



Conditioning equine athletes on water treadmills significantly improves peak oxygen consumption

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Abstract

Equine water treadmills (WT) were initially designed for rehabilitation of musculoskeletal injuries, but are also commonly used for conditioning sport horses, however the effects are not well documented. The purpose of this study was to test the effect of an 18-day WT conditioning programme on peak oxygen consumption ($\dot{V}O_{2peak}$). Nine unfit Thoroughbreds were used in a randomised controlled trial. Six horses worked daily for 18 days in stifle-height water (WT group), while 3 control horses worked without water (dry treadmill group (DT)). Preconditioning and postconditioning maximal exercise racetrack tests (800 m) were performed using a portable ergospirometry system. Measured outcomes were $\dot{V}O_2$, tidal volume, minute ventilation, breathing frequency, heart rate, blood lactate and instantaneous and average speed. The workload as assessed by $\dot{V}O_2$ was 21.7 per cent of preconditioning $\dot{V}O_{2peak}$ values for WT horses. $\dot{V}O_{2peak}$ on the racetrack increased by 16.1 per cent from preconditioning to postconditioning in the WT horses ($P=0.03$), but did not change in the DT horses. Therefore, exercising horses in high water heights may improve conditioning.

Introduction

High-intensity exercise ('hard' to 'maximal' intensities: 60 per cent to 100 per cent $\dot{V}O_{2max}$)¹ is important in improving fitness in horses. However, traditional training programmes with strenuous exercise over ground may cause excessive strain and overloading on skeletal support structures, resulting in lower limb injuries in horses.² It has been shown in humans and dogs that buoyancy during water treadmill (WT) training reduces ground reaction forces (GRFs), likely reducing the pressure on joints.³⁻⁵ The high degree of resistance created by water increases the workload without an increase in concussive forces.⁶ Previous studies with humans suggest that WT training can achieve the same

submaximal and maximal physiological responses and cardiorespiratory fitness as land treadmill training.^{3 7-11}

WTs are gaining popularity in the equine world as an aid in equine rehabilitation and conditioning.¹² However, there is a lack of controlled research findings regarding the effects of exercising horses in water. Unlike traditional treadmills, workload in a WT is a function of water height and, to a lesser extent, treadmill speed.¹³ This is because the presence and height of water increases resistance and influences gait biomechanics. With increasing water height, the horse adopts an increased flight arc resulting in decreased stride frequency and increased stride length.¹⁴ Previously conducted work has shown that water at the height of the stifle significantly increases oxygen consumption ($\dot{V}O_2$) and heart rate (HR) when compared with water at the height of the mid-cannon bone, or no water at all (dry treadmill).¹³ Previous studies investigated the effects of a mild four-week and a more strenuous eight-week WT conditioning protocol on horses. However, neither of these protocols was able to elucidate significant cardiocirculatory (V_{200} (the speed at which HR=200 bpm) and haematocrit) or muscular property (gluteal and superficial digital flexor) changes.^{15 16}

In order to better understand the effects of WT conditioning, consideration of a wider range of indicators of fitness may be warranted. HR, whole blood lactate concentration (LA) and $\dot{V}O_2$ are typically

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measured to assess athletic fitness. $\dot{V}O_2$ is considered to be the single best measure of skeletal muscle aerobic capacity and cardiovascular fitness.⁶ Its periodic measurement serves as a reference for assessing changes in fitness, with horses with higher $\dot{V}O_{2\max}$ values having a greater aerobic capacity.¹⁷ $\dot{V}O_{2\max}$ is the product of cardiac output and the arteriovenous oxygen content difference.¹⁸ Similarly, peak oxygen consumption ($\dot{V}O_{2\text{peak}}$), or the greatest $\dot{V}O_2$ obtained during a test, can also be used to assess aerobic performance. While measuring $\dot{V}O_{2\max}$ on a treadmill is common practice, field measurements are much more complex and require mobile systems. The availability of portable ergospirometry systems for this purpose is extremely limited and is still under development. $\dot{V}O_{2\max}$ determined under field conditions in horses has been reported; however, the mask design was thought to restrict ventilation.¹⁹ A new ergospirometry system has recently been designed and validated²⁰ and was used in the present study to evaluate $\dot{V}O_2$ and ventilation.

Given the lack of equine conditioning data on WTs, the goal of this study was to determine whether WT conditioning using a high water level improved fitness. The specific objectives were therefore to assess the effect of an 18-day WT conditioning protocol on $\dot{V}O_{2\text{peak}}$, ventilation, running speed and HR when measured during a high-intensity test on a racetrack. LA values were monitored following the racetrack test. Additionally, workload while on the WT was quantified by $\dot{V}O_2$. The authors hypothesised that improved fitness would be observed in the horses conditioned in water compared with a control group.

Materials and methods

Horses

Nine privately owned Thoroughbred horses (two mares, seven geldings; median age: 10.0 years (quartiles: 10.0–14.0)) were enrolled in a prospective, randomised controlled study using repeated measures on all horses. Horses were competitive polo ponies that had been out of training since the end of the competitive season (deconditioned for six months on pasture). Six horses were randomly assigned to the treatment group and underwent WT training, while the remaining three were worked on the same treadmill without water (DT). Body weight was measured before all measurements (pretraining and post-training) using a portable scale (Horse Weigh, Powys, Wales) (pre-exercise median:

586.0 kg, IQR: 581.0–614.0; postexercise median: 594.0 kg, IQR: 571.0–618.0). Horses were fed a combined diet of hay and concentrate feed, which was tailored individually to ensure that horses maintained a consistent body weight. No horse had a history of recent lameness, health issues or poor performance. Exclusion criteria included: cardiac murmur >2/6, presence of ECG abnormalities excluding AV blocks, lameness score >1/5 and intolerance of WT training or track testing. Visual lameness and physical examination, including lung and cardiac auscultation occurred before assignment of group, training and track testing. Cardiovascular pathologies were ruled out by cardiac auscultation, ECG analysis and the absence of a history of exercise intolerance. All examinations were carried out by a board-certified veterinary internal medicine and sports medicine and rehabilitation specialist. Owners completed a consent form.

Water treadmill training

WT training occurred at a private rehabilitation and conditioning facility in Alberta, Canada. All horses were stabled on-site and were given a week to acclimatise to the facility and treadmill (Horse Trainer, Bygmarken, Denmark) training. Horses were turned out in small, individual pens during the day, and housed in stalls overnight. The belt speed of the WT was calibrated before the start of the study. Preconditioning sessions without water were conducted during this week to ensure that horses could work safely on the treadmill. Horses were not sedated during this process or during conditioning.

All horses were trained for a total of 18 days (5 days per week), for the same length of time, at a speed of 1.45 m/s, based on common practices. The WT group horses were given days 1–8 to incrementally increase total working time and water height in the WT (table 1), after which they were trained daily for 20-minute sessions for 9 days (days 9–18). Warm-up and cool-down exercise occurred while the treadmill was being filled and emptied, respectively (10 minutes for each, exclusive of the 20-minute workout). The total maximum workout time was 40 minutes for both groups (from days 9 to 18). The DT group worked on the same treadmill under the same conditions listed above, but without water. The DT horses followed the same schedule as the WT horses for incrementally increasing duration over the first 8 days, and then worked for 20 minutes per day for days 9–18 (exclusive of the warm-up and cool-down

Day	1	2	3	4	5	6	7	8	9
Water height	Carpus	Carpus	Stifle	Stifle	Stifle	Stifle	Stifle	Stifle	Stifle
Duration (minutes)	11	12	12	14	16	17	18	19	20

Protocol for all WT horses for the first eight days of training. Water height was determined using anatomical locations on horses individually. Duration is given in minutes and excludes warm-up (filling) and cool-down (emptying time). Days 9–18 occurred with water at stifle height for the entire duration of 20 minutes. A speed of 1.45 m/s was set for the entire conditioning period.
WT, water treadmill.

periods of 20 minutes total). The WT is housed indoors in a climate-controlled room. Water temperature was a median of 14.0°C (13.0–15.0).

Racetrack fitness testing

All horses underwent an incremental exercise test on a racetrack before and postcompletion of the treadmill training period. The pretraining field fitness test occurred one week before the beginning of the training period. The post-training field fitness test occurred two days after the completion of the training period. All horses were tested on the same day. The first step consisted of 300m at ~4 m/s, which was followed by two 300m steps at ~6 and 8 m/s, respectively, and culminated in an 800m gallop at the fastest speed that the horse was capable of. The jockey was a high-quality rider that was able to illicit maximal responses from the horses. The same jockey was used throughout. The approximate speed at each step was determined using Global Positioning System (GPS) technology, and constantly directly communicated to the jockey via mobile phone. The track was groomed with mechanical equipment on each morning that testing occurred.

Measured outcomes

Oxygen consumption and ventilation

A portable ergospirometer (Department of Veterinary Clinical Sciences, Pullman, USA) was used, as has been previously described.²⁰ The mask was installed on the horses and connected to a gas analysis and data acquisition system in a backpack on the jockey immediately before the maximal intensity test.

$\dot{V}O_2$ was also measured on the WT once during conditioning on day 9. The same ergospirometry system was used, with the exception that a full facemask was placed over the horse's face (no bit and bridle).²⁰ Both masks were padded to minimise dead space.

Calibration of the mask system (flowmeter and gas analyser) was conducted before each measurement as per the manufacturer's instructions. Data were obtained using customised software provided with the ergospirometry system. Breath-by-breath recordings were analysed for the final 30 seconds of each exercise condition. Ambient temperature, barometric pressure, humidity, jockey weight (jockey + saddleweight = 88.0 kg) and horse weight were collected and included in calculations of $\dot{V}O_{2peak}$ and ventilatory volumes. $\dot{V}O_{2peak}$ was considered to be achieved when $\dot{V}O_2$ plateaued and maximum heart rate was reached. $\dot{V}O_{2peak}$ was averaged over six breaths at this point, as per the manufacturers guidelines.

Heart rate measurements

HR was monitored continuously during the field fitness tests using a telemetric ECG device and software (Engel Engineering Service, Heusenstamm, Germany). Average

HR was calculated for the final 30 seconds at each exercise speed.

Speed

Speed was measured using GPS data from the ECG. Instantaneous maximum speed was determined based on the sampling rate (one second) of the GPS, which meant that speed was reported at one-second intervals. Speed data were also averaged over the entire maximal intensity field test (800m), as well as over the final 30 seconds.

Blood lactate measurements

Venous blood samples (2 ml) were collected in vacutainer tubes containing potassium oxalate 5, 60 and 80 minutes postmaximal exercise. LA concentration was immediately measured using a handheld analyser (EKF Diagnostics, Penarth, Wales) according to the manufacturer's recommendations.

Statistical analysis

The data were not normally distributed. Mann-Whitney U tests were used to compare pretraining WT with pretraining DT and post-training WT with post-training DT data for all parameters ($\dot{V}O_2$, respiratory frequency (RF), tidal volume (V_T), minute ventilation (\dot{V}_E)), blood lactate (5, 60, 80 minutes post), HR_{max} , HR recovery and speed (maximum, average speed, final 30 seconds)). Wilcoxon matched-pairs rank-sum statistical tests were used to compare preconditioning versus postconditioning values for all parameters mentioned above. Statistical significance was set at $P \leq 0.05$ for all tests. All values are reported as median and IQR to accommodate non-normal data.

Results

No horses were excluded from this study following enrolment (n=9), based on the exclusion criteria. Environmental conditions did not differ significantly between testing days: ambient temperature 15.0°C (13.5–19.5); barometric pressure 664.0 mm Hg (660.5–665.0 mm Hg); humidity 30 per cent (28–46). Racetrack conditions ranged between 'good' and 'fast' based on North American track standards.

Effect of water treadmill conditioning on peak oxygen consumption

All horses (n=9) were of a similar fitness level before conditioning ($\dot{V}O_{2peak}$ of all horses preconditioning: 103.1 ml/(kg.min) (87.2–110.2)) ($P=0.71$). Postconditioning, $\dot{V}O_{2peak}$ was significantly greater in the WT horses than the DT horses ($P=0.02$). $\dot{V}O_{2peak}$ significantly increased by an average of 16.1 per cent in the WT horses (n=6) (preconditioning: 96.3 ml/(kg.min) (87.5–113.1), postconditioning: 121.0 ml/(kg.min) (101.7–141.7)) ($P=0.03$) (table 2, figure 1a). In comparison, $\dot{V}O_{2peak}$ did not significantly change, and

Table 2 Preconditioning and postconditioning physiological responses of Thoroughbreds during a maximal intensity field test after an 18-day WT or DT training protocol

	WT preconditioning n=6	WT postconditioning n=6	DT preconditioning n=3	DT postconditioning n=3
$\dot{V}O_{2peak}$ (ml/(kg.min))	96.3 (87.5–113.1)	121.0 (101.7–141.7)*	103.1 (92.8–106.7)	84.2 (76.8–86.3)†
RF (breaths/minute)	134.4 (132.0–141.0)	143.4 (129.8–149.2)	128.8 (125.5–136.2)	140.8 (135.4–146.0)
V_T (litre)	12.1 (11.9–13.3)	12.2 (12.0–13.6)	12.8 (11.2–13.7)	12.8 (11.6–13.7)
\dot{V}_E (l/min)	1659.5 (1529.3–1852.0)	1763.0 (1730.5–1851.0)	1567.0 (1466.5–1725.0)	1797.5 (1691.3–1845.3)
HR_{max} (bpm)	218 (211–225)	212 (205–217)	212 (210–215)	209 (207–211)
5 minutes lactate (mmol/l)	19.0 (17.3–20.8)	19.6 (18.0–20.4)	13.3 (11.5–16.0)	16.3 (13.8–16.7)
60 minutes lactate (mmol/l)	11.8 (11.2–12.9)	12.4 (11.6–12.7)	7.5 (7.0–9.0)	9.1 (8.2–9.5)
80 minutes lactate (mmol/l)	8.5 (7.9–9.1)	9.4 (8.7–10.3)	4.6 (4.2–5.0)	6.1 (5.8–6.6)

Physiological responses during a maximal test of nine Thoroughbreds before and after 18 days of conditioning (WT training with water at the height of the stifle, 1.45 m/s; DT training without water, 1.45 m/s); 5, 60 and 80 minutes lactate=postexercise lactate. All values are presented as median (IQR).

*Values that are significantly different from WT preconditioning.

†Values that are significantly different from WT postconditioning.

DT, dry treadmill; HR_{max} , maximum heart rate; RF, respiratory frequency; \dot{V}_E , minute ventilation; $\dot{V}O_{2peak}$, peak oxygen consumption; V_T , tidal volume; WT, water treadmill.

even showed a tendency to decrease in the DT horses (n=3) (preconditioning: 103.1 ml/(kg.min) (92.8–106.7), postconditioning: 84.2 ml/(kg.min) (76.8–86.3)) (table 2, figure 1b).

Workload of water treadmill exercise

Workload, as assessed by oxygen consumption, was significantly greater with a high water height compared with no water ($P=0.04$). With water at the height of the stifle and at a speed of 1.45 m/s, WT horses had a median $\dot{V}O_2$ of 22.0 ml/(kg.min) (18.0–24.9), representing 21.7 per cent of their preconditioning $\dot{V}O_{2peak}$. While walking at the same speed without water, DT horses had a median $\dot{V}O_2$ of 14.6 ml/(kg.min) (14.5–15.6), representing 15.5 per cent of their pre-conditioning $\dot{V}O_{2peak}$.

Ventilation during the maximal intensity field test

There was no difference in any measured ventilatory parameters (RF, V_T , \dot{V}_E) at baseline before conditioning or postconditioning between the two groups (WT and DT).

Respiratory frequency

Maximum RF did not change between preconditioning and postconditioning in both the WT and DT horses. The median of all horses' RF values was 138.1 breaths/min (129.1–143.4) (table 2).

Tidal volume

Tidal volume did not change between preconditioning and postconditioning in both the WT and DT horses. The median of all horses' V_T values was 12.6 litres (11.9–13.9) (table 2).

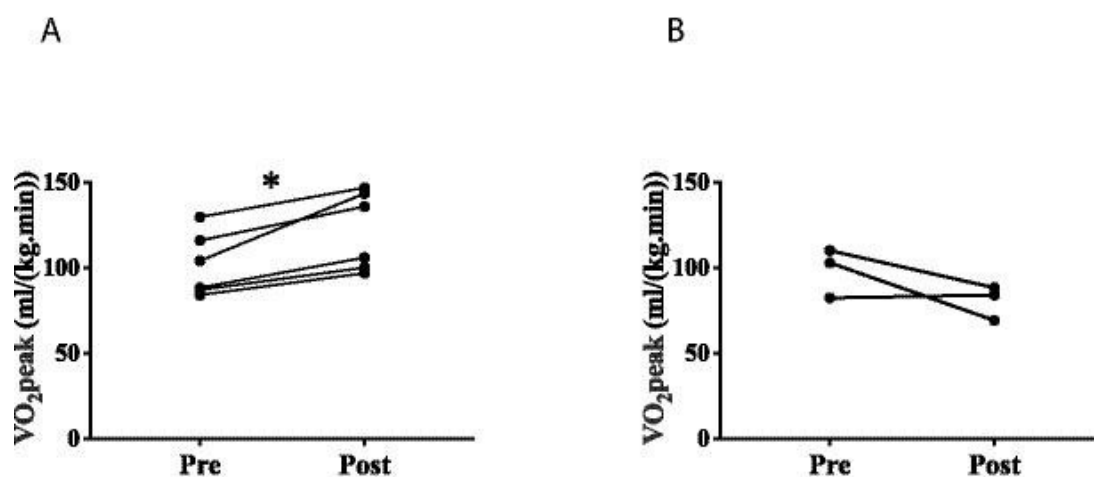


Figure 1 Peak oxygen consumption ($\dot{V}O_{2peak}$ in ml/(kg.min)) in two groups of horses preconditioning and postconditioning. figure 1A shows a significant increase of $\dot{V}O_{2peak}$ (n=6) after 18 total days of water treadmill (WT) training (9 days under maximal conditions: water at the height of the stifle, 1.45 m/s). figure 1B shows a non-significant decrease of $\dot{V}O_{2peak}$ (n=3) after 18 days of training on a dry treadmill (DT) at the same speed. Asterisk (*) denotes significant differences.

Minute ventilation

Minute ventilation did not change between preconditioning and postconditioning in both the WT and DT horses. The median of all horses' \dot{V}_E values was 1741.01/min (1567.5–1879.8) (table 2).

Heart rate during maximal intensity field test

Baseline preconditioning and postconditioning HR_{max} values did not differ between the two groups (WT and DT) (table 2). Neither WT nor DT training affected postconditioning HR_{max} values (table 2). The median of all horses' HR_{max} was 212 bpm (208–218).

HR recovery time (time needed to reach 50 per cent of HR_{max}) was unchanged by conditioning for both groups (353 seconds (265–445)).

Speed during maximal intensity field test

Preconditioning instantaneous maximal speeds were higher in the DT group than the WT group ($P=0.02$). Instantaneous maximal speeds did not change with either type of training (WT or DT). The instantaneous maximal speed achieved by WT horses was 16.0 m/s

(15.7–17.0) pretraining and 17.1 m/s (16.3–17.3) post-training. The DT horses' instantaneous maximum speed was 16.9 m/s (16.5–17.1) pre-training and 17.5 m/s (17.5–17.8) post-training.

To assess endurance, average speeds were also analysed. Average speed over the entire maximal intensity field test (800 m) increased by 17.4 per cent in the WT horses from 8.7 m/s (8.2–9.0) preconditioning to 10.5 m/s (9.7–10.8) postconditioning ($P=0.03$) (figure 2a). Elapsed time over the test (800 m) decreased from an average of 92 seconds preconditioning, to an average of 76 seconds postconditioning in the WT horses, but did not change in the DT horses. The average speed over the final bout of exercise (final 30 seconds before crossing the finish line) also increased by 12.1 per cent in the WT horses from 8.0 m/s (6.8–8.3) to 9.1 m/s (9.0–9.6) ($P=0.03$) (figure 2c). Average speed and final 30 seconds speed did not change in the DT horses (figure 2b and d).

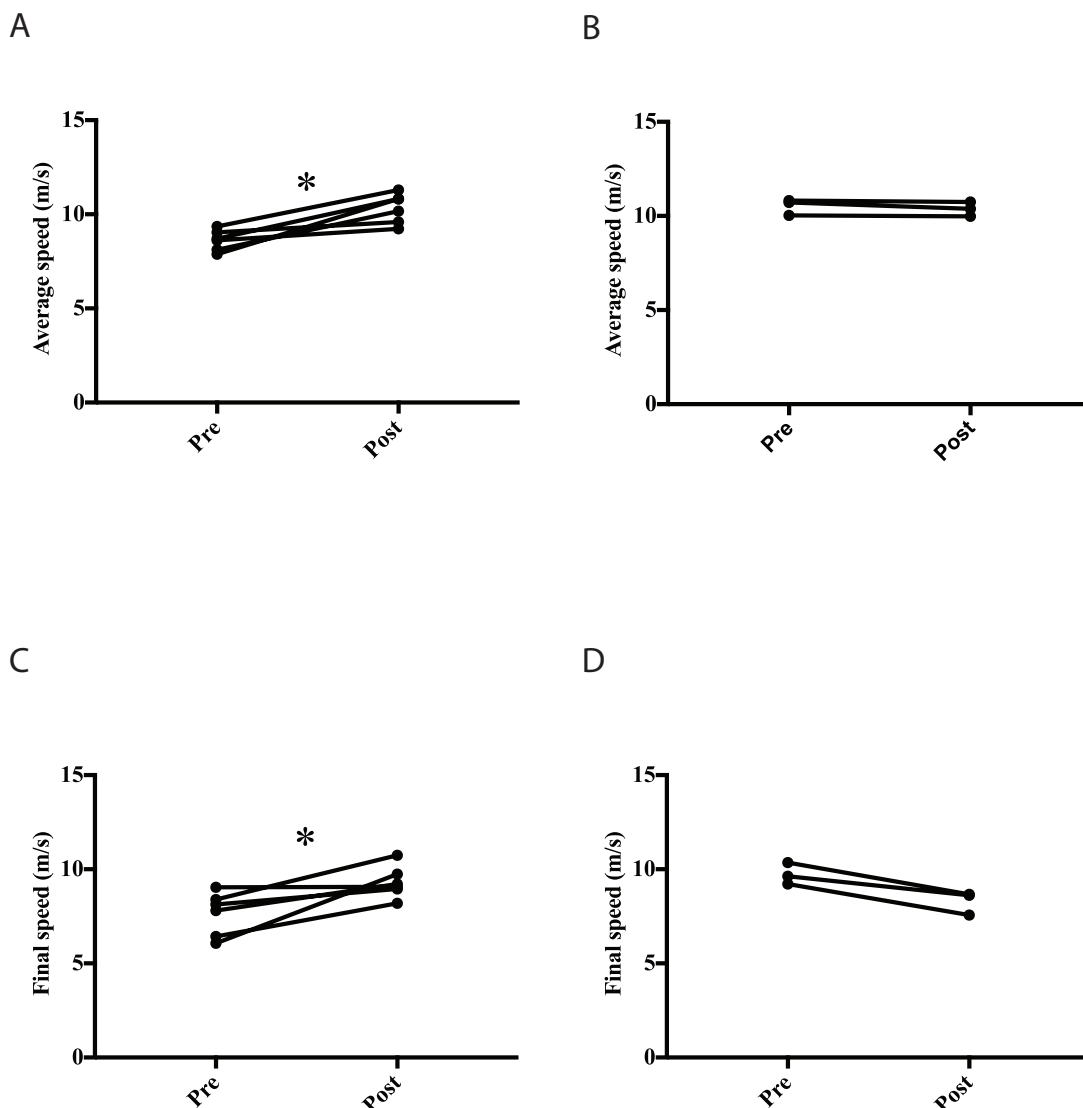


Figure 2 Average speeds over an entire maximal intensity test (a, b) and over the final 30 seconds of the test (c, d) in two groups of horses preconditioning and postconditioning (a and c following 18 days of water treadmill (WT) training; b and d following 18 days of dry treadmill (DT) training). Asterisks (*) denote significant differences.

Lactate postmaximal intensity field test

Preconditioning and postconditioning LA concentrations 5, 60 and 80 minutes postexercise were the same for the two groups (table 2). LA levels were not affected by WT or DT training (table 2). Median LA concentrations for all horses, including preconditioning and postconditioning, were as follows: 5 minutes postexercise—17.9 mmol/L (16.5–20.1), 60 minutes postexercise—10.9 mmol/L (9.4–12.4) and 80 minutes postexercise—7.9 mmol/L (6.1–9.3).

Discussion

While equine WT conditioning is offered by many facilities, the effects of this exercise on cardiorespiratory parameters have not been well documented. The authors found that 18 days of WT conditioning significantly increased $\dot{V}O_{2peak}$. While this WT training protocol did not increase the instantaneous maximum speed reached by the horses on the racetrack, it did improve their endurance, as seen by the maintenance of higher speeds during the duration of the gallop (increased average speed over entire test, increased average speed over the final 30 seconds).

Effect of water treadmill conditioning on peak oxygen consumption and ventilation

The authors were able to reliably measure oxygen consumption ($\dot{V}O_2$ and $\dot{V}O_{2peak}$), as well as ventilatory parameters (RF, V_T , \dot{V}_E) both during a maximal intensity field test and during WT training. Recently, the Cosmed K4b² system and Equimask were used to compare $\dot{V}O_2$ measurements during incremental tests in Standardbred trotters on the track and treadmill. However, this system was found to restrict breathing due to resistance at high flow rates which may have caused premature fatigue in the horses.¹⁹ Due to lower resistance of the mask systems used in the current study, horses were able to perform to the best of their abilities.²⁰

Previous work has focused on the effect of traditional treadmill training on $\dot{V}O_{2max}$ of Thoroughbreds. Evans and Rose observed a 23 per cent increase in $\dot{V}O_{2max}$ after a seven-week protocol (4.0–8.3 m/s, 3–6° incline).²¹ Similarly, after a nine-week conditioning programme (6° incline; combination of light, aerobic and interval training), $\dot{V}O_{2max}$ increased by 25 per cent in another group of Thoroughbreds.²² In comparison, the WT conditioning protocol the authors used resulted in a 16.1 per cent increase in $\dot{V}O_{2peak}$.

There are important differences between $\dot{V}O_{2peak}$ and $\dot{V}O_{2max}$. $\dot{V}O_{2peak}$ is a measured parameter and uses a supramaximal intensity exercise of a long enough duration to reach steady state without specific speed requirements. On the other hand, $\dot{V}O_{2max}$ is a calculated parameter and necessitates the performance of a standardised exercise during steps of incremental intensity, which requires a tight control of the galloping speed. In the present study the testing was done on a

racetrack, where, contrary to high-speed treadmill experiments, it is difficult to accurately control the speed imposed to the horses; a $\dot{V}O_{2peak}$ protocol was therefore implemented to report the effects of conditioning using a WT. Increases in $\dot{V}O_{2peak}$ might be detected because an exercise test is harder, of different duration or conducted under different ambient conditions. The existence of such factors make it impossible to attribute increases in $\dot{V}O_{2peak}$ to improved cardiovascular fitness alone.

Traditional treadmill training has been found to improve $\dot{V}O_{2max}$ through cardiac rather than respiratory adaptations.^{21,22} Previous studies have found no change in \dot{V}_E following training, and noted that the change in $\dot{V}O_{2max}$ can likely be attributed to cardiovascular and haematological adaptations.^{21,22} In this study, cardiac output was not measured, as this is difficult to do in the field, especially on client-owned horses.

Increases in $\dot{V}O_{2max}$ in humans can occur through a change in the breathing strategy, where RF is decreased and V_T is increased, effectively reducing the work of breathing.^{23,24} Similar to the findings of Art and Lekeux,²⁵ maximum RF did not change in the present study, likely due to the locomotor-respiratory coupling that is present in Thoroughbreds at high speeds.²⁶ It has previously been shown that ventilation is not affected by training in horses, so the authors would not expect to see a change in V_T or \dot{V}_E .^{22,27,28}

The non-significant trend to decrease $\dot{V}O_{2peak}$ in the DT horses was possibly the result of reduced exercise compared with pre-experiment conditions. Before baseline measurements, horses had been turned out in herds in large fields where, despite a lack of formal exercise, horses likely self-exercised. In comparison, for the duration of the study, horses were housed in much smaller paddocks and stall where their primary form of exercise was the treadmill. For the DT horses, the workload was very light, as reflected by previously reported HRs on the treadmill.¹³

Workload of water treadmill exercise

While the mask used was designed for measurements of high intensity in mind, satisfactory measurements were obtained during the low intensities of WT training during this study. Despite variability in breathing patterns, there were sufficient sequences of breaths that were entrained with locomotion to allow accurate analysis.

While working in water at the height of the stifle, horses had $\dot{V}O_2$ values slightly higher than what the authors previously reported under similar conditions.¹³ Working at 21.7 per cent of $\dot{V}O_{2peak}$ is of low intensity and is not adequate to replace many forms of submaximal^{21,29} and maximal training (ie, gallop work). However, this study proves that these conditions are in fact sufficient to induce significant increases in $\dot{V}O_{2peak}$. Additionally, research on humans has

indicated that WTs result in greater increases in lean muscle mass, compared with traditional treadmills.³ Although not established in horses, it is understood that the presence and height of water reduces the vertical ground reaction forces in dogs⁴ and humans,³ while encouraging increased range of motion through the back and joints.^{30–33} This indicates that WTs may have protective effects while improving cardiorespiratory fitness.

Heart rate

Previous work has indicated that HR_{max} of horses does not change with training^{21 29 34} and the results for both groups are consistent with this. All horses had HR_{max} values that were lower than previously described in Thoroughbreds,³⁵ but were within the range suggested by Betros and others for middle-aged Standardbreds (213±3 bpm).²⁹ Previous work on the WT with water at the height of the stifle at 1.39 m/s resulted in peak HR values of 69 bpm (65–78), similar to HR values of horses walking at 1.7 m/s (60–80 bpm).^{14 36 37}

HR recovery time did not change with either form of training. However, this may be more indicative of stress rather than fitness. Following the gallop, horses were led back to the barn where there were other horses, had equipment and tack removed and had blood drawn, as well as other forms of normal activity in a busy barn. As such, variation in recovery times may be due to varying levels of stress.

Speed

While horses consistently achieved the same maximal speeds preconditioning and postconditioning, WT training resulted in the maintenance of higher speeds across the duration of the maximal intensity test, with greater average finishing speeds (in the last 30 seconds of the maximal test). Although not measured in the current study, it is possible that average finishing speeds improved after WT training due to increased strength of propulsive muscles and improved postural stability.³⁰ Depending on track surface and race distance, it is accepted in horse racing that five to six lengths=one second. Given the decrease in average time over the course of the sprint, this would result in an increase of 80–96 lengths over 800 m, which is a vast improvement.

Lactate

In this study, conditioning had no apparent effect on LA concentrations in either group. Five-minute postexercise LA values were similar to those previously reported (16.32±4.81 mmol/L) following a racetrack test (speed >11 m/s, time ≤180 seconds),³⁸ however LAs may take up to 10 minutes to peak.³⁹ Within 60 minutes, LA concentrations were approaching 50 per cent of their peak value. This finding is in contrast to previous reports on the rate of postexercise disappearance of

lactate in plasma in response to maximal exercise.³⁹ Whereas, plasma LA concentrations usually decrease to 50 per cent of their peak postexercise value within 60 minutes of completing exercise, the rate of decrease of LAs is considerably slower.³⁹ This is not surprising and is likely explained by the active movement of LA from plasma into erythrocytes postexercise in order to maintain as good a LA diffusion gradient as possible from skeletal muscle to plasma⁴⁰; that is, clearance of LA from plasma is partly due to its movement into erythrocytes which in turn hinders the clearance of LA from those cells. Additionally, the rate of LA clearance may have been reduced by a passive recovery (in stalls) rather than an active recovery (walking).⁴¹

Conclusions

WT training under the conditions previously studied is considered to be submaximal exercise.¹³ However, despite the relatively low-intensity nature of WT exercises, a protocol employing a high water height was able to significantly increase $\dot{V}O_2$ peak and endurance in Thoroughbreds. Therefore, the inclusion of WT protocols in the training programmes of athletic horses may have a beneficial conditioning effect.

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