The Effects of High-Intensity Interval Training in Well-Trained Rowers

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ABSTRACT

Several recent studies have reported substantial performance and physiological gains in well-trained endurance runners, swimmers and cyclists following a period of high-intensity interval training (HIT). The aim of the current study was to compare traditional rowing training (CT) to HIT in well-trained rowers. **Methods:** Subjects included 5 male and 5 female rowers (mean ± SD; age = 19 ± 2 years; height = 176 ± 8 cm; mass = 73.7 ± 9.8 kg; $\dot{V}O_{2\,peak}$ = 4.37 ± 1.08 L.min^{-1}). Baseline testing included a 2000 m time-trial and a maximal exercise test to determine $\dot{V}O_{2\,peak}$, 4-minute all-out power and 4 mmol.L^{-1} blood lactate threshold. Following baseline testing rowers were randomly allocated to HIT or CT, which they performed seven times over a 4-week period. HIT involved 8 x 2.5 minute intervals at 90% of the velocity maintained at $\dot{V}O_{2\,peak}$, with individual recoveries returning to 70% of the subjects' maximal heart rate between intervals. CT intensity consisted of workloads corresponding to 2 and 3 mmol.L^{-1} blood lactate concentrations. On completion of HIT or CT rowers repeated the testing performed at baseline and were then allocated to the alternative training program and completed a crossover trial. **Results:** HIT produced greater improvements in 2000 m time (1.9 ± 0.9%; mean ± SD), 2000 m power (5.8 ± 3.0%) and relative $\dot{V}O_{2\,peak}$ (7.0 ± 6.4%), than CT. **Conclusion:** Four weeks of HIT improves 2000 m time-trial performance and relative $\dot{V}O_{2\,peak}$ in competitive rowers, more than a traditional approach.

KEY WORDS – *rowing, VO_2max, performance, endurance, training techniques*

INTRODUCTION

For already well-trained athletes, improvements in performance become difficult to attain and increases in training volume can potentially yield no improvements. Consequently, athletes and coaches must find alternative approaches to achieve greater physiological and performance gains.[1] Previous research would suggest that, for athletes who are already trained, improvements in endurance performance can be achieved through high-intensity interval training (HIT).[2] These performance improvements have been attributed to changes in maximum oxygen consumption, anaerobic threshold and economy.[3] Previous HIT studies performed on cyclists, swimmers and runners, have reported significant improvements in $\dot{V}O_{2\,max}$,[4] peak-power output,[5] lactate threshold[6] and time-trial performance,[7] and in the majority of these studies the prescription of intensity for the intervals has been based on power output, speed or velocity at ~ $\dot{V}O_{2\,max}$.

Compared to the volume of research that describes the physiological adaptations to traditional endurance exercise training in sedentary to moderately-trained individuals, relatively little work has examined the physiological and performance responses of already well-trained athletes to HIT. Moreover, far less has been published regarding the responses to HIT of well-trained rowers. It has been estimated that when rowing 2000 m at competition intensity, which takes approximately 6-7.5 minutes[8] (depending on boat class), 70-75% of the total energy is derived from aerobic metabolism and the remaining 25-30%

from anaerobic metabolism.[9] Surprisingly, with traditional training models, only a fraction of the total rowing distance and time is performed at competition intensity.[10] A possible explanation for the lower intensity training performed by rowers, is the suggestion that frequently elevated blood lactate levels lead to muscle damage and may subsequently affect the recovery of the athlete and the ability to continue with training.[11] Training intensity may also be lower in order to sustain the traditionally high volumes of training conducted throughout the majority of the rowing season. Previous research has shown that some methods of short-duration, high-intensity, intermittent exercise with individualised recovery can be performed for a prolonged period of time with only small increases in blood lactate concentration.[12] Furthermore, these types of training protocols, such as HIT, would allow rowers to train at or even above competition intensity for a prolonged period of time without experiencing the negative effects associated with continuously elevated blood lactate levels.

To our knowledge, there have not been any published studies that have investigated the effects of short-term (4-weeks) HIT in well-trained rowers. Therefore, the primary aim of the current study was to compare physiological and performance effects of HIT with the more traditional phase-interval training (CT) in well-trained rowers.

METHODS

Subjects

Ten well-trained state representative rowers volunteered to take part in the current study. Subjects were 5 female (mean ± SD; age = 19 ± 2 years; height = 170 ± 7 cm; mass = 67.6 ± 10.5 kg; $\dot{V}O_{2\,peak}$= 3.38 ± 0.28 $L \cdot min^{-1}$) and 5 male (mean ± SD; age = 19 ± 2 years; height = 182 ± 5 cm; mass = 79.1 ± 5.45 kg; $\dot{V}O_{2\,peak}$ = 5.36 ± 0.14 $L \cdot min^{-1}$) rowers. The majority of the subjects (4 males and 3 females) were competing in the lightweight rowing category during the current study. All subjects were members of a state representative rowing team preparing for the National Youth Cup Regatta, with the study taking place in the build up to their competition. Subjects were required to give informed consent prior to any testing taking place. A pre-exercise health-screening questionnaire and a Physical Activity Readiness Questionnaire (PAR-Q) were completed by all subjects prior to taking part in the study to ensure that there were no contra-indications to vigorous exercise. The research was conducted according to National Health and Medical Research Council Guidelines after approval by the Institutional Human Research Ethics Committee.

Experimental design

The current training study was a crossover trial, with two different training conditions each lasting 4-weeks: HIT and a CT training protocol which acted as the control condition. Prior to taking part in the current study, subjects were already implementing similar traditional ergometer sessions (CT) in their training programs. Subjects were informed that there were no demonstrated advantages of one method over the other and that the study was simply comparing two types of ergometer training protocols. Subjects performed baseline testing and were then randomly assigned to either 4-weeks of HIT or CT. On completion of the 4-week training period subjects were then re-tested and assigned to the alternative training program that they had not yet completed. Following 4-weeks of training subjects were again re-tested. Testing consisted of a 2000 m time-trial (TT) on a rowing ergometer (Concept II, Model-C, Vermont, USA) and an incremental rowing exercise test 48-72 hours later where $\dot{V}O_{2\,peak}$ was determined and blood lactate concentrations were measured. Testing was repeated after the first training intervention at week 4 and again following the second training intervention at week 8. Subjects were instructed to arrive at the testing sessions in a rested and hydrated state after fasting for at least two hours, and were told to avoid strenuous exercise in the 48 hours preceding a test session. Subjects were also asked to complete food diaries on the day before baseline testing sessions and to replicate this diet before the 4 and 8 week testing sessions. Throughout the 8-week duration of the study, all subjects were required to keep a detailed training diary, containing information on all training performed over that time. Each subject was tested at approximately the same time of day throughout the study and performance tests were always conducted on the same ergometer.

2000 m performance trial

The 2000 m TT was performed on an air-braked Concept IIc rowing ergometer. The use of the Concept IIc rowing ergometer is believed to simulate the metabolic and biochemical demands of on-water rowing and can be used to assess rowing performance.[13] The subjects were already familiar with the use of this apparatus and the TT testing procedure before taking part in the study. The test-retest reliability of the 2000 m TT on a Concept IIc ergometer has been previously examined with a coefficient of variation of 0.6% (95% CI = 0.4-1%) being reported.[14] All subjects performed a 10-minute self selected warm-up and stretches prior to the test, which was replicated before each TT. Power output, stroke rate and 500m split times were updated continuously on the computer display of the rowing ergometer during the TT and average values were presented for each measure at the completion of the TT. Time to complete the TT was recorded as the criterion dependent variable. Heart rate was measured continuously (s610, Polar Electro Oy, Finland) during the TT. Before each subject performed their test, the vanes of the ergometer were adjusted to set the appropriate drag factor that corresponded to their weight division (lightweight female = 110, lightweight male/heavyweight female = 120, heavyweight male = 130), as defined by Rowing Australia Testing Guidelines (Australian Institute of Sport). There was no verbal encouragement given to the subjects during the test, in order to control psychological motivation.

Progressive exercise test

A progressive incremental exercise test was also performed on a Concept IIc rowing ergometer to determine $\dot{V}O_{2\,peak}$, power corresponding to 4 $mmol.L^{-1}$ blood lactate concentration, mean 4-minute all-out power (PkPO) and peak heart rate. The incremental exercise test was performed according to the Australian physiological assessment of rowing guidelines,[8] which the subjects were accustomed to. According to the guidelines, the starting power output and step increments were related to each subjects' TT time and the drag factor on the rowing ergometer was adjusted to match their weight class. Subjects performed 7 x 4-minute incremental steps, with the last step being an all-out effort. They were asked to maintain their target power output during each step of the test, as visually displayed on the rowing ergometer monitor. All stages were followed by 1-minute of passive rest during which a fingertip capillary blood sample was collected to determine blood lactate concentration (Lactate Pro, Arkray, Japan). Cardiorespiratory-metabolic variables were measured throughout the progressive exercise test using a two-way non-rebreathing mouthpiece system (Hans Rudolf, Kansas, USA) connected to a metabolic analyzer (Vacumed Vista-CPX, Ventura, USA). The analyzer was calibrated before each test using alpha gases of known concentration, according to the manufacturer's instructions. During the progressive exercise test, each subject was encouraged to give a maximal effort during the final stage. The investigators providing the encouragement were blinded to the training condition each rower had been undertaking. $\dot{V}O_{2\,peak}$ was taken as the highest $\dot{V}O_2$ value recorded during a 1-minute period of the final stage in the incremental test. The mean power output achieved during the final 4-minute stage was deemed as PkPO and was used to set HIT training intensity. The 4 $mmol.L^{-1}$ blood lactate threshold was determined via a software package (ADAPT v1.2, Australian Institute of Sport).

Training

Subjects used training diaries to record work completed for both HIT and CT ergometer sessions. Furthermore, subjects also recorded any other training that was completed supplementary to the ergometer training sessions (e.g. cycling, running, weights). Type of training, duration, heart rate and distance or mean power (where appropriate) were recorded in the training diaries for each training session completed. We could then determine total work (kJ) completed during ergometer training by multiplying mean power and session duration. Subjects also gave an intensity rating following each training session using the CR 10 Borg Scale[15] for Rating of Perceived Exertion (RPE). To quantify the amount of other training that was completed in both HIT and CT interventions, the present study used a method focusing on the session rating of perceived exertion (RPE). The session RPE method provides a mechanism for quantifying the exercise intensity component, as well as calculating an individual representation of the combined intensity and duration of training sessions.[16] This is achieved by multiplying the RPE of each session by the duration (minutes) of the session. The training that the rowers were performing supplementary to their ergometer sessions was very similar, as they were all part of the same squad in preparation for an upcoming regatta. Their training was overseen by the same coaches and the only major difference in training between the groups was the ergometer protocol they were undertaking twice a week.

High-intensity interval training protocols

The HIT group trained twice per week for 4-weeks, completing 7 HIT sessions (only one session was completed in the final week due to re-testing). At each HIT session, subjects completed 8 intervals at 90% of PkPO (final workload) taken from the incremental exercise test. Each interval was 2.5 minutes in duration. The 90% intensity was chosen as it has been demonstrated to approximate (r = 0.94) the power output that correlates to a blood lactate concentration of ~10 $mmol.L^{-1}$ in rowers (unpublished observations from elite rowers tested at the Tasmanian Institute of Sport, Australia). The slightly lower than PkPO intensity, in contrast to previous studies, was chosen due to the coaches' request that training intensities not produce blood lactate concentrations in excess of 10 $mmol.L^{-1}$ for their athletes. The work:rest ratio during the HIT sessions varied for each individual. Between each interval, subjects continued rowing at 40% of their PkPO until their heart rate returned to ≤70% of its maximum, as used in previous studies.[17] When this was achieved, subjects were to start their next interval. If the recovery time between intervals was longer than 5 minutes, subjects were instructed to stop rowing and wait until their heart rate dropped to the target value. The intensity of exercise chosen for recovery between intervals has been demonstrated to achieve an efficient rate of lactate removal as well as rapid heart rate recovery.[18] Each session lasted approximately 60-minutes.

Control group training protocols

The protocol used for the CT group involved two different ergometer training sessions to be completed each week (Phase I and Phase II). Both sessions used intensities based on the blood lactate curve from the incremental exercise test. The ergometer work loads (W) used corresponded to blood lactate concentrations of 2 and 3 $mmol.L^{-1}$. The two protocols are shown in Table 1. The training sessions lasted 60 minutes and 55 minutes for Phase I and Phase II protocols respectively. This included a 10 minute warm-up and cool-down that was replicated for each session. Using previous pilot data, we estimated the total work that would be completed in both the HIT and CT sessions would be similarly matched for energy expenditure but due to the variable nature of the HIT could not ensure that the energy expenditure was identical for each rower. Subjects were familiar with the CT protocol, and had performed a similar type of ergometer session in their training prior to taking part in the current study.

Data analysis

Each subject's change score from pre- to post-training intervention was expressed as a percentage of their baseline score (value obtained immediately prior to the training intervention). Results from our measured variables were analysed using paired t-tests for each training intervention, and independent t-tests were used to analyse training diary data, with statistical significance set at $p < 0.05$ for all analyses. Mean effects of training and their 90% confidence limits were estimated using an Excel (Microsoft Office, 2003) spreadsheet.[19] The spreadsheet also computed chances that the true effects of the training were substantial, when a value for the smallest worthwhile change was entered. The data analysis also provided meaningful inferences and the clinical significance that HIT had on performance. Measures of reliability known as Coefficient of Variation (CV) were used as the smallest substantial/worthwhile change for each of the variables. As identified previously,[14] mean power in a 2000 m TT has a reported a CV of 2%, while time to complete a 2000 m rowing TT has a 1% CV. The CV data for $\dot{V}O_{2\,peak}$, 4 $mmol.L^{-1}$ power output and PkPO were 2.2%, 1% and 2% respectively as identified from quality assurance data maintained for testing protocols utilized at the Tasmanian Institute of Sport (unpublished observations). To determine whether there was any order effect of the two different training interventions, mean change in variables (TT and $\dot{V}O_{2\,peak}$) achieved during the first 4-weeks were compared with improvements attained during the second 4-week period. Group statistics are shown as means ± standard deviations.

RESULTS

As displayed in Figure 1, HIT was associated with significantly greater improvements in 2000 m time (1.9 ± 0.9%, $p = 0.02$), 2000 m power (5.8 ± 3.0%, $p = 0.03$) and relative $\dot{V}O_{2\,peak}$ (7.0 ± 6.4%, $p = 0.03$), when compared to CT. HIT was also associated with improvements in absolute $\dot{V}O_{2\,peak}$, PkPO and 4 mmol.L^{-1} power, however these were not significant when compared to CT. In raw terms, the HIT intervention produced an 8.2 ± 3.8 second improvement in the TT, compared to a 2.3 ± 5 second improvement following the CT intervention.

Table 2 presents the raw pre and post results for each measured variable in both HIT and CT conditions. The table also provides the raw difference between the change in HIT and the change in CT, with 90% confidence limits. Table 2 provides meaningful inferences and clinical significance that HIT had on performance. The chances that HIT had a positive, negative or trivial effect on performance was calculated using values for the smallest worthwhile change for each variable. The likelihood that HIT was beneficial compared with CT for all of our key dependant variables (except 4 mmol.L^{-1} lactate threshold) was ≥74% (Table 2).

Subjects reported 100% adherence to both ergometer training protocols, with all subjects completing the 7 sessions for each training intervention. However, despite the best efforts of the researchers the training diary completion rate was 75%. Analysis of the completed training diaries showed that there were no significant differences ($p = 0.84$) between the work completed during ergometer training in the 2 groups (HIT = 3142 ± 1184 kJ; CT = 2986 ± 1037kJ) during each 4-week training intervention. Moreover, there were also no significant differences ($p = 0.99$) between the two groups for the total amount of training performed, as identified by the session RPE method (HIT = 12009 ± 9047; CT = 12250 ± 6392).

Intervention order had no affect on TT performance, with no significant difference ($p = 0.64$) between the first and second 4-week training period. Mean TT performance improved during each condition regardless of intervention order (Table 3).

DISCUSSION

The major finding of the present study was that HIT significantly improved rowing performance and physiology when compared to CT. The percentage improvements in TT time, TT power and relative $\dot{V}O_{2\,peak}$ were all greater following HIT when compared to CT. The current study is the first to demonstrate that acute (4-weeks) HIT significantly improves performance in already well-trained rowers.

In terms of performance improvements over a 4-week period of training, both HIT and CT interventions produced notable results. It would appear that the more traditional CT was also a successful method of training for improving TT performance; however the benefits associated with the HIT intervention were significantly greater. In terms of the practical significance to the sport of rowing, the current study shows improvements of ~8 seconds in TT performance following HIT, which equates to approximately a 4.5 boat-length improvement in a 2000 m single sculling race. In comparison, the ~ 2 second improvement in TT during the CT intervention would equate to approximately 1 boat length in the same 2000 m race.

While there is limited research regarding the effects of HIT on TT performance in rowers, other studies have shown improvements in running and cycling time trial performance following HIT.[17] A comprehensive review on HIT[3] has shown performance improvements of between 3-8.3% following interval training at maximal and supra-maximal intensities. In runners HIT has been associated with ~ 3% improvements in 5 km[20] and 10 km[21] running times in middle and long distance runners. A study investigating the effects of different HIT methods in highly-trained cyclists[22] reported 40 km time-trial improvements of between 4.4-5.8% following 4-weeks of similar HIT protocols. For rowers, previous research has indicated that TT performance enhancement is associated with improvements in $\dot{V}O_{2\,peak}$ values, peak power output and power achieved at 4 $mmol.L^{-1}$ lactate threshold,[23] all of which improved in response to HIT in the present study.

Our finding that $\dot{V}O_{2\,peak}$ improved by 7.0% following HIT is in agreement with previous research in runners, swimmers and cyclists,[17] and is likely to be the main contributing factor in the greater performance improvement following HIT. Several studies have shown an increase in $\dot{V}O_{2\,peak}$ of 5-15%, following various HIT methods.[4, 22, 24] A study using a similar HIT method in highly-trained runners[4] noted similar significant improvements in $\dot{V}O_{2\,peak}$ (4.9%; $p < 0.05$). Furthermore, research on the effects of interval training in highly-trained cyclists[22] showed an 8% improvement in $\dot{V}O_{2\,peak}$ after 4-weeks of HIT. In the present study, $\dot{V}O_{2\,peak}$ increased in all but one rower following HIT, while during the CT condition the response was quite varied, with some rowers increasing and some decreasing their $\dot{V}O_{2\,peak}$ after 4-weeks of training. The improvement of $\dot{V}O_{2\,peak}$ following HIT may be attributed to both peripheral and central adaptations. While genetics and initial fitness level contribute to improvements in $\dot{V}O_{2\,peak}$, it seems that the HIT training stimulus (intensity, duration, frequency and recovery) plays a major role in the magnitude of the improvement.[2] Our findings support the view that training at or close to the velocity corresponding with $\dot{V}O_{2\,peak}$ may be the most effective means of eliciting additional improvements in $\dot{V}O_{2\,peak}$ in already highly trained athletes.[1, 4]

Blood lactate levels are linked to the muscle respiratory capacity, and the ability to elicit less lactate at a given submaximal power output is a determinant of successful rowing performance.[13] Previous studies have established that the power which elicits a blood lactate concentration of 4 mmol.L^{-1} is one of the best predictors of competition performance in trained rowers.[25, 26] In the current study, both HIT and CT produced significant changes in 4 mmol.L^{-1} lactate threshold with pre- to post-training improvements of 5.0 and 4.9% respectively. However, there was no significant difference between the two interventions for change in lactate threshold suggesting that the improved TT performance after HIT was most likely due to the improvement in $\dot{V}O_{2\,peak}$. However, investigation of the exact mechanisms that may have been responsible for the improvements in both TT performance and $\dot{V}O_{2\,peak}$ found after HIT in rowers is still warranted.

The present study used 7 HIT sessions to induce significant performance improvements in rowers. It has been reported that 6, 8 and 12 HIT sessions all improved 40 km time trial performance in cyclists by ~3.5%.[7, 27] However, it appears that increasing the number of HIT sessions from 6 to 12 does not result in any further improvement in cycling performance. Indeed, most of the HIT-induced improvements in both peak power output and 40 km time trial performance appear to be complete after only 6 HIT sessions,[28] whether this is the same for rowing training remains unanswered. Additional to the optimal number of HIT sessions in rowing, the frequency of HIT may also be an area of future research. While it is now known that 7 HIT sessions were adequate in providing performance benefits in rowers, little is known about the optimal number and periodisation of HIT sessions into a rowing training plan (i.e. 6 HIT sessions in 2 weeks vs 6 HIT sessions in 6 weeks).

PRACTICAL APPLICATIONS

The improvement of ~8 seconds in 2000 m time-trial performance following HIT equates to approximately a 4.5 boat-length improvement in a 2000 m single sculling race compared to a 1 boat length improvement following CT. HIT was also a more successful method in improving $\dot{V}O_{2\,peak}$ when compared to the more traditional CT.

CONCLUSION

The present study has extended the findings of previous investigations into HIT showing that TT performance, $\dot{V}O_{2\,peak}$ and lactate threshold can be significantly improved using 4-weeks HIT in well-trained athletes. Furthermore, this is the first study to show improvements of ~2% (~8seconds) in a 2000 m rowing time-trial following 4-weeks of HIT using well-trained rowers. Further studies are required to examine the central and peripheral adaptations that may occur following HIT programs to explain improvements in performance in the already well-trained athlete. Moreover, considering the current study is the first to show these improvements after 4-weeks of HIT in rowers, additional investigations are necessary to determine the optimal volume and periodisation of HIT into a rowing training program.

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Table 1 – Phase-interval training protocols used during the CT trial. Individual power outputs corresponding to target blood lactate concentrations were prescribed based on results from the progressive exercise test.

	Time (mins)	Intensity (mmol.L.$^{-1}$)
Phase I	10	2
	5	3
	10	2
	5	3
	10	2
Phase II	5	2
	10	3
	5	2
	10	3
	5	2

Table 2 – 2000 m performance trial and progressive exercise test results pre- and post- HIT and CT trials, including the effect of HIT relative to CT and likelihoods of clinically substantial differences.

Variable	HIT		CT		ΔHIT - ΔCT Raw Difference ± 90% Confidence Intervals	Likelihood (%) of HIT being positive/trivial/negative
	Pre	Post	Pre	Post		
2000 m time (seconds)	437 ± 40	429 ± 40	434 ± 36	432 ± 38	-6 ± 3.8	76% / 24% / 0%
2000m Power (watts)	279 ± 74	296 ± 81	284 ± 69	289 ± 74	12 ± 8.2	88% / 12% / 0%
VO_{2peak} (mL.kg^{-1} min^{-1})	53.2 ± 6.4	57 ± 8.4	54.8 ± 7.3	54.2 ± 7.8	4.4 ± 3.4	94% / 5% / 1%
VO_{2peak} (L.min^{-1})	3.95 ± 0.91	4.22 ± 1.06	4.06 ± 0.91	4.04 ± 0.93	0.29 ± 0.4	81% / 13% / 6%
PkPO* (watts)	292 ± 88	310 ± 85	297 ± 75	308 ± 82	7 ± 10.7	78% / 14% / 8%
4mmol.L^{-1} Power (watts)	208 ± 52	217 ± 49	209 ± 43	220 ± 51	-2 ± 14	30% / 19% / 51%

* Mean 4-min all-out power achieved in the final stage of the progressive exercise test.

Table 3 – The effect of intervention order on 2000 m time-trial (TT) performance. Values are shown as means ± standard deviations.

	2000 m time (seconds)				
Intervention order:	**TT1**	**TT2**	**TT2 – TT1**	**TT3**	**TT3 – TT2**
HIT then CT	448 ± 38	441 ± 39	-7 ± 4	439 ± 37	-2 ± 3
CT then HIT	424 ± 35	421 ± 42	-3 ± 8	412 ± 42	-9 ± 3

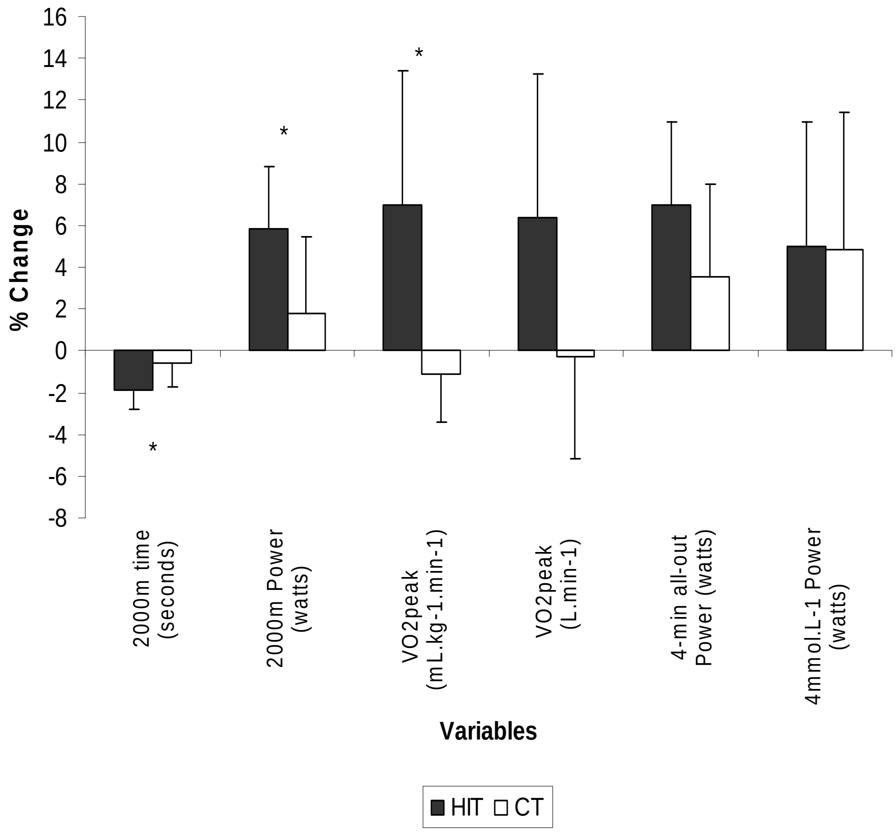

Figure 1 – Percentage change in measured variables after both HIT and CT. The figure demonstrates a significantly greater improvement following HIT when compared to CT for 2000m time, 2000m power and relative VO_{2peak}. * Significantly different to CT ($p < 0.05$).