1.62 ± 0.40 Hz and R1: 0.22 ± 0.02 vs. R4: 0.64 ± 0.38 Hz, P < 0.05). Hence, recovery repetition induced a decrease in RR standard deviation (R3: 10.5 ± 3.96 vs. R5: 6.17 ± 2.65 ms, P > 0.05) and in the long-term index of the Poincaré plot (SD2) (R1: 43.29 ± 28.90 vs. R5: 18.19 ± 9.35 ms, P < 0.05).

Conclusion
The increase in fHF during interval training could be induced by modifications of breathing and stride frequency linked to the fatigue. The decrease in the Poincaré plot SD2 and RR standard deviation during successive recovery bouts could be linked with recovery deterioration. Further studies must be conducted to verify these results with new ambulatory respiratory and kinematic devices.
Effect of detraining on cardiorespiratory measurements in young Thoroughbred horses

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Introduction

Thoroughbred racehorses often experience interruptions to their training and competition programs because of illness, injury or other factors that reduce their physical activity. It is important to identify the effects of these changes and to understand the mechanisms causing associated changes in physical capacities and athletic performance. We hypothesized that detraining of young Thoroughbreds decreases aerobic capacity by uniformly decreasing all components of the circulatory oxygen transport system.

Material and methods

We trained 6 Thoroughbred yearlings for 6 mo using a conventional program for yearlings in the Japan Racing Association then detrained them for 10 wk while allowing them free range on 2 ha pastures for 8 h/d and stall rest at night. Treadmill measurements of O2 transport variables were made before training (PRE), after training (TR) and detraining (DT). A step-test protocol identified each horses specific aerobic capacity (VO2max/Mb) and speed to attain it, and a steady-state run at VO2max was used to quantify O2 transport variables.

Results

The VO2max/Mb increased by 13.5% from PRE to TR and decreased by 8.8% from TR to DT. The major factor associated with this difference was specific stroke volume (calculated by the Fick Principle) increasing by 19.3% from PRE to TR and decreasing by 8.8% from TR to DT.

Conclusion

These data suggest that cardiac structural changes have the most significant initial effect on aerobic performance in detraining and that free exercise at pasture for 8 h/d is an insufficient activity to maintain high aerobic capacity in trained young horses.
Heart rate variability in detecting recovery and overtraining in trotters

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Introduction

Endurance training induces changes in autonomic nervous system functions of the body. High-performance sports with high intensity training include the risk of overtraining. Heart rate variability (HRV) provides a non-invasive measurement of the autonomic regulation of heart rate. Measuring of HRV with modern telemetric technology is quick and easy. Since HRV is affected by changes in the autonomic nervous system, it might be an early stage indicator of over-reaching or over-training. Thereby changes in resting heart rate responses could be a sensitive and easy way to measure training-induced stress.

Material and methods

The aim of the study was to detect the recovery and the possible overtraining status by measuring HRV. The measurements reflected the responses of the previous day activities during different training periods including basic-training, pre-competition and competition during one year period.

Results

The HRV was at the highest during the pre-competition period ($P < 0.001$) and it decreased significantly during the competition period ($P < 0.001$), indicating an increased stress load. Walking in the equine-exerciser increased HRV significantly compared to complete rest or jogging as previous day activities during basic training and pre-competition periods ($P < 0.001$). This suggests, that the horses are more relaxed if they are able to exercise moderately compared to standing still or anaerobic exercise.

Conclusion

According to this study, HRV can be used to estimate the state of fitness and to detect recovery even after one bout of exercise. However, for the diagnosis of the overtraining syndrome, other confirmatory measures may also be required in addition to HRV to exclude other possible causes of underperformance.
The effect of exercise on a positive and negative incline on heart rate and stride characteristics

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Introduction

A knowledge of the energetic cost of running is important in order to describe workloads under field conditions where terrain is variable (Schroter and Marlin, 2002). The energetic cost and the effect on stride characteristics of flat and positively inclined running in horses has been extensively described. However, as far as we are aware, there are no published studies describing the response of horses to negative incline (i.e. downhill) running.

Material and methods

Four horses of mixed breed were studied. Following a standardised warm-up (10 min walk at 1.5 m/s, 5 min trot at 3.0 m/s, 5 min walk at 1.5 m/s, all 0% incline), each horse then exercised at walk (1.5 m/s) and trot (3.0 m/s) for 3 min on a treadmill set at −5%, 0% or +5% slope in a random order. Heart rate (HR) and stride characteristics were recorded during the last minute of each exercise step.

Results

Mean HR at walk was not significantly different between 0% (56±8 bpm), -5% (68±16 bpm) and +5% (88±14 bpm), although there was a trend for HR at +5% to be higher than at 0% (P=0.08). HR at trot was not different between −5% (91±22 bpm) and 0% (98±13 bpm), but +5% was significantly higher than 0% (118±20 bpm; P=0.031). Stride frequency, stride duration and stride length were unaffected by either positive or negative incline at either walk or trot when compared with 0% or with each other.

Conclusion

As previously demonstrated, positively inclined treadmill exercise increases heart rate. However, a negative incline of -5% did not significantly reduce heart rate at walk or trot compared with 0%. Furthermore, negative inclined exercise at walk or trot had no effect on stride characteristics.