Original paper

The effects of increased absolute training intensity on adaptations to endurance exercise training

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1. Introduction

It has become increasingly common for previously sedentary people to initiate endurance training to improve their endurance capability. The objective of endurance training is to improve the physiological components that determine the average speed or power of performance. The most important physiological determinants of endurance performance are the individual's maximum oxygen uptake ($\dot{V}O_{2\max}$) and the fractional percentage of $\dot{V}O_{2\max}$ that can be sustained which is commonly estimated by the lactate threshold.⁴ In order to improve these physiological determinants individuals aiming to improve their endurance performance should

gradually increase the intensity of training over a period of time. The progressive increase in training intensity from the proceeding exercise session reputedly stresses the body's ability to regulate homeostasis⁵; as a consequence the body is reputed to adapt to the increasing homeostatic challenge occurring during exercise in order to minimise changes in homeostasis in succeeding exercise bouts.¹ Despite the assumed and anecdotal importance of progressive increments in exercise training intensity, little scientific literature exists on how important progression is in evoking physiological changes to endurance exercise training. Hickson et al. (1981) revealed that $\dot{V}O_{2\max}$ increases after 3 weeks of endurance training but will plateau by the fourth week of training if the initial work-rate is maintained. Consequently, Hickson et al. (1981) reported that unless the training stimulus increases, further improvements in oxy-

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gen consumption would not result. However, there appears to be little literature comparing the changes in oxygen consumption and lactate threshold where the initial exercise intensity is maintained or incrementally elevated each session. Therefore, the primary focus of this study was to compare the effect of increasing exercise intensity during an endurance training regime to an endurance training regime where the initial work-rate is maintained, on changes in maximum oxygen consumption and lactate threshold. A second objective is to investigate if changes $\dot{V}O_{2\max}$ and the exercise lactate threshold improves 5000 m time trial run performance.

2. Methods

Twenty-eight healthy participants (14 men and 14 women) who had not engaged in any regular running for several months and no previous competitive running history volunteered for this study. One participant did not complete the study due to injury and therefore, his/her data were omitted from the analysis. The participants had the following characteristics: age = 20.8 ± 4.8 years; height = 174.3 ± 8.3 cm; mass = 70.6 ± 12.8 kg. All participants provided written informed consent in accordance with the guidelines of the University's Human Research Ethics Committee.

Participants were randomly assigned into two treatments incrementally elevated and a regime where running intensity remained unchanged (INC or CON), matched for gender and pre-training lactate threshold velocity (LTv). Both treatments required the participants to complete 20 min treadmill runs 3 times a week for 6 weeks, with the first running session commencing $0.8 \text{ km} \cdot \text{h}^{-1}$ less than the LTv. Every training and testing session was completed at the same time of day for each participant. $\dot{V}O_{2\max}$ and lactate threshold were determined in an incremental treadmill test prior to and within 48 h of completion of the final training session. In INC, treadmill velocity was increased by $0.1 \text{ km} \cdot \text{h}^{-1}$ every session, while in CON, treadmill speed was kept constant for the duration of the training. Menstrual cycle was not controlled in the present study as the phase of menstrual cycle has no effect on endurance performance and its determinants.¹⁰

Prior to engaging in the study, participants completed a 5000 m time trial on the running track used in the study to assist them adopting the most appropriate pacing strategy. Twenty-four hours prior to pre- and post-testing, each participant consumed approximately 8–10 g of carbohydrate per kg of body weight, slept a minimum of 7 h, and consumed adequate fluid to ensure clear coloured urine. The laboratory ambient temperature was controlled at 20°C and relative humidity ranged between 50 and 60%. Prior to commencement of testing, participants were fitted with a two-way breathing valve (Hans Rudolph, USA) through which expired air was collected into an online metabolic system (Moxus,

USA), previously calibrated in accordance with the manufacturers instructions. Each participant was required to complete a 6 min warm up. Participants then completed an incremental treadmill test in order to determine $\dot{V}O_{2\max}$ and LT. Participants commenced treadmill running at $9 \text{ km} \cdot \text{h}^{-1}$ on a 1% gradient (Austradex, Australia), and ran for 1 min before coming off the treadmill. During a 1 min rest period 25 μL of blood was extracted from the fingertip and collected into a micro-capillary tube for blood lactate concentration analysis. The blood sample was injected into an automated lactate analyser (YSI 2300, Yellow Springs), calibrated according to the manufacturer's specifications using a two-point calibration method of 5 and 30 mM l^{-1} , respectively. After the 1 min rest period used to extract a blood sample, the treadmill speed was then progressively increased by $1 \text{ km} \cdot \text{h}^{-1}$. This incremental progression in speed alternated with 1 min rest periods to allow blood sampling was repeated until volitional exhaustion. $\dot{V}O_{2\max}$ was determined as the highest 60 s O_2 value recorded during the test and confirmed as a peak result if the respiratory exchange ratio (RER) exceeded 1.10. The LT was determined at the treadmill intensity where blood lactate concentration increased by 0.22 mmol above the basal level.⁶ The maximal treadmill velocity ($V_{\max}$) was determined from the final speed that could be sustained for 1 min. The 5000 m time trial runs were performed at a recreational park at approximately the same time of day for both the pre- and post-test and verbal instruction and encouragement was provided to ensure each participant ran at their maximal effort.

Differences between groups and within groups over time were analysed using a 2×2 (group $\times$ time) repeated measures analysis of variance (RMANOVA) with main effects for group and time, and a group $\times$ time interaction. Assumptions were checked using Levene tests (equality of within-group variances), Box M tests (equality of within-group covariance matrices), and normal Q - Q plots and Kolmogorov-Smirnov-Lilliefors and Shapiro-Wilks tests (within-group normality). Within group changes from pre- to post-training were also examined using t -tests for dependent measures. The data are expressed in absolute figures, percentage change after training and upper and lower confidence intervals (95% CI).

Significance was set at $p \leq 0.05$ for all analyses.

3. Results

Table 1 presents the mean changes in physiological measures and 5000 m time trial performance. Our analyses show that $\dot{V}O_{2\max}$ increased significantly over time under both INC ($p = 0.005$) and CON ($p = 0.001$) treatments, although the changes in $\dot{V}O_{2\max}$ under the two treatments did not differ significantly ($p = 0.127$). LTv increased significantly over time in INC (0.004) but was not significantly different in CON over time ($p = 0.082$); the increase in LTv was significantly greater in INC compared to CON ($p = 0.010$). $\text{LT}\dot{V}O_2$

Table 1

Pre-training vs. post-training values in the regime where treadmill-running intensity was incrementally elevated (INC) and a regime where running intensity remained unchanged (CON) for maximum oxygen uptake ($\dot{V}O_{2\max}$), velocity at lactate threshold (LTv), oxygen uptake at lactate threshold (LTVO₂), highest speed achieved during testing ($V_{\max}$) and 5000 m time trial performance time (time trial) in the different training groups

	Group	
	INC	CON
$\dot{V}O_{2\max}$ (ml·min ⁻¹)		
Pre	3022 (2615–3392)	3165 (2792–3538)
Post	3273* (2746–3493)	3255* (2896–3614)
% change	7.7	2.8
LTv (km·h ⁻¹)		
Pre	13.7 (12.6–14.5)	13.7 (12.8–14.6)
Post	14.9* [†] (13.9–15.6)	13.9 (13.1–14.7)
% change	7.7	1.7
LTVO ₂ (ml min ⁻¹ km·h ⁻¹)		
Pre	2443 (2110–2776)	2616 (2272–2962)
Post	2656* [†] (2335–2976)	2686* (2354–3019)
% change	8.0	2.6
$V_{\max}$ (km·h ⁻¹)		
Pre	18.5 (17.3–19.7)	17.9 (16.7–19.1)
Post	19.4* (18.3–20.4)	18.2 (17.2–19.3)
% change	4.4	1.7
Time trial (min)		
Pre	25.7 (23.6–27.8)	25.3 (23.1–27.5)
Post	24.4* (22.4–26.4)	24.5* (22.5–26.7)
% change	5.0	3.0

Values are expressed in absolute figures, percentage change after training and upper and lower confidence intervals (95% CI).

* Significantly greater than pre-training value at the $p \leq 0.05$ level of significance.

[†] Significantly greater change than CON group at the $p \leq 0.05$ level of significance.

increased significantly over time in both INC ($p=0.001$) and CRT ($p=0.008$); the increase in LTVO₂ was significantly greater in INC compared to CON ($p=0.042$). $V_{\max}$ increased significantly over time in INC ($p=0.005$) but not in CON ($p=0.104$). The increase in $V_{\max}$ was not significantly greater in INC compared with that of CON ($p=0.054$). 5000 m time trial performance time decreased significantly over time under both INC and CON treatments ($p<0.000$) although the changes in 5000 m time trial performance in the two treatments did not differ significantly ($p=0.166$).

4. Discussion

This study showed that treadmill-running performed 3 times weekly for 6 weeks, significantly improved $\dot{V}O_{2\max}$, $\dot{V}O_{\max}$, LTVO₂, LT and 5000 m time trial performance. However, the key finding is that progressively increasing the training intensity of each session resulted in significantly greater change in LTVO₂ and LT velocity compared to a training regime where the run intensity remained constant. Furthermore, this study showed that changes in $\dot{V}O_{2\max}$ were not significantly different between the intervention treatments nor was 5000 m time trial performance.

The change in $\dot{V}O_{2\max}$ after 6 weeks of endurance training in the present study (~ 3 – 7%) is substantially less than the $\sim 18\%$ change observed by Hickson et al. (1981) after 6 weeks of training, despite similar initial pre-exercise $\dot{V}O_{2\max}$ values. However, the discrepancy in magnitude of change in $\dot{V}O_{2\max}$ between Hickson et al. (1981) and the present study is probably attributable to differences in the volume and intensity of training used. In Hickson et al. (1981) study participants alternated high-intensity bicycle interval training with 40 min continuous running on alternate days for 6 days per week. The run duration (20 min) the frequency (three runs weekly) used in the present study are the minimal dose of exercise recommended by the ACSM for eliciting improvements in $\dot{V}O_{2\max}$.¹ Subsequently greater changes in $\dot{V}O_{2\max}$ may be expected if training duration and frequency are increased.¹¹ Interestingly, the change in $\dot{V}O_{2\max}$ did not differ significantly between the INC and CON in the present study. The maximal cardiac output (a function of the maximal stroke volume and heart rate being attained) is the major limiting factor in $\dot{V}O_{2\max}$ in endurance-trained individuals.² Therefore, it is evident from this study that the improvement in cardiac output was most likely similar between treatments.

The available literature describing the effects of progressive overload on endurance performance appears limited to two investigations dating back over 25 years.^{5,6} Hickson et al. (1981) revealed that changes

in $\dot{V}O_{2\max}$ will plateau within weeks of initiating training, and will only increase further if the training intensity is increased. This highlights the importance of progressively increasing the exercise intensity from preceding sessions to maximise improvements in the individuals $\dot{V}O_{2\max}$. However the importance of progressively increasing exercise intensity on the LT has not been previously reported. Our data provide unique evidence that the endurance training adaptations responsible for changes in the LT may be inhibited if exercise intensity is not progressively elevated. Consequently "Progressive overload" is also important to improve the LT.

The adaptations reputed to increase the LT are consequent to improving lactate removal or decreasing lactate production³ and are believed to be different to those adaptations related to changes in $\dot{V}O_{2\max}$. Physiological adaptations associated include a greater number of increased cell lactate transporters increasing the exchange and removal of lactate from the blood, an increase in mitochondria enhancing skeletal muscle oxidative capacity and a greater concentration of fat oxidation enzymes and triglycerides in muscle cells reducing reliance on anaerobic metabolism and carbohydrate oxidation.⁷ To induce the physiological adaptations that increase the LT, training intensity needs to be around the LT.⁸ As the optimal stimulus to improve LT is to train close to the intensity eliciting LT,⁸ the present data support the notion that training intensity has to be continually increased to ensure continued improvements in LT. During this investigation training at speeds just below LT ($0.8 \text{ km}\cdot\text{h}^{-1}$ less than LT) were insufficient to induce adaptations to the level of INC training, however from our data it is apparent that training at speeds below LT will still have a small but significant effect on LT. The present study showed that commencing running at $0.8 \text{ km}\cdot\text{h}^{-1}$ less than the pre-training LT velocity and increasing training intensity each session by $0.1 \text{ km}\cdot\text{h}^{-1}$ is sustainable over 18 runs performed over 6 weeks, as all participants were able to complete the final training run (session 18). Individuals with low-exercise motivation or who are physically compromised by injury or pathology may benefit from our findings. It is clear that while progressive overload is recommended to enhance changes in cardio-respiratory fitness, some improvements in markers of fitness occur irrespective of incremental increases in exercise intensity.

Despite our findings that progressive overload is central to improvements in the LT, a number of issues remain to be addressed. In the present investigation we could not clearly distinguish if the greater improvements in INC were consequential to the elevation in intensity or in fact a result of the greater distance covered due to the progressive increases in run velocity. The participants in the INC covered approximately 20% greater distance at the conclusion of the training regime. Further research would incorporate a constant intensity group that runs the equivalent distance as the INC group to determine potential differences between incremen-

tal increases in run intensity vs. incremental increases in run duration. Additionally, while this study provides evidence that progressive increments of $0.1 \text{ km}\cdot\text{h}^{-1}$ were sustainable over 6 weeks, little scientific literature exists on the amount of exercise sessions (or time length) an individual is able to sustain if exercise is progressively elevated from the preceding training session. It is important that the temporal limits of the body's ability to adapt to specific incremental changes in exercise intensity be established in order to effectively plan the appropriate rate of change in training intensity in a periodised program. Presently, the American College of Sports Medicine recommends adjustments in intensity of no more than 5% of heart rate reserve every 6th session,¹ however the scientific rationale of this recommendation is not clear. The present investigation found that significant changes in markers of aerobic fitness will occur as a result of increases in intensity of as little as 2.3% per week. This information may be used by individuals and exercise professionals aiming to improve cardio-respiratory or endurance fitness by providing evidence of sustainable rates of exercise intensity increments.

5000 m time trial performance improved in INC and CON (4% vs. 3%) but was not significantly different between the treatments although there appears to be a trend for INC having a greater effect on time trial performance as the p value was close to significance ($p=0.054$). It was anticipated that improvements in 5000 m time trial would be greater in INC due to the greater improvement in LT. An improvement in LT would be expected to improve 5000 m time trial performance as the exercise intensity at which lactic acid accumulates to fatiguing levels is increased.⁹ However, most likely the participants' inexperience in 5000 m time trial running and their ability to adopt an appropriate pace resulted in variations in time trial performance that may have masked any lactate threshold change on performance. Furthermore, the physiological determinants of the 5000 m time trial performance in the present study were limited to measurements of $\dot{V}O_{2\max}$ and LT; it is clear that running economy, anaerobic capacity and anaerobic power are also important determinants of running performance.

5. Conclusion

In conclusion, the present study showed that INC and CON were both effective in producing significant changes in $\dot{V}O_{2\max}$, $V_{\max}$, $LT\dot{V}O_2$, LTv and 5000 m time trial performance. Progressive incremental increases in exercise intensity evoked significantly greater change in $V_{\max}$, $LT\dot{V}O_2$ and LTv than a training regime where intensity remained unchanged. This study shows that individuals initiating endurance training should apply the principle of "progressive overload" to maximise endurance training adaptations.

Practical implications

- Sustaining treadmill-running velocity at $0.8 \text{ km} \cdot \text{h}^{-1}$ less than the lactate threshold for 20 min on three occasions per week for 6 weeks will result in positive gains in endurance performance.
- Greater improvements in lactate threshold will occur if the exercise intensity is incrementally increased each session.
- A progressive and sustained increase in run speed of $0.1 \text{ km} \cdot \text{h}^{-1}$ is tolerable in 18 runs performed over a 6 week training regime for previously sedentary individuals initiating exercise.

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References

1. Armstrong L, Balady JG, Berry MJ, Davy BM, Davy KP, Franklin B, et al. *ACSM's guidelines for exercise testing and prescription*. 7th ed. USA: Lippincott Williams and Wilkins; 2000. p. 150.
2. Bassett D, Howley ET. Limiting factors for maximal oxygen uptake and determinants of endurance performance. *Medicine and Science in Sports and Exercise* 1988;**30**:1381–98.
3. Becker DM, Vaccaro P. Anaerobic threshold alterations caused by endurance training in young children. *Journal of Sports Medicine and Physical Fitness* 1983;**23**(4):445–9.
4. Coyle EF, Coggan AR, Hopper MK, Walters TJ. Determinants of endurance in well trained cyclists. *Journal of Applied Physiology* 1988;**64**:2622–30.
5. Hickson RC, Hughes JM, Eshani AA, Holloszy JO. Time course of the adaptive responses of aerobic power and heart-rate to training. *Medicine and Science in Sports and Exercise* 1981;**13**(1):17–20.
6. Hickson RC, Bomze HA, Holloszy JO. Linear increase in aerobic power induced by a strenuous program of endurance exercise. *Journal of Applied Physiology* 1977;**42**:372–6.
7. Jones AM, Carter H. The effect of endurance training on parameters of aerobic fitness. *Sports Medicine* 2000;**29**(6):373–86.
8. Londeree BR. Effect of training on lactate/ventilatory thresholds: a meta-analysis. *Medicine and Science in Sports and Exercise* 1997;**29**(6):837–43.
9. Stegmann H, Kindermann W. Comparison of prolonged exercise tests at the individual anaerobic threshold and the fixed anaerobic threshold of 4 mmol L^{-1} lactate. *International Journal of Sports Medicine* 1982;**3**:105–10.
10. Wasserman K, Hansen JE, Sue DY, Whipp FJ, Casaburi R. *Principles of exercise testing and interpretation*. 2nd ed. Philadelphia: Lea & Febiger; 1994. p. 17–32.
11. Wenger HA, Bell GJ. The interactions of intensity, frequency and duration of exercise training in altering cardiorespiratory fitness. *Sports Medicine* 1986;**3**:346–56.