**Abbiss, Quod et al. 2009 – Accuracy of the Velotron ergometer**

Abbiss, C. R.; Quod, M. J.; Levin, G.; Martin, D. T.; Laursen, P. B. (2009):

## Accuracy of the Velotron ergometer and SRM power meter.

In: *Int J Sports Med* 30 (2), S. 107–112. DOI: 10.1055/s-0028-1103285.

*Abstract:*

The purpose of this study was to determine the accuracy of the Velotron cycle ergometer and the SRM power meter using a dynamic calibration rig over a range of exercise protocols commonly applied in laboratory settings. These trials included two sustained constant power trials (250 W and 414 W), two incremental power trials and three high-intensity interval power trials. To further compare the two systems, 15 subjects performed three dynamic 30 km performance time trials. The Velotron and SRM displayed accurate measurements of power during both constant power trials (<1% error). However, during high-intensity interval trials the Velotron and SRM were found to be less accurate (3.0%, CI=1.6-4.5% and -2.6%, CI=-3.2--2.0% error, respectively). During the dynamic 30 km time trials, power measured by the Velotron was 3.7+/-1.9% (CI=2.9-4.8%) greater than that measured by the SRM. In conclusion, the accuracy of the Velotron cycle ergometer and the SRM power meter appears to be dependent on the type of test being performed. Furthermore, as each power monitoring system measures power at various positions (i.e. bottom bracket vs. rear wheel), caution should be taken when comparing power across the two systems, particularly when power is variable.

**Abbiss, Quod et al. 2006 – Dynamic pacing strategies**

Abbiss, Chris R.; Quod, Marc J.; Martin, David T.; Netto, Kevin J.; Nosaka, Kazunori; Lee, Hamilton et al. (2006):

## Dynamic pacing strategies during the cycle phase of an Ironman triathlon.

In: *Med Sci Sports Exerc* 38 (4), S. 726–734. DOI: 10.1249/01.mss.0000210202.33070.55.

*Abstract:*

INTRODUCTION

A nonlinear dynamic systems model has previously been proposed to explain pacing strategies employed during exercise.

PURPOSE

This study was conducted to examine the pacing strategies used under varying conditions during the cycle phase of an Ironman triathlon.

METHODS

The bicycles of six well-trained male triathletes were equipped with SRM power meters set to record power output, cadence, speed, and heart rate. The flat, three-lap, out-and-back cycle course, coupled with relatively consistent wind conditions (17-30 km x h(-1)), enabled comparisons to be made between three consecutive 60-km laps and relative wind direction (headwind vs tailwind).

RESULTS

Participants finished the cycle phase (180 km) with consistently fast performance times (5 h, 11 +/- 2 min; top 10% of all finishers). Average power output (239 +/- 25 to 203 +/- 20 W), cadence (89 +/- 6 to 82 +/- 8 rpm), and speed (36.5 +/- 0.8 to 33.1 +/- 0.8 km x h(-1)) all significantly decreased with increasing number of laps (P < 0.05). These variables, however, were not significantly different between headwind and tailwind sections. The deviation (SD) in power output and cadence did not change with increasing number of laps; however, the deviations in torque (6.8 +/- 1.6 and 5.8 +/- 1.3 N x m) and speed (2.1 +/- 0.5 and 1.6 +/- 0.3 km x h(-1)) were significantly greater under headwind compared with tailwind conditions, respectively. The

median power frequency tended to be lower in headwind (0.0480 +/- 0.0083) compared with tailwind (0.0531 +/- 0.0101) sections.

CONCLUSION

These data show evidence that a nonlinear dynamic pacing strategy is used by well-trained triathletes throughout various segments and conditions of the Ironman cycle phase. Moreover, an increased variation in torque and speed was found in the headwind versus the tailwind condition.

**Abel, Burkett et al. 2010 – The exercise profile**

Abel, T.; Burkett, B.; Schneider, S.; Lindschulten, R.; Strüder, H. K. (2010):

## The exercise profile of an ultra-long handcycling race: the Styrkeprøven experience.

In: *Spinal Cord* 48 (12), S. 894–898. DOI: 10.1038/sc.2010.40.

*Abstract:*

BACKGROUND

The high mechanical efficiency of the geared handcycle makes it suitable for elite athletes to train and even compete in races with able-bodied (recreational) cyclists. However, the actual exercise profile for endurance events has not been quantified.

OBJECTIVE

To guide future training regimes in a safe and effective process, the aim of this research was to quantify the workload, speed, cadence and heart rate parameters during 6000 km of training and within a 540 km ultra-long races.

METHODS

One spinal cord injured participant (lesion level Th4, ASIA B) handcycle (modified Shark S Sopur--Sunrisemedical, Malsch, Germany) was equipped with Schoberer Bike Measurement System (SRM) crank. For the laboratory test, a Cyclus II Ergometer was used. The energy intake and quality was determined during the time of race (540 km).

RESULTS

Workload at a defined metabolic situation was augmented through training by 63.8% from 90.0 to 147.6 W. The athlete finished the 540 km race with an average speed of 21.6 km $h^{-1}$ and a total race time of 38:52 h.

CONCLUSIONS

Ultra-long-term races in a handcycle can be suited by well-trained persons with a spinal cord injury. The quality of the training preparation time (for example, intensity and volume) is of immense importance to reach an adequate physiological capacity and to avoid serious injuries or medical problems.

**Antonutto, Capelli et al. 1999 – Effects of microgravity on maximal**

Antonutto, G.; Capelli, C.; Girardis, M.; Zamparo, P.; Di Prampero, P. E. (1999):

## Effects of microgravity on maximal power of lower limbs during very short efforts in humans.

In: *J Appl Physiol* 86 (1), S. 85–92.

*Abstract:*

The maximal power of the lower limbs was determined in four astronauts (age 37-53 yr) 1) during maximal pushes of approximately 250 ms on force platforms ["maximal explosive power" (MEP)] or 2) during all-out bouts of 6-7 s on an isokinetic cycloergometer [pedal frequency 1 Hz: maximal cycling power (MCP)]. The measurements were done before and immediately after spaceflights of 31-180 days. Before flight, peak and mean values were 3.18 +/- 0.38 and 1.5 +/- 0. 13 (SD) kW for MEP and 1.17 +/- 0.12 and 0.68 +/- 0.08 kW for MCP, respectively. After reentry, MEP was reduced to 67% after 31 days and to 45% after 180 days. MCP decreased less, attaining approximately 75% of preflight level, regardless of the flight duration. The recovery of MCP was essentially complete 2 wk after reentry, whereas that of MEP was slower, a complete recovery occurring after an estimated time close to that spent in flight. In the same subjects, the muscle mass of the lower limbs, as assessed by NMR, decreased by 9-13%, irrespective of flight duration (J. Zange, K. Muller, M. Schuber, H. Wackerhage, U. Hoffmann, R. W. G unther, G. Adam, J. M. Neuerburg, V. E. Sinitsyn, A. O. Bacharev, and O. I. Belichenko. Int. J. Sports Med. 18, Suppl. 4: S308-S309, 1997). The larger fall in maximal power, compared with that in muscle mass, suggests that a fraction of the former (especially relevant for MEP) is due to the effects of weightlessness on the motor unit recruitment pattern.

**Arkesteijn, Hopker et al. 2013 – The Effect of Turbo Trainer**

Arkesteijn, M.; Hopker, J.; Jobson, S.; Passfield, L. (2013):

## The Effect of Turbo Trainer Cycling on Pedalling Technique and Cycling Efficiency.

In: *Int J Sports Med* 34 (06), S. 520–525. DOI: 10.1055/s-0032-1327658.

*Abstract:*

Cycling can be performed on the road or indoors on stationary ergometers. The purpose of this study was to investigate differences in cycling efficiency, muscle activity and pedal forces during cycling on a stationary turbo trainer compared with a treadmill. 19 male cyclists cycled on a stationary turbo trainer and on a treadmill at 150, 200 and 250 W. Cycling efficiency was determined using the Douglas bags, muscle activity patterns were determined using surface electromyography and pedal forces were recorded with instrumented pedals. Treadmill cycling induced a larger muscular contribution from Gastrocnemius Lateralis, Biceps Femoris and Gluteus Maximus of respectively 14%, 19% and 10% compared with turbo trainer cycling ($p<0.05$). Conversely, Turbo trainer cycling induced larger muscular contribution from Vastus Lateralis, Rectus Femoris and Tibialis Anterior of respectively 7%, 17% and 14% compared with treadmill cycling ($p<0.05$). The alterations in muscle activity resulted in a better distribution of power during the pedal revolution, as determined by an increased Dead Centre size ($p<0.05$). Despite the alterations in muscle activity and pedalling technique, no difference in efficiency between treadmill (18.8±0.7%) and turbo trainer (18.5±0.6%) cycling was observed. These results suggest that cycling technique and type of ergometer can be altered without affecting cycling efficiency.

**Ashenden, Gore et al. 1999 – Skin-prick blood samples are reliable**

Ashenden, M. J.; Gore, C. J.; Burge, C. M.; Clough, M. L.; Bourdon, P. C.; Dobson, G. P.; Hahn, A. G. (1999):

## Skin-prick blood samples are reliable for estimating Hb mass with the CO-dilution technique.

In: *Eur J Appl Physiol Occup Physiol* 79 (6), S. 535–537.

*Abstract:*

Investigation of the impact of environmental stimuli such as altitude exposure on hemoglobin mass currently rely on invasive techniques that require venous blood sampling. This study assessed the feasibility of lancet skin pricks as an alternative to venepuncture to estimate hemoglobin mass with the carbon monoxide (CO) dilution technique, with the intent of making the technique accessible to technicians without phlebotomy training. Sixteen healthy volunteers rebreathed CO via a small-volume rebreathing apparatus. Blood was sampled simultaneously with a glass syringe (VEN) from a superficial forearm vein and with a capillary tube from either a lanced fingertip or earlobe (CAP). As a control, VEN blood was then aliquoted into capillary tubes (CONTROL-CAP). Samples were assayed for carboxy-hemoglobin (HbCO) using a diode-array spectrophotometer. Mean %HbCO was higher in CAP than VEN (bias 0.3+/-0.2%HbCO, $p < 0.01$), but VEN and CONTROL-CAP were not different ($p = 0.55$). Compared to VEN, Hb mass derived from CAP samples was overestimated by 1.7% (15+/-22 g Hb, $p = 0.01$). CAP samples to estimate Hb mass demonstrated a technical error of measurement of 2.7%, which is comparable to the 1.9% reported previously with VEN samples. We conclude that using CAP samples gives a reliable measure of %HbCO, and will make the estimation of Hb mass with the CO-technique accessible to technicians without phlebotomy training.

**Ashenden, Gore et al. 2000 – Simulated moderate altitude elevates serum**

Ashenden, M. J.; Gore, C. J.; Dobson, G. P.; Boston, T. T.; Parisotto, R.; Emslie, K. R. et al. (2000):

## Simulated moderate altitude elevates serum erythropoietin but does not increase reticulocyte production in well-trained runners.

In: *Eur. J. Appl. Physiol.* 81 (5), S. 428–435. DOI: 10.1007/s004210050064.

*Abstract:*

The purpose of this study was to investigate whether the modest increases in serum erythropoietin (sEpo) experienced after brief sojourns at simulated altitude are sufficient to stimulate reticulocyte production. Six well-trained middle-distance runners (HIGH, mean maximum oxygen uptake, VO2max = 70.2 ml x kg(-1) x min(-1) spent 8-11 h per night for 5 nights in a nitrogen house that simulated an altitude of 2650 m. Five squad members (CONTROL, mean VO2max= 68.9 ml x kg(-1) x min(-1) undertook the same training, which was conducted under near-sea-level conditions (600 m altitude), and slept in dormitory-style accommodation also at 600 m altitude. For both groups, this 5-night protocol was undertaken on three occasions, with a 3-night interim between successive exposures. Venous blood samples were measured for sEpo after 1 and 5 nights of hypoxia on each occasion. The percentage of reticulocytes was measured, along with a range of reticulocyte parameters that are sensitive to changes in erythropoiesis. Mean serum erythropoietin levels increased significantly ($P < 0.01$) above baseline values [mean (SD) 7.9 (2.4) mU x ml(-1)] in the HIGH group after the 1st night [11.8 (1.9) mU x ml(-1), 57%], and were also higher on the 5th night [10.7 (2.2) mU x ml(-1), 42%] compared with the CONTROL group, whose erythropoietin levels did not change. After athletes spent 3 nights at near sea level, the change in sEpo during subsequent hypoxic exposures was markedly attenuated (13% and -4% change during the second exposure; 26% and 14% change during the third exposure; 1st and 5th nights of each block, respectively). The increase in sEpo was insufficient to stimulate reticulocyte production at any time point. We conclude that when daily training loads are controlled, the modest increases in sEpo known to occur following brief exposure to a simulated altitude of 2650 m are insufficient to stimulate reticulocyte production.

**Ashenden, Gore et al. 1999 – Live high, train low does**

Ashenden, M. J.; Gore, C. J.; Dobson, G. P.; Hahn, A. G. (1999):

## "Live high, train low" does not change the total haemoglobin mass of male endurance athletes sleeping at a simulated altitude of 3000 m for 23 nights.

In: *Eur J Appl Physiol Occup Physiol* 80 (5), S. 479–484.

*Abstract:*

The purpose of this study was to document the effect of 23 days of "live high, train low" on the haemoglobin mass of endurance athletes. Thirteen male subjects from either cycling, triathlon or cross-country skiing backgrounds participated in the study. Six subjects (HIGH) spent 8-10 h per night in a "nitrogen house" at a simulated altitude of 3000 m in normobaric hypoxia, whilst control subjects slept at near sea level (CONTROL, n = 7). Athletes logged their daily training sessions, which were conducted at 600 m. Total haemoglobin mass (as measured using the CO-rebreathing technique) did not change when measured before (D1 or D2) and after (D28) 23 nights of hypoxic exposure [HIGH 990 (127) vs 972 (97) g and CONTROL 1042 (133) vs 1033 (138) g, before and after simulated altitude exposure, respectively]. Nor was there any difference in the substantial array of reticulocyte parameters measured using automated flow cytometry prior to commencing the study (D1), after 6 (D10) and 15 (D19) nights of simulated altitude, or 1 day after leaving the nitrogen house (D28)

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when HIGH and CONTROL groups were compared. We conclude that red blood cell production is not stimulated in male endurance athletes who spend 23 nights at a simulated altitude of 3000 m.

**Ashenden, Gore et al. 1999 – Effects of a 12-day live**

Ashenden, M. J.; Gore, C. J.; Martin, D. T.; Dobson, G. P.; Hahn, A. G. (1999):

## Effects of a 12-day "live high, train low" camp on reticulocyte production and haemoglobin mass in elite female road cyclists.

In: *Eur J Appl Physiol Occup Physiol* 80 (5), S. 472–478.

*Abstract:*

The aim of this study was to document the effect of "living high, training low" on the red blood cell production of elite female cyclists. Six members of the Australian National Women's road cycling squad slept for 12 nights at a simulated altitude of 2650 m in normobaric hypoxia (HIGH), while 6 team-mates slept at an altitude of 600 m (CONTROL). HIGH and CONTROL subjects trained and raced as a group throughout the 70-day study. Baseline levels of reticulocyte parameters sensitive to changes in erythropoeisis were measured 21 days and 1 day prior to sleeping in hypoxia (D1 and D20, respectively). These measures were repeated after 7 nights (D27) and 12 nights (D34) of simulated altitude exposure, and again 15 days (D48) and 33 days (D67) after leaving the altitude house. There was no increase in reticulocyte production, nor any change in reticulocyte parameters in either the HIGH or CONTROL groups. This lack of haematological response was substantiated by total haemoglobin mass measures (CO-rebreathing), which did not change when measured on D1, D20, D34 or D67. We conclude that in elite female road cyclists, 12 nights of exposure to normobaric hypoxia (2650 m) is not sufficient to either stimulate reticulocyte production or increase haemoglobin mass.

**Ashenden, Hahn et al. 2001 – A comparison of the physiological**

Ashenden, M. J.; Hahn, A. G.; Martin, D. T.; Logan, P.; Parisotto, R.; Gore, C. J. (2001):

## A comparison of the physiological response to simulated altitude exposure and r-HuEpo administration.

In: *J Sports Sci* 19 (11), S. 831–837. DOI: 10.1080/026404101753113778.

*Abstract:*

Concerns have been raised about the morality of using simulated altitude facilities in an attempt to improve athletic performance. One assumption that has been influential in this debate is the belief that altitude houses simply mimic the physiological effects of illegal recombinant human erythropoietin (r-HuEpo) doping. To test the validity of this assumption, the haematological and physiological responses of 23 well-trained athletes exposed to a simulated altitude of 2650-3000 m for 11-23 nights were contrasted with those of healthy volunteers receiving a low dose (150 IU x kg(-1) per week) of r-HuEpo for 25 days. Serial blood samples were analysed for serum erythropoietin and percent reticulocytes; maximal oxygen uptake (VO2max) was assessed before and after r-HuEpo administration or simulated altitude exposure. The group mean increase in serum erythropoietin (422% for r-HuEpo vs 59% for simulated altitude), percent reticulocytes (89% vs 30%) and VO2max (6.6% vs -2.0%) indicated that simulated altitude did not induce the changes obtained with r-HuEpo administration. Based on the disparity of these responses, we conclude that simulated altitude facilities should not be considered unethical based solely on the tenet that they provide an alternative means of obtaining the benefits sought by illegal r-HuEpo doping.

**Ashenden, Gore et al. 2003 – Effect of altitude on second-generation**

Ashenden, Michael J.; Gore, Christopher J.; Parisotto, Robin; Sharpe, Ken; Hopkins, Will G.; Hahn, Allan G. (2003):

## Effect of altitude on second-generation blood tests to detect erythropoietin abuse by athletes.

In: *Haematologica* 88 (9), S. 1053–1062.

*Abstract:*

BACKGROUND AND OBJECTIVES

ON- and OFF-model scores derived from blood parameters sensitive to erythropoiesis have been shown to be a useful tool to identify athletes who are currently injecting erythropoietin to enhance performance or those who have recently stopped doing so. We investigated changes in blood parameters and model scores during and after exposure to terrestrial and simulated altitudes.

DESIGN AND METHODS

We retrospectively evaluated changes in hematologic data collected from 19 elite cyclists who lived and trained 2690 m above sea level for 26-31 days, from six elite Kenyan runners who lived 2100 m above sea level but descended to compete at sea level competitions, and from 39 well-trained subjects who resided at sea level but slept at a simulated altitude of 2650-3000 m for 20-23 days of either consecutive or intermittent nightly exposure.

RESULTS

Upon ascent to a terrestrial altitude, ON- and OFF-model scores increased immediately, mainly because of an increase in hemoglobin concentration. Scores had not returned fully to baseline three weeks after return to sea level, because of the persistence of the raised hemoglobin concentration for the ON and OFF scores and a fall in reticulocyte percentage for OFF scores. Effects were smaller or negligible for simulated altitude. For Kenyan runners, ON- and OFF-model scores decreased within seven days of descent to sea level.

INTERPRETATION AND CONCLUSIONS

Our results reinforce the notion that caution should be exercised when interpreting blood results from athletes who have recently been exposed to either terrestrial or simulated altitude, and appropriate allowance should be made for the effect of altitude on blood model scores.

**Aughey, Clark et al. 2006 – Interspersed normoxia during live high**

Aughey, R. J.; Clark, S. A.; Gore, C. J.; Townsend, N. E.; Hahn, A. G.; Kinsman, T. A. et al. (2006):

## Interspersed normoxia during live high, train low interventions reverses an early reduction in muscle Na+, K +ATPase activity in well-trained athletes.

In: *Eur. J. Appl. Physiol.* 98 (3), S. 299–309. DOI: 10.1007/s00421-006-0280-z.

*Abstract:*

Hypoxia and exercise each modulate muscle Na(+), K(+)ATPase activity. We investigated the effects on muscle Na(+), K(+)ATPase activity of only 5 nights of live high, train low hypoxia (LHTL), 20 nights consecutive (LHTLc) versus intermittent LHTL (LHTLi), and acute sprint exercise. Thirty-three athletes were assigned to control (CON, n = 11), 20-nights LHTLc (n = 12) or 20-nights LHTLi (4 x 5-nights LHTL interspersed with 2-nights CON, n = 10) groups. LHTLc and LHTLi slept at a simulated altitude of 2,650 m (F(I)O(2) 0.1627) and lived and trained by day under normoxic conditions; CON lived, trained, and slept in normoxia. A quadriceps muscle biopsy was taken at rest and immediately after standardised sprint exercise, before (Pre) and after 5-nights (d5) and 20-nights (Post) LHTL interventions and analysed for Na(+), K(+)ATPase maximal activity (3-O-MFPase) and content ([(3)H]-ouabain binding). After only 5-nights LHTLc, muscle 3-O-MFPase activity declined by 2% (P < 0.05). In LHTLc, 3-O-MFPase activity remained below Pre after 20 nights. In contrast, in LHTLi, this small initial decrease was reversed after 20 nights, with restoration of 3-O-MFPase activity to Pre-intervention levels. Plasma [K(+)] was unaltered by any LHTL. After acute sprint exercise 3-O-MFPase activity was reduced (12.9 +/- 4.0%, P < 0.05), but [(3)H]-ouabain binding was unchanged. In conclusion, maximal Na(+), K(+)ATPase activity declined after only 5-nights LHTL, but the inclusion of additional interspersed normoxic nights reversed this effect, despite athletes receiving the same amount of hypoxic exposure. There were no effects of consecutive or intermittent nightly LHTL on the acute decrease in Na(+), K(+)ATPase activity with sprint exercise effects or on plasma [K(+)] during exercise.

**Aughey, Gore et al. 2005 – Chronic intermittent hypoxia and incremental**

Aughey, R. J.; Gore, C. J.; Hahn, A. G.; Garnham, A. P.; Clark, S. A.; Petersen, A. C. et al. (2005):

## Chronic intermittent hypoxia and incremental cycling exercise independently depress muscle in vitro maximal Na+-K+-ATPase activity in well-trained athletes.

In: *J. Appl. Physiol.* 98 (1), S. 186–192. DOI: 10.1152/japplphysiol.01335.2003.

*Abstract:*

Athletes commonly attempt to enhance performance by training in normoxia but sleeping in hypoxia [live high and train low (LHTL)]. However, chronic hypoxia reduces muscle Na(+)-K(+)-ATPase content, whereas fatiguing contractions reduce Na(+)-K(+)-ATPase activity, which each may impair performance. We examined whether LHTL and intense exercise would decrease muscle Na(+)-K(+)-ATPase activity and whether these effects would be additive and sufficient to impair performance or plasma K(+) regulation. Thirteen subjects were randomly assigned to two fitness-matched groups, LHTL (n = 6) or control (Con, n = 7). LHTL slept at simulated moderate altitude (3,000 m, inspired O(2) fraction = 15.48%) for 23 nights and lived and trained by day under normoxic conditions in Canberra (altitude approximately 600 m). Con lived, trained, and slept in normoxia. A standardized incremental exercise test was conducted before and after LHTL. A vastus lateralis muscle biopsy was taken at rest and after exercise, before and after LHTL or Con, and analyzed for maximal Na(+)-K(+)-ATPase activity [K(+)-stimulated 3-O-methylfluorescein phosphatase (3-O-MFPase)] and Na(+)-K(+)-ATPase content ([(3)H]ouabain binding sites). 3-O-MFPase activity was decreased by -2.9 +/- 2.6% in LHTL (P < 0.05) and was depressed immediately after exercise (P < 0.05) similarly in Con and LHTL (-13.0 +/- 3.2 and -11.8 +/- 1.5%, respectively). Plasma K(+) concentration during exercise was unchanged by LHTL; [(3)H]ouabain binding was unchanged with LHTL or exercise. Peak oxygen consumption was reduced in LHTL (P < 0.05) but not in Con, whereas exercise work was unchanged in either group. Thus LHTL had a minor effect on, and incremental exercise reduced, Na(+)-K(+)-ATPase activity. However, the small LHTL-induced depression of 3-O-MFPase activity was insufficient to adversely affect either K(+) regulation or total work performed.

**Austin, Nilwik et al. 2010 – In vivo operational fascicle lengths**

Austin, Neal; Nilwik, Rachel; Herzog, Walter (2010):

## In vivo operational fascicle lengths of vastus lateralis during sub-maximal and maximal cycling.

In: *J Biomech* 43 (12), S. 2394–2399. DOI: 10.1016/j.jbiomech.2010.04.016.

*Abstract:*

Instantaneous contractile characteristics of skeletal muscle, during movement tasks, can be determined and related to steady state mechanical properties such as the force-length relationship with the use of ultrasound imaging. A previous investigation into the contractile characteristics of the vastus lateralis (VL) during cycling has shown that fascicles operate on the "weak" descending limb of the force-length relationship, thus not taking advantage of the "strong" plateau region. The purpose of this study was to investigate if VL fascicle lengths change from sub-maximal to maximal cycling conditions, and if maximal cycling results in VL fascicle lengths which operate across the plateau of the force-length relationship. Fifteen healthy male subjects (age 20.9+/-1.8yr, wt. 67.0+/-6.3kg, ht. 176.7+/-7.2cm) were tested to establish the maximal force-length relationship for the VL through ten maximal isometric contractions at various knee angles. Subjects then cycled on an SRM

cycle ergometer at cadences of 50 and 80 revolutions per minute at 100W, 250W, and maximal effort. Fascicle lengths were determined at crank angles of 0, 90, and 180 degrees . Fascicles operated at or near the plateau of the maximal force-length relationship for maximal cycling, while operating on the descending limb during sub-maximal conditions for both cadences. However, when comparing the fascicle operating range for the sub-maximal cycling conditions to the corresponding sub-maximal force-length relationships, the VL now also operated across the plateau region. We concluded from these results that regardless of cycling effort, the VL operated through the ideal plateau region of the corresponding force-length relationship, hence always working optimally. We hypothesize that this phenomenon is due to the coupling of series elastic compliance and length dependent calcium sensitivity in the VL.

**Balmer, Davison et al. 2000 – Peak power predicts performance power**

Balmer, J.; Davison, R. C.; Bird, S. R. (2000):

## Peak power predicts performance power during an outdoor 16.1-km cycling time trial.

In: *Med Sci Sports Exerc* 32 (8), S. 1485–1490.

*Abstract:*

PURPOSE

To assess i) the reproducibility of peak power output recorded during a maximal aerobic power test (MAP), and ii) its validity to predict endurance performance during a field based 16.1-km time trial (16.1-km TT).

METHODS

Two studies were completed: for part I, nine subjects performed three MAP tests; for part II, 16 subjects completed a MAP test and 16.1-km TT. Power output was recorded using an SRM power meter and was calculated as peak power output (PPO) recorded during 60 s of MAP and mean power output for the 16.1-km TT (16.1-km TT(PO)).

RESULTS

There was no difference between PPO recorded during the three MAP trials, mean coefficient of variation for individual cyclists was 1.32% (95%CI = 0.97-2.03), and test-retest reliability expressed as an intraclass correlation coefficient was 0.99 (95%CI = 0.96-1.00). A highly significant relationship was found between PPO and 16.1-km TT(PO) ($r = 0.99$, $P < 0.001$) but not for PPO and 16.1-km TT time ($r = 0.46$. $P > 0.05$).

CONCLUSION

The results show that PPO affords a valid and reliable measure of endurance performance which can be used to predict average power during a 16.1-km TT but not performance time.

**Balmer, Davison et al. 2000 – Reliability of an air-braked ergometer**

Balmer, J.; Davison, R. C.; Bird, S. R. (2000):

## Reliability of an air-braked ergometer to record peak power during a maximal cycling test.

In: *Med Sci Sports Exerc* 32 (10), S. 1790–1793.

*Abstract:*

PURPOSE

To assess the reliability of the Kingcycle ergometer, this study compared peak power recorded using a Kingcycle and SRMTM power meters during Kingcycle maximal aerobic power tests.

METHODS

The study was completed in two parts: for part 1, nine subjects completed three maximal tests with a stabilizing kit attached to the Kingcycle rig and calibration of the Kingcycle checked against SRM (MAP(C)); and for part 2, nine subjects completed two maximal tests without the stabilizing kit and the Kingcycle calibrated using the standard procedure (MAP(S)). Each MAP(C) test was separated by 1 wk; however, MAPs tests were separated by 54 +/- 32 d, (mean +/- SD). Testing procedure was repeated for each MAP and peak power output was calculated as the highest average power output recorded during any 60-s period of the MAP test using the Kingcycle (King(PPO)) and SRM (SRM(PPO)).

RESULTS

Coefficient of variations (CVs) for King(PPO) were larger than those of SRM(PPO); 2.0% (95%CI = 1.5-3.0) versus 1.3% (95%CI = 1.0-2.0) and 4.6% (95%CI = 2.7-7.6) versus 3.6% (95%CI = 2.1-6.0) for MAPC( and MAP(S), respectively. During all tests, King(PPO) was higher than SRM(PPO) by an average of approximately 10% (P < 0.001).

CONCLUSIONS

Investigators should be aware of the discrepancy between the two systems when assessing peak power and that SRM cranks provide a more reproducible measure of peak power than the Kingcycle ergometer.

**Balmer, Davison et al. 2000 – The validity of power output**

Balmer, J.; Davison, R. C.; Coleman, D. A.; Bird, S. R. (2000):

## The validity of power output recorded during exercise performance tests using a Kingcycle air-braked cycle ergometer when compared with an SRM powermeter.

In: *Int J Sports Med* 21 (3), S. 195–199. DOI: 10.1055/s-2000-9466.

*Abstract:*

This study assessed the validity of power output recorded using an air-braked cycle ergometer (Kingcycle) when compared with a power measuring crankset (SRM). For part one of the study thirteen physically active subjects completed a continuous incremental exercise test (OBLA), for part two of the study twelve trained cyclists completed two tests; a maximal aerobic power test (MAP) and a 16.1 km time-trial (16.1 km TT). The following were compared; the peak power output (PPO) recorded for 1 min during MAP, the average power output for the duration of the time-trial and power output recorded during each stage of OBLA. For all tests, power output recorded using Kingcycle was significantly higher than SRM (P < 0.001). Ratio limits of agreement between SRM and Kingcycle for OBLA showed a bias (P < 0.00) of 0.90 (95%CI = 0.90-0.91) with a random error of X or / 1.07, and for PPO and 16.1 km TT ratio limits of agreement were 0.90 (95%CI = 0.88-0.92) X or / 1.07 and 0.92 (95% CI = 0.90-0.94) X or / 1.07, respectively. These data revealed that the Kingcycle ergometry system did not provide a valid measure of power output when compared with SRM.

**Balmer, Bird et al. 2004 – Mechanically braked Wingate powers**

Balmer, James; Bird, Steve; Davison, R. C. Richard; Doherty, Mike; Smith, Paul (2004):

## Mechanically braked Wingate powers: agreement between SRM, corrected and conventional methods of measurement.

In: *J Sports Sci* 22 (7), S. 661–667. DOI: 10.1080/02640410310001655831.

*Abstract:*

In this study, we assessed the agreement between the powers recorded during a 30 s upper-body Wingate test using three different methods. Fifty-six men completed a single test on a Monark 814E mechanically braked ergometer fitted with a Schoberer Rad Messtechnik (SRM) powermeter. A commercial software package (Wingate test kit version 2.21, Cranlea, UK) was used to calculate conventional and corrected (with accelerative

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forces) values of power based on a resistive load (5% body mass) and flywheel velocity. The SRM calculated powers based on torque (measured at the crank arm) and crank rate. Values for peak 1 and 5 s power and mean 30 s power were measured. No significant differences ($P > 0.05$) were found between the three methods for 30 s power values. However, the corrected values for peak 1 and 5 s power were 36 and 23% higher ($P < 0.05$) respectively than those for the conventional method, and 27 and 16% higher ($P < 0.05$) respectively than those for the SRM method. The conventional and SRM values for peak 1 and 5 s power were similar ($P > 0.05$). Power values recorded using each method were influenced by sample time ($P < 0.05$). Our results suggest that these three measures of power are similar when sampled over 30 s, but discrepancies occur when the sample time is reduced to either 1 or 5 s.

**Balmer, Bird et al. 2008 – Effect of age on 16.1-km**

Balmer, James; Bird, Steve; Davison, Richard; Lucia, Alejandro (2008):

## Effect of age on 16.1-km time-trial performance.

In: *J Sports Sci* 26 (2), S. 197–206. DOI: 10.1080/02640410701446901.

*Abstract:*

In this study, we assessed the performance of trained senior (n = 6) and veteran (n = 6) cyclists (mean age 28 years, s = 3 and 57 years, s = 4 respectively). Each competitor completed two cycling tests, a ramped peak aerobic test and an indoor 16.1-km time-trial. The tests were performed using a Kingcycle ergometer with the cyclists riding their own bicycle fitted with an SRM powermeter. Power output, heart rate, and gas exchange variables were recorded continuously and blood lactate concentration [HLa] was assessed 3 min after the peak ramped test and at 2.5-min intervals during the time-trial. Peak values for power output (RMP(max)), heart rate (HR(peak)), oxygen uptake (VO2(peak)), and ventilation (V(Epeak)) attained during the ramped test were higher in the senior group ($P < 0.05$), whereas [HLa](peak), RER(peak), V(E): VO2(peak), and economy(peak) were similar between groups ($P > 0.05$). Time-trial values (mean for duration of race) for power output (W(TT)), heart rate (HR(TT)), VO2 (VO(2TT)), and V(E) (V(ETT)) were higher in the seniors ($P < 0.05$), but [HLa](TT), RER(TT), V(ETT): VO2(TT), and economy(TT) were similar between the groups ($P > 0.05$). Time-trial exercise intensity, expressed as %RMP(max), %HR(peak), % VO2(peak), and % V(Epeak), was similar ($P > 0.05$) for seniors and veterans (W(TT): 81%, s = 2 vs. 78%, s = 8; HR(TT): 96%, s = 4 vs. 94%, s = 4; VO2(TT): 92%, s = 4 vs. 95%, s = 10; V(ETT): 89%, s = 8 vs. 85%, s = 8, respectively). Overall, seniors attained higher absolute values for power output, heart rate, VO2, and V(E) but not blood lactate concentration, respiratory exchange ratio (RER), V(E): VO2, and economy. Veterans did not accommodate age-related declines in time trial performance by maintaining higher relative exercise intensity.

**Barratt – SRM Torque Analysis of Standing**

Barratt, Paul:

## SRM Torque Analysis of Standing Starts in Track Cycling (P85). In: The Engineering of Sport 7

Volume 1, S. 443–448.

*Abstract:*

The SRM (Schoberer Rad Messtechnik, Welldorf, Germany) power monitoring system has been used extensively in applied field based studies to provide an accurate measurement of cycling power (Gardner et al. 2005). The SRM system consists of a PowerMeter (instrumented crank), a PowerControl (data logger and onboard data display), and a sensor cable (linking data transfer from crank to the onboard powercontrol). One limitation of the SRM system is an inability to attain power outputs until one entire crank revolution is achieved. A crucial element of track cycling time trial events is the standing start in which the athlete is generating maximum torque at low cadence. In this performance setting the cyclist accelerates the bicycle from rest and consequently initial power data is not recorded by the standard SRM system.

A modification to the SRM system is described which allows for collection of instantaneous crank torque. The modification consists of an electronic de-modulator developed by SRM and a multi-channel datalogger (DL16CAN, Tellert, Germany) connected in series between the PowerMeter and the PowerControl. The pulse width modulated signal from the PowerMeter is de-modulated into a cadence voltage signal and a torque frequency signal. The signals are synchronised and recorded separately on a time base. The modification allows crank torque to be acquired at 200Hz. This equipment has opened up a new avenue of analysis in a previously under-researched and ultimately performance impacting area of track cycling.

**Bassett, Kyle et al. 1999 – Comparing cycling world hour records**

Bassett, D. R.; Kyle, C. R.; Passfield, L.; Broker, J. P.; Burke, E. R. (1999):

## Comparing cycling world hour records, 1967-1996: modeling with empirical data.

In: *Med Sci Sports Exerc* 31 (11), S. 1665–1676.

*Abstract:*

PURPOSE

The world hour record in cycling has increased dramatically in recent years. The present study was designed to compare the performances of former/current record holders, after adjusting for differences in aerodynamic equipment and altitude. Additionally, we sought to determine the ideal elevation for future hour record attempts.

METHODS

The first step was constructing a mathematical model to predict power requirements of track cycling. The model was based on empirical data from wind-tunnel tests, the relationship of body size to frontal surface area, and field power measurements using a crank dynamometer (SRM). The model agreed reasonably well with actual measurements of power output on elite cyclists. Subsequently, the effects of altitude on maximal aerobic power were estimated from published research studies of elite athletes. This information was combined with the power requirement equation to predict what each cyclist's power output would have been at sea level. This allowed us to estimate the distance that each rider could have covered using state-of-the-art equipment at sea level. According to these calculations, when racing under equivalent conditions, Rominger would be first, Boardman second, Merckx third, and Indurain fourth. In addition, about 60% of the increase in hour record distances since Bracke's record (1967) have come from advances in technology and 40% from physiological improvements.

RESULTS AND CONCLUSIONS

To break the current world hour record, field measurements and the model indicate that a cyclist would have to deliver over 440 W for 1 h at sea level, or correspondingly less at altitude. The optimal elevation for future hour record attempts is predicted to be about 2500 m for acclimatized riders and 2000 m for unacclimatized riders.

**Bentley, McNaughton et al. 2001 – Peak power output**

Bentley, D. J.; McNaughton, L. R.; Thompson, D.; Vleck, V. E.; Batterham, A. M. (2001):

## Peak power output, the lactate threshold, and time trial performance in cyclists.

In: *Med Sci Sports Exerc* 33 (12), S. 2077–2081.

*Abstract:*

PURPOSE

To determine the relationship between maximum workload (W(peak)), the workload at the onset of blood lactate accumulation (W(OBLA)), the lactate threshold (W(LTlog)) and the D(max) lactate threshold, and the average power output obtained during a 90-min (W(90-min)) and a 20-min (W(20-min)) time trial (TT) in a group of well-trained cyclists.

METHODS

Nine male cyclists (.VO(2max) 62.7 +/- 0.8 mL.kg(-1).min(-1)) who were competing regularly in triathlon or cycle TT were recruited for the study. Each cyclist performed four tests on an SRM isokinetic cycle ergometer over a 2-wk period. The tests comprised 1) a continuous incremental ramp test for determination of maximal oxygen uptake (.VO(2max) (L.min(-1) and mL.kg(-1).min(-1)); 2) a continuous incremental lactate test to measure W(peak), W(OBLA), W(LTlog), and the D(max) lactate threshold; and 3) a 20-min TT and 4) a 90-min TT, both to determine the average power output (in watts).

RESULTS

The average power output during the 90-min TT (W(90-min)) was significantly (P < 0.01) correlated with W(peak) (r = 0.91), W(LTlog) (r = 0.91), and the D(max) lactate threshold (r = 0.77, P < 0.05). In contrast, W(20-min) was significantly (P < 0.05) related to .VO(2max) (L.min(-1)) (r = 0.69) and W(LTlog) (r = 0.67). The D(max) lactate threshold was not significantly correlated to W(20-min) (r = 0.45). Furthermore, W(OBLA) was not correlated to W(90-min) (r = 0.54) or W(20-min) (r = 0.23). In addition, .VO(2max) (mL.kg(-1).min(-1)) was not significantly related to W(90-min) (r = 0.11) or W(20-min) (r = 0.47).

CONCLUSION

The results of this study demonstrate that in subelite cyclists the relationship between maximum power output and the power output at the lactate threshold, obtained during an incremental exercise test, may change depending on the length of the TT that is completed.

### Bertucci, Crequy et al. 2012 – Validity and Reliability

Bertucci, W.; Crequy, S.; Chiementin, X. (2012):

## Validity and Reliability of the G-Cog BMX Powermeter.

In: *Int J Sports Med. DOI:* 10.1055/s-0031-1301319.

*Abstract:*

The aim of this study was to test the validity and reliability of the G-Cog which is a new BMX power meter allowing for the measurements of the power output (250 Hz) at the BMX rear wheel during actual cycling and laboratory conditions. Sprints in road cycling (6-8 s) from static start and incremental tests in the laboratory (100-400 W) have been performed to analyse the validity and reliability of the power output values by comparison with 2 devices: The PowerTap and the SRM which are considered as the gold standard. The most important finding of this study is that the G-Cog power output data were not valid and reliable during sprint and standardised laboratory tests compared with the SRM and the PowerTap devices. During the sprint and the laboratory tests the ratio limits of agreement of the power output differences between the SRM and G-Cog were 1.884×÷1.970 (95%CI=0.956-3.711) and 12.126×÷16.281 (95%CI=0.745-197.430), respectively. In conclusion, the G-Cog must be used with caution regarding the power output measurements. Nevertheless, the G-Cog could be used for the first time to analyse the determinants of the BMX performance from the pedalling profile.

### Bertucci, Duc et al. 2005 – Validity and reliability

Bertucci, W.; Duc, S.; Villerius, V.; Grappe, F. (2005):

## Validity and reliability of the Axiom PowerTrain cycle ergometer when compared with an SRM powermeter.

In: *Int J Sports Med* 26 (1), S. 59–65. DOI: 10.1055/s-2004-817855.

*Abstract:*

The purpose of this study was to determine the validity and the reliability of a stationary electromagnetically-braked cycle ergometer (Axiom PowerTrain) against the SRM power measuring crankset. Nineteen male competitive cyclists completed four tests on their bicycle equipped with a 20-strain gauges SRM crankset: a maximal aerobic power (MAP) test and three 10-min time trials (TTs) with three different simulated slopes (0, 3, and 6 %). The Axiom ergometer overestimated ($p < 0.05$) the SRM power output during the last stage of the MAP test and during TTs, by 5 % and 12 %, respectively. Power output (PO) of the Axiom ergometer drifted significantly ($p < 0.05$) with the time during TT. These findings indicate that the Axiom ergometer does not provide a valid measure of PO compared with SRM. However, the small coefficient of variation (2.2 %) during the MAP test indicates that the Axiom provides a reliable PO and that it can be used e.g. for relative PO comparisons with competitive cyclists during a race season.

**Bertucci, Duc et al. 2005 – Validity and reliability**

Bertucci, W.; Duc, S.; Villerius, V.; Pernin, J. N.; Grappe, F. (2005):

## Validity and reliability of the PowerTap mobile cycling powermeter when compared with the SRM Device.

In: *Int J Sports Med* 26 (10), S. 868–873. DOI: 10.1055/s-2005-837463.

*Abstract:*

The SRM power measuring crank system is nowadays a popular device for cycling power output (PO) measurements in the field and in laboratories. The PowerTap (CycleOps, Madison, USA) is a more recent and less well-known device that allows mobile PO measurements of cycling via the rear wheel hub. The aim of this study is to test the validity and reliability of the PowerTap by comparing it with the most accurate (i.e. the scientific model) of the SRM system. The validity of the PowerTap is tested during i) sub-maximal incremental intensities (ranging from 100 to 420 W) on a treadmill with different pedalling cadences (45 to 120 rpm) and cycling positions (standing and seated) on different grades, ii) a continuous sub-maximal intensity lasting 30 min, iii) a maximal intensity (8-s sprint), and iiii) real road cycling. The reliability is assessed by repeating ten times the sub-maximal incremental and continuous tests. The results show a good validity of the PowerTap during sub-maximal intensities between 100 and 450 W (mean PO difference -1.2 +/- 1.3 %) when it is compared to the scientific SRM model, but less validity for the maximal PO during sprint exercise, where the validity appears to depend on the gear ratio. The reliability of the PowerTap during the sub-maximal intensities is similar to the scientific SRM model (the coefficient of variation is respectively 0.9 to 2.9 % and 0.7 to 2.1 % for PowerTap and SRM). The PowerTap must be considered as a suitable device for PO measurements during sub-maximal real road cycling and in sub-maximal laboratory tests.

**Bertucci, Taiar et al. 2005 – Differences between sprint tests**

Bertucci, W.; Taiar, R.; Grappe, F. (2005):

## Differences between sprint tests under laboratory and actual cycling conditions.

In: *J Sports Med Phys Fitness* 45 (3), S. 277–283.

*Abstract:*

AIM

The aim of this study was to compare the maximal power output (POpeak) and force-velocity relationships in sprint cycling obtained from a laboratory protocol and from a field test during actual cycling locomotion.

METHODS

Seven male competitive cyclists performed 6 sprints (3 in the seated position and 3 in the standing position) on an ergo-trainer (Tacx, Netherlands) and 6 sprints during actual cycling locomotion in a gymnasium. The bicycle

was equipped with the SRM Training System (Schoberer Rad Messtechnik, Germany) to measure (200 Hz) the power output (PO, W), the pedalling cadence (rpm), and the velocity (kmxh-1). From these measurements, the maximal force on the pedal (Fmax), the theoretical maximal force (Fo, N) and the theoretical maximal pedalling cadence (V0, rpm) were determined. During each sprint test the lateral bicycle oscillations were measured from a video analysis.

RESULTS

During standing and seated sprints in the gymnasium, Fo and Fmax were significantly higher ($p<0.05$) compared with sprints on the ergo-trainer (+12% and +32%, respectively). The POpeak during sprints in seated and standing positions in the gymnasium was significantly ($p<0.05$) lower (-4%) and higher (+6%) respectively, compared with the ergo-trainer. For standing position in the gymnasium the kinematics analysis indicated a 24 degrees mean lateral bicycle oscillation compared with 0 degrees on the ergo trainer.

CONCLUSION

The results of this study indicate that POpeak, Fo, and time to obtain POpeak were different between laboratory and actual cycling conditions. To obtain a valid estimation of the maximal power output, it is necessary to perform sprint tests during actual cycling locomotion. Thus, in the laboratory, it is advisable to use a cycle ergometer that enables natural lateral oscillations.

**Bertucci, Grappe et al. 2005 – Effects on the crank torque**

Bertucci, William; Grappe, Frederic; Girard, Amaury; Betik, Andrew; Rouillon, Jean Denis (2005):

## Effects on the crank torque profile when changing pedalling cadence in level ground and uphill road cycling.

In: *J Biomech* 38 (5), S. 1003–1010. DOI: 10.1016/j.jbiomech.2004.05.037.

*Abstract:*

Despite the importance of uphill cycling performance during cycling competitions, there is very little research investigating uphill cycling, particularly concerning field studies. The lack of research is partly due to the difficulties in obtaining data in the field. The aim of this study was to analyse the crank torque in road cycling on level and uphill using different pedalling cadences in the seated position. Seven male cyclists performed four tests in the seated position (1) on level ground at 80 and 100 rpm, and (2) on uphill road cycling (9.25% grade) at 60 and 80 rpm.The cyclists exercised for 1 min at their maximal aerobic power. The bicycle was equipped with the SRM Training System (Schoberer, Germany) for the measurement of power output (W), torque (Nm), pedalling cadence (rpm), and cycling velocity (km h(-1)). The most important finding of this study indicated that at maximal aerobic power the crank torque profile (relationship between torque and crank angle) varied substantially according to the pedalling cadence and with a minor effect according to the terrain. At the same power output and pedalling cadence (80 rpm) the torque at a 45 degrees crank angle tended ($p < 0.06$) to be higher (+26%) during uphill cycling compared to level cycling. During uphill cycling at 60 rpm the peak torque was increased by 42% compared with level ground cycling at 100 rpm. When the pedalling cadence was modified, most of the variations in the crank torque profile were localised in the power output sector (45 degrees to 135 degrees).

**Bertucci, Grappe et al. 2007 – Laboratory versus outdoor cycling conditions**

Bertucci, William; Grappe, Frederic; Groslambert, Alain (2007):

## Laboratory versus outdoor cycling conditions: differences in pedaling biomechanics.

In: *J Appl Biomech* 23 (2), S. 87–92.

*Abstract:*

The aim of our study was to compare crank torque profile and perceived exertion between the Monark ergometer (818 E) and two outdoor cycling conditions: level ground and uphill road cycling. Seven male cyclists performed seven tests in seated position at different pedaling cadences: (a) in the laboratory at 60, 80, and 100 rpm; (b) on level terrain at 80 and 100 rpm; and (c) on uphill terrain (9.25% grade) at 60 and 80 rpm. The cyclists exercised for 1 min at their maximal aerobic power. The Monark ergometer and the bicycle were equipped with the SRM Training System (Schoberer, Germany) for the measurement of power output (W), torque (Nxm), pedaling cadence (rpm), and cycling velocity (kmxh-1). The most important findings of this study indicate that at maximal aerobic power the crank torque profiles in the Monark ergometer (818 E) were significantly different (especially on dead points of the crank cycle) and generate a higher perceived exertion compared with road cycling conditions.

**Billaut, Gore et al. 2012 – Enhancing team-sport athlete performance**

Billaut, François; Gore, Christopher J.; Aughey, Robert J. (2012):

## Enhancing team-sport athlete performance: is altitude training relevant?

In: *Sports Med* 42 (9), S. 751–767. DOI: 10.2165/11634050-000000000-00000.

*Abstract:*

Field-based team sport matches are composed of short, high-intensity efforts, interspersed with intervals of rest or submaximal exercise, repeated over a period of 60-120 minutes. Matches may also be played at moderate altitude where the lower oxygen partial pressure exerts a detrimental effect on performance. To enhance run-based performance, team-sport athletes use varied training strategies focusing on different aspects of team-sport physiology, including aerobic, sprint, repeated-sprint and resistance training. Interestingly, 'altitude' training (i.e. living and/or training in O(2)-reduced environments) has only been empirically employed by athletes and coaches to improve the basic characteristics of speed and endurance necessary to excel in team sports. Hypoxia, as an additional stimulus to training, is typically used by endurance athletes to enhance performance at sea level and to prepare for competition at altitude. Several approaches have evolved in the last few decades, which are known to enhance aerobic power and, thus, endurance performance. Altitude training can also promote an increased anaerobic fitness, and may enhance sprint capacity. Therefore, altitude training may confer potentially-beneficial adaptations to team-sport athletes, which have been overlooked in contemporary sport physiology research. Here, we review the current knowledge on the established benefits of altitude training on physiological systems relevant to team-sport performance, and conclude that current evidence supports implementation of altitude training modalities to enhance match physical performances at both sea level and altitude. We hope that this will guide the practice of many athletes and stimulate future research to better refine training programmes.

**Bouillod, Pinot et al. 2016 – Validity, Sensitivity**

Bouillod, Anthony; Pinot, Julien; Soto-Romero, Georges; Bertucci, William; Grappe, Frederic (2016):

## Validity, Sensitivity, Reproducibility and Robustness of the Powertap, Stages and Garmin Vector Power Meters in Comparison With the SRM Device.

In: *Int J Sports Physiol Perform*, S. 1–26. DOI: 10.1123/ijspp.2016-0436.

*Abstract:*

A large number of power meters were produced on the market for nearly 20 years and according to user requirements. PURPOSE: This study aimed to determine the validity, sensitivity, reproducibility and robustness of the Powertap (PWT), Stages (STG) and Garmin Vector (VCT) power meters in comparison with the SRM device. METHODS: A national-level male competitive cyclist was required to complete three laboratory cycling tests that included a sub-maximal incremental test, a sub-maximal 30-min continuous test and a sprint test. Two additional tests were performed: the first on vibration exposures in the laboratory and the second in the field. RESULTS: The VCT provided a significantly lower 5 s power output (PO) during the sprint test with a low gear ratio compared with the POSRM (-36.9%). The POSTG was significantly lower than the POSRM within the heavy exercise intensity zone (zone 2, -5.1%) and the low part of the severe intensity zone (zone 3, -4.9%). The POVCT was significantly lower than the POSRM only within zone 2 (-4.5%). The POSTG was significantly lower in standing position than in the seated position (-4.4%). The reproducibility of the PWT, STG and VCT was similar to that of the SRM system. The POSTG and POVCT were significantly decreased from a vibration frequency of 48 Hz and 52 Hz, respectively. CONCLUSIONS: The PWT, STG and the VCT systems appear to be reproducible, but the validity, sensitivity and robustness of the STG and VCT systems should be treated with some caution according to the conditions of measurement.

**Brickley, Dekerle et al. 2007 – Assessment of Maximal Aerobic Power**

Brickley, G.; Dekerle, J.; Hammond, A.; Pringle, J.; Carter, H. (2007):

## Assessment of Maximal Aerobic Power and Critical Power in a Single 90-s Isokinetic All-Out Cycling Test.

In: *Int J Sports Med* 28 (5), S. 414–419. DOI: 10.1055/s-2006-924513.

*Abstract:*

The purpose of this study was to establish the validity of a 90-s all-out test for the estimation of maximal oxygen uptake (V·O2max) and submaximal aerobic ability as represented by critical power. We hypothesized that the fall in power output by the end of the 90-s all-out test (end power) would represent the exhaustion of anaerobic work capability, and as such, would correspond with the critical power. Sixteen active individuals (mean ± SD: 30 ± 6 years; 69.6 ± 9.9 kg) carried out a series of tests: (i) an incremental ramp test to determine V·O2max, (ii) three fixed-work rate trials to exhaustion to determine critical power, and (iii) two 90-s all-out tests to measure end power and peak V·O2. End power (292 ± 65 W) was related to (r = 0.89) but was significantly higher (p < 0.01) than critical power (264 ± 50 W). The mean ± 95 % limits of agreement (29 ± 65 W) were too low to use these variables interchangeably. The peak V·O2 in the 90-s trial was significantly lower than the V·O2max (3435 ± 682 ml · min-1 vs. 3929 ± 784 ml · min-1; p < 0.01); mean ± 95 % limits of agreement was equal to 495 ± 440 mL · min-1. The 90-s all-out test cannot, therefore, assess both V·O2max and critical power in adult performers. The duration of all-out exercise required to allow V·O2 to attain its maximum is longer than 90 s.

**Broker, Kyle et al. 1999 – Racing cyclist power requirements**

Broker, J. P.; Kyle, C. R.; Burke, E. R. (1999):

## Racing cyclist power requirements in the 4000-m individual and team pursuits.

In: *Med Sci Sports Exerc* 31 (11), S. 1677–1685.

*Abstract:*

PURPOSE

The purpose of this paper is: 1) to present field test data describing the power requirements of internationally competitive individual and team pursuiters, and 2) to develop a theoretical model for pursuit power based upon on these tests.

METHODS

In preparing U.S. cycling's pursuit team for the 1996 Atlanta Olympics, U.S. team scientists measured cycling power of seven subjects on the Atlanta track using a crank dynamometer (SRM) at speeds from 57 to 60 kph. By using these field data and other tests, mathematical models were devised which predict both individual and team pursuit performance. The field data indicate the power within a pace line at 60 kph averages 607 W in lead position (100%), 430 W in second position (70.8%), 389 W in third position (64.1%), and 389 W in fourth position (64.0%). A team member requires about 75% of the energy necessary for cyclists riding alone at the

same speed. These results compare well with field measurements from a British pursuit team, to recent wind tunnel tests, and to earlier bicycle coast down tests.

RESULTS

The theoretical models predict performance with reasonable accuracy when the average power potential of an individual or team is known, or they may be used to estimate the power of pursuit competitors knowing race times. The model estimates that Christopher Boardman averaged about 520 W when setting his 1996, 4000-m individual pursuit record of 4 min 11.114 s and the Italian 4000-m pursuit team averaged about 480 W in setting their record of 4:00.958. Both used the "Superman" cycling position.

CONCLUSIONS

These records would be very difficult to break using less aerodynamic riding positions, due to the extraordinarily high power requirements.

**Brosnan, Martin et al. 2000 – Impaired interval exercise responses**

Brosnan, M. J.; Martin, D. T.; Hahn, A. G.; Gore, C. J.; Hawley, J. A. (2000):

## Impaired interval exercise responses in elite female cyclists at moderate simulated altitude.

In: *J. Appl. Physiol.* 89 (5), S. 1819–1824.

*Abstract:*

The effect of hypoxia on the response to interval exercise was determined in eight elite female cyclists during two interval sessions: a sustained 3 x 10-min endurance set (5-min recovery) and a repeat sprint session comprising three sets of 6 x 15-s sprints (work-to-relief ratios were 1:3, 1:2, and 1:1 for the 1st, 2nd, and 3rd sets, respectively, with 3 min between each set). During exercise, cyclists selected their maximum power output and breathed either atmospheric air (normoxia, 20.93% O(2)) or a hypoxic gas mix (hypoxia, 17.42% O(2)). Power output was lower in hypoxia vs. normoxia throughout the endurance set (244+/-18 vs. 226+/-17, 234+/-18 vs. 221+/-25, and 235+/-18 vs. 221+/-25 W for 1st, 2nd, and 3rd sets, respectively; P< 0.05) but was lower only in the latter stages of the second and third sets of the sprints (452+/-56 vs. 429+/-49 and 403+/-54 vs. 373+/- 43 W, respectively; P<0.05). Hypoxia lowered blood O(2) saturation during the endurance set (92.9+/-2.9 vs. 95.4+/-1.5%; P<0.05) but not during repeat sprints. We conclude that, when elite cyclists select their maximum exercise intensity, both sustained (10 min) and short-term (15 s) power are impaired during hypoxia, which simulated moderate ( approximately 2,100 m) altitude.

**Cangley, Passfield et al. 2011 – The Effect of Variable Gradients**

Cangley, P.; Passfield, L.; Carter, H.; Bailey, M. (2011):

## The Effect of Variable Gradients on Pacing in Cycling Time-Trials.

In: *Int J Sports Med* 32 (02), S. 132–136. DOI: 10.1055/s-0030-1268440.

*Abstract:*

It has been reported that performance in cycling time-trials is enhanced when power is varied in response to gradient although such a mechanical pacing strategy has never been confirmed experimentally in the field. The aim of this study was, therefore, to assess the efficacy of mechanical pacing by comparing a constant power strategy of 255 W with a variable power strategy that averaged to 255 W over an undulating time-trial course. 20 experienced cyclists completed 4 trials over a 4 km course with 2 trials at an average constant power of 253 W and 2 trials where power was varied in response to gradient and averaged 260 W. Time normalised to 255 W was 411±31.1 s for the constant power output trials and 399±29.5 s for the variable power output trials. The variable power output strategy therefore reduced completion time by 12±8 s (2.9%) which was significant (p<0.001). Participants experienced difficulty in applying a constant power strategy over an undulating course

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which acted to reduce their time gain. It is concluded that a variable power strategy can improve cycling performance in a field time-trial where the gradient is not constant.

**Carpes, Rossato et al. 2007 – Bilateral pedaling asymmetry**

Carpes, F. P.; Rossato, M.; Faria, I. E.; Bolli Mota, C. (2007):

## Bilateral pedaling asymmetry during a simulated 40-km cycling time-trial.

In: *J Sports Med Phys Fitness* 47 (1), S. 51–57.

*Abstract:*

AIM

This study investigated the pedaling asymmetry during a 40-km cycling time-trial (TT).

METHODS

Six sub-elite competitive male cyclists pedaled a SRM Training Systems cycle ergometer throughout a simulated 40-km TT. A SRM scientific crank dynamometer was used to measure the bilateral crank torque (N.m) and pedaling cadence (rpm). All data were analyzed into 4 stages with equal length obtained according to total time. Comparisons between each stage of the 40-km TT were made by an analysis of variance (ANOVA). Dominant (DO) and non-dominant (ND) crank peak torque asymmetry was determined by the equation: asymmetry index (AI%)=[(DO-ND)/DO] 100. Pearson correlation analysis was performed to verify the relationship between exercise intensity, mean and crank peak torque.

RESULTS

The crank peak torque was significantly ($P<0.05$) greater in the 4th stage compared with other stages. During the stages 2 and 3, was observed the AI% of 13.51% and 17.28%, respectively. Exercise intensity (%VO(2max)) was greater for stage 4 ($P<0.05$) and was highly correlated with mean and crank peak torque ($r=0.97$ and $r=0.92$, respectively) for each stage.

CONCLUSIONS

The DO limb was always responsible for the larger crank peak torque. It was concluded that pedaling asymmetry is present during a simulated 40-km TT and an increase on crank torque output and exercise intensity elicits a reduction in pedaling asymmetry.

**Clark, Bourdon et al. 2007 – The effect of acute simulated**

Clark, Sally A.; Bourdon, P. C.; Schmidt, W.; Singh, B.; Cable, G.; Onus, K. J. et al. (2007):

## The effect of acute simulated moderate altitude on power, performance and pacing strategies in well-trained cyclists.

In: *Eur. J. Appl. Physiol.* 102 (1), S. 45–55. DOI: 10.1007/s00421-007-0554-0.

*Abstract:*

Athletes regularly compete at 2,000-3,000 m altitude where peak oxygen consumption (VO2peak) declines approximately 10-20%. Factors other than VO2peak including gross efficiency (GE), power output, and pacing are all important for cycling performance. It is therefore imperative to understand how all these factors and not just VO2peak are affected by acute hypobaric hypoxia to select athletes who can compete successfully at these altitudes. Ten well-trained, non-altitude-acclimatised male cyclists and triathletes completed cycling tests at four simulated altitudes (200, 1,200, 2,200, 3,200 m) in a randomised, counter-balanced order. The exercise protocol comprised 5 x 5-min submaximal efforts (50, 100, 150, 200 and 250 W) to determine submaximal VO2 and GE and, after 10-min rest, a 5-min maximal time-trial (5-minTT) to determine VO2peak and mean power output (5-minTT(power)). VO2peak declined 8.2 +/- 2.0, 13.9 +/- 2.9 and 22.5 +/- 3.8% at 1,200, 2,200 and 3,200 m compared with 200 m, respectively, $P < 0.05$. The corresponding decreases in 5-minTT(power) were 5.8 +/- 2.9, 10.3 +/- 4.3 and 19.8 +/- 3.5% ($P < 0.05$). GE during the 5-minTT was not different across the four altitudes. There was no change in submaximal VO2 at any of the simulated altitudes, however, submaximal efficiency decreased at 3,200 m compared with both 200 and 1,200 m. Despite substantially reduced power at simulated altitude, there was no difference in pacing at the four altitudes for athletes whose first trial was at 200 or 1,200 m; whereas athletes whose first trial was at 2,200 or 3,200 m tended to mis-pace that effort. In conclusion, during the 5-minTT there was a dose-response effect of hypoxia on both VO2peak and 5-minTT(power) but no effect on GE.

**Clark, Quod et al. 2009 – Time course of haemoglobin mass**

Clark, Sally A.; Quod, M. J.; Clark, M. A.; Martin, D. T.; Saunders, P. U.; Gore, C. J. (2009):

## Time course of haemoglobin mass during 21 days live high:train low simulated altitude.

In: *Eur. J. Appl. Physiol.* 106 (3), S. 399–406. DOI: 10.1007/s00421-009-1027-4.

*Abstract:*

The aim of this study was to determine the time course of changes in haemoglobin mass (Hb(mass)) in well-trained cyclists in response to live high:train low (LHTL). Twelve well-trained male cyclists participated in a 3-week LHTL protocol comprising 3,000 m simulated altitude for ~14 h/day. Prior to LHTL duplicate baseline measurements were made of Hb(mass), maximal oxygen consumption (VO(2max)) and serum erythropoietin (sEPO). Hb(mass) was measured weekly during LHTL and twice in the week thereafter. There was a 3.3% increase in Hb(mass) and no change in VO(2max) after LHTL. The mean Hb(mass) increased at a rate of ~1% per week and this was maintained in the week after cessation of LHTL. The sEPO concentration peaked after two nights of LHTL but there was only a trivial correlation ($r = 0.04$, $P = 0.89$) between the increase in sEPO and the increase in Hb(mass). Athletes seeking to gain erythropoietic benefits from moderate altitude need to spend >12 h/day in hypoxia.

**Clark, Johnson 2010 – Selenium stable isotope investigation**

Clark, Scott K.; Johnson, Thomas M. (2010):

## Selenium stable isotope investigation into selenium biogeochemical cycling in a lacustrine environment: Sweitzer Lake, Colorado.

In: *J. Environ. Qual.* 39 (6), S. 2200–2210.

*Abstract:*

We present a comprehensive set of Se concentration and isotope ratio data collected over a 3-yr period from dissolved, sediment-hosted, and organically bound Se in a Se-contaminated lake and littoral wetland. Median isotope ratios of these various pools of Se spanned a narrow isotopic range (delta80/76Se(SRM-3149)) = 1.14-2.40 per thousand). Selenium (VI) reduction in the sediments is an important process in this system, but its isotopic impact is muted by the lack of direct contact between surface waters and reduction sites within sediments. This indicates that using Se isotope data as an indicator of microbial or abiotic Se oxyanion reduction is not effective in this or other similar systems. Isotopic data suggest that most Se(IV) in the lake originates from oxidation of organically bound Se rather than directly through Se(VI) reduction. Mobilization of Se(VI) from bedrock involves only a slight isotopic shift. Temporally constant isotopic differences observed in Se(VI) from two catchment areas suggest the potential for tracing Se(VI) from different source areas. Phytoplankton isotope ratios are close to those of the water, with a small depletion in heavy isotopes (0.56 per thousand). Fish tissues nearly match the phytoplankton, being only slightly depleted in the heavier isotopes. This suggests the potential for Se isotopes as migration indicators. Volatile, presumably methylated Se was isotopically very close to median values for phytoplankton and macrophytes, indicating a lack of isotopic fractionation during methylation.



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### Coleman, Wiles et al. 2005 – Reliability of sprint test indices

Coleman, D. A.; Wiles, J. D.; Nunn, M.; Smith, M. F. (2005):

## Reliability of sprint test indices in well-trained cyclists.

In: *Int J Sports Med* 26 (5), S. 383–387. DOI: 10.1055/s-2004-821226.

*Abstract:*

The study aim was to assess reliability of repeated laboratory sprint tests in well-trained endurance cyclists. Eleven male cyclists (mean +/- standard deviation: 27 +/- 6 yr, 1.79 +/- 0.04 m, 70.1 +/- 3.3 kg) performed a maximal 30-second sprint test on four separate occasions using their own bicycle fitted with an SRM powermeter on a Kingcycle air-braked ergometer. Peak power output (W (peak)), mean power (W (mean)) and an index of fatigue (FI) were calculated. Three minutes post sprint, capillarised blood lactate measurements were taken and analysed. No significant differences (p > 0.05) were found between trials for W (peak), W (mean), FI and blood lactate concentration. Repeatability of W (peak), W (mean), and fatigue index improved across trials 2 and 3 when compared to trials 1 and 2. The highest CV for these variables was recorded between trials 3 and 4. The CV for W (peak) was 4.5 +/- 1.6 %, W (mean) 2.4 +/- 1.2 %, and FI 17.2 +/- 7.1 %. Intraclass reliability coefficients were 0.93 (95 % CI 0.84 - 0.98), 0.94 (95 % CI 0.86 - 0.98) and 0.89 (95 % CI 0.69 - 0.95) respectively. Blood lactate concentration ranged between 5.35 and 14.52 mmol.l(-1), with a mean CV of 12.1 +/- 4.2 %. The CV for trials 2 and 3 revealed the highest CV for blood lactate concentration (15.1 %). The lowest CV for this variable (10.2 %) was recorded between trials 3 and 4. The intraclass reliability coefficient for blood lactate concentration was 0.79 (95 % CI 0.58 - 0.93). The results of this study indicate that there is no improvement in the reliability of sprint test indices when assessing well-trained, experienced cyclists, riding on their own cycle equipment.

### Doherty, Balmer et al. 2003 – Reliability of a combined 3-min

Doherty, M.; Balmer, J.; Davison, R. C. R.; Robinson, L.; Smith, P. M. (2003):

## Reliability of a combined 3-min constant load and performance cycling test.

In: *Int J Sports Med* 24 (5), S. 366–371. DOI: 10.1055/s-2003-40700.

*Abstract:*

Most fitness assessments either use a constant load to exhaustion (exercise capacity test) or an "all-out" effort (performance test). The purpose of this study was to determine the reliability of a high-intensity assessment that combined a constant load element with a performance test. Ten moderately trained male cyclists completed a ramp test to voluntary exhaustion in order to measure maximum minute power output (mean +/- s, 349.3 w +/- 55.0 w). On two other occasions subjects cycled at a constant load at maximum minute power output for 2-min immediately followed by a 1-min performance test. All tests were conducted on the subjects' own bicycles using a Kingcycle trade mark test rig. Power output was measured each second using SRM trade mark Power Cranks. The data were analysed by measuring the reliability of each 30 s of the 3-min test together with the peak power and the peak cadence achieved in the performance element of the test. There was no systematic bias in the data from trial 1 to trial 2 for any of the 6, 30 s blocks of the test, the peak power (mean, 95 % CI, 413.8 w, 357.8 - 469.7 w and 403.8 w, 339.9 - 467.6 w, trial 1 and trial 2, respectively) or peak cadence (95.0 rev x min(-1), 89.5 - 100.5 rev x min(-1) and 95.1 rev x min(-1), 90.0 - 100.1 rev x min(-1), trial 1 and trial 2, respectively). Mean (+/- s) total distance over the 3-min was 2.23 +/- 0.23 km and 2.26 +/- 0.26 km for trial 1 and trial 2 respectively (p > 0.05). The coefficients of variation ranged from 0.9 - 5.4 % and the intraclass correlation coefficients ranged from 0.96 - 0.99. It is concluded that in moderately trained subjects, the 3-min combination test provides reliable data and could therefore be used for short-term, high-intensity cycling intervention studies.

**Duc, Betik et al. 2005 – EMG activity does not change**

Duc, S.; Betik, A-C; Grappe, F. (2005):

## EMG activity does not change during a time trial in competitive cyclists.

In: *Int J Sports Med* 26 (2), S. 145–150. DOI: 10.1055/s-2004-817922.

*Abstract:*

The purpose of the present study was to measure the electromyographic (EMG) activity of four lower limb muscles and the propulsive torque during a cycling time-trial (TT). Nine competitive cyclists (V.O (2max): 73.8 +/- 5.3 ml . min (-1) . kg (-1)) performed two tests separated over a one-week period on a friction-load cycle ergometer equipped with a SRM crankset scientific system: 1) a continuous incremental test for the determination of the peak power output (PPO); and 2) a 30-min TT test at a self-selected work intensity. The EMG activity of the vastus medialis (VM), the rectus femoris (RF), the biceps femoris (BF), and the gastrocnemius medialis (GAS), and the propulsive torque were recorded every 5 min for 10 s. There was no time effect on the power output, the pedalling cadence, and the mean propulsive torque. The EMG activity of the VM and the RF muscles was unchanged during the TT ($p > 0.05$). The EMG activity of the two knee flexor muscles (BF and GAS) tended to increase with time but it was not significant ($p > 0.05$). The EMG/torque of the VM and the RF muscles tended to decrease with time but it was not significant ($p > 0.05$). The lack of increase in the EMG activity of the four investigated muscles seems to indicate that the subjects performed the TT test at a muscular work steady-state.

**Duc, Villerius et al. 2007 – Validity and reproducibility**

Duc, S.; Villerius, V.; Bertucci, W.; Grappe, F. (2007):

## Validity and reproducibility of the ErgomoPro power meter compared with the SRM and Powertap power meters.

In: *International journal of sports physiology and performance* 2 (3), S. 270–281.

*Abstract:*

OBJECTIVE (PURPOSE):

The ErgomoPro (EP) is a power meter that measures power output (PO) during outdoor and indoor cycling via 2 optoelectronic sensors located in the bottom bracket axis. The aim of this study was to determine the validity and the reproducibility of the EP compared with the SRM crank set and Powertap hub (PT).

METHODS:

The validity of the EP was tested in the laboratory during 8 submaximal incremental tests (PO: 100 to 400 W), eight 30-min submaximal constant-power tests (PO = 180 W), and 8 sprint tests (PO > 750 W) and in the field during 8 training sessions (time: 181 +/- 73 min; PO: approximately 140 to 160 W). The reproducibility was assessed by calculating the coefficient of PO variation (CV) during the submaximal incremental and constant tests.

RESULTS:

The EP provided a significantly higher PO than the SRM and PT during the submaximal incremental test: The mean PO differences were +6.3% +/- 2.5% and +11.1% +/- 2.1% respectively. The difference was greater during field training sessions (+12.0% +/- 5.7% and +16. 5% +/- 5.9%) but lower during sprint tests (+1.6% +/- 2.5% and +3.2% +/- 2.7%). The reproducibility of the EP is lower than those of the SRM and PT (CV = 4.1% +/- 1.8%, 1.9% +/- 0.4%, and 2.1% +/- 0.8%, respectively).

CONCLUSIONS:

The EP power meter appears less valid and reliable than the SRM and PT systems.

SRM in Science

**Duc, Villerius et al. 2005 – Muscular activity level during pedalling**

Duc, S.; Villerius, V.; Bertucci, W.; Pernin, J. N.; Grappe, F. (2005):

## Muscular activity level during pedalling is not affected by crank inertial load.

In: *Eur. J. Appl. Physiol.* 95 (2-3), S. 260–264. DOI: 10.1007/s00421-005-1401-9.

*Abstract:*

The aim of the present study was to investigate the influence of gear ratio (GR) and thus crank inertial load (CIL), on the activity levels of lower limb muscles. Twelve competitive cyclists performed three randomised trials with their own bicycle equipped with a SRM crankset and mounted on an Axiom ergometer. The power output ( approximately 80% of maximal aerobic power) and the pedalling cadence were kept constant for each subject across all trials but three different GR (low, medium and high) were indirectly obtained for each trial by altering the electromagnetic brake of the ergometer. The low, medium and high GR (mean +/- SD) resulted in CIL of 44 +/- 3.7, 84 +/- 6.5 and 152 +/- 17.9 kg.m(2), respectively. Muscular activity levels of the gluteus maximus (GM), the vastus medialis (VM), the vastus lateralis (VL), the rectus femoris (RF), the medial hamstrings (MHAM), the gastrocnemius (GAS) and the soleus (SOL) muscles were quantified and analysed by mean root mean square (RMS(mean)). The muscular activity levels of the measured lower limb muscles were not significantly affected when the CIL was increased approximately four fold. This suggests that muscular activity levels measured on different cycling ergometers (with different GR and flywheel inertia) can be compared among each other, as they are not influenced by CIL.

**Duc, Villerius et al. 2007 – Validity and reproducibility**

Duc, Sebastien; Villerius, Vincent; Bertucci, William; Grappe, Frederic (2007):

## Validity and reproducibility of the ErgomoPro power meter compared with the SRM and Powertap power meters.

In: *Int J Sports Physiol Perform* 2 (3), S. 270–281.

*Abstract:*

PURPOSE

The ErgomoPro (EP) is a power meter that measures power output (PO) during outdoor and indoor cycling via 2 optoelectronic sensors located in the bottom bracket axis. The aim of this study was to determine the validity and the reproducibility of the EP compared with the SRM crank set and Powertap hub (PT).

METHODS

The validity of the EP was tested in the laboratory during 8 submaximal incremental tests (PO: 100 to 400 W), eight 30-min submaximal constant-power tests (PO = 180 W), and 8 sprint tests (PO > 750 W) and in the field during 8 training sessions (time: 181 +/- 73 min; PO: approximately 140 to 160 W). The reproducibility was assessed by calculating the coefficient of PO variation (CV) during the submaximal incremental and constant tests.

RESULTS

The EP provided a significantly higher PO than the SRM and PT during the submaximal incremental test: The mean PO differences were +6.3% +/- 2.5% and +11.1% +/- 2.1% respectively. The difference was greater during field training sessions (+12.0% +/- 5.7% and +16.5% +/- 5.9%) but lower during sprint tests (+1.6% +/- 2.5% and +3.2% +/- 2.7%). The reproducibility of the EP is lower than those of the SRM and PT (CV = 4.1% +/- 1.8%, 1.9% +/- 0.4%, and 2.1% +/- 0.8%, respectively).

CONCLUSIONS

The EP power meter appears less valid and reliable than the SRM and PT systems.

### Eastwood, Sharpe et al. 2012 – Within-subject variation in hemoglobin mass

Eastwood, Annette; Sharpe, Ken; Bourdon, Pitre C.; Woolford, Sarah M.; Saunders, Philo U.; Robertson, Eileen Y. et al. (2012):

## Within-subject variation in hemoglobin mass in elite athletes.

In: *Med Sci Sports Exerc* 44 (4), S. 725–732. DOI: 10.1249/MSS.0b013e318238ea7f.

*Abstract:*

UNLABELLED

Illicit autologous blood transfusion to improve performance in elite sport is currently undetectable, but the stability of longitudinal profiles of an athlete's hemoglobin mass (Hbmass) might be used to detect such practices.

PURPOSE

Our aim was to quantify within-subject variation of Hbmass in elite athletes, and the effects of potentially confounding factors such as reduced training or altitude exposure.

METHODS

A total of 130 athletes (43 females and 87 males) were measured for Hbmass an average of six times during a period of approximately 1 yr using carbon monoxide rebreathing. Linear mixed models were used to quantify within-subject variation of Hbmass and its associated analytical and biological components for males and females, as well as the effects of reduced training and moderate altitude exposure in certain athletes.

RESULTS

The maximum within-subject coefficient of variation (CV) for Hbmass was 3.4% for males and 4.0% for females. The analytical CV was ~2.0% for both males and females, and the long-term biological CV, after allowing for analytical variation, was 2.8% for males and 3.5% for females. On average, self-reported reduced training resulted in a 2.8% decrease in Hbmass and altitude exposure increased Hbmass by 1.5% to 2.9%, depending on the duration and type of exposure.

CONCLUSIONS

The within-subject CV for Hbmass of ~4% indicates that athletes may experience changes up to ~20% with a 1-in-1000 probability. Changes of this magnitude for measures taken a few months apart suggest that Hbmass has a limited capacity to detect autologous blood doping. However, changes in Hbmass may be a useful indicator when combined with other measures of blood manipulation.

### Ebert, Martin et al. 2005 – Power output during women's World

Ebert, Tammie R.; Martin, David T.; McDonald, Warren; Victor, James; Plummer, John; Withers, Robert T. (2005):

## Power output during women's World Cup road cycle racing.

In: *Eur. J. Appl. Physiol.* 95 (5-6), S. 529–536. DOI: 10.1007/s00421-005-0039-y.

*Abstract:*

Little information exists on the power output demands of competitive women's road cycle racing. The purpose of our investigation was to document the power output generated by elite female road cyclists who achieved success in FLAT and HILLY World Cup races. Power output data were collected from 27 top-20 World Cup finishes (19 FLAT and 8 HILLY) achieved by 15 nationally ranked cyclists (mean +/- SD; age: 24.1+/-4.0 years; body mass: 57.9+/-3.6 kg; height: 168.7+/-5.6 cm; VO2max 63.6+/-2.4 mL kg(-1) min(-1); peak power during graded exercise test (GXT(peak power)): 310+/-25 W). The GXT determined GXT(peak power), VO2peak lactate threshold (LT) and anaerobic threshold (AT). Bicycles were fitted with SRM powermeters, which recorded power (W), cadence (rpm), distance (km) and speed (km h(-1)). Racing data were analysed to establish time in power output and metabolic threshold bands and maximal mean power (MMP) over different durations. When compared to HILLY, FLAT were raced at a similar cadence (75+/-8 vs. 75+/-4 rpm, P=0.93) but higher speed (37.6+/-2.6 vs. 33.9+/-2.7 km h(-1), P=0.008) and power output (192+/-21 vs. 169+/-17

W, P=0.04; 3.3+/-0.3 vs. 3.0+/-0.4 W kg(-1), P=0.04). During FLAT races, riders spent significantly more time above 500 W, while greater race time was spent between 100 and 300 W (LT-AT) for HILLY races, with higher MMPs for 180-300 s. Racing terrain influenced the power output profiles of our internationally competitive female road cyclists. These data are the first to define the unique power output requirements associated with placing well in both flat and hilly women's World Cup cycling events.

**Ebert, Martin et al. 2006 – Power output during a professional**

Ebert, Tammie R.; Martin, David T.; Stephens, Brian; Withers, Robert T. (2006):

## Power output during a professional men's road-cycling tour.

In: *Int J Sports Physiol Perform* 1 (4), S. 324–335.

*Abstract:*

PURPOSE

To quantify the power-output demands of men's road-cycling stage racing using a direct measure of power output.

METHODS

Power-output data were collected from 207 races over 6 competition years on 31 Australian national male road cyclists. Subjects performed a maximal graded exercise test in the laboratory to determine maximum aerobic-power output, and bicycles were fitted with SRM power meters. Races were described as flat, hilly, or criterium, and linear mixed modeling was used to compare the races.

RESULTS

Criterium was the shortest race and displayed the highest mean power output (criterium 262 +/- 30 v hilly 203 +/- 32 v flat 188 +/- 30 W), percentage total race time above 7.5 W/kg (criterium 15.5% +/- 4.1% v hilly 3.8% +/- 1.7% v flat 3.5% +/- 1.4%) and SD in power output (criterium 250 v hilly 165 v flat 169 W). Approximately 67%, 80%, and 85% of total race time was spent below 5 W/kg for criterium, hilly and flat races, respectively. About 70, 40, and 20 sprints above maximum aerobic-power output occurred during criterium, hilly, and flat races, respectively, with most sprints being 6 to 10 s.

CONCLUSIONS

These data extend previous research documenting the demands of men's road cycling. Despite the relatively low mean power output, races were characterized by multiple high-intensity surges above maximum aerobic-power output. These data can be used to develop sport-specific interval-training programs that replicate the demands of competition.

**Emonson, Aminuddin et al. 1997 – Training-induced increases in sea level**

Emonson, D. L.; Aminuddin, A. H.; Wight, R. L.; Scroop, G. C.; Gore, C. J. (1997):

## Training-induced increases in sea level VO2max and endurance are not enhanced by acute hypobaric exposure.

In: *Eur J Appl Physiol Occup Physiol* 76 (1), S. 8–12.

*Abstract:*

The present study used untrained subjects to examine the effect of acute hypobaric exposure during endurance training on subsequent exercise performance at sea level. Two groups, each of nine subjects, completed 5 weeks of endurance training [cycle ergometer exercise for 45 min, three times per week at a heart rate corresponding to 70% of that achieved at the maximal O2 consumption (VO2max) either at sea level or at high altitude] in a hypobaric chamber, under either normobaric [sea level, SL; 750 mmHg (100 kPa) approximately 90 m] or hypobaric [altitude, ALT; 554 mmHg (73.4 kPa) approximately 2500 m] conditions and the changes in SL VO2max, SL endurance time and peak blood lactate during the endurance test compared. While each group

showed increases in both SL VO2max (approximately 12%) and SL endurance time (approximately 71%), there were no significant differences between the groups [SL VO2max, mean (SE)-SL group: pre-training = 42.4 (3.5), post-training = 46.1 (3.5) ml.kg-1.min-1, P < 0.005; ALT group: pre-training = 40.8 (2.6), post-training = 47.2 (3.4) ml.kg-1.min-1, P < 0.01; SL endurance time-SL group: pre-training 7.1 (1.5), post-training 11.8 (2.9) min, P < 0.01; ALT group: pre-training = 7.5 (0.6), post-training = 13.3 (1.4) min, P < 0.001]. Peak blood lactate during the endurance test was not altered by either training regimen. It is concluded that acute exposure of untrained subjects to hypobaric hypoxia during endurance training has no synergistic effect on the degree of improvement in either SL VO2max or endurance time.

**Faiss, Praz et al. 2007 – The effect of mountain bike**

Faiss, R.; Praz, M.; Meichtry, A.; Gobelet, C.; Deriaz, O. (2007):

## The effect of mountain bike suspensions on vibrations and off-road uphill performance.

In: *J Sports Med Phys Fitness* 47 (2), S. 151–158.

*Abstract:*

AIM

This study evaluates the effect of front suspension (FS) and dual suspension (DS) mountain-bike on performance and vibrations during off-road uphill riding.

METHODS

Thirteen male cyclists (27+/-5 years, 70+/-6 kg, VO(2max)59+/-6 mL.kg(-1).min(-1), mean+/-SD) performed, in a random sequence, at their lactate threshold, an off-road uphill course (1.69 km, 212 m elevation gain) with both type of bicycles. Variable measured: a) VO(2) consumption (K4b2 analyzer, Cosmed), b) power output (SRM) c) gain in altitude and d) 3-D accelerations under the saddle and at the wheel (Physilog, EPFL, Switzerland). Power spectral analy- sis (Fourier) was performed from the vertical acceleration data.

RESULTS

Respectively for the FS and DS mountain bike: speed amounted to 7.5+/-0.7 km.h(-1) and 7.4+/-0.8 km.h(-1), (NS), energy expenditure 1.39+/-0.16 kW and 1.38+/-0.18, (NS), gross efficiency 0.161+/-0.013 and 0.159+/-0.013, (NS), peak frequency of vibration under the saddle 4.78+/-2.85 Hz and 2.27+/-0.2 Hz (P<0.01) and median-frequency of vertical displacements of the saddle 9.41+/-1.47 Hz and 5.78+/-2.27 Hz (P<0.01).

CONCLUSION

Vibrations at the saddle level of the DS bike are of low frequencies whereas those of the FS bike are mostly of high frequencies. In the DS bike, the torque produced by the cyclist at the pedal level may generate low frequency vibrations. We conclude that the DS bike absorbs more high frequency vibrations, is more comfortable and performs as well as the FS bicycle.

**Frese, Valdivieso et al. 2016 – Expression of Metabolic and Myogenic**

Frese, S.; Valdivieso, P.; Jaecker, V. C.; Harms, S. A.; Konou, T. M.; Tappe, K. A. et al. (2016):

## Expression of Metabolic and Myogenic Factors during two Competitive Seasons in Elite Junior Cyclists.

In: *Dtsch Z Sportmed* 2016 (06), S. 150–158. DOI: 10.5960/dzsm.2016.239.

**Fu, Townsend et al. 2007 – Intermittent hypobaric hypoxia exposure does**

Fu, Qi; Townsend, Nathan E.; Shiller, S. Michelle; Martini, Emily R.; Okazaki, Kazunobu; Shibata, Shigeki et al. (2007):

## Intermittent hypobaric hypoxia exposure does not cause sustained alterations in autonomic control of blood pressure in young athletes.

In: *Am. J. Physiol. Regul. Integr. Comp. Physiol.* 292 (5), R1977-84. DOI: 10.1152/ajpregu.00622.2006.

*Abstract:*

Intermittent hypoxia (IH), which refers to the discontinuous use of hypoxia to reproduce some key features of altitude acclimatization, is commonly used in athletes to improve their performance. However, variations of IH are also used as a model for sleep apnea, causing sustained sympathoexcitation and hypertension in animals and, thus, raising concerns over the safety of this model. We tested the hypothesis that chronic IH at rest alters autonomic control of arterial pressure in healthy trained individuals. Twenty-two young athletes (11 men and 11 women) were randomly assigned to hypobaric hypoxia (simulated altitude of 4,000-5,500 m) or normoxia (500 m) in a double-blind and placebo-controlled design. Both groups rested in a hypobaric chamber for 3 h/day, 5 days/wk for 4 wk. In the sitting position, resting hemodynamics, including heart rate (HR), blood pressure (BP), cardiac output (Q(c), C(2)H(2) rebreathing), stroke volume (SV = Q(c)/HR), and total peripheral resistance (TPR = mean BP/Q(c)), were measured, dynamic cardiovascular regulation was assessed by spectral and transfer function analysis of cardiovascular variability, and cardiac-vagal baroreflex function was evaluated by a Valsalva maneuver, twice before and 3 days after the last chamber exposure. We found no significant differences in HR, BP, Q(c), SV, TPR, cardiovascular variability, or cardiac-vagal baroreflex function between the groups at any time. These results suggest that exposure to intermittent hypobaric hypoxia for 4 wk does not cause sustained alterations in autonomic control of BP in young athletes. In contrast to animal studies, we found no secondary evidence for sustained physiologically significant sympathoexcitation in this model.

**Gardner, Martin et al. 2009 – Velocity-specific fatigue**

Gardner, A. Scott; Martin, David T.; Jenkins, David G.; Dyer, Iain; van Eiden, Jan; Barras, Martin; Martin, James C. (2009):

## Velocity-specific fatigue: quantifying fatigue during variable velocity cycling.

In: *Med Sci Sports Exerc* 41 (4), S. 904–911. DOI: 10.1249/MSS.0b013e318190c2cc.

*Abstract:*

UNLABELLED

Previous investigators have quantified fatigue during short maximal cycling trials ( approximately 30 s) by calculating a fatigue index. Other investigators have reported a curvilinear power-pedaling rate relationship during short fatigue-free maximal cycling trials (<6 s). During maximal trials, pedaling rates may change with fatigue. Quantification of fatigue using fatigue index is therefore complicated by the power-pedaling rate relationship.

PURPOSE

The purpose of this study was to quantify fatigue while accounting for the effects of pedaling rate on power.

METHODS

Power and pedaling rate were recorded during Union Cycliste Internationale sanctioned 200-m time trials by eight male (height = 181.5 +/- 4.3 cm, mass = 87.0 +/- 8.0 kg) world-class sprint cyclists with SRM power meters and fixed-gear track bicycles. Data from the initial portion of maximal acceleration were used to establish maximal power-pedaling rate relationships. Fatigue was quantified three ways: 1) traditional fatigue index, 2) fatigue index modified to account for the power-pedaling rate relationship (net fatigue index), and 3) work deficit, the difference between actual work done and work that might have been accomplished without fatigue.

RESULTS

Fatigue index (55.4% +/- 6.4%) was significantly greater than net fatigue index (41.0% +/- 7.9%, P < 0.001), indicating that the power-pedaling rate relationship accounted for 14.3% +/- 7% of the traditional fatigue index value. Work deficit (23.3% +/- 6%) was significantly less than either measure of fatigue (P < 0.001).

CONCLUSION

Net fatigue index and work deficit account for the power-pedaling rate relation and therefore more precisely quantify fatigue during variable velocity cycling. These measures can be used to compare fatigue during different fatigue protocols, including world-class sprint cycling competition. Precise quantification of fatigue during elite cycling competition may improve evaluation of training status, gear ratio selection, and fatigue resistance.

**Gardner, Martin et al. 2007 – Maximal torque- and power-pedaling rate**

Gardner, A. Scott; Martin, James C.; Martin, David T.; Barras, Martin; Jenkins, David G. (2007):

## Maximal torque- and power-pedaling rate relationships for elite sprint cyclists in laboratory and field tests.

In: *Eur. J. Appl. Physiol.* 101 (3), S. 287–292. DOI: 10.1007/s00421-007-0498-4.

*Abstract:*

Performance models provide an opportunity to examine cycling in a broad parameter space. Variables used to drive such models have traditionally been measured in the laboratory. The assumption, however, that maximal laboratory power is similar to field power has received limited attention. The purpose of the study was to compare the maximal torque- and power-pedaling rate relationships during "all-out" sprints performed on laboratory ergometers and on moving bicycles with elite cyclists. Over a 3-day period, seven male (mean +/- SD; 180.0 +/- 3.0 cm; 86.2 +/- 6.1 kg) elite track cyclists completed two maximal 6 s cycle ergometer trials and two 65 m sprints on a moving bicycle; calibrated SRM powermeters were used and data were analyzed per revolution to establish torque- and power-pedaling rate relationships, maximum power, maximum torque and maximum pedaling rate. The inertial load of our laboratory test was (37.16 +/- 0.37 kg m(2)), approximately half as large as the field trials (69.7 +/- 3.8 kg m(2)). There were no statistically significant differences between laboratory and field maximum power (1791 +/- 169; 1792 +/- 156 W; P = 0.863), optimal pedaling rate (128 +/- 7; 129 +/- 9 rpm; P = 0.863), torque-pedaling rate linear regression slope (-1.040 +/- 0.09; -1.035 +/- 0.10; P = 0.891) and maximum torque (266 +/- 20; 266 +/- 13 Nm; P = 0.840), respectively. Similar torque- and power-pedaling rate relationships were demonstrated in laboratory and field settings. The findings suggest that maximal laboratory data may provide an accurate means of modeling cycling performance.

**Gardner, Stephens et al. 2004 – Accuracy of SRM and power**

Gardner, Andrew S.; Stephens, Shaun; Martin, David T.; Lawton, Evan; Lee, Hamilton; Jenkins, David (2004):

## Accuracy of SRM and power tap power monitoring systems for bicycling.

In: *Med Sci Sports Exerc* 36 (7), S. 1252–1258.

*Abstract:*

PURPOSE

: Although manufacturers of bicycle power monitoring devices SRM and Power Tap (PT) claim accuracy to within 2.5%, there are limited scientific data available in support. The purpose of this investigation was to assess the accuracy of SRM and PT under different conditions.

METHODS

: First, 19 SRM were calibrated, raced for 11 months, and retested using a dynamic CALRIG (50-1000 W at 100 rpm). Second, using the same procedure, five PT were repeat tested on alternate days. Third, the most accurate SRM and PT were tested for the influence of cadence (60, 80, 100, 120 rpm), temperature (8 and 21

degrees C) and time (1 h at ~300 W) on accuracy. Finally, the same SRM and PT were downloaded and compared after random cadence and gear surges using the CALRIG and on a training ride.

RESULTS

: The mean error scores for SRM and PT factory calibration over a range of 50 - 1000 W were 2.3 +/- 4.9% and -2.5 +/- 0.5%, respectively. A second set of trials provided stable results for 15 calibrated SRM after 11 months (-0.8 +/- 1.7%), and follow-up testing of all PT units confirmed these findings (-2.7 +/- 0.1%). Accuracy for SRM and PT was not largely influenced by time and cadence; however, power output readings were noticeably influenced by temperature (5.2% for SRM and 8.4% for PT). During field trials, SRM average and max power were 4.8% and 7.3% lower, respectively, compared with PT.

CONCLUSIONS

: When operated according to manufacturers instructions, both SRM and PT offer the coach, athlete, and sport scientist the ability to accurately monitor power output in the lab and the field. Calibration procedures matching performance tests (duration, power, cadence, and temperature) are, however, advised as the error associated with each unit may vary.

**Garvican, Hammond et al. 2013 – Lower Running Performance and Exacerbated**

Garvican, Laura A.; Hammond, Kristal; Varley, Matthew C.; Gore, Christopher J.; Billaut, Francois; Aughey, Robert J. (2013):

## Lower Running Performance and Exacerbated Fatigue in Soccer Played at 1600 m.

In: *Int J Sports Physiol Perform*.

*Abstract:*

PURPOSE: This study investigated the decrement in running performance of elite soccer players competing at low altitude and time-course for abatement of these decrements. METHODS: Twenty elite youth soccer players had their activity profile, in a sea level (SL) and two altitude (Alt, 1600 m, d4 and d6) matches measured with a global positioning system. Measures expressed in metres per minute of match time (m.min-1) were: total distance; low and high-velocity running (LoVR, 0.01-4.16 m.s-1; HiVR, 4.17-10.0 m.s-1) and frequency of maximal accelerations (Accel, >2.78 m.s-2). The peak and subsequent stanza for each measure were identified and a transient fatigue index calculated. Mean heart rate (HR) during the final minute of a sub-maximal running task (5-min, 11 km.h-1) was recorded at SL and for 10d at Alt. Differences were determined between SL and Alt using percentage change, and effect size statistic with 90% confidence intervals. RESULTS: Mean HR almost certainly increased on d1 (5.4%, ES 1.01±0.35) and remained probably elevated on both d2 (ES 0.42±0.31) and d3 (ES 0.30±0.25) returning to baseline at d5. Total distance was almost certainly lower than SL (ES -0.76±0.37) at d4, and remained probably reduced on d6 (ES -0.42±0.36). HiVR probably decreased at d4 vs. SL (-0.47±0.59), with no clear effect of altitude at d6 (-0.08±0.41). Transient fatigue in matches was evident at SL and Alt with a possibly greater decrement at Alt. a Despite some physiological adaptation, match running performance of youth soccer players is compromised for at least six days at low altitude.

**Garvican, Martin et al. 2007 – Variability of erythropoietin response**

Garvican, Laura A.; Martin, David T.; Clark, Sally A.; Schmidt, Walter F.; Gore, Christopher J. (2007):

## Variability of erythropoietin response to sleeping at simulated altitude: a cycling case study.

In: *Int J Sports Physiol Perform* 2 (3), S. 327–331.

SRM in Science

### Garvican, Pottgiesser et al. 2011 – The contribution of haemoglobin mass

Garvican, Laura A.; Pottgiesser, Torben; Martin, David T.; Schumacher, Yorck Olaf; Barras, Martin; Gore, Christopher J. (2011):

## The contribution of haemoglobin mass to increases in cycling performance induced by simulated LHTL.

In: *Eur. J. Appl. Physiol.* 111 (6), S. 1089–1101. DOI: 10.1007/s00421-010-1732-z.

*Abstract:*

We sought to determine whether improved cycling performance following 'Live High-Train Low' (LHTL) occurs if increases in haemoglobin mass (Hb(mass)) are prevented via periodic phlebotomy during hypoxic exposure. Eleven, highly trained, female cyclists completed 26 nights of simulated LHTL (16 h day(-1), 3000 m). Hb(mass) was determined in quadruplicate before LHTL and in duplicate weekly thereafter. After 14 nights, cyclists were pair-matched, based on their Hb(mass) response (ΔHb(mass)) from baseline, to form a response group (Response, n = 5) in which Hb(mass) was free to adapt, and a Clamp group (Clamp, n = 6) in which ΔHb(mass) was negated via weekly phlebotomy. All cyclists were blinded to the blood volume removed. Cycling performance was assessed in duplicate before and after LHTL using a maximal 4-min effort (MMP(4min)) followed by a ride time to exhaustion test at peak power output (T (lim)). VO(2peak) was established during the MMP(4min). Following LHTL, Hb(mass) increased in Response (mean ± SD, 5.5 ± 2.9%). Due to repeated phlebotomy, there was no ΔHb(mass) in Clamp (-0.4 ± 0.6%). VO(2peak) increased in Response (3.5 ± 2.3%) but not in Clamp (0.3 ± 2.6%). MMP(4min) improved in both the groups (Response 4.5 ± 1.1%, Clamp 3.6 ± 1.4%) and was not different between groups (p = 0.58). T (lim) increased only in Response, with Clamp substantially worse than Response (-37.6%; 90% CL -58.9 to -5.0, p = 0.07). Our novel findings, showing an ~4% increase in MMP(4min) despite blocking an ~5% increase in Hb(mass), suggest that accelerated erythropoiesis is not the sole mechanism by which LHTL improves performance. However, increases in Hb(mass) appear to influence the aerobic contribution to high-intensity exercise which may be important for subsequent high-intensity efforts.

### Garvican, Saunders et al. 2012 – Hemoglobin mass response to simulated

Garvican, Laura A.; Saunders, Philo U.; Pyne, David B.; Martin, David T.; Robertson, Eileen Y.; Gore, Christopher J. (2012):

## Hemoglobin mass response to simulated hypoxia "blinded" by noisy measurement?

In: *J. Appl. Physiol.* 112 (10), 1797-8; author reply 1799. DOI: 10.1152/japplphysiol.00212.2012.

### Giacomoni, Billaut et al. 2006 – Effects of the Time

Giacomoni, M.; Billaut, F.; Falgairette, G. (2006):

## Effects of the Time of Day on Repeated All-Out Cycle Performance and Short-Term Recovery Patterns.

In: *Int J Sports Med* 27 (6), S. 468–474. DOI: 10.1055/s-2005-865822.

*Abstract:*

The effect of the time of day on repeated cycle sprint performance and short-term recovery patterns was investigated in 12 active male subjects (23 ± 2 years, 76.4 ± 4.2 kg, 1.80 ± 0.06 m, 9.5 ± 4.5 h · week-1 of physical activity). Subjects performed ten 6-s maximal sprints inter-spaced by 30 s rest in the morning (08 : 00 - 10 : 00 h) and in the evening (17 : 00 - 19 : 00 h) on separate days. During the intermittent exercise, peak power output (PPO, watts), total mechanical work (W, kJ), peak pedalling rate (PPR, rev · min-1), and peak efficient torque (PTCK, Nm) were recorded. The values at the 1st, the 5th, and the 10th sprints were used as mechanical indices of fatigue occurrence. Intra-aural temperature and maximal voluntary contraction of knee extensors muscles (MVC) were measured before (pre), immediately after (post) the cycle bouts and following a 5-min passive recovery period (post5). The MVC indices were used to further confirm occurrence of neuromuscular fatigue and to assess short-term recovery patterns from all-out intermittent effort. During the MVC, electromyographic activity of the vastus lateralis muscle was recorded and analysed as its root mean square (RMS). The torque produced per unit RMS was calculated and used as index of neuromuscular efficiency (NME). A main effect for the sprint number was observed for all cycle performance parameters ($p < 0.05$). The main effect for the time of day was not significant for any biomechanical indices of neuromuscular performance. A significant interaction effect of the time of day and the sprint repetition was demonstrated on PTCK ($F_{2,22} = 4.3$, $p < 0.05$). The decrease in PTCK consecutive to sprint repetition was sharper in the evening compared to the morning (sprint 10 [% of sprint 1]: - 9.5 % in the evening vs. - 2.2 % in the morning, $p < 0.05$). Significant interaction effects of the time of day and the condition (i. e. pre, post, post5) were also demonstrated for RMS ($F_{2,22} = 3.6$, $p < 0.05$) and NME ($F_{2,22} = 4.5$, $p < 0.05$) during MVC. These interactions were characterised by similar patterns of fatigue occurrence (i. e. post vs. pre condition) in the morning (+ 7.5 % for RMS, - 19.6 % for NME) as in the evening (+ 10.2 % for RMS, - 19.4 % for NME) but different patterns of short-term recovery (i. e. post5 vs. post condition; $p < 0.05$) in the morning (- 7.3 % for RMS, + 13.7 % for NME) compared to the evening (+ 3.3 % for RMS, - 1.8 % for NME). These results suggest that short-term recovery patterns of neuromuscular function are slower in the evening compared to the morning.

**González-Haro, Galilea et al. 2008 – Comparison of different theoretical models**

González-Haro, Carlos; Galilea, Pedro A.; Escanero, Jesús F. (2008):

## Comparison of different theoretical models estimating peak power output and maximal oxygen uptake in trained and elite triathletes and endurance cyclists in the velodrome.

In: *J Sports Sci* 26 (6), S. 591–601. DOI: 10.1080/02640410701646245.

*Abstract:*

The aim of this study was to assess which of the equations that estimate peak power output and maximal oxygen uptake (VO2max) in the velodrome adapt best to the measurements made by reference systems. Thirty-four endurance cyclists and triathletes performed one incremental test in the laboratory and two tests in the velodrome. Maximal oxygen uptake and peak power output were measured with an indirect calorimetry system in the laboratory and with the SRM training system in the velodrome. The peak power output and VO2max of the field test were estimated by means of different equations. The agreement between the estimated and the reference values was assessed with the Bland-Altman method. The equation of Olds et al. (1995) showed the best agreement with respect to the peak power output reference values, and that of McCole et al. (1990) was the only equation to show good agreement with respect to the VO2max reference values. The VO2max values showed a higher coefficient of determination with respect to maximal aerobic speed when they were expressed in relative terms. In conclusion, the equations of Olds et al. (1995) and McCole et al. (1990) were best at estimating peak power output and VO2max in the velodrome, respectively.

**González-Haro, Galilea Ballarini et al. 2007 – Comparison of nine theoretical models**

González-Haro, Carlos; Galilea Ballarini, P. A.; Soria, M.; Drobnic, F.; Escanero, J. F. (2007):

## Comparison of nine theoretical models for estimating the mechanical power output in cycling.

In: *Br J Sports Med* 41 (8), 506-9; discussion 509. DOI: 10.1136/bjsm.2006.034934.

*Abstract:*

OBJECTIVE

To assess which of the equations used to estimate mechanical power output for a wide aerobic range of exercise intensities gives the closest value to that measured with the SRM training system.

METHODS

Thirty four triathletes and endurance cyclists of both sexes (mean (SD) age 24 (5) years, height 176.3 (6.6) cm, weight 69.4 (7.6) kg and Vo(2)max 61.5 (5.9) ml/kg/min) performed three incremental tests, one in the laboratory and two in the velodrome. The mean mechanical power output measured with the SRM training system in the velodrome tests corresponding to each stage of the tests was compared with the values theoretically estimated using the nine most referenced equations in literature (Whitt (Ergonomics 1971;14:419-24); Di Prampero et al (J Appl Physiol 1979;47:201-6); Whitt and Wilson (Bicycling science. Cambridge: MIT Press, 1982); Kyle (Racing with the sun. Philadelphia: Society of Automotive Engineers, 1991:43-50); Menard (First International Congress on Science and Cycling Skills, Malaga, 1992); Olds et al (J Appl Physiol 1995;78:1596-611; J Appl Physiol 1993;75:730-7); Broker (USOC Sport Science and Technology Report 1-24, 1994); Candau et al (Med Sci Sports Exerc 1999;31:1441-7)). This comparison was made using the mean squared error of prediction, the systematic error and the random error.

RESULTS

The equations of Candau et al, Di Prampero et al, Olds et al (J Appl Physiol 1993;75:730-7) and Whitt gave a moderate mean squared error of prediction (12.7%, 21.6%, 13.2% and 16.5%, respectively) and a low random error (0.5%, 0.6%, 0.7% and 0.8%, respectively).

CONCLUSIONS

The equations of Candau et al and Di Prampero et al give the best estimate of mechanical power output when compared with measurements obtained with the SRM training system.

### Goosey-Tolfrey, Castle et al. 2006 – Aerobic capacity and peak power

Goosey-Tolfrey, V.; Castle, P.; Webborn, N.; Abel, T. (2006):

## Aerobic capacity and peak power output of elite quadriplegic games players.

In: *Br J Sports Med* 40 (8), S. 684–687. DOI: 10.1136/bjsm.2006.026815.

*Abstract:*

BACKGROUND

Participation in wheelchair sports such as tennis and rugby enables people with quadriplegia to compete both individually and as a team at the highest level. Both sports are dominated by frequent, intermittent, short term power demands superimposed on a background of aerobic activity.

OBJECTIVE

To gain physiological profiles of highly trained British quadriplegic athletes, and to examine the relation between aerobic and sprint capacity.

METHODS

Eight male quadriplegic athletes performed an arm crank exercise using an ergometer fitted with a Schoberer Rad Messtechnik (SRM) powermeter. The sprint test consisted of three maximum-effort sprints of five seconds duration against a resistance of 2%, 3%, and 4% of body mass. The highest power output obtained was recorded (PPO). Peak oxygen consumption (V(O2peak)), peak heart rate (HR(peak)), and maximal power output (PO(aer)) were determined.

RESULTS

Mean PO(aer) was 67.7 (16.2) W, mean V(O2peak) was 0.96 (0.17) litres/min, and HR(peak) was 134 (19) beats/min for the group. There was high variability among subjects. Peak power over the five second sprint for the group was 220 (62) W. There was a significant correlation between V(O2peak) (litres/min) and PO(aer) (W) ($r = 0.74$, $p<0.05$).

CONCLUSIONS

SRM in Science

These British quadriplegic athletes have relatively high aerobic fitness when compared with the available literature. Moreover, the anaerobic capacity of these athletes appeared to be relatively high compared with paraplegic participants.

**Gordon, Franklin et al. 2007 – Further mechanical considerations between polar**

Gordon, R. S.; Franklin, K. L.; Davies, B.; Baker, J. S. (2007):

## Further mechanical considerations between polar and SRM mobile ergometer systems during laboratory-based high-intensity, intermittent cycling activity.

In: *Res Sports Med* 15 (4), S. 241–247. DOI: 10.1080/15438620701525540.

*Abstract:*

The purpose of this article is to outline mechanical issues related to the use of the Polar S710 heart monitor with Power Unit when compared with the SRM Powercrank system. There are issues outlined in this article that refer to the suitability of the Polar S710 for the quantification of performance during downhill cycling that relate to chain vibration, chain tension, and time interval sampling rates.

**Gore, Hahn et al. 1998 – Altitude training at 2690m does**

Gore, C. J.; Hahn, A.; Rice, A.; Bourdon, P.; Lawrence, S.; Walsh, C. et al. (1998):

## Altitude training at 2690m does not increase total haemoglobin mass or sea level VO2max in world champion track cyclists.

In: *J Sci Med Sport* 1 (3), S. 156–170.

*Abstract:*

Haemoglobin mass (Hb mass), maximum oxygen consumption (VO2max), simulated 4000 m individual pursuit cycling performance (IP4000), and haematological markers of red blood cell (RBC) turnover were measured in 8 male cyclists before and after (A) 31 d of altitude training at 2690 m. The dependent variables were measured serially after altitude on d A3-4, A8-9 and A20-21. There was no significant change in Hb mass over the course of the study and VO2max at d A9 was significantly lower than the baseline value (79.3 +/- 0.7 versus 81.4 +/- 0.6 ml x kg(-1) x min(-1), respectively). No increase in Hb mass or VO2max was probably due to initial values being close to the natural physiological limit with little scope for further change. When the IP4000 was analysed as a function of the best score on any of the three test days after altitude training there was a 4% improvement that was not reflected in a corresponding change in VO2max or Hb mass. RBC creatine concentration was significantly reduced after altitude training, suggesting a decrease in the average age of the RBC population. However, measurement of reticulocyte number and serum concentrations of erythropoietin, haptoglobin and bilirubin before and after altitude provided no evidence of increased RBC turnover. The data suggest that for these elite cyclists any benefit of altitude training was not from changes in VO2max or Hb mass, although this does not exclude the possibility of improved anaerobic capacity.

**Gore, Hahn 2005 – Letter to the editors**

Gore, C. J.; Hahn, A. G. (2005):

## Letter to the editors - Re: Heinicke K, Heinicke I, Schmidt W, Wolfarth B. A three-week traditional altitude training increases hemoglobin mass and red cell volume in elite biathlon athletes. Int J Sports Med 2005; 26: 350-355.

In: *Int J Sports Med* 26 (6), 504-5; author reply 506-7. DOI: 10.1055/s-2005-865832.

**Gore, Hahn et al. 2001 – Live high:train low increases muscle**

Gore, C. J.; Hahn, A. G.; Aughey, R. J.; Martin, D. T.; Ashenden, M. J.; Clark, S. A. et al. (2001):

## Live high:train low increases muscle buffer capacity and submaximal cycling efficiency.

In: *Acta Physiol. Scand.* 173 (3), S. 275–286. DOI: 10.1046/j.1365-201X.2001.00906.x.

*Abstract:*

This study investigated whether hypoxic exposure increased muscle buffer capacity (beta(m)) and mechanical efficiency during exercise in male athletes. A control (CON, n=7) and a live high:train low group (LHTL, n=6) trained at near sea level (600 m), with the LHTL group sleeping for 23 nights in simulated moderate altitude (3000 m). Whole body oxygen consumption (VO2) was measured under normoxia before, during and after 23 nights of sleeping in hypoxia, during cycle ergometry comprising 4 x 4-min submaximal stages, 2-min at 5.6 +/- 0.4 W kg(-1), and 2-min 'all-out' to determine total work and VO(2peak). A vastus lateralis muscle biopsy was taken at rest and after a standardized 2-min 5.6 +/- 0.4 W kg(-1) bout, before and after LHTL, and analysed for beta(m) and metabolites. After LHTL, beta(m) was increased (18%, P < 0.05). Although work was maintained, VO(2peak) fell after LHTL (7%, P < 0.05). Submaximal VO2 was reduced (4.4%, P < 0.05) and efficiency improved (0.8%, P < 0.05) after LHTL probably because of a shift in fuel utilization. This is the first study to show that hypoxic exposure, per se, increases muscle buffer capacity. Further, reduced VO2 during normoxic exercise after LHTL suggests that improved exercise efficiency is a fundamental adaptation to LHTL.

**Gore, Hahn et al. 1997 – VO2max and haemoglobin mass**

Gore, C. J.; Hahn, A. G.; Burge, C. M.; Telford, R. D. (1997):

## VO2max and haemoglobin mass of trained athletes during high intensity training.

In: *Int J Sports Med* 18 (6), S. 477–482. DOI: 10.1055/s-2007-972667.

*Abstract:*

The correlation between relative haemoglobin mass (Hb mass, g x kg[-1]) and relative maximal oxygen consumption (VO2max, ml x kg(-1) x min[-1]) in 62 trained athletes (33 male runners, 12 male rowers and 17 female rowers) with national and/ or international competitive experience was examined. The correlation between Hb mass and VO2max was highest for the female rowers (n=17, r=0.92, p<0.0001), lower for the male rowers (n = 12, r=0.79, p < 0.005) and lowest for the male runners (n=33, r=0.48, p = 0.005). These results suggest that, within an athletic sample, Hb mass may be used to estimate potential aerobic power. In a second series of experiments, Hb mass was measured before and after three different training programs in sub-sets of the subjects used in the earlier study. Hb mass did not change following 12 weeks of intense rowing training, 4 weeks of heat training (32 degrees C), or 4 weeks of medium-altitude training (1740 m). The corresponding increases in VO2max were 7.8%, no change and 2.1 %, respectively. These results suggest that heat or altitude training does not increase Hb mass in trained athletes. Previous studies that demonstrate increases in total red cell volume following altitude acclimatization used subjects with only modest aerobic power, whereas the present study used trained subjects. It is concluded that trained athletes with erythrocythemic hypervolemia have limited capability to increase further either total red cell volume or Hb mass.

**Gore, Hahn et al. 1996 – Increased arterial desaturation in trained**

Gore, C. J.; Hahn, A. G.; Scroop, G. C.; Watson, D. B.; Norton, K. I.; Wood, R. J. et al. (1996):

## Increased arterial desaturation in trained cyclists during maximal exercise at 580 m altitude.

In: *J. Appl. Physiol.* 80 (6), S. 2204–2210.

*Abstract:*

This study utilized a hypobaric chamber to compare the effects of mild hypobaria (MH; 50 mmHg, approximately 580 m altitude) on blood O2 status and maximal O2 consumption (VO2max) in 9 untrained and 11 trained (T) cyclists with VO2max values of 51 +/- 3 and 77 +/- 1 ml.kg-1.min-1, respectively. In both groups, arterial O2 saturation (SaO2) decreased significantly during maximal exercise, and this effect was enhanced with MH. Both these responses were significantly greater in the T cyclists in whom the final SaO2 during MH was 86.5 +/- 0.9%. When the group data were combined, approximately 65% of the variance in SaO2 could be attributed to a widened alveolar-arterial Po2 difference. The arterial PO2 during maximal exercise at sea level in the T group was on the steeper portion of the hemoglobin-O2-loading curve (T, 68.3 +/- 1.3 Torr; untrained, 89.0 +/- 2.9 Torr) such that a similar decrease in arterial PO2 in the two groups in response to MH resulted in a significantly greater fall in both SaO2 and calculated O2 content in the T group. As a consequence, the VO2max fell significantly only in the T group (mean change, -6.8 +/- 1.5%; range, + 1.2 to - 12.3%), with approximately 70% of this decrease being due to a fall in O2 content. This is the lowest altitude reported to decrease VO2max, suggesting that T athletes are more susceptible to a fall in inspired PO2.

**Gore, Little et al. 1997 – Reduced performance of male**

Gore, C. J.; Little, S. C.; Hahn, A. G.; Scroop, G. C.; Norton, K. I.; Bourdon, P. C. et al. (1997):

## Reduced performance of male and female athletes at 580 m altitude.

In: *Eur J Appl Physiol Occup Physiol* 75 (2), S. 136–143.

*Abstract:*

This study examined the effect of mild hypobaria (MH) on the peak oxygen consumption (VO2peak) and performance of ten trained male athletes [x (SEM); VO2peak = 72.4 (2.2) ml x kg(-1) x min(-1)] and ten trained female athletes [VO2peak = 60.8 (2.1) ml x kg(-1) x min(-1)]. Subjects performed 5-min maximal work tests on a cycle ergometer within a hypobaric chamber at both normobaria (N, 99.33 kPa) and at MH (92.66 kPa), using a counter-balanced design. MH was equivalent to 580 m altitude. VO2peak at MH decreased significantly compared with N in both men [-5.9 (0.9)%] and women [-3.7 (1.0)%]. Performance (total kJ) at MH was also reduced significantly in men [-3.6 (0.8)%] and women [-3.8 (1.2)%]. Arterial oxyhaemoglobin saturation (SaO2) at VO2peak was significantly lower at MH compared with N in both men [90.1 (0.6)% versus 92.0 (0.6)%] and women [89.7 (3.1)% versus 92.1 (3.0)%]. While SaO2 at VO2peak was not different between men and women, it was concluded that relative, rather than absolute. VO2peak may be a more appropriate predictor of exercise-induced hypoxaemia. For men and women, it was calculated that 67-76% of the decrease in VO2peak could be accounted for by a decrease in O2 delivery, which indicates that reduced O2 tension at mild altitude (580 m) leads to impairment of exercise performance in a maximal work bout lasting approximately 5 min.

**Gore, McSharry et al. 2008 – Preparation for football competition**

Gore, C. J.; McSharry, P. E.; Hewitt, A. J.; Saunders, P. U. (2008):

## Preparation for football competition at moderate to high altitude.

In: *Scand J Med Sci Sports* 18 Suppl 1, S. 85–95. DOI: 10.1111/j.1600-0838.2008.00836.x.

*Abstract:*

Analysis of approximately 100 years of home-and-away South American World Cup matches illustrate that football competition at moderate/high altitude (>2000 m) favors the home team, although this is more than compensated by the likelihood of sea-level teams winning at home against the same opponents who have descended from altitude. Nevertheless, the home team advantage at altitudes above approximately 2000 m may reflect that traditionally, teams from sea level or low altitude have not spent 1-2 weeks acclimatizing at altitude. Despite large differences between individuals, in the first few days at high altitude (e.g. La Paz, 3600 m) some players experience symptoms of acute mountain sickness (AMS) such as headache and disrupted sleep, and their maximum aerobic power (VO2max) is approximately 25% reduced while their ventilation, heart rate and blood lactate during submaximal exercise are elevated. Simulated altitude for a few weeks before competition at altitude can be used to attain partial ventilatory acclimation and ameliorated symptoms of AMS. The variety of simulated altitude exposures usually created with enriched nitrogen mixtures of air include resting or exercising for a few hours per day or sleeping approximately 8 h/night in hypoxia. Preparation for competition at moderate/high altitude by training at altitude is probably superior to simulated exposure; however, the optimal duration at moderate/high altitude is unclear. Preparing for 1-2 weeks at moderate/high altitude is a reasonable compromise between the benefits associated with overcoming AMS and partial restoration of VO2max vs the likelihood of detraining.

**Gore, Rodríguez et al. 2006 – Increased serum erythropoietin but not**

Gore, Christopher J.; Rodríguez, Ferran A.; Truijens, Martin J.; Townsend, Nathan E.; Stray-Gundersen, James; Levine, Benjamin D. (2006):

## Increased serum erythropoietin but not red cell production after 4 wk of intermittent hypobaric hypoxia (4,000-5,500 m).

In: *J. Appl. Physiol.* 101 (5), S. 1386–1393. DOI: 10.1152/japplphysiol.00342.2006.

*Abstract:*

This study tested the hypothesis that athletes exposed to 4 wk of intermittent hypobaric hypoxia exposure (3 h/day, 5 days/wk at 4,000-5,500 m) or double-blind placebo increase their red blood cell volume (RCV) and hemoglobin mass (Hbmass) secondary to an increase in erythropoietin (EPO). Twenty-three collegiate level athletes were measured before (Pre) and after (Post) the intervention for RCV via Evans blue (EB) dye and in duplicate for Hbmass using CO rebreathing. Hematological indexes including EPO, soluble transferrin receptor, and reticulocyte parameters were measured on 8-10 occasions spanning the intervention. The subjects were randomly divided among hypobaric hypoxia (Hypo, n = 11) and normoxic (Norm, n = 12) groups. Apart from doubling EPO concentration 3 h after hypoxia there was no increase in any of the measures for either Hypo or Norm groups. The mean change in RCV from Pre to Post for the Hypo group was 2.3% (95% confidence limits = -4.8 to 9.5%) and for the Norm group was -0.2% (-5.7 to 5.3%). The corresponding changes in Hbmass were 1.0% (-1.3 to 3.3%) for Hypo and -0.3% (-2.6 to 3.1%) for Norm. There was good agreement between blood volume (BV) from EB and CO: EB BV = 1.03 x CO BV + 142, r2 = 0.85, P < 0.0001. Overall, evidence from four independent techniques (RCV, Hbmass, reticulocyte parameters, and soluble transferrin receptor) suggests that intermittent hypobaric hypoxia exposure did not accelerate erythropoiesis despite the increase in serum EPO.

**Gore, Clark et al. 2007 – Nonhematological mechanisms of improved sea-level**

Gore, Christopher John; Clark, Sally A.; Saunders, Philo U. (2007):

## Nonhematological mechanisms of improved sea-level performance after hypoxic exposure.

In: *Med Sci Sports Exerc* 39 (9), S. 1600–1609. DOI: 10.1249/mss.0b013e3180de49d3.



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*Abstract:*

Altitude training has been used regularly for the past five decades by elite endurance athletes, with the goal of improving performance at sea level. The dominant paradigm is that the improved performance at sea level is due primarily to an accelerated erythropoietic response due to the reduced oxygen available at altitude, leading to an increase in red cell mass, maximal oxygen uptake, and competitive performance. Blood doping and exogenous use of erythropoietin demonstrate the unequivocal performance benefits of more red blood cells to an athlete, but it is perhaps revealing that long-term residence at high altitude does not increase hemoglobin concentration in Tibetans and Ethiopians compared with the polycythemia commonly observed in Andeans. This review also explores evidence of factors other than accelerated erythropoiesis that can contribute to improved athletic performance at sea level after living and/or training in natural or artificial hypoxia. We describe a range of studies that have demonstrated performance improvements after various forms of altitude exposures despite no increase in red cell mass. In addition, the multifactor cascade of responses induced by hypoxia includes angiogenesis, glucose transport, glycolysis, and pH regulation, each of which may partially explain improved endurance performance independent of a larger number of red blood cells. Specific beneficial nonhematological factors include improved muscle efficiency probably at a mitochondrial level, greater muscle buffering, and the ability to tolerate lactic acid production. Future research should examine both hematological and nonhematological mechanisms of adaptation to hypoxia that might enhance the performance of elite athletes at sea level.

**Gough, Sharpe et al. 2013 – The effects of injury**

Gough, C. E.; Sharpe, K.; Garvican, L. A.; Anson, J. M.; Saunders, P. U.; Gore, C. J. (2013):

## The effects of injury and illness on haemoglobin mass.

In: *Int J Sports Med* 34 (9), S. 763–769. DOI: 10.1055/s-0033-1333692.

*Abstract:*

This study sought to quantify the effects of reduced training, surgery and changes in body mass on haemoglobin mass (Hbmass) in athletes. Hbmass of 15 athletes (6 males, 9 females) was measured 9±6 (mean±SD) times over 162±198 days, during reduced training following injury or illness. Additionally, body mass (n=15 athletes) and episodes of altitude training (n=2), iron supplementation (n=5), or surgery (n=3) were documented. Training was recorded and compared with pre-injury levels. Analysis used linear mixed models for ln(Hbmass), with Sex, Altitude, Surgery, Iron, Training and log(Body Mass) as fixed effects, and Athlete as a fixed and random effect. Reduced training and surgery led to 2.3% (p=0.02) and 2.7% (p=0.04) decreases in Hbmass, respectively. Altitude and iron increased Hbmass by 2.4% (p=0.03) and 4.2% (p=0.05), respectively. The effect of changes in body mass on Hbmass was not statistically significant (p=0.435).The estimates for the effects of surgery and altitude on Hbmass should be confirmed by future research using a larger sample of athletes. These estimates could be used to inform the judgements of experts examining athlete biological passports, improving their interpretation of Hbmass perturbations, which athletes claim are related to injury, thereby protecting innocent athletes from unfair sanctioning.

**Gough, Saunders et al. 2012 – Influence of altitude training modality**

Gough, Clare E.; Saunders, Philo U.; Fowlie, John; Savage, Bernard; Pyne, David B.; Anson, Judith M. et al. (2012):

## Influence of altitude training modality on performance and total haemoglobin mass in elite swimmers.

In: *Eur. J. Appl. Physiol.* 112 (9), S. 3275–3285. DOI: 10.1007/s00421-011-2291-7.

*Abstract:*

We compared changes in performance and total haemoglobin mass (tHb) of elite swimmers in the weeks following either Classic or Live High:Train Low (LHTL) altitude training. Twenty-six elite swimmers (15 male, 11 female, 21.4 ± 2.7 years; mean ± SD) were divided into two groups for 3 weeks of either Classic or LHTL



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altitude training. Swimming performances over 100 or 200 m were assessed before altitude, then 1, 7, 14 and 28 days after returning to sea-level. Total haemoglobin mass was measured twice before altitude, then 1 and 14 days after return to sea-level. Changes in swimming performance in the first week after Classic and LHTL were compared against those of Race Control (n = 11), a group of elite swimmers who did not complete altitude training. In addition, a season-long comparison of swimming performance between altitude and non-altitude groups was undertaken to compare the progression of performances over the course of a competitive season. Regardless of altitude training modality, swimming performances were substantially slower 1 day (Classic 1.4 ± 1.3% and LHTL 1.6 ± 1.6%; mean ± 90% confidence limits) and 7 days (0.9 ± 1.0% and 1.9 ± 1.1%) after altitude compared to Race Control. In both groups, performances 14 and 28 days after altitude were not different from pre-altitude. The season-long comparison indicated that no clear advantage was obtained by swimmers who completed altitude training. Both Classic and LHTL elicited ~4% increases in tHb. Although altitude training induced erythropoeisis, this physiological adaptation did not transfer directly into improved competitive performance in elite swimmers.

**Groslambert, Grappe et al. 2004 – A perceptive individual time trial**

Groslambert, A.; Grappe, F.; Bertucci, W.; Perrey, S.; Girard, A. J.; Rouillon, J. D. (2004):

## A perceptive individual time trial performed by triathletes to estimate the anaerobic threshold. A preliminary study.

In: *J Sports Med Phys Fitness* 44 (2), S. 147–156.

*Abstract:*

AIM

The aim of the study was to test the ability to estimate the power output (PO) and heart rate (HR) associated with ''anaerobic threshold'' levels for triathletes by means of a 30-min perceptive individual time trial (PITT30).

METHODS

Thirteen triathletes (8 males and 5 females) performed an incremental exercise test to estimate maximal parameters such as oxygen uptake, power output and heart rate. From this incremental exercise test, the individual anaerobic threshold (IAT) and ventilatory threshold (VT) for all subjects were estimated. Then, the subjects completed a PITT30 at self-selected work intensity on a stationary ergometer equipped with the SRM Training System. Mean values of PO, HR, and pedalling cadence were recorded continuously between the 5th and the 30th min of the test.

RESULTS

Significant correlations were observed between the mean PO recorded during PITT30 and PO measured at IAT ($r=0.88$; $p<0.0001$) and at VT ($r=0.89$; $p<0.0001$). Furthermore, bias and limits of agreement confirm the degree of association between the 3

METHODS

However, PITT30 over-estimated HR values compared to the values obtained at IAT and VT.

CONCLUSION

It was concluded that, for triathletes, mean PO measured with PITT30 allows a partial valid estimation of PO associated with 2 known methods of ''anaerobic threshold'' determination. The application of PITT30 may offer a useful tool for athletes and coaches to estimate the ''anaerobic threshold'' in order to control accurately the training effects.

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### Haakonssen, Martin et al. 2013 – Energy expenditure of constant

Haakonssen, Eric C.; Martin, David T.; Burke, Louise M.; Jenkins, David G. (2013):

## Energy expenditure of constant- and variable-intensity cycling: power meter estimates.

In: *Med Sci Sports Exerc* 45 (9), S. 1833–1840. DOI: 10.1249/MSS.0b013e31828e18e6.

*Abstract:*

PURPOSE

The objective of this study is to compare the effects of constant- and variable-intensity cycling on gross efficiency (GE) and to compare estimates of energy expenditure (EE) made using indirect calorimetry (CAL) with estimates derived from commercially available power meters.

METHODS

Nine national team female road cyclists completed a GE test (GEtest = 4 min at approximately 45%, approximately 55%, approximately 65%, and approximately 75% maximal aerobic power (MAP)) before and after 10.5 min of either constant- (CON)- or variable- (VAR)-intensity cycling averaging approximately 55% MAP. GE measured before, after, and during CON and VAR cycling was compared. Total EE (kJ) for 10.5 min of VAR cycling was estimated using indirect CAL and compared with estimates on the basis of mechanical power [Schoberer Rad Messtechnik (SRM)] using the group mean GE, each athlete's mean GE, and each athlete's power to GE regression.

RESULTS

There was no effect of VAR on GEtests ($P = 0.74$). GE reduced from 19.1% ± 0.4% (mean ± SE) during the pretrial GEtests to 18.7% ± 0.4% during the posttrial GEtests ($P < 0.05$) in both conditions. Differences in GE (mean ± SD) measured during CON (18.4% ± 1.6%) and VAR cycling (18.6% ± 1.1%) were trivial ($P = 0.28$). SRM-based estimates of EE were most accurate when using individual athlete's power GE regression using Pre- and Post-VAR GEtest data combined (Δ(Equation is included in full-text article.)(%) ± 90% CI, 0.3 ± 0.8; R 0.98, $P < 0.001$). Group mean estimates were within approximately 1% of CAL, although individual errors were approximately 11%.

CONCLUSION

Findings support the use of calibrated power meters for estimating cycling EE. For trained female road cyclists, total mechanical work (kJ) multiplied by 5.3 (GE = 19%) provides a valid estimation of total EE during variable-intensity cycling <75% MAP, although determining each athlete's GE improves accuracy greatly.

### Hahn, Gore 2001 – The effect of altitude

Hahn, A. G.; Gore, C. J. (2001):

## The effect of altitude on cycling performance: a challenge to traditional concepts.

In: *Sports Med* 31 (7), S. 533–557.

*Abstract:*

Acute exposure to moderate altitude is likely to enhance cycling performance on flat terrain because the benefit of reduced aerodynamic drag outweighs the decrease in maximum aerobic power [maximal oxygen uptake (VO2max)]. In contrast, when the course is mountainous, cycling performance will be reduced at moderate altitude. Living and training at altitude, or living in an hypoxic environment (approximately 2500 m) but training near sea level, are popular practices among elite cyclists seeking enhanced performance at sea level. In an attempt to confirm or refute the efficacy of these practices, we reviewed studies conducted on highly-trained athletes and, where possible, on elite cyclists. To ensure relevance of the information to the conditions likely to be encountered by cyclists, we concentrated our literature survey on studies that have used 2- to 4-week exposures to moderate altitude (1500 to 3000 m). With acclimatisation there is strong evidence of decreased production or increased clearance of lactate in the muscle, moderate evidence of enhanced muscle buffering capacity (beta m) and tenuous evidence of improved mechanical efficiency (ME) of cycling. Our analysis of the relevant literature indicates that, in contrast to the existing paradigm, adaptation to natural or simulated moderate altitude does not stimulate red cell production sufficiently to increase red cell volume (RCV) and haemoglobin mass (Hb(mass)). Hypoxia does increase serum erthyropoietin levels but the next step in the erythropoietic cascade is not clearly established; there is only weak evidence of an increase in young red blood cells (reticulocytes). Moreover, the collective evidence from studies of highly-trained athletes indicates that adaptation to hypoxia is unlikely to enhance sea level VO2max. Such enhancement would be expected if RCV and Hb(mass) were elevated. The accumulated results of 5 different research groups that have used controlled study designs indicate that continuous living and training at moderate altitude does not improve sea level performance of high level athletes. However, recent studies from 3 independent laboratories have consistently shown small improvements after living in hypoxia and training near sea level. While other research groups have attributed the improved performance to increased RCV and VO2max, we cite evidence that changes at the muscle level (beta m and ME) could be the fundamental mechanism. While living at altitude but training near sea level may be optimal for enhancing the performance of competitive cyclists, much further research is required to confirm its benefit. If this benefit does exist, it probably varies between individuals and averages little more than 1%.

**Hahn, Gore et al. 2001 – An evaluation of the concept**

Hahn, A. G.; Gore, C. J.; Martin, D. T.; Ashenden, M. J.; Roberts, A. D.; Logan, P. A. (2001):

## An evaluation of the concept of living at moderate altitude and training at sea level.

In: *Comp. Biochem. Physiol., Part A Mol. Integr. Physiol.* 128 (4), S. 777–789.

*Abstract:*

Despite equivocal findings about the benefit of altitude training, current theory dictates that the best approach is to spend several weeks living at > or =2500 m but training near sea level. This paper summarizes six studies in which we used simulated altitude (normobaric hypoxia) to examine: (i) the assumption that moderate hypoxia compromises training intensity (two studies); and (ii) the nature of physiological adaptations to sleeping in moderate hypoxia (four studies). When submaximal exercise was >55% of sea level maximum oxygen uptake (VO2max), 1800 m simulated altitude significantly increased heart rate, blood lactate and perceived exertion of skiers. In addition, cyclists self-selected lower workloads during high-intensity exercise in hypoxia (2100 m) than in normoxia. Consequently, our findings partially confirm the rationale for 'living high, training low'. In the remaining four studies, serum erythropoietin increased 80% in the early stages of hypoxic exposure, but the reticulocyte response did not significantly exceed that of control subjects. There was no significant increase in haemoglobin mass (Hb(mass)) and VO2max tended to decrease. Performance in exercise tasks lasting approximately 4 min showed a non-significant trend toward improvement (1.0+/-0.4% vs. 0.1+/-0.4% for a control group; P=0.13 for group x time interaction). We conclude that sleeping in moderate hypoxia (2650-3000 m) for up to 23 days may offer practical benefit to elite athletes, but that any effect is not likely due to increased Hb(mass) or VO2max.

**Hajoglou, Foster et al. 2005 – Effect of warm-up on cycle**

Hajoglou, Amanda; Foster, Carl; Koning, Jos J. de; Lucia, Alejandro; Kernozek, Thomas W.; Porcari, John P. (2005):

## Effect of warm-up on cycle time trial performance.

In: *Med Sci Sports Exerc* 37 (9), S. 1608–1614.

*Abstract:*

PURPOSE

This study was designed to determine the effect of warm-up on 3-km cycling time trial (TT) performance, and the influence of accelerated VO(2) kinetics on such effect.

METHODS

Eight well-trained road cyclists, habituated to 3-km time trials, performed randomly ordered 3-km TT after a) no warm-up (NWU), b) easy warm-up (EWU) (15 min comprised of 5-min segments at 70, 80, and 90% of ventilatory threshold (VT) followed by 2 min of rest), or c) hard warm-up (HWU) (15 min comprised of 5-min segments at 70, 80, and 90% VT, plus 3 min at the respiratory compensation threshold (RCT) followed by 6 min of rest). VO(2) and power output (SRM), aerobic and anaerobic energy contributions, and VO(2) kinetics (mean response time to 63% of the VO(2) observed at 2 km) were determined throughout each TT.

RESULTS

Three-kilometer TT performance was (P < 0.05) improved for both EWU (266.8 +/- 12.0 s) (-2.8%) and HWU (267.3 +/- 10.4 s) (-2.6%) versus NWU (274.4 +/- 12.1 s). The gain in performance was predominantly during the first 1000 m in both EWU (48% of gain) and HWU (53% of gain). This reflected a higher power output during the first 1000 m in both EWU (384 W) and HWU warm-up (386 W) versus NWU (344 W) trials. The mean response time was faster in both EWU (45 +/- 10 s) and HWU (41 +/- 12 s) versus NWU (52 +/- 13 s) trials. There were no differences in anaerobic power output during the trials, but aerobic power output during the first 1000 m was larger during both EWU (203 W) and HWU (208 W) versus NWU (163 W) trials.

CONCLUSIONS

During endurance events of intermediate duration (4-5 min), performance is enhanced by warm-up irrespective of warm-up intensity. The improved performance is related to an acceleration of VO(2) kinetics.

**Hopker, Myers et al. 2010 – Validity and reliability**

Hopker, J.; Myers, S.; Jobson, S. A.; Bruce, W.; Passfield, L. (2010):

## Validity and reliability of the Wattbike cycle ergometer.

In: *Int J Sports Med* 31 (10), S. 731–736. DOI: 10.1055/s-0030-1261968.

*Abstract:*

The purpose of this study was to assess the validity and reliability of the Wattbike cycle ergometer against the SRM Powermeter using a dynamic calibration rig (CALRIG) and trained and untrained human participants. Using the CALRIG power outputs of 50-1 250 W were assessed at cadences of 70 and 90 rev x min(-1). Validity and reliability data were also obtained from 3 repeated trials in both trained and untrained populations. 4 work rates were used during each trial ranging from 50-300 W. CALRIG data demonstrated significant differences (P<0.05) between SRM and Wattbike across the work rates at both cadences. Significant differences existed in recorded power outputs from the SRM and Wattbike during steady state trials (power outputs 50-300 W) in both human populations (156±72 W vs. 153±64 W for SRM and Wattbike respectively; P<0.05). The reliability (CV) of the Wattbike in the untrained population was 6.7% (95%CI 4.8-13.2%) compared to 2.2% with the SRM (95%CI 1.5-4.1%). In the trained population the Wattbike CV was 2.6% (95%CI 1.8-5.1%) compared to 1.1% with the SRM (95%CI 0.7-2.0%). These results suggest that when compared to the SRM, the Wattbike has acceptable accuracy. Reliability data suggest coaches and cyclists may need to use some caution when using the Wattbike at low power outputs in a test-retest setting.

**Hurst, Atkins 2006 – Agreement between polar and SRM**

Hurst, Howard T.; Atkins, Stephen (2006):

## Agreement between polar and SRM mobile ergometer systems during laboratory-based high-intensity, intermittent cycling activity.

In: *J Sports Sci* 24 (8), S. 863–868. DOI: 10.1080/02640410500245678.

*Abstract:*

The purpose of this study was to assess the agreement between two mobile cycle ergometer systems for recording high-intensity, intermittent power output. Twelve trained male cyclists (age 31.4 +/- 9.8 years) performed a single 3 min intermittent cycle test consisting of 12 all-out efforts, separated by periods of passive recovery ranging from 5 to 15 s. Power output was recorded using a Polar S710 heart rate monitor and power sensor kit and an SRM Powercrank system for each test. The SRM used torque and angular velocity to calculate power, while the S710 used chain speed and vibration to calculate power. Significant differences (P < 0.05) in power were found at 8 of the 12 efforts. A significant difference (P = 0.001) was also found when power was averaged over all 12 intervals. Mean power was 556 +/- 102 W and 446 +/- 61 W for the SRM and S710 respectively. The S710 underestimated power by an average of 23% with random errors of */[division sign] 24% when compared with the SRM. Random errors ranged from 36% to 141% with a median of 51%. The results indicate there was little agreement between the two systems and that the Polar S710 did not provide a valid measure of power during intermittent cycling activity when compared with the SRM. Power recorded by the S710 system was influenced greatly by chain vibration and sampling rates.

**Hurst, Atkins 2006 – Power output of field-based downhill**

Hurst, Howard Thomas; Atkins, Stephen (2006):

## Power output of field-based downhill mountain biking.

In: *J Sports Sci* 24 (10), S. 1047–1053. DOI: 10.1080/02640410500431997.

*Abstract:*

The purpose of this study was to assess the power output of field-based downhill mountain biking. Seventeen trained male downhill cyclists (age 27.1 +/- 5.1 years) competing nationally performed two timed runs of a measured downhill course. An SRM powermeter was used to simultaneously record power, cadence, and speed. Values were sampled at 1-s intervals. Heart rates were recorded at 5-s intervals using a Polar S710 heart rate monitor. Peak and mean power output were 834 +/- 129 W and 75 +/- 26 W respectively. Mean power accounted for only 9% of peak values. Paradoxically, mean heart rate was 168 +/- 9 beats x min(-1) (89% of age-predicted maximum heart rate). Mean cadence (27 +/- 5 rev x min(-1)) was significantly related to speed (r = 0.51; P < 0.01). Analysis revealed an average of 38 pedal actions per run, with average pedalling periods of 5 s. Power and cadence were not significantly related to run time or any other variable. Our results support the intermittent nature of downhill mountain biking. The poor relationships between power and run time and between cadence and run time suggest they are not essential pre-requisites to downhill mountain biking performance and indicate the importance of riding dynamics to overall performance.

**Jobson, Woodside et al. 2008 – Allometric Scaling of Uphill Cycling**

Jobson, S.; Woodside, J.; Passfield, L.; Nevill, A. (2008):

## Allometric Scaling of Uphill Cycling Performance.

In: *Int J Sports Med* 29 (09), S. 753–757. DOI: 10.1055/s-2007-989441.

*Abstract:*

Previous laboratory-based investigations have identified optimal body mass scaling exponents in the range 0.79 - 0.91 for uphill cycling. The purpose of this investigation was to evaluate whether or not these exponents are also valid in a field setting. A proportional allometric model was used to predict the optimal power-to-mass ratios associated with road-based uphill time-trial cycling performance. The optimal power function models predicting mean cycle speed during a 5.3 km, 5.4 % road hill-climb time-trial were (V˙O2max · m−1.24)0.55 and (RMPmax · m−1.04)0.54, explained variance being 84.6 % and 70.5 %, respectively. Slightly higher mass exponents were observed when the mass predictor was replaced with the combined mass of cyclist and equipment (mC). Uphill cycling speed was proportional to (V˙O2max · mC−1.33)0.57 and (RMPmax · mC−1.10)0.59. The curvilinear exponents, 0.54 - 0.59, identified a relatively strong curvilinear relationship between cycling speed and energy cost, suggesting that air resistance remains influential when cycling up a gradient of 5.4 %. These results provide some support for previously reported uphill cycling mass exponents derived in laboratories. However, the exponents reported here were a little higher than those reported previously, a finding possibly explained by a lack of geometric similarity in this sample.

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### Jobson, Passfield et al. 2009 – The analysis and utilization

Jobson, Simon A.; Passfield, Louis; Atkinson, Greg; Barton, Gabor; Scarf, Philip (2009):

## The analysis and utilization of cycling training data.

In: *Sports Med* 39 (10), S. 833–844. DOI: 10.2165/11317840-000000000-00000.

*Abstract:*

Most mathematical models of athletic training require the quantification of training intensity and quantity or 'dose'. We aim to summarize both the methods available for such quantification, particularly in relation to cycle sport, and the mathematical techniques that may be used to model the relationship between training and performance. Endurance athletes have used training volume (kilometres per week and/or hours per week) as an index of training dose with some success. However, such methods usually fail to accommodate the potentially important influence of training intensity. The scientific literature has provided some support for alternative methods such as the session rating of perceived exertion, which provides a subjective quantification of the intensity of exercise; and the heart rate-derived training impulse (TRIMP) method, which quantifies the training stimulus as a composite of external loading and physiological response, multiplying the training load (stress) by the training intensity (strain). Other methods described in the scientific literature include 'ordinal categorization' and a heart rate-based excess post-exercise oxygen consumption method. In cycle sport, mobile cycle ergometers (e.g. SRM and PowerTap) are now widely available. These devices allow the continuous measurement of the cyclists' work rate (power output) when riding their own bicycles during training and competition. However, the inherent variability in power output when cycling poses several challenges in attempting to evaluate the exact nature of a session. Such variability means that average power output is incommensurate with the cyclist's physiological strain. A useful alternative may be the use of an exponentially weighted averaging process to represent the data as a 'normalized power'. Several research groups have applied systems theory to analyse the responses to physical training. Impulse-response models aim to relate training loads to performance, taking into account the dynamic and temporal characteristics of training and, therefore, the effects of load sequences over time. Despite the successes of this approach it has some significant limitations, e.g. an excessive number of performance tests to determine model parameters. Non-linear artificial neural networks may provide a more accurate description of the complex non-linear biological adaptation process. However, such models may also be constrained by the large number of datasets required to 'train' the model. A number of alternative mathematical approaches such as the Performance-Potential-Metamodel (PerPot), mixed linear modelling, cluster analysis and chaos theory display conceptual richness. However, much further research is required before such approaches can be considered as viable alternatives to traditional impulse-response models. Some of these methods may not provide useful information about the relationship between training and performance. However, they may help describe the complex physiological training response phenomenon.

### Julian, Gore et al. 2004 – Intermittent normobaric hypoxia does not

Julian, Colleen G.; Gore, Christopher J.; Wilber, Randall L.; Daniels, Jack T.; Fredericson, Michael; Stray-Gundersen, James et al. (2004):

## Intermittent normobaric hypoxia does not alter performance or erythropoietic markers in highly trained distance runners.

In: *J. Appl. Physiol.* 96 (5), S. 1800–1807. DOI: 10.1152/japplphysiol.00969.2003.

*Abstract:*

This study was designed to test the hypothesis that intermittent normobaric hypoxia at rest is a sufficient stimulus to elicit changes in physiological measures associated with improved performance in highly trained distance runners. Fourteen national-class distance runners completed a 4-wk regimen (5:5-min hypoxia-to-normoxia ratio for 70 min, 5 times/wk) of intermittent normobaric hypoxia (Hyp) or placebo control (Norm) at rest. The experimental group was exposed to a graded decline in fraction of inspired O2: 0.12 (week 1), 0.11 (week 2), and 0.10 (weeks 3 and 4). The placebo control group was exposed to the same temporal regimen but breathed fraction of inspired O2 of 0.209 for the entire 4 wk. Subjects were matched for training history, gender, and baseline measures of maximal O2 uptake and 3,000-m time-trial performance in a randomized, balanced, double-blind design. These parameters, along with submaximal treadmill performance (economy,

heart rate, lactate, and ventilation), were measured in duplicate before, as well as 1 and 3 wk after, the intervention. Hematologic indexes, including serum concentrations of erythropoietin and soluble transferrin receptor and reticulocyte parameters (flow cytometry), were measured twice before the intervention, on days 1, 5, 10, and 19 of the intervention, and 10 and 25 days after the intervention. There were no significant differences in maximal O2 uptake, 3,000-m time-trial performance, erythropoietin, soluble transferrin receptor, or reticulocyte parameters between groups at any time. Four weeks of a 5:5-min normobaric hypoxia exposure at rest for 70 min, 5 days/wk, is not a sufficient stimulus to elicit improved performance or change the normal level of erythropoiesis in highly trained runners.

**Karsten, Jobson et al. 2014 – High Agreement between Laboratory**

Karsten, B.; Jobson, S. A.; Hopker, J.; Jimenez, A.; Beedie, C. (2014):

## High Agreement between Laboratory and Field Estimates of Critical Power in Cycling.

In: *Int J Sports Med* 35 (4), S. 298–303. DOI: 10.1055/s-0033-1349844.

*Abstract:*

The purpose of this study was to investigate the level of agreement between laboratory-based estimates of critical power (CP) and results taken from a novel field test. Subjects were fourteen trained cyclists (age 40±7 yrs; body mass 70.2±6.5 kg; VO2max 3.8±0.5 L · min-1). Laboratory-based CP was estimated from 3 constant work-rate tests at 80%, 100% and 105% of maximal aerobic power (MAP). Field-based CP was estimated from 3 all-out tests performed on an outdoor velodrome over fixed durations of 3, 7 and 12 min. Using the linear work limit (Wlim) vs. time limit (Tlim) relation for the estimation of CP1 values and the inverse time (1/t) vs. power (P) models for the estimation of CP2 values, field-based CP1 and CP2 values did not significantly differ from laboratory-based values (234±24.4 W vs. 234±25.5 W (CP1); P<0.001; limits of agreement [LOA], -10.98-10.8 W and 236±29.1 W vs. 235±24.1 W (CP2); P<0.001; [LOA], -13.88-17.3 W. Mean prediction errors for laboratory and field estimates were 2.2% (CP) and 27% (W'). Data suggest that employing all-out field tests lasting 3, 7 and 12 min has potential utility in the estimation of CP.

**Karsten, Jobson et al. 2013 – The 3-min Test Does not**

Karsten, B.; Jobson, S. A.; Hopker, J.; Passfield, L.; Beedie, C. (2013):

## The 3-min Test Does not Provide a Valid Measure of Critical Power Using the SRM Isokinetic Mode.

In: *Int J Sports Med. DOI:* 10.1055/s-0033-1349093.

*Abstract:*

Recent datas suggest that the mean power over the final 30 s of a 3-min all-out test is equivalent to Critical Power (CP) using the linear ergometer mode. The purpose of the present study was to identify whether this is also true using an "isokinetic mode". 13 cyclists performed: 1) a ramp test; 2) three 3-min all-out trials to establish End Power (EP) and work done above EP (WEP); and 3) 3 constant work rate trials to determine CP and the work done above CP (W') using the work-time (=CP1/W'1) and 1/time (=CP2/W'2) models. Coefficient of variation in EP was 4.45% between trials 1 and 2, and 4.29% between trials 2 and 3. Limits of Agreement for trials 1-2 and trials 2-3 were -2±38 W. Significant differences were observed between EP and CP1 (+37 W, P<0.001), between WEP and W'1(-6.2 kJ, P=0.001), between EP and CP2 (+31 W, P<0.001) and between WEP and W'2 (-4.2 kJ, P=0.006). Average SEE values for EP-CP1 and EP-CP2 of 7.1% and 6.6% respectively were identified. Data suggest that using an isokinetic mode 3-min all-out test, while yielding a reliable measure of EP, does not provide a valid measure of CP.

### Kinsman, Gore et al. 2005 – Sleep in athletes undertaking protocols

Kinsman, T. A.; Gore, C. J.; Hahn, A. G.; Hopkins, W. G.; Hawley, J. A.; McKenna, M. J. et al. (2005):

## Sleep in athletes undertaking protocols of exposure to nocturnal simulated altitude at 2650 m.

In: *J Sci Med Sport* 8 (2), S. 222–232.

*Abstract:*

A popular method to attempt to enhance performance is for athletes to sleep at natural or simulated moderate altitude (SMA) when training daily near sea level. Based on our previous observation of periodic breathing in athletes sleeping at SMA, we hypothesised that athletes' sleep quality would also suffer with hypoxia. Using two typical protocols of nocturnal SMA (2650 m), we examined the effect on the sleep physiology of 14 male endurance-trained athletes. The selected protocols were Consecutive (15 successive exposure nights) and Intermittent (3x 5 successive exposure nights, interspersed with 2 normoxic nights) and athletes were randomly assigned to follow either one. We monitored sleep for two successive nights under baseline conditions (B; normoxia, 600 m) and then at weekly intervals (nights 1, 8 and 15 (N1, N8 and N15, respectively)) of the protocols. Since there was no significant difference in response between the protocols being followed (based on n=7, for each group) we are unable to support a preference for either one, although the likelihood of a Type II error must be acknowledged. For all athletes (n=14), respiratory disturbance and arousal responses between B and N1, although large in magnitude, were highly individual and not statistically significant. However, SpO2 decreased at N1 versus B ($p<0.001$) and remained lower on N8 ($p<0.001$) and N15 ($p<0.001$), not returning to baseline level. Compared to B, arousals were more frequent on N8 ($p=0.02$) and N15 ($p=0.01$). The percent of rapid eye movement sleep (REM) increased from N1 to N8 ($p=0.03$) and N15 ($p=0.01$). Overall, sleeping at 2650 m causes sleep disturbance in susceptible athletes, yet there was some improvement in REM sleep over the study duration.

### Kinsman, Hahn et al. 2003 – Sleep quality responses to atmospheric

Kinsman, T. A.; Hahn, A. G.; Gore, C. J.; Martin, D. T.; Chow, C. M. (2003):

## Sleep quality responses to atmospheric variation: case studies of two elite female cyclists.

In: *J Sci Med Sport* 6 (4), S. 436–442.

*Abstract:*

Strategies applied during sleep to potentially enhance athlete performance use different atmospheric conditions. High altitude conditions are known to affect sleep adversely but the effects of mild-moderate altitude and O2 enrichment at mild altitude are uncertain. We performed case studies using two elite female road cyclists (mass and maximal aerobic power of 62 kg, 65.8 ml x kg(-1) x min(-1); 57 kg, 62.7 ml x kg(-1) x min(-1)) to examine changes in sleep for different atmospheric conditions applied throughout the preparation for, and during, an International Stage race. Conditions were: i) normoxia (600 m), ii) simulated moderate altitude (2650 m), iii) natural mild altitude (1380 m) and iv) O2 enrichment at mild altitude (30% O2@ 1300-1500 m). We measured respiratory disturbances, arousals, number of awakenings, blood oxygen saturation (SpO2), heart rate (HR), rapid eye movement sleep (REM) and deep sleep. Respiratory disturbances, SpO2 and HR responses were similar for both cyclists for all conditions. Compared with normoxia, both cyclists had somewhat reduced REM at natural mild altitude and moderate simulated altitude but differed in their REM and deep sleep responses to O2 enrichment. Compared with mild altitude, both showed increased awakenings and deep sleep with O2 enrichment. Only one cyclist clearly increased her REM sleep with O2 enrichment compared to mild altitude. Our data highlight two different sleep quality responses to atmospheric variation.

**Kinsman, Hahn et al. 2002 – Respiratory events and periodic breathing**

Kinsman, Tahnee A.; Hahn, Allan G.; Gore, Christopher J.; Wilsmore, Bradley R.; Martin, David T.; Chow, Chin-Moi (2002):

## Respiratory events and periodic breathing in cyclists sleeping at 2,650-m simulated altitude.

In: *J. Appl. Physiol.* 92 (5), S. 2114–2118. DOI: 10.1152/japplphysiol.00737.2001.

*Abstract:*

We examined the initial effect of sleeping at a simulated moderate altitude of 2,650 m on the frequency of apneas and hypopneas, as well as on the heart rate and blood oxygen saturation from pulse oximetry (SpO2) during rapid eye movement (REM) and non-rapid eye movement (NREM) sleep of 17 trained cyclists. Pulse oximetry revealed that sleeping at simulated altitude significantly increased heart rate (3 +/- 1 beats/min; means +/- SE) and decreased SpO2 (-6 +/- 1%) compared with baseline data collected near sea level. In response to simulated altitude, 15 of the 17 subjects increased the combined frequency of apneas plus hypopneas from baseline levels. On exposure to simulated altitude, the increase in apnea was significant from baseline for both sleep states (2.0 +/- 1.3 events/h for REM, 9.9 +/- 6.2 events/h for NREM), but the difference between the two states was not significantly different. Hypopnea frequency was significantly elevated from baseline to simulated altitude exposure in both sleep states, and under hypoxic conditions it was greater in REM than in NREM sleep (7.9 +/- 1.8 vs. 4.2 +/- 1.3 events/h, respectively). Periodic breathing episodes during sleep were identified in four subjects, making this the first study to show periodic breathing in healthy adults at a level of hypoxia equivalent to 2,650-m altitude. These results indicate that simulated moderate hypoxia of a level typically chosen by coaches and elite athletes for simulated altitude programs can cause substantial respiratory events during sleep.

**Kinsman, Townsend et al. 2005 – Sleep disturbance at simulated altitude**

Kinsman, Tahnee A.; Townsend, Nathan E.; Gore, Christopher J.; Hahn, Allan G.; Clark, Sally A.; Aughey, Robert J. et al. (2005):

## Sleep disturbance at simulated altitude indicated by stratified respiratory disturbance index but not hypoxic ventilatory response.

In: *Eur. J. Appl. Physiol.* 94 (5-6), S. 569–575. DOI: 10.1007/s00421-005-1368-6.

*Abstract:*

At high altitudes, the clinically defined respiratory disturbance index (RDI) and high hypoxic ventilatory response (HVR) have been associated with diminished sleep quality. Increased RDI has also been observed in some athletes sleeping at simulated moderate altitude. In this study, we investigated relationships between the HVR of 14 trained male endurance cyclists with variable RDI and sleep quality responses to simulated moderate altitude. Blood oxygen saturation (SpO2%), heart rate, RDI, arousal rate, awakenings, sleep efficiency, rapid eye movement (REM) sleep, non-REM sleep stages 1, 2 and slow wave sleep as percentages of total sleep time (%TST) were measured for two nights at normoxia of 600 m and one night at a simulated altitude of 2,650 m. HVR and RDI were not significantly correlated with sleep stage, arousal rate or awakening response to nocturnal simulated altitude. SpO2 was inversely correlated with total RDI (r = -0.69, P = 0.004) at simulated altitude and with the change in arousal rate from normoxia (r = -0.65, P = 0.02). REM sleep response to simulated altitude correlated with the change, relative to normoxia, in arousal (r = -0.63, P = 0.04) and heart rate (r = -0.61, P = 0.04). When stratified, those athletes at altitude with RDI >20 h(-1) (n = 4) and those with <10 h(-1) (n = 10) exhibited no difference in HVR but the former had larger falls in SpO2 (P = 0.05) and more arousals (P = 0.03). Neither RDI (without stratification) nor HVR were sufficiently sensitive to explain any deterioration in REM sleep or arousal increase. However, the stratified RDI provides a basis for determining potential sleep disturbance in athletes at simulated moderate altitude.

SRM in Science

**Kirkland, Coleman et al. 2008 – Validity and reliability**

Kirkland, A.; Coleman, D.; Wiles, J. D.; Hopker, J. (2008):

## Validity and reliability of the Ergomopro powermeter.

In: *Int J Sports Med* 29 (11), S. 913–916. DOI: 10.1055/s-2008-1038621.

*Abstract:*

The aim of this investigation was to assess the validity and reliability of the Ergomopro powermeter. Nine participants completed trials on a Monark ergometer fitted with Ergomopro and SRM powermeters simultaneously recording power output. Each participant completed multiple trials at power outputs ranging from 50 to 450 W. The work stages recorded were 60 s in duration and were repeated three times. Participants also completed a single trial on a cycle ergometer designed to assess bilateral contributions to work output (Lode Excaliber Sport PFM). The power output during the trials was significantly different between all three systems, ($p < 0.01$) 231.2 +/- 114.2 W, 233.0 +/- 112.4 W, 227.8 +/- 108.8 W for the Monark, SRM and Ergomopro system, respectively. When the bilateral contributions were factored into the analysis, there were no significant differences between the powermeters ($p = 0.58$). The reliability of the Ergomopro system (CV%) was 2.31 % (95 % CI 2.13 - 2.52 %) compared to 1.59 % (95 % CI 1.47 to 1.74 %) for the Monark, and 1.37 % (95 % CI 1.26 - 1.50 %) for the SRM powermeter. These results indicate that the Ergomopro system has acceptable accuracy under these conditions. However, based on the reliability data, the increased variability of the Ergomopro system and bilateral balance issues have to be considered when using this device.

**Loughlin, Skiles et al. 2001 – An ion exchange liquid chromatography/mass**

Loughlin, A. F.; Skiles, G. L.; Alberts, D. W.; Schaefer, W. H. (2001):

## An ion exchange liquid chromatography/mass spectrometry method for the determination of reduced and oxidized glutathione and glutathione conjugates in hepatocytes.

In: *J Pharm Biomed Anal* 26 (1), S. 131–142.

*Abstract:*

A rugged LC-MS/MS method was developed to quantify reduced and oxidized glutathione (GSH and GSSG, respectively) in rat hepatocytes. In addition, GSH conjugates can be detected, characterized and measured in the same analysis. Samples were treated with acetonitrile and iodoacetic acid to precipitate proteins and trap free GSH, respectively. These highly polar analytes were separated by ion exchange chromatography using conditions that were developed to be amenable to electrospray ionization and provide baseline chromatographic resolution. A solvent gradient with a total run time of 13 min was used to elute the analytes, as well as any highly retained components in the samples that would otherwise accumulate on the HPLC column and degrade the chromatography. The analytes were detected using either selected ion monitoring (SIM) using an ion trap mass spectrometer or selected reaction monitoring (SRM) using a triple quadrupole mass spectrometer. The ranges for quantification of GSH and GSSG using an ion trap were 0.651-488 microM and 0.817-327 microM, respectively. Using SRM with the triple quadrupole instrument, the ranges of quantification for GSH and GSSG were 0.163-163 microM and 0.0816-81.6 microM, respectively. The accuracy and precision for both methods were within 15%. The utility of the method was demonstrated by treating rat hepatocytes with model compounds menadione and precocene I. Menadione, which contains a quinone moiety that undergoes redox cycling and induces concentration- and time-dependent oxidative stress in hepatocytes, resulted in decreased GSH concentrations with concomitant increase in concentrations of GSSG, as well as a GSH-menadione conjugate. When hepatocytes were incubated with precocene I, a time-dependent decrease in GSH concentrations was observed with concomitant increase in a GSH-precocene conjugate. GSSG concentrations did not increase in the presence of precocene I, consistent with its lack of redox activity. This analytical method has general utility for simultaneously investigating the potential of test compounds to induce both oxidative stress from redox cycling in vitro and the formation of GSH conjugates.

SRM in Science

**MacIntosh, Svedahl et al. 2004 – Fatigue and optimal conditions**

MacIntosh, Brian R.; Svedahl, Krista; Kim, Minhan (2004):

## Fatigue and optimal conditions for short-term work capacity.

In: *Eur. J. Appl. Physiol.* 92 (4-5), S. 369–375. DOI: 10.1007/s00421-004-1177-3.

*Abstract:*

There is an optimal load and corresponding velocity at which peak power output occurs. It is reasonable to expect that these conditions will change as a result of fatigue during 30 s of all-out cycling. This study evaluated optimal velocity after 30 s of maximal isokinetic cycle ergometer exercise and tested the hypothesis that progressive adjustment of velocity (optimized) during 30 s of all-out cycling would permit greater short-term work capacity (STWC). Non-fatigued optimal cadence [NF(OC), 109.6 (2.5) rpm] was determined for ten males on an SRM ergometer using regression analysis of the torque-angular velocity relation during a 7-s maximal acceleration. Fatigued optimal cadence [73.4 (2.4) rpm] was determined in the same way, immediately after a 30-s isokinetic test at NF(OC). A subsequent trial with cadence decreasing in steps from NF(OC) to a conservative estimate of fatigued optimal cadence [83.9 (2.8) rpm] was completed to see if more work could be done with a more optimal cadence during the test. STWC was not different ( P=0.50) between the constant [23,681 (764) J] and optimized [23,679 (708) J] conditions. Another more radical progressive change in cadence with four subjects yielded the same result (no increase in STWC). Extraneous factors apparently contribute more to variability in STWC than differences between constant and adjusted optimization of conditions.

**MacRae HS-H, Hise et al. 2000 – Effects of front and dual**

MacRae HS-H; Hise, K. J.; Allen, P. J. (2000):

## Effects of front and dual suspension mountain bike systems on uphill cycling performance.

In: *Med Sci Sports Exerc* 32 (7), S. 1276–1280.

*Abstract:*

PURPOSE

The purpose of this study was to evaluate the effects of front suspension (FS) and dual suspension (DS) mountain bike designs on time-trial performance and physiological responses during uphill cycling on a paved- and off-road course.

METHODS

Six trained male cyclists (35.6 +/- 9 yr, 76.9 +/- 8.8 kg, VO2 peak 58.4 +/- 5.6 mL x kg(-1) x min-1)) were timed using both suspension systems on an uphill paved course (1.62 km, 183-m elevation gain) and an uphill off-road course (1.38 km, 123-m elevation gain). During the field trials, VO2 was monitored continuously with a KB1-C portable gas analyzer, and power output with an SRM training system.

RESULTS

On the paved course, total ride time on FS (10.4 +/- 0.7 min) and DS (10.4 +/- 0.8 min) was not different (P > 0.05). Similarly, total ride time on the off-road course was not significantly different on the FS bike (8.3 +/- 0.7 min) versus the DS bike (8.4 +/- 1.1 min). For each of the course conditions, there was no significant difference between FS and DS in average minute-by-minute VO2, whether expressed in absolute (ABS; L x min(-1)) or relative (REL; mL x [kg body wt +/- kg bike wt(-1)] x min(-1) values. Average power output (W) was significantly lower for ABS FS versus DS (266.1 +/- 61.6 W vs 341.9 +/- 61.1 W, P < 0.001) and REL FS versus DS (2.90 +/- 0.55 W x kg(-1) vs 3.65 +/- 0.53 W x kg(-1), P < 0.001) during the off-road trials. Power output on the paved course was also significantly different for ABS FS versus DS (266.6 +/- 52 W vs 345.4 +/- 53.4 W, P < 0.001) and REL FS versus DS (2.99 +/- 0.55 W x kg(-1) vs 3.84 +/- 0.54 W x kg(-1), P < 0.001).

CONCLUSION

We conclude that despite significant differences in power output between FS and DS mountain bike systems during uphill cycling, these differences do not translate into significant differences in oxygen cost or time to complete either a paved- or off-road course.

**Maier, Steiner et al. 2014 – Reliability of power meter calibration**

Maier, T.; Steiner, T.; Trösch, S.; Müller, B.; Wehrlin, J. P. (2014):

## Reliability of power meter calibration by mathematical modelling of treadmill cycling.

In: *J Sci Cycling* (Vol. 3(2), 28).

*Abstract:*

New power meters that are installed on various parts of the bike entered the market recently. Calibration of power meters is essential to ensure correct power output readings for testing and training. The use of a dynamic calibration rig was proposed as the preferred method to calibrate cycle ergometers (Woods et al., 1994: International Journal of Sports Medicine, 15(4), 168-171). While this works for power meters that measure power output after its transmission through the crank axle, it is not suitable for systems installed on the pedals or the crank arm (e.g. Garmin Vector, Kéo Power, Stages, Rotor Power). Therefore, we want to propose a new method to dynamically calibrate all available power meters. The purpose of our study was to quantify the typical error of this method used to assess load characteristics of power meters. Thirty power meters (14 SRM, 8 Powertap, 5 Quarq, 3 Garmin Vector) mainly used by cyclists of the Swiss national mountain bike team were analysed. Each cyclist rode his own bike equipped with his power meter on a motorized treadmill (Poma, Dürrröhrsdorf-Dittersbach, Germany), after executing all calibration procedures according to the manufacturer. Cyclists rode with a velocity v = 3.5 m s-1 at an inclination of α1 = 1° and α2 = 7°. These corresponded to power demands of approximately 1 W kg-1 and 5 W kg-1, respectively. Power output measurements were averaged over 1 min for both inclinations. The total mass m of the cyclist, his equipment and bike was measured on a calibrated scale (Model 861, Seca, Reinach, Switzerland). To eliminate any contribution of rolling or aerodynamic resistance, the difference in power output between the two inclinations was calculated as ΔP = m · g · v · (sinα2 − sinα1). The ratio between the measured difference and that calculated by the mathematical model was defined as the load characteristic of the power meter. A value of 1 indicates perfect agreement between the measurement and the model. The procedure was performed twice. The typical error of measurement and its 95% confidence interval for the load characteristic was calculated from the 30 repeated trials (Hopkins, 2000: Sports Medicine, 30(1), 1-15). The typical error for the load characteristic was 1.5% with a 95% confidence interval of 1.1% to 1.9%. The change in the mean from trial 1 to trial 2 was 0.1% with a 95% confidence interval of -0.7% to 0.9%. The typical error of 1.5% demonstrates a high reliability of the method used to assess the load characteristic of a power meter, which can easily be enhanced by performing multiple trials. The value for a convenient triple measurement follows as 1.5% / 31/2 = 0.9% (Hopkins, 2000). The typical error presented here is comparable to the reliability reported for the calibration with a dynamic calibration rig (Woods et al., 1994). Our calibration method is easy to administer, time efficient and independent of the power meter system, rolling resistance or cyclist riding style. Even though the method does not assess absolute power output readings, it detects systematic measurement error. To further evaluate the load characteristic, an assumption concerning the drivetrain loss is necessary. After personal communication with J. Smith (www.friction-facts.com, December 6, 2013), we assume a drivetrain loss of 2% in power output difference scores. A valid system located on the crank would therefore measure a 2% higher difference in power output than predicted by the mathematical model. We conclude, that calibrating power meters by mathematical modelling of treadmill cycling is highly reliable and convenient.

**Maier, Schmid et al. 2017 – Accuracy of Cycling Power Meters**

Maier, Thomas; Schmid, Lucas; Muller, Beat; Steiner, Thomas; Wehrlin, Jon Peter (2017):

## Accuracy of Cycling Power Meters against a Mathematical Model of Treadmill Cycling.

In: *Int J Sports Med. DOI:* 10.1055/s-0043-102945.

*Abstract:*

The aim of this study was to compare the accuracy among a high number of current mobile cycling power meters used by elite and recreational cyclists against a first principle-based mathematical model of treadmill cycling. 54 power meters from 9 manufacturers used by 32 cyclists were calibrated. While the cyclist coasted downhill on a motorised treadmill, a back-pulling system was adjusted to counter the downhill force. The system was then loaded 3 times with 4 different masses while the cyclist pedalled to keep his position. The mean deviation (trueness) to the model and coefficient of variation (precision) were analysed. The mean deviations of the power meters were -0.9+/-3.2% (mean+/-SD) with 6 power meters deviating by more than+/-5%. The coefficients of variation of the power meters were 1.2+/-0.9% (mean+/-SD), with Stages varying more than SRM ($p<0.001$) and PowerTap ($p<0.001$). In conclusion, current power meters used by elite and recreational cyclists vary considerably in their trueness; precision is generally high but differs between manufacturers. Calibrating and adjusting the trueness of every power meter against a first principle-based reference is advised for accurate measurements.

**Mc Naughton, Sherman et al. 2005 – Portable gas analyser Cosmed K4b2**

Mc Naughton, L. R.; Sherman, R.; Roberts, S.; Bentley, D. J. (2005):

## Portable gas analyser Cosmed K4b2 compared to a laboratory based mass spectrometer system.

In: *J Sports Med Phys Fitness* 45 (3), S. 315–323.

*Abstract:*

AIM

The purpose of this study was to systematically test the accuracy of an automated, portable, gas analysis system, the Cosmed K4b2 with a laboratory based mass spectrometer system, the Morgan EX670 across a number of gas and ventilation parameters.

METHODS

Eight subjects (mean+/-SE) age, 23.7+/-1.1 y, height, 1.78+/-0.01 m, mass, 74.4+/-2.1 kg performed a V.O2max test and a submaximal exercise test at 150, 200, 250 and 300 Watts (W), on an SRM cycle ergometer. The Morgan EX670 system and the K4b2 were randomly connected in series, using the same breath for the calculation of gas and ventilatory parameters.

RESULTS

The K4b2 system reads significantly higher than the Morgan EX 670 for both VO2 and V.CO2 at 250 (VO2/V.CO2: $p<0.05$, $p<0.002$), and 300 W (VO2/V.CO2: $p<0.002$, $p<0.005$). Unsystematic bias between the 2 analysers varies between 1% and 16% and systematic bias between 3% and 8%.

CONCLUSION

There are some significant unsystematic and systematic differences between these 2 systems and laboratories should endeavour to utilise either one or the other piece of equipment to test their subjects.

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SRM in Science

**McDaniel, Subudhi et al. 2005 – Torso stabilization reduces the metabolic**

McDaniel, John; Subudhi, Andrew; Martin, James C. (2005):

## Torso stabilization reduces the metabolic cost of producing cycling power.

In: *Can J Appl Physiol* 30 (4), S. 433–441.

*Abstract:*

Many researchers have used cycling exercise to evaluate muscle metabolism. Inherent in such studies is an assumption that changes in whole-body respiration are due solely to respiration at the working muscle. Some researchers, however, have speculated that the metabolic cost of torso stabilization may contribute to the metabolic cost of cycling. Therefore, our primary purpose was to determine whether a torso stabilization device would reduce the metabolic cost of producing cycling power. Our secondary purpose was to determine the validity of the ergometer used in this study. Nine male cyclists cycled on a Velotron cycle ergometer at mechanical power outputs intended to elicit 50, 75, and 100% of their ventilatory threshold at 40, 60, and 80 rpm, with and without torso stabilization. Power was controlled by the Velotron in iso-power mode and measured with an SRM powermeter. We determined metabolic cost by indirect calorimetery and recorded power output. Torso stabilization significantly reduced metabolic cost of producing submaximal power (1%), and reduction tended to be greatest at the lower pedaling rates where pedaling force was greatest (1.6% at 40 rpm, 1.2% at 60 rpm, 0.2% at 80 rpm). Power, measured with the SRM powermeter, was strongly correlated with that specified to the Velotron ergometer control unit (R(2) > 0.99). We conclude that muscular contractions associated with torso stabilization elicit significant metabolic costs, which tend to be greatest at low pedaling rates. Researchers who intend to make precise inferences regarding metabolism in the working muscles of the legs may wish to provide torso stabilization as a means of reducing variability, particularly when comparing metabolic data across a wide range of pedaling rates.

**McLean, Buttifant et al. 2013 – Physiological and performance responses**

McLean, Blake D.; Buttifant, David; Gore, Christopher J.; White, Kevin; Liess, Carsten; Kemp, Justin (2013):

## Physiological and performance responses to a preseason altitude-training camp in elite team-sport athletes.

In: *Int J Sports Physiol Perform* 8 (4), S. 391–399.

*Abstract:*

PURPOSE

Little research has been done on the physiological and performance effects of altitude training on team-sport athletes. Therefore, this study examined changes in 2000-m time-trial running performance (TT), hemoglobin mass (Hbmass), and intramuscular carnosine content of elite Australian Football (AF) players after a preseason altitude camp.

METHODS

Thirty elite AF players completed 19 days of living and training at either moderate altitude (~2130 m; ALT, n = 21) or sea level (CON, n = 9). TT performance and Hbmass were assessed preintervention (PRE) and postintervention (POST1) in both groups and at 4 wk after returning to sea level (POST2) in ALT only.

RESULTS

Improvement in TT performance after altitude was likely 1.5% (± 4.8-90%CL) greater in ALT than in CON, with an individual responsiveness of 0.8%. Improvements in TT were maintained at POST2 in ALT. Hbmass after altitude was very likely increased in ALT compared with CON (2.8% ± 3.5%), with an individual responsiveness of 1.3%. Hbmass returned to baseline at POST2. Intramuscular carnosine did not change in either gastrocnemius or soleus from PRE to POST1.

CONCLUSIONS

A preseason altitude camp improved TT performance and Hbmass in elite AF players to a magnitude similar to that demonstrated by elite endurance athletes undertaking altitude training. The individual responsiveness of

both TT and Hbmass was approximately half the group mean effect, indicating that most players gained benefit. The maintenance of running performance for 4 wk, despite Hbmass returning to baseline, suggests that altitude training is a valuable preparation for AF players leading into the competitive season.

**Menaspa, Quod et al. 2015 – Physical Demands of Sprinting**

Menaspa, P.; Quod, M.; Martin, D. T.; Peiffer, J. J.; Abbiss, C. R. (2015):

## Physical Demands of Sprinting in Professional Road Cycling.

In: *International journal of sports medicine* 36 (13), S. 1058–1062. DOI: 10.1055/s-0035-1554697.

*Abstract:*

The aim of this study was to quantify the demands of road competitions ending with sprints in male professional cycling. 17 races finished with top-5 results from 6 male road professional cyclists (age, 27.0+/-3.8 years; height, 1.76+/-0.03 m; weight, 71.7+/-1.1 kg) were analysed. SRM power meters were used to monitor power output, cadence and speed. Data were averaged over the entire race, different durations prior to the sprint (60, 10, 5 and 1 min) and during the actual sprint. Variations in power during the final 10 min of the race were quantified using exposure variation analysis. This observational study was conducted in the field to maximize the ecological validity of the results. Power, cadence and speed were statistically different between various phases of the race (p<0.001), increasing from 316+/-43 W, 95+/-4 rpm and 50.5+/-3.3 km.h(-1) in the last 10 min, to 487+/-58 W, 102+/-6 rpm and 55.4+/-4.7 km.h(-1) in the last min prior to the sprint. Peak power during the sprint was 17.4+/-1.7 W.kg(-1). Exposure variation analysis revealed a significantly greater number of short-duration high-intensity efforts in the final 5 min of the race, compared with the penultimate 5 min (p=0.010). These findings quantify the power output requirements associated with high-level sprinting in men's professional road cycling and highlight the need for both aerobic and anaerobic fitness.

**Meyer, Gabriel et al. 2003 – Metabolic profile of 4 h**

Meyer, T.; Gabriel, H. H. W.; Auracher, M.; Scharhag, J.; Kindermann, W. (2003):

## Metabolic profile of 4 h cycling in the field with varying amounts of carbohydrate supply.

In: *Eur. J. Appl. Physiol.* 88 (4-5), S. 431–437. DOI: 10.1007/s00421-002-0712-3.

*Abstract:*

Several laboratory studies have demonstrated a performance-enhancing effect of carbohydrate (CHO) supplementations during endurance sessions of long duration. However, the transferability of these results to real training and competition circumstances has not been conclusively shown. Therefore, we tried to test the influence of graded CHO substitution on substrate utilization and selected physiological parameters under standardized but practically orientated field conditions. Fourteen endurance-trained male subjects [mean (SD): 25 (5) years, 72 (9) kg, .VO(2max) 67 (6) ml.min(-1).kg(-1), individual anaerobic threshold (IAT) 269 (30) W] after a stepwise increasing pre-test had to perform three 4-h endurance rides on their own bicycles with simultaneous spiroergometry: constant workload 70% IAT (monitoring by SRM-System). Before and during exercise, solutions without (0%), with 6% or 12% CHO were administered double-blindly and in randomized order (total volume: 50 ml.kg(-1)). After cessation of exercise, significant differences between 0% and both CHO concentrations were detected for blood glucose (GLU; 75 mg dl(-1) for 0% vs 101 mg dl(-1) for 6% vs 115 mg dl(-1) for 12%; P<0.001) and respiratory exchange ratio (0.84 vs 0.88 vs 0.90; P<0.01; correlation to GLU: r=0.46, P<0.05). Free fatty acids (0.19 vs 0.16 vs 0.10 mmol l(-1)) and glycerol (0.41 vs 0.22 vs 0.12 mmol l(-1)) were significantly different between the endurance trials in a dose-dependent manner (both P<0.001). Lactate concentration ( P=0.42) and heart rate ( P=0.12) had no significant influence from CHO substitution. We conclude that CHO substitution during 4-h endurance training inhibits lipolysis in a dose-dependent manner and enhances aerobic glycolysis. This proves that earlier laboratory findings can be replicated under field conditions using modern portable equipment.

**Mijnarends, Meijers et al. 2013 – Validity and reliability of tools**

Mijnarends, Donja M.; Meijers, Judith M. M.; Halfens, Ruud J. G.; Ter Borg, Sovianne; Luiking, Yvette C.; Verlaan, Sjors et al. (2013):

## Validity and reliability of tools to measure muscle mass, strength, and physical performance in community-dwelling older people: a systematic review.

In: *J Am Med Dir Assoc* 14 (3), S. 170–178. DOI: 10.1016/j.jamda.2012.10.009.

*Abstract:*

BACKGROUND

This study critically appraises the measurement properties of tools to measure muscle mass, strength, and physical performance in community-dwelling older people. This can support the selection of a valid and reliable set of tools that is feasible for future screening and identification of sarcopenia.

METHODS

The databases PubMed, Cumulative Index to Nursing and Allied Health Literature (CINAHL), and Cochrane were systematically searched (January 11, 2012). Studies were included if they investigated the measurement properties or feasibility, or both, of tools to measure muscle mass, strength, and physical performance in community-dwelling older people aged ≥60 years. The consensus-based standards for the selection of health status measurement instruments (COSMIN) checklist was used for quality appraisal of the studies.

RESULTS

Sixty-two publications were deemed eligible, including tools for muscle mass (n = 16), muscle strength (n = 15), and physical performance (n = 31). Magnetic resonance imaging, computed tomography, and a 4-compartment model were used as gold standards for muscle mass assessment. Other frequently used measures of muscle mass are dual-energy x-ray and the bioelectrical impedance (BIA); however, reliability data of the BIA are lacking. Handheld dynamometry and gait speed or a short physical performance battery provide a valid and reliable measurement of muscle strength and physical performance, respectively.

CONCLUSIONS

It can be concluded that several tools are available for valid and reliable measurements of muscle mass, strength, and performance in clinical settings. For a home-setting BIA, handheld dynamometry and gait speed or a short physical performance battery are the most valid, reliable, and feasible. The combination of selected instruments and its use for the screening and identification of sarcopenia in community-dwelling older people need further evaluation.

**Millet, Tronche et al. 2003 – Validity and reliability**

Millet, G. P.; Tronche, C.; Fuster, N.; Bentley, D. J.; Candau, R. (2003):

## Validity and reliability of the Polar S710 mobile cycling powermeter.

In: *Int J Sports Med* 24 (3), S. 156–161. DOI: 10.1055/s-2003-39083.

*Abstract:*

The purpose of this study was to determine the validity and reliability of a new mobile bike-powermeter, Polar S710, in laboratory and field conditions, against the SRM crankset. Eight trained subjects performed in a random order six uphill cycling trials of 6-min duration at three different intensities (60 %, 75 % and 90 % of peak power output [PPO]). In addition, 44 other cyclists performed in the laboratory three cycling bouts each of 5-min duration at three different pedal cadences (60, 90 and 110 rpm) at the same absolute intensity (approximately 150 W). Bias between the two devices was correlated (r = 0.79) with the mean power in field conditions; with the S710 reading higher (p < 0.001) by 7.4 +/- 5.1 % than the SRM in the range of power studied. In other words, the mean differences between the two devices increased as the exercise intensity increased. The mean power output obtained with S710 was significantly higher (p < 0.001) by 6.8 +/- 7.9 W (bias x divided-by random error = 1.042 x divided-by 1.049) than the power obtained with SRM in laboratory

conditions. Ninety-five percent of the differences of power measured with the S710 ranged between 21.4 W above to 8.3 W below the SRM in laboratory conditions. Mean differences between the two devices increased as the pedalling cadence increased (0.6 +/- 3.8 %, 4.4 +/- 3.7 % and 7.8 +/- 4.4 % at cadence of 60, 90 and 110 rpm respectively). Coefficients of variation in mean power across the four field-based trials at 75 % PPO was 2.2 % and 1.9 % for S710 and SRM, respectively. In conclusion, the S710 recorded power outputs higher than the SRM system in both field and laboratory conditions. Pedalling cadence and exercise intensity influenced differences in mean power. These characteristics make S710 a useful device for recreational cyclists but not for elite cyclists or scientists who require a greater accuracy and validity. However, the limits of the present study (short-term duration testing; single tested variables as intensity, posture, pedalling cadence) require further investigation for generalizing the present results to extensive use in "real world" cycling.

**Millet, Tronche et al. 2002 – Level ground and uphill cycling**

Millet, Grégoire P.; Tronche, Cyrille; Fuster, Nicolas; Candau, Robin (2002):

## Level ground and uphill cycling efficiency in seated and standing positions.

In: *Med Sci Sports Exerc* 34 (10), S. 1645–1652. DOI: 10.1249/01.MSS.0000031482.14781.D7.

*Abstract:*

PURPOSE

This study was designed to examine the effects of cycling position (seated or standing) during level-ground and uphill cycling on gross external efficiency (GE) and economy (EC).

METHODS

Eight well-trained cyclists performed in a randomized order five trials of 6-min duration at 75% of peak power output either on a velodrome or during the ascent of a hill in seated or standing position. GE and EC were calculated by using the mechanical power output that was measured by crankset (SRM) and energy consumption by a portable gas analyzer (Cosmed K4b(2)). In addition, each subject performed three 30-s maximal sprints on a laboratory-based cycle ergometer or in the field either in seated or standing position.

RESULTS

GE and EC were, respectively, 22.4 +/- 1.5% (CV = 5.6%) and 4.69 +/- 0.33 kJ x L(-1) (CV = 5.7%) and were not different between level seated, uphill seated, or uphill standing conditions. Heart rate was significantly ( < 0.05) higher in standing position. In the uphill cycling trials, minute ventilation was higher ( < 0.05) in standing than in seated position. The average 30-s power output was higher ( < 0.01) in standing (803 +/- 103 W) than in seated position (635 +/- 123 W) or on the stationary ergometer (603 +/- 81 W).

CONCLUSION

Gradient or body position appears to have a negligible effect on external efficiency in field-based high-intensity cycling exercise. Greater short-term power can be produced in standing position, presumably due to a greater force developed per revolution. However, the technical features of the standing position may be one of the most determining factors affecting the metabolic responses.

**Mornieux, Gollhofer et al. 2010 – Muscle Coordination while Pulling**

Mornieux, G.; Gollhofer, A.; Stapelfeldt, B. (2010):

## Muscle Coordination while Pulling up During Cycling.

In: *Int J Sports Med* 31 (12), S. 843–846. DOI: 10.1055/s-0030-1263140.

*Abstract:*

The aim of this study was to determine the influence of the pull up action on the pedalling mechanics and muscle coordination during cycling. 9 elite cyclists pedalled at 320 watts with their preferred technique and while pulling up. The pull up action increased significantly the pedalling effectiveness during the upstroke and around the bottom dead centre. This was associated with a significant enhancement of the biceps femoris activity (48%), an earlier onset of activation of the tibialis anterior, i. e., 211±83° vs. 259±22° (crank angle) and a delayed offset of activation of the gastrocnemius lateralis, i. e., 244±19° vs. 216±39°. Consequently, co-activities between tibialis anterior and gastrocnemius lateralis muscles over 55±65° (crank angle range), as well as between the biceps femoris and the tibialis anterior over 48±57° were generated. These higher co-activities were necessary to stiffen the ankle joint and to power the pedal during the upstroke. Thus changes in muscle coordination improved the pedalling effectiveness during the upstroke phase but would probably lead to impairment of the oxygen consumption. Therefore, training the pull up action could be of interest to optimize this muscle coordination associated with better pedalling effectiveness by additionally relieving hip or knee extensors during the downstroke.

**Mornieux, Stapelfeldt et al. 2008 – Effects of Pedal Type**

Mornieux, G.; Stapelfeldt, B.; Gollhofer, A.; Belli, A. (2008):

## Effects of Pedal Type and Pull-Up Action during Cycling.

In: *Int J Sports Med* 29 (10), S. 817–822. DOI: 10.1055/s-2008-1038374.

*Abstract:*

The aim of this study was to determine the influence of different shoe-pedal interfaces and of an active pulling-up action during the upstroke phase on the pedalling technique. Eight elite cyclists (C) and seven non-cyclists (NC) performed three different bouts at 90 rev · min−1 and 60 % of their maximal aerobic power. They pedalled with single pedals (PED), with clipless pedals (CLIP) and with a pedal force feedback (CLIPFBACK) where subjects were asked to pull up on the pedal during the upstroke. There was no significant difference for pedalling effectiveness, net mechanical efficiency (NE) and muscular activity between PED and CLIP. When compared to CLIP, CLIPFBACK resulted in a significant increase in pedalling effectiveness during upstroke (86 % for C and 57 % NC, respectively), as well as higher biceps femoris and tibialis anterior muscle activity ($p < 0.001$). However, NE was significantly reduced ($p < 0.008$) with 9 % and 3.3 % reduction for C and NC, respectively. Consequently, shoe-pedal interface (PED vs. CLIP) did not significantly influence cycling technique during submaximal exercise. However, an active pulling-up action on the pedal during upstroke increased the pedalling effectiveness, while reducing net mechanical efficiency.

**Neville, Zaher et al. 2009 – Lower limb influence on standing**

Neville, V.; Zaher, N.; Pain, M. T. G.; Folland, J. P. (2009):

## Lower limb influence on standing arm-cranking ('grinding').

In: *Int J Sports Med* 30 (10), S. 713–718. DOI: 10.1055/s-0029-1231044.

*Abstract:*

Standing arm-cranking ('grinding') is predominantly an upper-body exercise, however, the contribution of the legs to this activity is unknown. The purpose of the study was to examine the influence of normal lower-limb movement on physiological strain during arm-cranking. Eight elite professional America's Cup grinders performed two exercise trials, on an adjustable standing arm-crank ergometer with SRM powercrank, in a cross-over design. Each trial comprised of two 5-min stages at the same work rate ( approximately lactate threshold) with the knee joint splinted or normal movement available. Vertical ground reaction forces (VGRF) and knee joint angle were determined from two force plates and sagittal plane video, respectively. Work rate was identical for the two conditions (246 (14) vs. 246 (13) W, p=0.7). Knee joint range of motion and unilateral VGRF amplitude were greater during normal compared with splinted arm-cranking (both p<0.01). There was no difference in VO2 (p=0.2) between the two conditions, however, there was greater VCO2 (8%, p=0.001), RER (11%, p<0.001), V(E) (17%, p<0.001) and HR (7 (3) beats.min(-1), p<0.001) during splinted compared with normal arm-cranking. Furthermore, the rise in BLa was greater after splinted than normal arm-cranking (4.8 (0.8) vs. 3.7 (1.0) mmol.L(-1), p=0.04). These data suggest that the lower-limbs play an integral role in standing arm-cranking, and restricted leg movement markedly affects the cardiovascular and metabolic responses to this activity.

SRM in Science

**Neville, Pain et al. 2009 – Aerobic power and peak power**

Neville, Vernon; Pain, Matthew T. G.; Folland, Jonathan P. (2009):

## Aerobic power and peak power of elite America's Cup sailors.

In: *Eur. J. Appl. Physiol.* 106 (1), S. 149–157. DOI: 10.1007/s00421-009-1002-0.

*Abstract:*

Big-boat yacht racing is one of the only able bodied sporting activities where standing arm-cranking ('grinding') is the primary physical activity. However, the physiological capabilities of elite sailors for standing arm-cranking have been largely unreported. The purpose of the study was to assess aerobic parameters, VO(2peak) and onset of blood lactate (OBLA), and anaerobic performance, torque-crank velocity and power-crank velocity relationships and therefore peak power (P (max)) and optimum crank-velocity (omega(opt)), of America's Cup sailors during standing arm-cranking. Thirty-three elite professional sailors performed a step test to exhaustion, and a subset of ten grinders performed maximal 7 s isokinetic sprints at different crank velocities, using a standing arm-crank ergometer. VO(2peak) was 4.7 +/- 0.5 L/min (range 3.6-5.5 L/min) at a power output of 332 +/- 44 W (range 235-425 W). OBLA occurred at a power output of 202 +/- 31 W (61% of W(max)) and VO(2) of 3.3 +/- 0.4 L/min (71% of VO(2peak)). The torque-crank velocity relationship was linear for all participants (r = 0.9 +/- 0.1). P (max) was 1,420 +/- 37 W (range 1,192-1,617 W), and omega(opt) was 125 +/- 6 rpm. These data are among the highest upper-body anaerobic and aerobic power values reported. The unique nature of these athletes, with their high fat-free mass and specific selection and training for standing arm cranking, likely accounts for the high values. The influence of crank velocity on peak power implies that power production during on-board 'grinding' may be optimised through the use of appropriate gear-ratios and the development of efficient gear change mechanisms.

**Neville, Pain et al. 2010 – Influence of crank length**

Neville, Vernon; Pain, Matthew T. G.; Kantor, Jonathan; Folland, Jonathan P. (2010):

## Influence of crank length and crank-axle height on standing arm-crank (grinding) power.

In: *Med Sci Sports Exerc* 42 (2), S. 381–387. DOI: 10.1249/MSS.0b013e3181b46f3a.

*Abstract:*

OBJECTIVE

To determine the optimal crank length and crank-axle height for maximum power production during standing arm cranking ("grinding").

METHODS

Nine elite professional America's Cup grinders (age = 36 +/- 2 yr, body mass = 104 +/- 1 kg, body fat = 13% +/- 2%) performed eight maximal 6-s sprints on an adjustable standing arm-crank ergometer fitted with an SRM power crank. The protocol included crank lengths of 162, 199, 236, and 273 mm and crank-axle heights of 850, 950, 1050, and 1150 mm. Peak power, ground reaction forces, and joint angles were determined and compared for different crank lengths and crank-axle heights with repeated-measures ANOVA.

RESULTS

Peak power was significantly different between crank lengths (P = 0.006), with 162 mm lower than all others (P < 0.03). Optimal crank length was 12.3% of arm span or 241 +/- 9 mm for this cohort of athletes. Peak power was significantly less for the crank-axle height of 850 mm compared with 1150 mm (P = 0.01). The optimal crank-axle height for peak power was between 50% and 60% of stature (950-1150 mm in this study). Hip flexion was greater at the lowest crank-axle height (850 mm) than at 1050 and 1150 mm (P < 0.01), and the resultant ground reaction force was also reduced compared with all other heights, indicating greater weight bearing by the upper body.

CONCLUSIONS

Changes in crank length and crank-axle height influence performance during maximal standing arm-crank ergometry. These results suggest that standard leg-cycle crank lengths are inappropriate for maximal arm-cranking performance. In addition, a crank-axle height of <50% of stature, which is typically used in America's Cup sailing, may attenuate performance.

**Neya, Enoki et al. 2013 – Increased hemoglobin mass and VO2max**

Neya, Mitsuo; Enoki, Taisuke; Ohiwa, Nao; Kawahara, Takashi; Gore, Christopher J. (2013):

## Increased hemoglobin mass and VO2max with 10 h nightly simulated altitude at 3000 m.

In: *Int J Sports Physiol Perform* 8 (4), S. 366–372.

*Abstract:*

PURPOSE

To quantify the changes of hemoglobin mass (Hbmass) and maximum oxygen consumption (VO2max) after 22 days training at 1300-1800 m combined with nightly exposure to 3000-m simulated altitude. We hypothesized that with simulated 3000-m altitude, an adequate beneficial dose could be as little as 10 h/24 h.

METHODS

Fourteen male collegiate runners were equally divided into 2 groups: altitude (ALT) and control (CON). Both groups spent 22 days at 1300-1800 m. ALT spent 10 h/night for 21 nights in simulated altitude (3000 m), and CON stayed at 1300 m. VO2max and Hbmass were measured twice before and once after the intervention. Blood was collected for assessment of percent reticulocytes (%retics), serum erythropoietin (EPO), ferritin, and soluble transferrin receptor (sTfR) concentrations.

RESULTS

Compared with CON there was an almost certain increase in absolute VO2max (8.6%, 90% confidence interval 4.8-12.6%) and a likely increase in absolute Hbmass (3.5%; 0.9-6.2%) at postintervention. The %retics were at least very likely higher in ALT than in CON throughout the 21 nights, and sTfR was also very likely higher in the ALT group until day 17. EPO of ALT was likely higher than that of CON on days 1 and 5 at altitude, whereas serum ferritin was likely lower in ALT than CON for most of the intervention.

CONCLUSIONS

Together the combination of the natural and simulated altitude was a sufficient total dose of hypoxia to increase both Hbmass and VO2max.

**Nimmerichter, Williams et al. 2010 – Evaluation of a field test**

Nimmerichter, A.; Williams, C.; Bachl, N.; Eston, R. (2010):

## Evaluation of a field test to assess performance in elite cyclists.

In: *Int J Sports Med* 31 (3), S. 160–166. DOI: 10.1055/s-0029-1243222.

*Abstract:*

The study aimed to assess the reproducibility of power output during a 4 min (TT4) and a 20 min (TT20) time-trial and the relationship with performance markers obtained during a laboratory graded exercise test (GXT). Ventilatory and lactate thresholds during a GXT were measured in competitive male cyclists (n=15; (.)VO (2max) 67+/-5 ml x min (-1) x kg (-1); P (max) 440+/-38W). Two 4 min and 20 min time-trials were performed on flat roads. Power output was measured using a mobile power-meter (SRM). Strong intraclass-correlations for TT4 ( R=0.98; 95% CL: 0.92-0.99) and TT20 ( R=0.98; 95% CL: 0.95-0.99) were observed. TT4 showed a bias+/-random error of - 0.8+/-23W or - 0.2+/-5.5%. During TT20 the bias+/-random error was - 1.8+/-14W or 0.6+/-4.4%. Both time-trials were strongly correlated with performance measures from the GXT (p<0.001). Significant differences were observed between power output during TT4 and GXT measures

(p<0.001). No significant differences were found between TT20 and power output at the second lactate-turn-point (LTP2) (p=0.98) and respiratory compensation point (RCP) (p=0.97). In conclusion, TT4 and TT20 mean power outputs are reliable predictors of aerobic endurance. TT20 was in agreement with power output at RCP and LTP2.

**Nimmerichter, Eston et al. 2011 – Longitudinal monitoring of power output**

Nimmerichter, Alfred; Eston, Roger G.; Bachl, Norbert; Williams, Craig (2011):

## Longitudinal monitoring of power output and heart rate profiles in elite cyclists.

In: *J Sports Sci* 29 (8), S. 831–840. DOI: 10.1080/02640414.2011.561869.

*Abstract:*

Power output and heart rate were monitored for 11 months in one female (V(.)O(2max): 71.5 mL · $kg^{-1}$ · $min^{-1}$) and ten male (V(.)O(2max): 66.5 ± 7.1 mL · $kg^{-1}$ · $min^{-1}$) cyclists using SRM power-meters to quantify power output and heart rate distributions in an attempt to assess exercise intensity and to relate training variables to performance. In total, 1802 data sets were divided into workout categories according to training goals, and power output and heart rate intensity zones were calculated. The ratio of mean power output to respiratory compensation point power output was calculated as an intensity factor for each training session and for each interval during the training sessions. Variability of power output was calculated as a coefficient of variation. There was no difference in the distribution of power output and heart rate for the total season ($P = 0.15$). Significant differences were observed during high-intensity workouts ($P < 0.001$). Performance improvements across the season were related to low-cadence strength workouts ($P < 0.05$). The intensity factor for intervals was related to performance ($P < 0.01$). The variability in power output was inversely associated with performance ($P < 0.01$). Better performance by cyclists was characterized by lower variability in power output and higher exercise intensities during intervals.

**Nimmerichter, Schnitzer et al. 2017 – Validity and Reliability**

Nimmerichter, Alfred; Schnitzer, Lukas; Prinz, Bernhard; Simon, Dieter; Wirth, Klaus (2017):

## Validity and Reliability of the Garmin Vector Power Meter in Laboratory and Field Cycling.

In: *Int J Sports Med. DOI:* 10.1055/s-0043-101909.

*Abstract:*

To assess the validity and reliability of the Garmin Vector against the SRM power meter, 6 cyclists completed 3 continuous trials at power outputs from 100-300 W at 50-90 rev.min-1 and a 5-min time trial in laboratory and field conditions. In field conditions only, a 30-s sprint was performed. Data were compared with paired samples t-tests, with the 95% limits of agreement (LoA) and the typical error. Reliability was calculated as the coefficient of variation (CV). There was no significant difference between the devices in power output in laboratory (p=0.245) and field conditions (p=0.312). 1-s peak power was significantly different between the devices (p=0.043). The LoA were ~1.0+/-5.0 W and ~0.5+/-0.5 rev.min-1 in both conditions. The LoA during the 30-s sprint was 6.3+/-38.9 W and for 1-s peak power it was 18.8+/-17.1 W. The typical error for power output was 2.9%, while during sprint cycling it was 7.4% for 30-s and 2.7% for 1-s peak power. For cadence, the typical error was below 1.0%. The mean CVs were ~1.0% and ~3.0% for the SRM and Garmin, respectively. These findings suggest, that the Garmin Vector is a valid alternative for training. However, during sprint cycling there is lower agreement with the SRM power meter. Both devices provide good reliability (CV<3.0%).



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SRM in Science

**Nimmerichter, Williams 2015 – Comparison of power output**

Nimmerichter, Alfred; Williams, Craig A. (2015):

## Comparison of power output during ergometer and track cycling in adolescent cyclists.

In: *Journal of strength and conditioning research / National Strength & Conditioning Association* 29 (4), S. 1049–1056. DOI: 10.1519/JSC.0000000000000723.

*Abstract:*

The aim of this study is to establish the level of agreement between test performance of young elite cyclists in a laboratory and a track field-based trial. Fourteen adolescent cyclists (age: 14.8 +/- 1.1 years; (Equation is included in full-text article.): 63.5 +/- 5.6 ml.min(-1).kg(-1)) performed 3 tests of 10 seconds, 1 minute, and 3 minutes on an air-braked ergometer (Wattbike) and on a 250-m track using their own bikes mounted with mobile power meters (SRM). The agreement between the maximum and mean power output (Pmax and Pmean) measured on the Wattbike and SRM was assessed with the 95% limits of agreement (LoA). Power output was strongly correlated between Wattbike and SRM for all tests (r = 0.94-0.96; p < 0.001). However, power output was significantly higher on the Wattbike compared with track cycling during all tests. The bias and 95% LoA were 76 +/- 78 W (8.8 +/- 9.5%; p = 0.003, d = 0.38) for Pmax10s and 82 +/- 55 W (10.9 +/- 7.9%; p < 0.001, d = 0.46) for Pmean10s. During the 1- and 3-minute test, the bias and 95% LoA were 72 +/- 30 W (17.9 +/- 7.1%; p < 0.001, d = 0.84) and 28 +/- 20 W (9.6 +/- 6.1%; p < 0.001, d = 0.51), respectively. Laboratory tests, as assessed using a stationary ergometer, resulted in maximal and mean power output scores that were consistently higher than a track field-based test using a mobile ergometer. These results might be attributed to the technical ability of the riders and their experience to optimize gearing and cadence to maximize performance. Prediction of field-based testing on the track from laboratory tests should be used with caution.

**O'Hara, Thomas et al. 2012 – Reliability of a High-Intensity Endurance**

O'Hara, J.; Thomas, A.; Seims, A.; Cooke, C.; King, R.F.G (2012):

## Reliability of a High-Intensity Endurance Cycling Test.

In: *Int J Sports Med* 33 (01), S. 18–25. DOI: 10.1055/s-0031-1284340.

*Abstract:*

This study assessed the reproducibility of performance and selected metabolic variables during a variable high-intensity endurance cycling test. 8 trained male cyclists (age: 35.9±7.7 years, maximal oxygen uptake: 54.3±3.9 mL·kg − 1·min − 1) completed 4 high-intensity cycling tests, performed in consecutive weeks. The protocol comprised: 20 min of progressive incremental exercise, where the power output was increased by 5% maximal workload (Wmax) every 5 min from 70% Wmax to 85% Wmax; ten 90 s bouts at 90% Wmax, separated by 180 s at 55% Wmax; 90% Wmax until volitional exhaustion. Blood samples were drawn and heart rate was monitored throughout the protocol. There was no significant order effect between trials for time to exhaustion (mean: 4 113.0±60.8 s) or total distance covered (mean: 4 6126.2±1 968.7 m). Total time to exhaustion and total distance covered showed very high reliability with a mean coefficient of variation (CV) of 1.6% (95% Confidence Intervals (CI) 0.0±124.3 s) and CV of 2.2% (95% CI 0.0 ±1904.9 m), respectively. Variability in plasma glucose concentrations across the time points was very small (CV 0.46-4.3%, mean 95% CI 0.0±0.33 to 0.0±0.94 mmol·L − 1). Plasma lactate concentrations showed no test order effect. The reliability of performance and metabolic variables makes this protocol a valid test to evaluate nutritional interventions in endurance cycling.

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### Parisotto, Gore et al. 2000 – Reticulocyte parameters as potential discriminators

Parisotto, R.; Gore, C. J.; Hahn, A. G.; Ashenden, M. J.; Olds, T. S.; Martin, D. T. et al. (2000):

## Reticulocyte parameters as potential discriminators of recombinant human erythropoietin abuse in elite athletes.

In: *Int J Sports Med* 21 (7), S. 471–479. DOI: 10.1055/s-2000-7421.

*Abstract:*

This study investigated using reticulocyte (retic) parameters as indirect markers of human recombinant erythropoietin (r-HuEPO) abuse in elite athletes. Absolute reticulocyte count (# retic), the per cell haemoglobin content of reticulocytes (CHr), reticulocyte haemoglobin mass per litre of blood (RetHb) and red blood cell:reticulocyte haemoglobin (RBCHb:RetHb) ratio were assessed using flow cytometry. Venous blood was drawn from 155 elite athletes from six sports during regular training to establish reference ranges (95% confidence interval) for these parameters. The reference ranges were compared with those of a non-athletic population (n = 23), four groups of athletes (n = 24) before and after exposure to simulated altitudes (2,500-3,000 m for 11-23 nights), two groups of elite cyclists (n = 13) before and after four weeks of training at natural altitude (1,780 and 2,690 m), and with those of non-athletic subjects from a separate study (n =24) before and 1-2 days after they were injected with 1,200 U x kg(-1) r-HuEPO over a 9-10 day period. Generally the changes induced by r-HuEPO injection exceeded by approximately 100% the magnitude of the changes associated with natural altitude exposure. Simulated altitude exposure did not significantly alter the reticulocyte parameters. From the sample of 155 non-users and 24 r-HuEPO users, the population mean and variance, as well as the 95% confidence limits for the population mean and population variance, were estimated. Relative to arbitrarily chosen cut-off levels, the confidence limits for the rate of true positives and rate of true negatives were also calculated. Based on the lowest rate of false positives and highest rate of true positives, the best discriminator between r-HuEPO users and non-users was # retic, marginally superior to RBCHb: RetHb ratio and RetHb. At a cut-off for # retic of 221 x 10(9)x L(-1) we could be 95% sure that we would find no more than 7 false positives in every 100,000 tests. We would expect to pick up 51.8% of users, and could be 95% sure of picking up at least 38% of current or recent users. This result highlights the potential power of retic parameters for detecting r-HuEPO abuse among athletes. However, the efficacy of these cut-offs for detecting r-HuEPO abuse is unknown if an athlete is a chronic user or stops using r-HuEPO several weeks before being tested.

### Passfield, Hopker et al. 2017 – Knowledge is power

Passfield, L.; Hopker, J. G.; Jobson, S.; Friel, D.; Zabala, M. (2017):

## Knowledge is power. Issues of measuring training and performance in cycling.

In: *J Sports Sci* 35 (14), S. 1426–1434. DOI: 10.1080/02640414.2016.1215504.

*Abstract:*

Mobile power meters provide a valid means of measuring cyclists' power output in the field. These field measurements can be performed with very good accuracy and reliability making the power meter a useful tool for monitoring and evaluating training and race demands. This review presents power meter data from a Grand Tour cyclist's training and racing and explores the inherent complications created by its stochastic nature. Simple summary methods cannot reflect a session's variable distribution of power output or indicate its likely metabolic stress. Binning power output data, into training zones for example, provides information on the detail but not the length of efforts within a session. An alternative approach is to track changes in cyclists' modelled training and racing performances. Both critical power and record power profiles have been used for monitoring training-induced changes in this manner. Due to the inadequacy of current methods, the review highlights the need for new methods to be established which quantify the effects of training loads and models their implications for performance.

SRM in Science

**Paton, Hopkins 2001 – Tests of cycling performance**

Paton, C. D.; Hopkins, W. G. (2001):

## Tests of cycling performance.

In: *Sports Med* 31 (7), S. 489–496.

*Abstract:*

Performance tests are an integral component of assessment for competitive cyclists in practical and research settings. Cycle ergometry is the basis of most of these tests. Most cycle ergometers are stationary devices that measure power while a cyclist pedals against sliding friction (e.g. Monark), electromagnetic braking (e.g. Lode), or air resistance (e.g. Kingcycle). Mobile ergometers (e.g. SRM cranks) allow measurement of power through the drive train of the cyclist's own bike in real or simulated competitions on the road, in a velodrome or in the laboratory. The manufacturers' calibration of all ergometers is questionable; dynamic recalibration with a special rig is therefore desirable for comparison of cyclists tested on different ergometers. For monitoring changes in performance of a cyclist, an ergometer should introduce negligible random error (variation) in its measurements; in this respect, SRM cranks appear to be the best ergometer, but more comparison studies of ergometers are needed. Random error in the cyclist's performance should also be minimised by choice of an appropriate type of test. Tests based on physiological measures (e.g. maximum oxygen uptake, anaerobic threshold) and tests requiring self-selection of pace (e.g. constant-duration and constant-distance tests) usually produce random error of at least approximately 2 to 3% in the measure of power output. Random error as low as approximately 1% is possible for measures of power in 'all-out' sprints, incremental tests, constant-power tests to exhaustion and probably also time trials in an indoor velodrome. Measures with such low error might be suitable for tracking the small changes in competitive performance that matter to elite cyclists.

**Paton, Hopkins 2006 – Ergometer error and biological variation**

Paton, C. D.; Hopkins, W. G. (2006):

## Ergometer error and biological variation in power output in a performance test with three cycle ergometers.

In: *Int J Sports Med* 27 (6), S. 444–447. DOI: 10.1055/s-2005-865781.

*Abstract:*

When physical performance is monitored with an ergometer, random error arising from the ergometer combines with biological variation from the subject to limit the precision of estimation of performance changes. We report here the contributions of ergometer error and biological variation to the error of measurement in a performance test with two popular cycle ergometers (air-braked Kingcycle, mobile SRM crankset) and a relatively new inexpensive mobile ergometer (PowerTap hub). Eleven well-trained male cyclists performed a familiarization trial followed by three 5-min time trials within 2 wk on a racing cycle fitted with the SRM and PowerTap and mounted on the Kingcycle. Mean power output in each trial was recorded with all ergometers simultaneously. A novel analysis using mixed modelling of log-transformed mean power provided estimates of the standard error of measurement as a coefficient of variation and its components arising from the ergometer and the cyclists. The usual errors of measurement were: Kingcycle 2.2 %, PowerTap 1.5 %, and SRM 1.6 % (90 % confidence limits +/- 1.3). The components of these errors arising purely from the ergometers and the cyclists were: Kingcycle 1.8 %, PowerTap 0.9 %, SRM 1.1 %, and cyclists 1.2 % (+/- 1.5). Thus, ergometer errors and biological variation made substantial contributions to the usual error of measurement. Use of the best ergometers and of test protocols that reduce biological variation would improve monitoring of the small changes that matter to elite athletes.

SRM in Science

**Périard, Caillaud et al. 2011 – Central and peripheral fatigue**

Périard, Julien D.; Caillaud, Corinne; Thompson, Martin W. (2011):

## Central and peripheral fatigue during passive and exercise-induced hyperthermia.

In: *Med Sci Sports Exerc* 43 (9), S. 1657–1665. DOI: 10.1249/MSS.0b013e3182148a9a.

*Abstract:*

PURPOSE

Hyperthermia was induced during prolonged exercise (ExH) and passive heating (PaH) to isolate the influence of exercise on neuromuscular function during a maximal voluntary isometric contraction (MVC) of the quadriceps under heat stress. The influence of cardiovascular strain in limiting endurance performance in the heat was also examined.

METHODS

On separate days, eight males cycled to exhaustion at 60% maximal oxygen uptake or were immersed in a water bath (~41°C) until rectal temperature (Tre) increased to 39.5°C. The ExH and PaH interventions were performed in ambient conditions of 38°C and 60% relative humidity with Tre reaching 39.8°C during exercise. Before (control) and after each intervention, voluntary activation and force production capacity were evaluated by superimposing an electrically stimulated tetanus during a 45-s MVC.

RESULTS

Force production decreased immediately after PaH and ExH compared with control, with the magnitude of decline being more pronounced after ExH ($P < 0.01$). Mean voluntary activation was also significantly depressed after both interventions ($P < 0.01$ vs control). However, the extent of decline in voluntary activation was maintained at ~90% during both PaH and ExH MVC. This decline accounted for 41.5% (PaH) and 33.1% (ExH) of the decrease in force production. In addition, exhaustion coincided with a marked increase in HR (~96% of maximum) and a decline in stroke volume (25%) and mean arterial pressure (10%) ($P < 0.05$).

CONCLUSIONS

The loss of force production capacity during hyperthermia originated from central and peripheral fatigue factors, with the combination of heat stress and previous contractile activity exacerbating the rate of decline. Thus, the observed significant rise in thermal strain in ExH and PaH impaired neuromuscular function and was associated with an exercise performance limiting increase in cardiovascular strain.

**Périard, Caillaud et al. 2012 – The role of aerobic fitness**

Périard, Julien D.; Caillaud, Corinne; Thompson, Martin W. (2012):

## The role of aerobic fitness and exercise intensity on endurance performance in uncompensable heat stress conditions.

In: *Eur. J. Appl. Physiol.* 112 (6), S. 1989–1999. DOI: 10.1007/s00421-011-2165-z.

*Abstract:*

The aim of this study was to examine the influence of aerobic fitness and exercise intensity on the development of thermal and cardiovascular strain in uncompensable heat stress conditions. In three separate trials, eight aerobically trained and eight untrained subjects cycled to exhaustion at 60% (H60%) and 75% (H75%) of maximal oxygen uptake [Formula: see text] in 40°C conditions, and for 60 min at 60% [Formula: see text] in 18°C conditions (CON). Training status had no influence on time to exhaustion between trained (61 ± 10 and 31 ± 9 min) and untrained (58 ± 12 and 26 ± 10 min) subjects (H60% and H75%, respectively). Rectal temperature at exhaustion was also not significantly different between trained (39.8 ± 0.3, 39.3 ± 0.6 and 38.2 ± 0.3°C) and untrained (39.4 ± 0.5, 38.8 ± 0.5 and 38.2 ± 0.4°C) subjects, but was different between trials (H60%, H75% and CON, respectively; $P < 0.01$). However, because exercise was terminated on reaching the ethics approved rectal temperature limit in four trained subjects in the H60% trial and two in the H75% trial, it is speculated that increased rectal temperature may have further occurred in this cohort. Nonetheless, exhaustion occurred >96% of maximum heart rate in both cohorts and was accompanied by significant declines in stroke volume (15-26%), cardiac output (5-10%) and mean arterial pressure (9-13%) ($P < 0.05$). The increase in cardiovascular strain appears to represent the foremost factor precipitating fatigue during moderate and high intensity aerobic exercise in the heat in both trained and untrained subjects.

**Périard, Cramer et al. 2011 – Cardiovascular strain impairs prolonged self-paced**

Périard, Julien D.; Cramer, Matthew N.; Chapman, Phillip G.; Caillaud, Corinne; Thompson, Martin W. (2011):

## Cardiovascular strain impairs prolonged self-paced exercise in the heat.

In: *Exp. Physiol.* 96 (2), S. 134–144. DOI: 10.1113/expphysiol.2010.054213.

*Abstract:*

It has been proposed that self-paced exercise in the heat is regulated by an anticipatory reduction in work rate based on the rate of heat storage. However, performance may be impaired by the development of hyperthermia and concomitant rise in cardiovascular strain increasing relative exercise intensity. This study evaluated the influence of thermal strain on cardiovascular function and power output during self-paced exercise in the heat. Eight endurance-trained cyclists performed a 40 km simulated time trial in hot (35°C) and thermoneutral conditions (20°C), while power output, mean arterial pressure, heart rate, oxygen uptake and cardiac output were measured. Time trial duration was 64.3 ± 2.8 min (242.1 W) in the hot condition and 59.8 ± 2.6 min (279.4 W) in the thermoneutral condition ($P < 0.01$). Power output in the heat was depressed from 20 min onwards compared with exercise in the thermoneutral condition ($P < 0.05$). Rectal temperature reached 39.8 ± 0.3 (hot) and 38.9 ± 0.2°C (thermoneutral; $P < 0.01$). From 10 min onwards, mean skin temperature was ~7.5°C higher in the heat, and skin blood flow was significantly elevated ($P < 0.01$). Heart rate was ~8 beats min(-1) higher throughout hot exercise, while stroke volume, cardiac output and mean arterial pressure were significantly depressed compared with the thermoneutral condition ($P < 0.05$). Peak oxygen uptake measured during the final kilometre of exercise at maximal effort reached 77 (hot) and 95% (thermoneutral) of pre-experimental control values ($P < 0.01$). We conclude that a thermoregulatory-mediated rise in cardiovascular strain is associated with reductions in sustainable power output, peak oxygen uptake and maximal power output during prolonged, intense self-paced exercise in the heat.

**Périard, Cramer et al. 2011 – Neuromuscular function following prolonged intense**

Périard, Julien D.; Cramer, Matthew N.; Chapman, Phillip G.; Caillaud, Corinne; Thompson, Martin W. (2011):

## Neuromuscular function following prolonged intense self-paced exercise in hot climatic conditions.

In: *Eur. J. Appl. Physiol.* 111 (8), S. 1561–1569. DOI: 10.1007/s00421-010-1781-3.

*Abstract:*

Muscle weakness following constant load exercise under heat stress has been associated with hyperthermia-induced central fatigue. However, evidence of central fatigue influencing intense self-paced exercise in the heat is lacking. The purpose of this investigation was to evaluate force production capacity and central nervous system drive in skeletal muscle pre- and post-cycle ergometer exercise in hot and cool conditions. Nine trained male cyclists performed a 20-s maximal voluntary isometric contraction (MVC) prior to (control) and following a 40-km time trial in hot (35°C) and cool (20°C) conditions. MVC force production and voluntary activation of the knee extensors was evaluated via percutaneous tetanic stimulation. In the cool condition, rectal temperature increased to 39.0°C and reached 39.8°C in the heat ($P < 0.01$). Following exercise in the hot and cool conditions, peak force declined by ~90 and ~99 N, respectively, compared with control ($P < 0.01$). Mean force decreased by 15% (hot) and 14% (cool) ($P < 0.01$ vs. control). Voluntary activation during the post-exercise MVC declined to 93.7% (hot) and 93.9% (cool) ($P < 0.05$ vs. control). The post-exercise decline in voluntary activation represented ~20% of the decrease in mean force production in both conditions. Therefore, the additional increase in rectal temperature did not exacerbate the loss of force production following self-paced exercise in the heat. The impairment in force production indicates that the fatigue exhibited by the quadriceps is mainly of peripheral origin and a consequence of the prolonged contractile activity associated with exercise.

**Perrey, Grappe et al. 2003 – Physiological and metabolic responses**

Perrey, S.; Grappe, F.; Girard, A.; Bringard, A.; Groslambert, A.; Bertucci, W.; Rouillon, J. D. (2003):

## Physiological and metabolic responses of triathletes to a simulated 30-min time-trial in cycling at self-selected intensity.

In: *Int J Sports Med* 24 (2), S. 138–143. DOI: 10.1055/s-2003-38200.

*Abstract:*

The aim of this study was to investigate the metabolic and physiological responses to a laboratory-based simulated 30-min individual time-trial (ITT 30 ) in cycling at a self-selected intensity. Twelve experienced triathletes (n = 4 women) performed a progressive incremental exercise test on a cycle ergometer to determine .VO2max (52 +/- 5 ml x min -1 x kg -1), maximum power output (300 +/- 12 W), and the second ventilatory threshold. Then, the subjects completed an ITT30 at self-selected work intensity on a stationary ergometer equipped with the SRM Training System. In all subjects, during the ITT30, heart rate and minute ventilation increased ($p < 0.05$) progressively whereas oxygen consumption and power output remained unchanged. Triathletes rode at consistent pacing corresponding to their highest steady state of blood lactate concentration that increased by no more than 1.0 mmol x l -1 during the final 20-min of ITT30. The self-selected intensity of triathletes during ITT30 represented 88 +/- 5 % (mean +/- SD) of .VO2max and was not significantly different to the energy demand corresponding to the second ventilatory threshold (84 +/- 5 % of .VO2max). Our data suggest that ITT 30 at a self-selected intensity is a good predictor of individual endurance capacity and may be used to estimate racing pace for training purposes. This performance test for the identification of the exercise intensity that demarcate "steady state" is less troublesome than some of the traditional methods, limiting testing to a single session.

**Pinot, Grappe 2011 – The record power profile**

Pinot, J.; Grappe, F. (2011):

## The record power profile to assess performance in elite cyclists.

In: *Int J Sports Med* 32 (11), S. 839–844. DOI: 10.1055/s-0031-1279773.

*Abstract:*

The purpose of this study was to assess the Record Power Profile (RPP) of cyclists, i. e., the relationship between different record Power Output (PO) and the corresponding durations through a whole race season. We hypothesized that PO of different effort durations could differ according to the cyclist's category and race performance profile. 17 cyclists (9 professionals and 8 elites) performed all trainings and competitions during 10 months with a mobile power meter device (SRM) mounted on their bike. The results show that the cyclists' RPP is a hyperbolic relationship between the different record PO and time durations. It significantly reflects the characteristics of different skills: (1) sprinters have the highest record PO within zone 5, (2) climbers present the highest record PO within zones 2-3 and, (3) climbers and flat specialists have higher zone 1 record PO than sprinters. These results suggest that the RPP represents "a signature" of the cyclists' physical capacity and that it allows the determination of different training intensities. The RPP appears as a new concept that is interesting for coaches and scientists in order to evaluate performance in cycling.



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SRM in Science

**Pottgiesser, Garvican et al. 2012 – Short-term hematological effects upon completion**

Pottgiesser, Torben; Garvican, Laura A.; Martin, David T.; Featonby, Jesse M.; Gore, Christopher J.; Schumacher, Yorck O. (2012):

## Short-term hematological effects upon completion of a four-week simulated altitude camp.

In: *Int J Sports Physiol Perform* 7 (1), S. 79–83.

*Abstract:*

Hemoglobin mass (tHb) is considered to be a main factor for sea-level performance after "live high-train low" (LHTL) altitude training, but little research has focused on the persistence of tHb following cessation of altitude exposure. The aim of the case study was to investigate short-term effects of various hematological measures including tHb upon completion of a simulated altitude camp. Five female cyclists spent 26 nights at simulated altitude (LHTL, 16.6 ± 0.4 h/d, 3000 m in an altitude house) where tHb was measured at baseline, at cessation of the camp, and 9 d thereafter. Venous blood measures (hemoglobin concentration, hematocrit, %reticulocytes, serum erythropoietin, ferritin, lactate dehydrogenase, and haptoglobin) were determined at baseline; on day 21 during LHTL; and at days 2, 5, and 9 after LHTL. Hemoglobin mass increased by 5.5% (90% confidence limits [CL] 2.5 to 8.5%, very likely) after the LHTL training camp. At day 9 after simulated LHTL, tHb decreased by 3.0% (90%CL -5.1 to -1.0%, likely). There was a substantial decrease in serum EPO (-34%, 90%CL -50 to -12%) at 2 d after return to sea level and a rise in ferritin (23%, 90%CL 3 to 46%) coupled with a decrease in %reticulocytes (-23%, 90%CL -34 to -9%) between day 5 and 9 after LHTL. Our findings show that following a hypoxic intervention with a beneficial tHb outcome, there may be a high probability of a rapid tHb decrease upon return to normoxic conditions. This highlights a rapid component in red-cell control and may have implications for the appropriate timing of altitude training in relation to competition.

**Quod, Martin et al. 2010 – The Power Profile Predicts Road**

Quod, M. J.; Martin, D. T.; Martin, J. C.; Laursen, P. B. (2010):

## The Power Profile Predicts Road Cycling MMP.

In: *Int J Sports Med* 31 (06), S. 397–401. DOI: 10.1055/s-0030-1247528.

*Abstract:*

Laboratory tests of fitness variables have previously been shown to be valid predictors of cycling time-trial performance. However, due to the influence of drafting, tactics and the variability of power output in mass-start road races, comparisons between laboratory tests and competition performance are limited. The purpose of this study was to compare the power produced in the laboratory Power Profile (PP) test and Maximum Mean Power (MMP) analysis of competition data. Ten male cyclists (mean±SD: 20.8±1.5 y, 67.3±5.5 kg, $\dot{V}O_2max$ 72.7±5.1 mL·kg−1·min−1) completed a PP test within 14 days of competing in a series of road races. No differences were found between PP results and MMP analysis of competition data for durations of 60-600 s, total work or estimates of critical power and the fixed amount of work that can be completed above critical power (W'). Self-selected cadence was 15±7 rpm higher in the lab. These results indicate that the PP test is an ecologically valid assessment of power producing capacity over cycling specific durations. In combination with MMP analysis, this may be a useful tool for quantifying elements of cycling specific performance in competitive cyclists.

**Reiser, Meyer et al. 2000 – Transferability of workload measurements**

Reiser, M.; Meyer, T.; Kindermann, W.; Daugs, R. (2000):

## Transferability of workload measurements between three different types of ergometer.

In: *Eur. J. Appl. Physiol.* 82 (3), S. 245–249. DOI: 10.1007/s004210050678.

*Abstract:*

The aim of this study was to test the transferability of workload measurements between three different types of bicycle ergometer. Two common ergometers (Lode Excalibur and Avantronic Cyclus 2) were compared with a powermeter (Schoberer SRM system) that enables the measurement of power output during road cycling. Twelve well-trained subjects participated in this study. Within 12 h, each subject carried out three separate graded incremental exercise tests on each of the ergometric devices, and their oxygen uptake (VO2) and heart rate were determined. The three test protocols were identical: after warm-up, four stages of 4 min each at exercise intensities of 100, 150, 200, and 250 W. Pedalling frequency was controlled and there was no difference between the three ergometers. Tests were administered in a random order. Neither VO2 nor heart rate was affected by the type of ergometer used. For a given intensity, the same values were found in the two laboratory tests and in the field test (VO2: $P = 0.425$; heart rate: $P = 0.845$). Thus, the transferability of workload measurements between two different laboratory cycling ergometers and an ambulatory device was proven. Equivalency was determined using VO2 and heart rate as indices of metabolic and cardiovascular strain, respectively.

**Reiser, Hart 2008 – Cycling on Rollers**

Reiser, R.; Hart, C. (2008):

## Cycling on Rollers: Kreitler Fan Resistance at Submaximal Levels of Effort.

In: *Int J Sports Med* 29 (3), S. 212–216. DOI: 10.1055/s-2007-965002.

*Abstract:*

The goal of this investigation was to characterize the commercially available fan unit for the Kreitler® Alloy rollers at submaximal levels of effort (≤ 500 W). A single cyclist rode six times at each of three fan inlet settings (closed, half, and full open) and five fan speeds (900, 1800, 2700, 3600, and 4500 rpm). Fan power requirements were isolated by subtracting roller resistance from separate trials. Power requirements relative to fan inlet and fan speed possessed a significant interaction with the main effects for each also significant (all $p < 0.001$). Power increased to the cube of fan speed, regardless of inlet opening ($r2 \geq 0.997$). Fan resistance was virtually non existent at 900 rpm. Fan resistance then significantly increased with increasing fan speed and inlet opening. At 4500 rpm power requirements of the fan reached 269 ± 6, 352 ± 7, and 406 ± 9 W with the inlet closed, half, and fully open, respectively ($p < 0.001$). The rear wheel-roller interaction supplied an additional 19 ± 2 W on up to 104 ± 4 W at the highest speed. Therefore, the fan unit increases the functionality of the rollers for a variety of training and testing environments.

**Richalet, Gore 2008 – Live and/or sleep high:train low**

Richalet, J-P; Gore, C. J. (2008):

## Live and/or sleep high:train low, using normobaric hypoxia.

In: *Scand J Med Sci Sports* 18 Suppl 1, S. 29–37. DOI: 10.1111/j.1600-0838.2008.00830.x.

*Abstract:*

The increase in oxygen transport elicited by several weeks of exposure to moderate to high altitude is used to increase physical performance when returning to sea level. However, many studies have shown that aerobic performance may not increase at sea level after a training block at high altitude. Subsequently, the concept of living high and training low was introduced in the early 1990s and was further modified to include simulated altitude using hypobaric or normobaric hypoxia. Review is given of the main studies that have used this procedure. Hematological changes are limited to insignificant or moderate increase in red cell mass, depending on the "dose" of hypoxia. Maximal aerobic performance is increased when the exposure to hypoxia is at least over 18 days. Submaximal performance and running economy have been found increased in several, but not all, studies. The tolerance (fatigue, sleep, immunological status, cardiac function) is good when the altitude or simulated altitude is not higher than 3000 m. Virtually no data are available about the effect of this procedure upon anaerobic performance. The wide spread of these techniques deserves further investigations.

**Roberts, Clark et al. 2003 – Changes in performance**

Roberts, A. D.; Clark, S. A.; Townsend, N. E.; Anderson, M. E.; Gore, C. J.; Hahn, A. G. (2003):

## Changes in performance, maximal oxygen uptake and maximal accumulated oxygen deficit after 5, 10 and 15 days of live high:train low altitude exposure.

In: *Eur. J. Appl. Physiol.* 88 (4-5), S. 390–395. DOI: 10.1007/s00421-002-0720-3.

*Abstract:*

Nineteen well-trained cyclists (14 males and 5 females, mean initial .VO(2max) 62.3 ml kg(-1 )min(-1)) completed a multistage cycle ergometer test to determine maximal mean power output in 4 min (MMPO(4min)), maximal oxygen uptake (.VO(2max)) and maximal accumulated oxygen deficit (MAOD). The athletes were divided into three groups, each of which completed 5, 10 or 15 days of both a control condition (C) and live high:train low altitude exposure (LHTL). The C groups lived and trained at the ambient altitude of 610 m. The LHTL groups spent 8-10 h night(-1) in normobaric hypoxia at a simulated altitude of 2,650 m, and trained at the ambient altitude of 610 m. The changes to MMPO(4min), .VO(2max) and MAOD in response to LHTL altitude exposure were not significantly different for the 5-, 10- and 15-day treatment periods. For the pooled data from all three treatment periods, there were significant increases in MMPO(4min) [mean (SD) 5.15 (0.83) W kg(-1) vs 5.34 (0.78) W kg(-1)] and MAOD [50.1 (14.2) ml kg(-1) vs 54.9 (13.1) ml kg(-1)] in the LHTL athletes between pre- and post-altitude exposure. There were no significant changes in MMPO(4min) [5.09 (0.76) W kg(-1) vs 5.16 (0.86) W kg(-1)] or MAOD [50.5 (14.1) ml kg(-1) vs 49.1 (13.0) ml kg(-1)] in the C athletes over the corresponding period. There were significant increases in .VO(2max) in the athletes during both the LHTL [63.2 (9.0) ml kg(-1 )min(-1) vs 64.1 (9.0) ml kg(-1 )min(-1)] and C [62.0 (8.6) ml kg(-1 )min(-1) vs 63.4 (9.2) ml kg(-1 )min(-1)] conditions. In these athletes, there was no difference in the impact of 5, 10 or 15 days of LHTL on the increases observed in MMPO(4min), .VO(2max) or MAOD; and LHTL increased MMPO(4min) and MAOD more than training at low altitude alone.

**Robertson, Saunders et al. 2010 – Reproducibility of performance changes**

Robertson, Eileen Y.; Saunders, Philo U.; Pyne, David B.; Aughey, Robert J.; Anson, Judith M.; Gore, Christopher J. (2010):

## Reproducibility of performance changes to simulated live high/train low altitude.

In: *Med Sci Sports Exerc* 42 (2), S. 394–401. DOI: 10.1249/MSS.0b013e3181b34b57.

*Abstract:*

UNLABELLED

Elite athletes often undertake multiple altitude exposures within and between training years in an attempt to improve sea level performance.

PURPOSE

To quantify the reproducibility of responses to live high/train low (LHTL) altitude exposure in the same group of athletes.

METHODS

Sixteen highly trained runners with maximal aerobic power (VO2max) of 73.1 +/- 4.6 and 64.4 +/- 3.2 mL x kg(-1) x min(-1) (mean +/- SD) for males and females, respectively, completed 2 x 3-wk blocks of simulated LHTL (14 h x d(-1), 3000 m) or resided near sea level (600 m) in a controlled study design. Changes in the 4.5-km time trial performance and physiological measures including VO2max, running economy and hemoglobin mass (Hb(mass)) were assessed.

RESULTS

Time trial performance showed small and variable changes after each 3-wk altitude block in both the LHTL (mean [+/-90% confidence limits]: -1.4% [+/-1.1%] and 0.7% [+/-1.3%]) and the control (0.5% [+/-1.5%] and -0.7% [+/-0.8%]) groups. The LHTL group demonstrated reproducible improvements in VO2max (2.1% [+/-2.1%] and 2.1% [+/-3.9%]) and Hb(mass) (2.8% [+/-2.1%] and 2.7% [+/-1.8%]) after each 3-wk block. Compared with those in the control group, the runners in the LHTL group were substantially faster after the first 3-wk block (LHTL - control = -1.9% [+/-1.8%]) and had substantially higher Hb(mass) after the second 3-wk block (4.2% [+/-2.1%]). There was no substantial difference in the change in mean VO2max between the groups after the first (1.2% [+/-3.3%]) or second 3-wk block (1.4% [+/-4.6%]).

CONCLUSIONS

Three-week LHTL altitude exposure can induce reproducible mean improvements in VO2max and Hb(mass) in highly trained runners, but changes in time trial performance seem to be more variable. Competitive performance is dependent not only on improvements in physiological capacities that underpin performance but also on a complex interaction of many factors including fitness, fatigue, and motivation.

**Robertson, Saunders et al. 2010 – Effectiveness of intermittent training**

Robertson, Eileen Y.; Saunders, Philo U.; Pyne, David B.; Gore, Christopher J.; Anson, Judith M. (2010):

## Effectiveness of intermittent training in hypoxia combined with live high/train low.

In: *Eur. J. Appl. Physiol.* 110 (2), S. 379–387. DOI: 10.1007/s00421-010-1516-5.

*Abstract:*

Elite athletes often undertake altitude training to improve sea-level athletic performance, yet the optimal methodology has not been established. A combined approach of live high/train low plus train high (LH/TL+TH) may provide an additional training stimulus to enhance performance gains. Seventeen male and female middle-distance runners with maximal aerobic power (VO2max) of 65.5 +/- 7.3 mL kg(-1) min(-1) (mean +/- SD) trained on a treadmill in normobaric hypoxia for 3 weeks (2,200 m, 4 week(-1)). During this period, the train high (TH) group (n = 9) resided near sea-level (approximately 600 m) while the LH/TL+TH group (n = 8) stayed in normobaric hypoxia (3,000 m) for 14 hours day(-1). Changes in 3-km time trial performance and physiological measures including VO2max, running economy and haemoglobin mass (Hb(mass)) were assessed. The LH/TL+TH group substantially improved VO2max (4.8%; +/-2.8%, mean; +/-90% CL), Hb(mass) (3.6%; +/-2.4%) and 3-km time trial performance (-1.1%; +/-1.0%) immediately post-altitude. There was no substantial improvement in time trial performance 2 weeks later. The TH group substantially improved VO2max (2.2%; +/-1.8%), but had only trivial changes in Hb(mass) and 3-km time-trial performance. Compared with TH, combined LH/TL+TH substantially improved VO2max (2.6%; +/-3.2%), Hb(mass) (4.3%; +/-3.2%), and time trial performance (-0.9%; +/-1.4%) immediately post-altitude. LH/TL+TH elicited greater enhancements in physiological capacities compared with TH, however, the transfer of benefits to time-trial performance was more variable.



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### Rodríguez, Truijens et al. 2007 – Performance of runners and swimmers

Rodríguez, Ferran A.; Truijens, Martin J.; Townsend, Nathan E.; Stray-Gundersen, James; Gore, Christopher J.; Levine, Benjamin D. (2007):

## Performance of runners and swimmers after four weeks of intermittent hypobaric hypoxic exposure plus sea level training.

In: *J. Appl. Physiol.* 103 (5), S. 1523–1535. DOI: 10.1152/japplphysiol.01320.2006.

*Abstract:*

This double-blind, randomized, placebo-controlled trial examined the effects of 4 wk of resting exposure to intermittent hypobaric hypoxia (IHE, 3 h/day, 5 days/wk at 4,000-5,500 m) or normoxia combined with training at sea level on performance and maximal oxygen transport in athletes. Twenty-three trained swimmers and runners completed duplicate baseline time trials (100/400-m swims, or 3-km run) and measures for maximal oxygen uptake (VO(2max)), ventilation (VE(max)), and heart rate (HR(max)) and the oxygen uptake at the ventilatory threshold (VO(2) at VT) during incremental treadmill or swimming flume tests. Subjects were matched for sex, sport, performance, and training status and divided randomly between hypobaric hypoxia (Hypo, n = 11) and normobaric normoxia (Norm, n = 12) groups. All tests were repeated within the first (Post1) and third weeks (Post2) after the intervention. Time-trial performance did not improve in either group. We could not detect a significant difference between groups for a change in VO(2max), VE(max), HR(max), or VO(2) at VT after the intervention (group x test interaction P = 0.31, 0.24, 0.26, and 0.12, respectively). When runners and swimmers were considered separately, Hypo swimmers appeared to increase VO(2max) (+6.2%, interaction P = 0.07) at Post2 following a precompetition taper and increased VO(2) at VT (+8.9 and +12.1%, interaction P = 0.007 and 0.006, at Post1 and Post2). We conclude that this "dose" of IHE was not sufficient to improve performance or oxygen transport in this heterogeneous group of athletes. Whether there are potential benefits of this regimen for specific sports or training/tapering strategies may require further study.

### Rylands, Roberts et al. 2015 – Variability in Laboratory vs

Rylands, Lee P.; Roberts, Simon J.; Hurst, Howard T. (2015):

## Variability in Laboratory vs. Field Testing of Peak Power, Torque, and Time of Peak Power Production Among Elite Bicycle Motocross Cyclists.

In: *Journal of strength and conditioning research / National Strength & Conditioning Association* 29 (9), S. 2635–2640. DOI: 10.1519/JSC.0000000000000884.

*Abstract:*

The aim of this study was to ascertain the variation in elite male bicycle motocross (BMX) cyclists' peak power, torque, and time of power production during laboratory and field-based testing. Eight elite male BMX riders volunteered for the study, and each rider completed 3 maximal sprints using both a Schoberer Rad Messtechnik (SRM) ergometer in the laboratory and a portable SRM power meter on an Olympic standard indoor BMX track. The results revealed a significantly higher peak power (p </= 0.001, 34 +/- 9%) and reduced time of power production (p </= 0.001, 105 +/- 24%) in the field tests when compared with laboratory-derived values. Torque was also reported to be lower in the laboratory tests but not to an accepted level of significance (p = 0.182, 6 +/- 8%). These results suggest that field-based testing may be a more effective and accurate measure of a BMX rider's peak power, torque, and time of power production.

SRM in Science

**Rylands, Roberts et al. 2017 – Effect of cadence selection**

Rylands, Lee P.; Roberts, Simon J.; Hurst, Howard T.; Bentley, Ian (2017):

## Effect of cadence selection on peak power and time of power production in elite BMX riders. A laboratory based study.

In: *J Sports Sci* 35 (14), S. 1372–1376. DOI: 10.1080/02640414.2016.1215491.

*Abstract:*

The aims of this study were to analyse the optimal cadence for peak power production and time to peak power in bicycle motocross (BMX) riders. Six male elite BMX riders volunteered for the study. Each rider completed 3 maximal sprints at a cadence of 80, 100, 120 and 140 revs . min-1 on a laboratory Schoberer Rad Messtechnik (SRM) cycle ergometer in isokinetic mode. The riders' mean values for peak power and time of power production in all 3 tests were recorded. The BMX riders produced peak power (1105 +/- 139 W) at 100 revs . min-1 with lower peak power produced at 80 revs . min-1 (1060 +/- 69 W, (F(2,15) = 3.162; P = .266; eta2 = 0.960), 120 revs . min-1 (1077 +/- 141 W, (F(2,15) = 4.348; P = .203; eta2 = 0.970) and 140 revs . min-1 (1046 +/- 175 W, (F(2,15) = 12.350; P = 0.077; eta2 = 0.989). The shortest time to power production was attained at 120 revs . min-1 in 2.5 +/- 1.07 s. Whilst a cadence of 80 revs . min-1 (3.5 +/- 0.8 s, (F(2,15) = 2.667; P = .284; eta2 = 0.800) 100 revs . min-1 (3.00 +/- 1.13 s, (F(2,15) = 24.832; P = .039; eta2 = 0.974) and 140 revs . min-1 (3.50 +/- 0.88 s, (F(2,15) = 44.167; P = .006; eta2 = 0.967)) all recorded a longer time to peak power production. The results indicate that the optimal cadence for producing peak power output and reducing the time to peak power output are attained at comparatively low cadences for sprint cycling events. These findings could potentially inform strength and conditioning training to maximise dynamic force production and enable coaches to select optimal gear ratios.

**Sassi, Rampinini et al. 2009 – Effects of gradient and speed**

Sassi, Aldo; Rampinini, Ermano; Martin, David T.; Morelli, Andrea (2009):

## Effects of gradient and speed on freely chosen cadence: the key role of crank inertial load.

In: *J Biomech* 42 (2), S. 171–177. DOI: 10.1016/j.jbiomech.2008.10.008.

*Abstract:*

The purpose of this study was to describe the relationship between road gradient (RG) and freely chosen cadence (FCC) in a group of professional cyclists during their normal training. In addition, a calculation of crank inertial load (CIL) was estimated in order to establish the relationship between FCC and CIL. Ten professional cyclists were monitored during training using commercially available power meters (Shoberer Rad Messtechnik (SRM), professional version). For each cyclist, recorded training sessions were reviewed to identify the hardest 6-8 training sessions (approximately 18 h of training). RG was estimated based on the relationship between power output, total mass and speed. The analysis was performed using 2113+/-317 samples of 30 s average data, collected on terrain ranging from -4%RG to 12%RG. The individual relationship between FCC and RG could be described by a linear regression model. There was a moderate correlation between FCC and CIL (group's r=0.42), and a multiple regression including the measured power output (WPO) increased the variance explained (R2=0.24). The correlation was very large between CIL and v (r=0.91), and was not strengthened by adding WPO as an independent variable (r=0.91). In conclusion, this investigation documents that in professional cyclists engaged in training, there is a linear decrease in FCC as RG increases (-4%RG and 12%RG). This decrease in FCC appears to be due to the reduction in v as slope increases. It is surmised that CIL plays a key role in the modulation of FCC.

### Saunders, Telford et al. 2004 – Improved running economy in elite

Saunders, P. U.; Telford, R. D.; Pyne, D. B.; Cunningham, R. B.; Gore, C. J.; Hahn, A. G.; Hawley, J. A. (2004):

## Improved running economy in elite runners after 20 days of simulated moderate-altitude exposure.

In: *J. Appl. Physiol.* 96 (3), S. 931–937. DOI: 10.1152/japplphysiol.00725.2003.

*Abstract:*

To investigate the effect of altitude exposure on running economy (RE), 22 elite distance runners [maximal O(2) consumption (Vo(2)) 72.8 +/- 4.4 ml x kg(-1) x min(-1); training volume 128 +/- 27 km/wk], who were homogenous for maximal Vo(2) and training, were assigned to one of three groups: live high (simulated altitude of 2,000-3,100 m)-train low (LHTL; natural altitude of 600 m), live moderate-train moderate (LMTM; natural altitude of 1,500-2,000 m), or live low-train low (LLTL; natural altitude of 600 m) for a period of 20 days. RE was assessed during three submaximal treadmill runs at 14, 16, and 18 km/h before and at the completion of each intervention. Vo(2), minute ventilation (Ve), respiratory exchange ratio, heart rate, and blood lactate concentration were determined during the final 60 s of each run, whereas hemoglobin mass (Hb(mass)) was measured on a separate occasion. All testing was performed under normoxic conditions at approximately 600 m. Vo(2) (l/min) averaged across the three submaximal running speeds was 3.3% lower (P = 0.005) after LHTL compared with either LMTM or LLTL. Ve, respiratory exchange ratio, heart rate, and Hb(mass) were not significantly different after the three interventions. There was no evidence of an increase in lactate concentration after the LHTL intervention, suggesting that the lower aerobic cost of running was not attributable to an increased anaerobic energy contribution. Furthermore, the improved RE could not be explained by a decrease in Ve or by preferential use of carbohydrate as a metabolic substrate, nor was it related to any change in Hb(mass). We conclude that 20 days of LHTL at simulated altitude improved the RE of elite distance runners.

### Saunders, Telford et al. 2009 – Improved running economy and increased

Saunders, P. U.; Telford, R. D.; Pyne, D. B.; Hahn, A. G.; Gore, C. J. (2009):

## Improved running economy and increased hemoglobin mass in elite runners after extended moderate altitude exposure.

In: *J Sci Med Sport* 12 (1), S. 67–72. DOI: 10.1016/j.jsams.2007.08.014.

*Abstract:*

There is conflicting evidence whether hypoxia improves running economy (RE), maximal O(2) uptake (V(O)(2max)), haemoglobin mass (Hb(mass)) and performance, and what total accumulated dose is necessary for effective adaptation. The aim of this study was to determine the effect of an extended hypoxic exposure on these physiological and performance measures. Nine elite middle distance runners were randomly assigned to a live high-train low simulated altitude group (ALT) and spent 46+/-8 nights (mean+/-S.D.) at 2860+/-41m. A matched control group (CON, n=9) lived and trained near sea level ( approximately 600m). ALT decreased submaximal V(O)(2) (Lmin(-1)) (-3.2%, 90% confidence intervals, -1.0% to -5.2%, p=0.02), increased Hb(mass) (4.9%, 2.3-7.6%, p=0.01), decreased submaximal heart rate (-3.1%, -1.8% to -4.4%, p=0.00) and had a trivial increase in V(O)(2max) (1.5%, -1.6 to 4.8; p=0.41) compared with CON. There was a trivial correlation between change in Hb(mass) and change in V(O)(2max) (r=0.04, p=0.93). Hypoxic exposure of approximately 400h was sufficient to improve Hb(mass), a response not observed with shorter exposures. Although total O(2) carrying capacity was improved, the mechanism(s) to explain the lack of proportionate increase in V(O)(2max) were not identified.

**Saunders, Ahlgrim et al. 2010 – An attempt to quantify**

Saunders, Philo U.; Ahlgrim, Christoph; Vallance, Brent; Green, Daniel J.; Robertson, Eileen Y.; Clark, Sally A. et al. (2010):

## An attempt to quantify the placebo effect from a three-week simulated altitude training camp in elite race walkers.

In: *Int J Sports Physiol Perform* 5 (4), S. 521–534.

*Abstract:*

PURPOSE

To quantify physiological and performance effects of hypoxic exposure, a training camp, the placebo effect, and a combination of these factors.

METHODS

Elite Australian and International race walkers (n = 17) were recruited, including men and women. Three groups were assigned: 1) Live High:Train Low (LHTL, n = 6) of 14 h/d at 3000 m simulated altitude; 2) Placebo (n = 6) of 14 h/d of normoxic exposure (600 m); and 3) Nocebo (n = 5) living in normoxia. All groups undertook similar training during the intervention. Physiological and performance measures included 10-min maximal treadmill distance, peak oxygen uptake (VO2peak), walking economy, and hemoglobin mass (Hbmass).

RESULTS

Blinding failed, so the Placebo group was a second control group aware of the treatment. All three groups improved treadmill performance by approx. 4%. Compared with Placebo, LHTL increased Hbmass by 8.6% (90% CI: 3.5 to 14.0%; P = .01, very likely), VO2peak by 2.7% (-2.2 to 7.9%; P = .34, possibly), but had no additional improvement in treadmill distance (-0.8%, -4.6 to 3.8%; P = .75, unlikely) or economy (-8.2%, -24.1 to 5.7%; P = .31, unlikely). Compared with Nocebo, LHTL increased Hbmass by 5.5% (2.5 to 8.7%; P = .01, very likely), VO2peak by 5.8% (2.3 to 9.4%; P = .02, very likely), but had no additional improvement in treadmill distance (0.3%, -1.9 to 2.5%; P = .75, possibly) and had a decrease in walking economy (-16.5%, -30.5 to 3.9%; P = .04, very likely).

CONCLUSION

Overall, 3-wk LHTL simulated altitude training for 14 h/d increased Hbmass and VO2peak, but the improvement in treadmill performance was not greater than the training camp effect.

**Saunders, Pyne et al. 2009 – Endurance training at altitude**

Saunders, Philo U.; Pyne, David B.; Gore, Christopher J. (2009):

## Endurance training at altitude.

In: *High Alt. Med. Biol.* 10 (2), S. 135–148. DOI: 10.1089/ham.2008.1092.

*Abstract:*

Since the 1968 Olympic Games when the effects of altitude on endurance performance became evident, moderate altitude training ( approximately 2000 to 3000 m) has become popular to improve competition performance both at altitude and sea level. When endurance athletes are exposed acutely to moderate altitude, a number of physiological responses occur that can comprise performance at altitude; these include increased ventilation, increased heart rate, decreased stroke volume, reduced plasma volume, and lower maximal aerobic power ((.)Vo(2max)) by approximately 15% to 20%. Over a period of several weeks, one primary acclimatization response is an increase in the volume of red blood cells and consequently of (.)Vo(2max). Altitudes > approximately 2000 m for >3 weeks and adequate iron stores are required to elicit these responses. However, the primacy of more red blood cells for superior sea-level performance is not clear-cut since the best endurance athletes in the world, from Ethiopia (approximately 2000 to 3000 m), have only marginally elevated hemoglobin concentrations. The substantial reduction in (.)Vo(2max) of athletes at moderate altitude implies that their training should include adequate short-duration (approximately 1 to 2 min), high-intensity efforts with long recoveries to avoid a reduction in race-specific fitness. At the elite level, athlete performance is not dependent solely on (.)Vo(2max), and the "smallest worthwhile change" in performance for improving race results is as little as 0.5%. Consequently, contemporary statistical approaches that utilize the concept of the smallest worthwhile change are likely to be more appropriate than conventional statistical methods when attempting to understand the potential benefits and mechanisms of altitude training.

**Saunders, Telford et al. 2009 – Improved race performance in elite**

Saunders, Philo U.; Telford, Richard D.; Pyne, David D.; Gore, Christopher J.; Hahn, Allan G. (2009):

## Improved race performance in elite middle-distance runners after cumulative altitude exposure.

In: *Int J Sports Physiol Perform* 4 (1), S. 134–138.

*Abstract:*

We quantified the effect of an extended live high-train low (LHTL) simulated altitude exposure followed by a series of training camps at natural moderate altitude on competitive performance in seven elite middle-distance runners (Vo2max 71.4 +/- 3.4 mL.min-1.kg-1, mean +/- SD). Runners spent 44 +/- 7 nights (mean +/- SD) at a simulated altitude of 2846 +/- 32 m, and a further 4 7- to 10-d training at natural moderate altitude (1700-2200 m) before racing. The combination of simulated LHTL and natural altitude training improved competitive performance by 1.9% (90% confidence limits, 1.3-2.5%). Middle-distance runners can confidently use a combination of simulated and natural altitude to stimulate adaptations responsible for improving performance.

**Sharpe, Hopkins et al. 2002 – Development of reference ranges**

Sharpe, Ken; Hopkins, Will; Emslie, Kerry R.; Howe, Chris; Trout, Graham J.; Kazlauskas, Rymantas et al. (2002):

## Development of reference ranges in elite athletes for markers of altered erythropoiesis.

In: *Haematologica* 87 (12), S. 1248–1257.

*Abstract:*

BACKGROUND AND OBJECTIVES

Our previous research developed two statistical models that are useful indicators of current (ON-model) or recently discontinued (OFF-model) recombinant human erythropoietin (rHuEPO) use by athletes. The component variables of the ON-model are hematocrit (Hct), reticulocyte hematocrit (RetHct), serum erythropoietin (EPO), percent macrocytes (%Macro), and soluble transferrin receptor (sTfr), whilst the OFF-model uses only the first three variables. Genetics and training modalities of elite athletes may conceivably produce unusual values for blood parameters related to erythropoiesis. The aims of this study were to develop reference ranges in elite athletes for key hematologic parameters as well as ON- and OFF-models scores, and to evaluate the effect of ethnicity, gender, residence at moderate altitude (approximately 2000 m) and within-individual variation on the variables and model scores.

DESIGN AND METHODS

Over a period of three weeks, 413 female and 739 male elite athletes from 12 countries visited laboratories to provide three blood samples for analysis of blood parameters sensitive to erythropoiesis. For each parameter and for the ON- and OFF-model scores, we used mixed modeling to establish the range within which we could be 95% certain that the value for a randomly chosen athlete would fall, taking into account various random effects (variation within and between subjects and laboratories) and fixed effects (means for different levels of ethnicity, age, sport, altitude of residency). We performed similar analyses for changes in the ON- and OFF-model scores between the three visits.

RESULTS

Most fixed effects were accompanied by clear-cut, small to moderate differences in several parameters. However, residency at moderate altitude was accompanied by a much higher hematocrit than residency nearer sea level, with the mean (and 95% confidence limits) for the difference being 2.3 (0.9 to 3.7) and 1.8 (0.1 to 3.5) units for males and females, respectively. Males at altitude also demonstrated a moderately higher ON-model score. Otherwise the influence of these effects was small for ON-, OFF- and changes in model scores.

INTERPRETATION AND CONCLUSIONS

Assessment of an athlete's blood parameters and ON- and OFF-model scores may need adjustment for training modalities and other characteristics of the subject. Changes in model scores (together with monitoring of urine samples for the presence of rHuEPO) provide a promising approach to detection of rHuEPO abuse, because they are less sensitive to subject characteristics and less variable than raw model scores.

### Simons, van Es et al. 2009 – Electrically assisted cycling

Simons, Monique; van Es, Eline; Hendriksen, Ingrid (2009):

## Electrically assisted cycling: a new mode for meeting physical activity guidelines?

In: *Med Sci Sports Exerc* 41 (11), S. 2097–2102. DOI: 10.1249/MSS.0b013e3181a6aaa4.

*Abstract:*

PURPOSE

The purpose of this study was to assess the potential of the electrically assisted bicycle (EAB) as a novel tool for meeting the physical activity guidelines in terms of intensity.

METHODS

Twelve habitually active adult subjects were requested to cycle a track of 4.3 km at an intensity they would normally choose for commuter cycling, using three different support settings: no support (NO), eco support (ECO), and power support (POW). For estimating the intensity, the oxygen consumption was measured by using a portable gas-analyzing system, and HR was simultaneously measured. The bicycle was equipped with the SRM Training System to measure subjects' power output, pedaling rate, and the cycle velocity.

RESULTS

Mean intensity was 6.1 MET for NO, 5.7 MET for ECO, and 5.2 MET for POW. Intensity was significantly lower in POW compared with that in NO. No differences were found between NO and ECO and between ECO and POW. Mean HR was significantly higher in NO compared with that in ECO and POW. The cycling speed with electrical support settings was significantly higher than cycling in the NO condition. Mean power output during cycling was significantly different among all three conditions. Most power outputs were supplied in the NO condition, and the lowest power output was supplied in the POW condition.

CONCLUSIONS

Intensity during cycling on an EAB, in all three measured conditions, is sufficiently high to contribute to the physical activity guidelines for moderate-intensity health-enhancing physical activity for adults (cutoff, 3 MET). Further study is needed to conclude whether these results still hold when using the EAB in regular daily life and in subjects with other fitness level.

### Smith, Davison et al. 2001 – Reliability of mean power recorded

Smith, M. F.; Davison, R. C.; Balmer, J.; Bird, S. R. (2001):

## Reliability of mean power recorded during indoor and outdoor self-paced 40 km cycling time-trials.

In: *Int J Sports Med* 22 (4), S. 270–274. DOI: 10.1055/s-2001-13813.

*Abstract:*

The purpose of this study was to assess reliability of both indoor and outdoor 40 km time-trial cycling performance. Eight trained cyclists completed three indoor 40 km time-trials on an air-braked ergometer (Kingcycle) and three outdoor 40 km time-trials on a local course. Power output was measured for all trials using the SRM powermeter. Mean performance time across three indoor trials was 54.21 +/- 2.59 (min:sec) and was significantly different (P<0.05) to mean time across three outdoor trials (57.29 +/- 3.22 min:sec). However, there was no significant difference (P = 0.34) for mean power across three indoor trials (303+/-35W) when compared to outdoor performances (312 +/- 23 W). Within-subject variation for mean power output expressed as a coefficient of variation (CV) improved in both indoors and outdoors for trials 2 and 3 (CV = 1.9%, 95% CI 1.0 - 3.4 and CV = 2.1 %, 95 % CI 1.1 - 3.8) when compared to trials 1 and 2 (CV=2.1%, 95% CI 1.2-3.8 and CV=2.4%, 95% CI 1.3-4.3). These findings indicate that power output measured using the SRM powermeter is highly reproducible for both laboratory-based and actual 40 km time-trial cycling performance.

**Sparks, Dove et al. 2014 – Validity and Reliability**

Sparks, S. Andy; Dove, Benjamin; Bridge, Craig A.; Midgely, Adrian W.; McNaughton, Lars R. (2014):

## Validity and Reliability of the Look Keo Power Pedal System for Measuring Power Output During Incremental and Repeated Sprint Cycling.

In: *Int J Sports Physiol Perform. DOI:* 10.1123/ijspp.2013-0317.

*Abstract:*

Powermeters have traditionally been integrated into the crankset but several manufacturers have designed new systems located elsewhere on the bike such as inside the pedals.

PURPOSE

This study aimed to determine the validity and reliability of the Keo power pedals during several laboratory cycling tasks.

METHODS

Ten active male participants (mean ± SD age 34.0 ± 10.6 y, height 1.77 ± 0.04 m, body mass 76.5 ± 10.7 kg), familiar with laboratory cycling protocols completed this study. Each participant was required to complete two laboratory cycling trials on an SRM ergometer (SRM, Germany) which was also fitted with the Keo power pedals (Look, France). The trials consisted of an incremental test to exhaustion followed by 10 min rest and then three 10 s sprint tests separated by 3 min of cycling at 100 W.

RESULTS

Over power ranges of 75-1147 W the Keo power pedal system produced typical error (TE) values of 0.40, 0.21 and 0.21 for the incremental, sprint and combined trials respectively, compared to the SRM. Mean differences of 21.0 W and 18.6 W were observed between trials 1 and 2 with the Keo system in the incremental and combined protocols respectively. In contrast the SRM produced differences of 1.3 W and 0.6 W for the same protocols respectively.

CONCLUSIONS

The power data from the Keo power pedals should be treated with some caution given the presence of mean differences between them and the SRM. Furthermore, this is exacerbated by poorer reliability than that of the SRM powermeter.

SRM in Science

**Stapelfeldt, Mornieux et al. 2007 – Development and evaluation**

Stapelfeldt, B.; Mornieux, G.; Oberheim, R.; Belli, A.; Gollhofer, A. (2007):

## Development and evaluation of a new bicycle instrument for measurements of pedal forces and power output in cycling.

In: *Int J Sports Med* 28 (4), S. 326–332. DOI: 10.1055/s-2006-924352.

*Abstract:*

Determination of pedal forces is a prerequisite to analyse cycling performance capability from a biomechanical point of view. Comparing existing pedal force measurement systems, there are methodological or practical limitations regarding the requirements of scientific sports performance research and enhancement. Therefore, the aim of this study was to develop and to validate a new bicycle instrument that enables pedal forces as well as power output measurements with a free choice of pedal system. The instrument (Powertec-System) is based on force transducer devices, using the Hall-Effect and being mounted between the crank and the pedal. Validation of the method was evaluated by determining the accuracy, the cross talk effect, the influence of lateral forces, the reproducibility and, finally, a possible drift under static conditions. Dynamic tests were conducted to validate the power output measurement in reference to the SRM-System. The mean error of the present system was -0.87 +/- 4.09 % and -1.86 +/- 6.61 % for, respectively, the tangential and radial direction. Cross talk, lateral force influence, reproducibility and drift mean values were < +/- 7 %, < or = 2.4 %, < 0.8 % and 0.02 N x min (-1), respectively. In dynamic conditions, the power output measurement error could be kept below 2.35 %. In conclusion, this method offers the possibility for both valid pedal forces and power output measurements. Moreover, the instrument allows measurements with every pedal system. This method has an interesting potential for biomechanical analyses in cycling research and performance enhancement.

**Stapelfeldt, Schwirtz et al. 2004 – Workload demands in mountain bike**

Stapelfeldt, B.; Schwirtz, A.; Schumacher, Y. O.; Hillebrecht, M. (2004):

## Workload demands in mountain bike racing.

In: *Int J Sports Med* 25 (4), S. 294–300. DOI: 10.1055/s-2004-819937.

*Abstract:*

This study aims at describing the workload demands during mountain bike races using direct power measurements, and to compare these data to power output and physiological findings from laboratory exercise tests. Power output (P, Watt) from 11 national team cyclists (9 male, 2 female) was registered continuously during 15 races using mobile crank dynamometers (SRM System). To evaluate the intensity of racing, incremental exercise tests with determination of P at aerobic and anaerobic thresholds (AT, IAT) and at exhaustion (MAX) were performed. Intensity zones were determined (zone 1 < AT; AT < zone 2 < IAT; IAT < zone 3 < MAX; zone 4 > MAX) and time spent during racing in these zones was calculated. Based on power output measurements P during racing was 246 +/- 12 W (male) and 193 +/- 1 W (female). P showed high variation throughout the race. In contrast heart rate (HR) was relatively stable during racing (male 177 +/- 6 bpm, female 172 +/- 7 bpm). 39 +/- 6 % of race time were spent in zone 1, 19 +/- 6 % in zone 2, 20 +/- 3 % in zone 3 and 22 +/- 6 % in zone 4. MTB races are characterized by a high oscillation in P with permanently elevated HR. A highly developed aerobic and anaerobic system is needed to sustain the high variation in workload.

**Tomas, Ross et al. 2010 – Fatigue during maximal sprint cycling**

Tomas, Aleksandar; Ross, Emma Z.; Martin, James C. (2010):

## Fatigue during maximal sprint cycling: unique role of cumulative contraction cycles.

In: *Med Sci Sports Exerc* 42 (7), S. 1364–1369. DOI: 10.1249/MSS.0b013e3181cae2ce.

*Abstract:*

UNLABELLED

Maximal cycling power has been reported to decrease more rapidly when performed with increased pedaling rates. Increasing pedaling rate imposes two constraints on the neuromuscular system: 1) decreased time for muscle excitation and relaxation and 2) increased muscle shortening velocity. Using two crank lengths allows the effects of time and shortening velocity to be evaluated separately.

PURPOSES

We conducted this investigation to determine whether the time available for excitation and relaxation or the muscle shortening velocity was mainly responsible for the increased rate of fatigue previously observed with increased pedaling rates and to evaluate the influence of other possible fatiguing constraints.

METHODS

Seven trained cyclists performed 30-s maximal isokinetic cycling trials using two crank lengths: 120 and 220 mm. Pedaling rate was optimized for maximum power for each crank length: 135 rpm for the 120-mm cranks (1.7 m x s(-1) pedal speed) and 109 rpm for the 220-mm cranks (2.5 m x s(-1) pedal speed). Power was recorded with an SRM power meter.

RESULTS

Crank length did not affect peak power: 999 +/- 276 W for the 120-mm crank versus 1001 +/- 289 W for the 220-mm crank. Fatigue index was greater (58.6% +/- 3.7% vs 52.4% +/- 4.8%, P < 0.01), and total work was less (20.0 +/- 1.8 vs 21.4 +/- 2.0 kJ, P < 0.01) with the higher pedaling rate-shorter crank condition. Regression analyses indicated that the power for the two conditions was most highly related to cumulative work (r2 = 0.94) and to cumulative cycles (r2 = 0.99).

CONCLUSIONS

These results support previous findings and confirm that pedaling rate, rather than pedal speed, was the main factor influencing fatigue. Our novel result was that power decreased by a similar increment with each crank revolution for the two conditions, indicating that each maximal muscular contraction induced a similar amount of fatigue.

**Townsend, Gore et al. 2016 – Ventilatory acclimatisation is beneficial**

Townsend, Nathan E.; Gore, Christopher J.; Ebert, Tammie R.; Martin, David T.; Hahn, Allan G.; Chow, Chin-Moi (2016):

## Ventilatory acclimatisation is beneficial for high-intensity exercise at altitude in elite cyclists.

In: *European journal of sport science* 16 (8), S. 895–902. DOI: 10.1080/17461391.2016.1139190.

*Abstract:*

AIM: The aim of this study was to examine the relationship between ventilatory adaptation and performance during altitude training at 2700 m. METHODS: Seven elite cyclists (age: 21.2 +/- 1.1 yr, body mass: 69.9 +/- 5.6 kg, height 176.3 +/- 4.9 cm) participated in this study. A hypoxic ventilatory response (HVR) test and a submaximal exercise test were performed at sea level prior to the training camp and again after 15 d at altitude (ALT15). Ventilation (VE), end-tidal carbon-dioxide partial pressure (PETCO2) and oxyhaemoglobin saturation via pulse oximetry (SpO2) were measured at rest and during submaximal cycling at 250 W. A hill climb (HC) performance test was conducted at sea level and after 14 d at altitude (ALT14) using a road of similar length

(5.5-6 km) and gradient (4.8-5.3%). Power output was measured using SRM cranks. Average HC power at ALT14 was normalised to sea level power (HC%). Multiple regression was used to identify significant predictors of performance at altitude. RESULTS: At ALT15, there was a significant increase in resting VE (10.3 +/- 1.9 vs. 12.2 +/- 2.4 L.min(-1)) and HVR (0.34 +/- 0.24 vs. 0.71 +/- 0.49 L.min(-1).%(-1)), while PETCO2 (38.4 +/- 2.3 vs. 32.1 +/- 3.3 mmHg) and SpO2 (97.9 +/- 0.7 vs. 94.0 +/- 1.7%) were reduced (P < .05). Multiple regression revealed DeltaHVR and exercise VE at altitude as significant predictors of HC% (adjusted r(2) = 0.913; P = 0.003). CONCLUSIONS: Ventilatory acclimatisation occurred during a 2 wk altitude training camp in elite cyclists and a higher HVR was associated with better performance at altitude, relative to sea level. These results suggest that ventilatory acclimatisation is beneficial for cycling performance at altitude.

**Townsend, Gore et al. 2005 – Hypoxic ventilatory response is correlated**

Townsend, Nathan E.; Gore, Christopher J.; Hahn, Allan G.; Aughey, Robert J.; Clark, Sally A.; Kinsman, Tahnee A. et al. (2005):

## Hypoxic ventilatory response is correlated with increased submaximal exercise ventilation after live high, train low.

In: *Eur. J. Appl. Physiol.* 94 (1-2), S. 207–215. DOI: 10.1007/s00421-004-1252-9.

*Abstract:*

This study tested the hypothesis that live high, train low (LHTL) would increase submaximal exercise ventilation (V(E)) in normoxia, and the increase would be related to enhanced hypoxic ventilatory response (HVR). Thirty-three cyclists/triathletes were divided into three groups: 20 consecutive nights of hypoxia (LHTLc, n = 12), 20 nights of intermittent hypoxia (4x5-night 'blocks' of hypoxia interspersed by two nights of normoxia, LHTLi, n = 10), or control (CON, n = 11). LHTLc and LHTLi slept 8-10 h per night in normobaric hypoxia (2,650 m), and CON slept under ambient conditions (600 m). Resting, isocapnic HVR (DeltaV(E)/Deltablood oxygen saturation) was measured in normoxia before (PRE) and after 15 nights (N15) hypoxia. Submaximal cycle ergometry was conducted PRE and after 4, 10, and 19 nights of hypoxia (N4, N10, and N19 respectively). Mean submaximal exercise V(E) was increased (P < 0.05) from PRE to N4 in LHTLc [74.4 (5.1) vs 80.0 (8.4) l min(-1); mean (SD)] and in LHTLi [69.0 (7.5) vs 76.9 (7.3) l min(-1)] and remained elevated in both groups thereafter, with no changes observed in CON at any time. Prior to LHTL, submaximal V(E) was not correlated with HVR, but this relationship was significant at N4 (r = 0.49, P = 0.03) and N19 (r = 0.77, P < 0.0001). Additionally, the increases in submaximal V(E) and HVR from PRE to N15-N19 were correlated (r = 0.51, P = 0.02) for the pooled data of LHTLc and LHTLi. These results suggest that enhanced hypoxic chemosensitivity contributes to increased exercise V(E) in normoxia following LHTL.

**Townsend, Gore et al. 2002 – Living high-training low increases hypoxic**

Townsend, Nathan E.; Gore, Christopher J.; Hahn, Allan G.; McKenna, Michael J.; Aughey, Robert J.; Clark, Sally A. et al. (2002):

## Living high-training low increases hypoxic ventilatory response of well-trained endurance athletes.

In: *J. Appl. Physiol.* 93 (4), S. 1498–1505. DOI: 10.1152/japplphysiol.00381.2002.

*Abstract:*

This study determined whether "living high-training low" (LHTL)-simulated altitude exposure increased the hypoxic ventilatory response (HVR) in well-trained endurance athletes. Thirty-three cyclists/triathletes were divided into three groups: 20 consecutive nights of hypoxic exposure (LHTLc, n = 12), 20 nights of intermittent hypoxic exposure (four 5-night blocks of hypoxia, each interspersed with 2 nights of normoxia, LHTLi, n = 10), or control (Con, n = 11). LHTLc and LHTLi slept 8-10 h/day overnight in normobaric hypoxia (approximately 2,650 m); Con slept under ambient conditions (600 m). Resting, isocapnic HVR (DeltaVE/DeltaSp(O(2)), where VE is minute ventilation and Sp(O(2)) is blood O(2) saturation) was measured in normoxia before hypoxia (Pre), after 1, 3, 10, and 15 nights of exposure (N1, N3, N10, and N15, respectively), and 2 nights after the exposure night 20 (Post). Before each HVR test, end-tidal PCO(2) (PET(CO(2))) and VE were measured during room air breathing at rest. HVR (l. min(-1). %(-1)) was higher (P < 0.05) in LHTLc than in Con at N1 (0.56 +/- 0.32 vs. 0.28 +/- 0.16), N3 (0.69 +/- 0.30 vs. 0.36 +/- 0.24), N10 (0.79 +/- 0.36 vs. 0.34 +/- 0.14), N15 (1.00 +/- 0.38 vs. 0.36 +/- 0.23), and Post (0.79 +/- 0.37 vs. 0.36 +/- 0.26). HVR at N15 was higher (P < 0.05) in LHTLi (0.67 +/- 0.33) than in Con and in LHTLc than in LHTLi. PET(CO(2)) was depressed in LHTLc and LHTLi compared with Con at all points after hypoxia (P < 0.05). No significant differences were observed for VE at any point. We conclude that LHTL increases HVR in endurance athletes in a time-dependent manner and decreases PET(CO(2)) in normoxia, without change in VE. Thus endurance athletes sleeping in mild hypoxia may experience changes to the respiratory control system.

**Truijens, Rodríguez et al. 2008 – The effect of intermittent hypobaric**

Truijens, Martin J.; Rodríguez, Ferran A.; Townsend, Nathan E.; Stray-Gundersen, James; Gore, Christopher J.; Levine, Benjamin D. (2008):

## The effect of intermittent hypobaric hypoxic exposure and sea level training on submaximal economy in well-trained swimmers and runners.

In: *J. Appl. Physiol.* 104 (2), S. 328–337. DOI: 10.1152/japplphysiol.01324.2006.

*Abstract:*

To evaluate the effect of intermittent hypobaric hypoxia combined with sea level training on exercise economy, 23 well-trained athletes (13 swimmers, 10 runners) were assigned to either hypobaric hypoxia (simulated altitude of 4,000-5,500 m) or normobaric normoxia (0-500 m) in a randomized, double-blind design. Both groups rested in a hypobaric chamber 3 h/day, 5 days/wk for 4 wk. Submaximal economy was measured twice before (Pre) and after (Post) the treatment period using sport-specific protocols. Economy was estimated both from the relationship between oxygen uptake (V(.-)o2) and speed, and from the absolute V(.-)o2 at each speed using sport-specific protocols. V(.-)o2 was measured during the last 60 s of each (3-4 min) stage using Douglas bags. Ventilation (V(.-)E), heart rate (HR), and capillary lactate concentration ([La(-)]) were measured during each stage. Velocity at maximal V(.-)o2 (velocity at V(.-)o2max) was used as a functional indicator of changes in economy. The average V(.-)o2 for a given speed of the Pre values was used for Post test comparison using a two-way, repeated-measures ANOVA. Typical error of measurement of V(.-)o2 was 4.7% (95% confidence limits 3.6-7.1), 3.6% (2.8-5.4), and 4.2% (3.2-6.9) for speeds 1, 2, and 3, respectively. There was no change in economy within or between groups (ANOVA interaction P = 0.28, P = 0.23, and P = 0.93 for speeds 1, 2, and 3). No differences in submaximal HR, [La-], Ve, or velocity at V(.-)o2(max) were found between groups. It is concluded that 4 wk of intermittent hypobaric hypoxia did not improve submaximal economy in this group of well-trained athletes.

**Vaile, Halson et al. 2008 – Effect of Hydrotherapy on Recovery**

Vaile, J.; Halson, S.; Gill, N.; Dawson, B. (2008):

## Effect of Hydrotherapy on Recovery from Fatigue.

In: *Int J Sports Med* 29 (7), S. 539–544. DOI: 10.1055/s-2007-989267.

*Abstract:*

The present study investigated the effects of three hydrotherapy interventions on next day performance recovery following strenuous training. Twelve cyclists completed four experimental trials differing only in 14-min recovery intervention: cold water immersion (CWI), hot water immersion (HWI), contrast water therapy (CWT), or passive recovery (PAS). Each trial comprised five consecutive exercise days of 105-min duration, including 66 maximal effort sprints. Additionally, subjects performed a total of 9-min sustained effort (time trial - TT). After completing each exercise session, athletes performed one of four recovery interventions (randomly assigned to each trial). Performance (average power), core temperature, heart rate (HR), and rating of perceived exertion (RPE) were recorded throughout each session. Sprint (0.1 - 2.2 %) and TT (0.0 - 1.7 %) performance were enhanced across the five-day trial following CWI and CWT, when compared to HWI and PAS.



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Additionally, differences in rectal temperature were observed between interventions immediately and 15-min post-recovery; however, no significant differences were observed in HR or RPE regardless of day of trial/intervention. Overall, CWI and CWT appear to improve recovery from high-intensity cycling when compared to HWI and PAS, with athletes better able to maintain performance across a five-day period.

**van der Woude, Horstman et al. 2008 – Power output and metabolic cost**

van der Woude, Lucas H. V.; Horstman, Astrid; Faas, Paul; Mechielsen, Sander; Bafghi, Hamid Abbasi; Koning, Jos J. de (2008):

## Power output and metabolic cost of synchronous and asynchronous submaximal and peak level hand cycling on a motor driven treadmill in able-bodied male subjects.

In: *Med Eng Phys* 30 (5), S. 574–580. DOI: 10.1016/j.medengphy.2007.06.006.

*Abstract:*

PURPOSE

To evaluate external power output and physiological responses of synchronous (SYNC) and asynchronous hand cycling (ASYNC) at submaximal and peak levels of exercise.

METHODS

n=9 able-bodied male subjects (age: 20.1+/-2.1 years) performed two (sub)maximal continuous hand cycle exercise tests, using the SYNC and ASYNC mode in a standardized commercial add-on hand cycle unit (counter-balanced order). Treadmill speed (1.89 and 2.17 m s(-1)) and slope (steps of +1%) were changed in a fixed sequence of 3-min exercise steps. Gears were adjusted to 65 rpm. External power output (PO) was continuously monitored with a strain-gauge instrumented chain ring ((SRM) Schoberer Rad Messtechnik). A conventional wheelchair drag test was performed to validate mean external power for each speed-slope combination. Heart rate (HR; bpm) and oxygen uptake (VO2; ml kg(-1) min(-1), SMTP) were continuously monitored. Paired T-tests and ANOVA for repeated measures evaluated effects of mode and exercise level (p<0.05).

RESULTS

Subjects reached peak levels of performance (RER: 1.05+/-0.07 versus 1.10+/-0.1 for SYNC and ASYNC). Peak PO and V(o2) were significantly higher for SYNC (81.6+/-11.8 W versus 68.5+/-10.6 W; 26.4+/-4.5 ml kg(-1) min(-1) versus 21.2+/-3.0 ml kg(-1) min(-1)). At submaximal exercise levels, gross mechanical efficiency (ME) was significantly higher for SYNC (12.1+/-0.9% versus 9.7+/-1.4% at 41 W). No significant differences were found for PO (at equal velocity and slope), as derived from the SRM (SYNC and ASYNC), and from the drag test.

DISCUSSION

The absence of any differences in PO between SYNC and ASYNC, and with respect to the drag test, rules out 'additional external work due to maintain the desired heading' in the ASYNC as an explanation for the lower performance in this mode. Lower peak performance and ME in ASYNC may be explained by the increased stabilizing muscle effort in the upper extremities and trunk in order to combine power production with stable steering. ASYNC is less efficient compared to SYNC. Similarly, peak performance capacity was higher for SYNC.

CONCLUSION

External work does not differ between SYNC and ASYNC hand cycling. SRM readings appear valid for PO monitoring in hand cycling within the studied range of PO. SYNC is more efficient than ASYNC and leads to higher peak performance.



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SRM in Science

### Villerius, Duc et al. 2008 – Physiological and Neuromuscular Responses

Villerius, V.; Duc, S.; Grappe, F. (2008):

## Physiological and Neuromuscular Responses of Competitive Cyclists during a Simulated Self-Paced Interval Training Session.

In: *Int J Sports Med* 29 (09), S. 770–777. DOI: 10.1055/s-2007-989317.

*Abstract:*

Responses of twelve competitive cyclists performing an interval training session, consisting of three successive 10-min self-paced exercise bouts separated by two 15-min active recovery periods, were studied. Power output (PO), heart rate, pedaling cadence, ventilatory variables, overall ratings of perceived exertion (RPE) and electromyographic (EMG) activity of the vastus lateralis, vastus medialis, biceps femoris and medial hamstrings were recorded during each exercise bout. Mean PO ($p < 0.05$) decreased significantly across the self-paced bouts, while RPE ($p < 0.01$) increased significantly. PO and EMG activity did not show significant changes between the 3rd and 9th minute of each self-paced bout. Every self-paced bout showed an oxygen uptake (V˙O2) slow component between the 3rd and 9th minute and there was no effect of bout order on the magnitude of the V˙O2 slow component. This study reveals that during an interval training session, moderately trained competitive cyclists are able to repeat three 10-min self-paced exercise bouts with only a slight decrease in PO (~ 3 %) and by maintaining unchanged physiological and neuromuscular responses. Moreover, the V˙O2 slow component during each exercise bout was not related to changes in muscle activity, as every exercise bout was performed at a muscular work steady state with a constant PO.

### Vogt, Roecker et al. 2008 – Cadence-power-relationship during decisive mountain ascents

Vogt, S.; Roecker, K.; Schumacher, Y. O.; Pottgiesser, T.; Dickhuth, H-H; Schmid, A.; Heinrich, L. (2008):

## Cadence-power-relationship during decisive mountain ascents at the Tour de France.

In: *Int J Sports Med* 29 (3), S. 244–250. DOI: 10.1055/s-2007-965353.

*Abstract:*

The aim of the study was to report the relationship between cadence and power developed by professional cyclists during high mountain ascents of the Tour de France. From the 10 cyclists (30 +/- 4 years, 178 +/- 8 cm, 69 +/- 6 kg) involved in the study, 108 ascents were recorded and analyzed using a mobile power measurement device (SRM Training Systems, Jülich, Germany). Based on topographic characteristics, the ascents were categorized into 1st and Hors Category (HC) climbs. During the ascents of the 1st Category climbs, power output averaged 312 +/- 43 W (4.5 +/- 0.6 W/kg) with a mean cadence of 73 +/- 6 rpm and a mean duration of 37 : 41 +/- 16 : 16 min. Power output averaged 294 +/- 36 W (4.3 +/- 0.6 W/kg) at a mean cadence of 70 +/- 6 rpm during 57 : 40 +/- 10 : 32 min on HC climbs. The maximal mean power for long durations (1800 s) showed a mean power output of 327 W and 346 W for the 1st and HC climbs, respectively. The evaluation of the cadence-power output and the distance per pedaling cycle-power output relationship shows that high power outputs are mainly yielded by higher pedaling cadences and higher gears.

### Vogt, Schumacher et al. 2007 – Power Output during the Tour

Vogt, S.; Schumacher, Y. O.; Roecker, K.; Dickhuth, H-H; Schoberer, U.; Schmid, A.; Heinrich, L. (2007):

## Power Output during the Tour de France.

In: *Int J Sports Med* 28 (9), S. 756–761. DOI: 10.1055/s-2007-964982.

*Abstract:*

The aim of this study was to evaluate the demands of riding a "Grand Tour" by monitoring both heart rate and power output in 15 professional cyclists. SRM power output profiles (SRM Trainingsystem, Jülich, Germany) were collected during 148 mass start stages during the 2005 Tour de France and analyzed to establish average power, heart rate (HR) and cadence produced in different terrain categories (flat [FLT]; semi-mountainous [SMT]; mountainous [MT]). The maximal mean power (MMP) for progressively longer durations was quantified. Average HR was similar between FLT (133 +/- 10 bpm) and SMT (134 +/- 8 bpm) but higher during MT (140 +/- 3 bpm). Average power output revealed a similar trend (FLT 218 +/- 21 W [3.1 +/- 0.3 W/kg], SMT 228 +/- 22 W [3.3 +/- 0.3 W/kg], and MT 234 +/- 13 W [3.3 +/- 0.2 W/kg]). Cadence during MT was approximately 6 - 7 rpm lower (81 +/- 15 rpm) compared to FLT or SMT. During MT stages, the MMP for 1800 sec. was highest (394 W vs. 342 W) but the MMP 15 was lower (836 W vs. 895 W) compared to FLT. The data document comprehensively the power output demands during the Tour de France.

**Vogt, Heinrich et al. 2006 – Power output during stage racing**

Vogt, Stefan; Heinrich, Lothar; Schumacher, Yorck Olaf; Blum, Andreas; Roecker, Kai; Dickhuth, Hans-Hermann; Schmid, Andreas (2006):

## Power output during stage racing in professional road cycling.

In: *Med Sci Sports Exerc* 38 (1), S. 147–151.

*Abstract:*

PURPOSE

The aim of the study was to evaluate the power output during a multistage professional road race using direct power measurements and to compare these results with the performance measurements using competition heart rate recordings.

METHODS

Six professional road cyclists performed an incremental cycling test during which peak power output, power output, and heart rate at the lactate threshold (LT) and at a lactate increase of 1 mM above the LT (LT + 1) were assessed. During a six-stage road race competition, power output was measured directly (SRM crankset). To analyze the time spent at different intensities during competition, the amount of competition time spent below LT (zone 1), between the LT and LT + 1 (zone 2), and above LT + 1 (zone 3) determined during laboratory testing were calculated for power output and heart rate.

RESULTS

During the five mass start stages, a mean power output of 220 +/- 22 W (3.1 +/- 0.2 W x kg(-1)) with a mean heart rate of 142 +/- 5 bpm was measured. Average power output during an uphill time trial was 392 +/- 60 W (5.5 +/- 0.4 W x kg(-1)) with a mean heart rate of 169 +/- 3 bpm. For the mass start stages, the average distribution of exercise time spent in different intensities calculated for power output and heart rate was 58 versus 38% for zone 1, 14 versus 38% for zone 2, and 28 versus 24% for zone 3.

CONCLUSION

Most of the competition time during the mass start stages was spent at intensities near the LT. Compared with power output, heart rate measurement underestimated the time spent at intensity zones 1 and 3, and overestimated the time spent in zone 2.

**Vogt, Schumacher et al. 2007 – Cycling power output produced**

Vogt, Stefan; Schumacher, Yorck Olaf; Blum, Andreas; Roecker, Kai; Dickhuth, Hans-Hermann; Schmid, Andreas; Heinrich, Lothar (2007):

## Cycling power output produced during flat and mountain stages in the Giro d'Italia: a case study.

In: *J Sports Sci* 25 (12), S. 1299–1305. DOI: 10.1080/02640410601001632.



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*Abstract:*

Until recently, the physiological demands of cycling competitions were mostly reflected by the measurement of heart rate and the indirect estimation of exercise intensity. The purpose of this case study was to illustrate the varying power output of a professional cyclist during flat and mountain stages of a Grand Tour (Giro d'Italia). Nine stage recordings of a cyclist of the 2005 Giro d'Italia were monitored using a mobile power measurement device (SRM Trainingssystem, Julich, Germany), which recorded direct power output and heart rate. Stages were categorized into flat (n = 5) and mountain stages (n = 4). Data were processed electronically, and the overall mean power in flat and mountain stages and maximal mean power for various durations were calculated. Mean power output was 132 W +/- 26 (2.0 W x kg(-1) +/- 0.4) for the flat and 235 W +/- 10 (3.5 W x kg(-1) +/- 0.1) for the mountain stages. Mountain stages showed higher maximal mean power (367 W) for longer durations (1800 s) than flat stages (239 W). Flat stages are characterized by a large variability of power output with short bursts of high power and long periods with reduced intensity of exercise, whereas mountain stages mostly require submaximal, constant power output over longer periods.

**Wahl, Mathes et al. 2013 – Acute Metabolic**

Wahl, P.; Mathes, S.; Köhler, K.; Achtzehn, S.; Bloch, W.; Mester, J. (2013):

## Acute Metabolic, Hormonal, and Psychological Responses to Different Endurance Training Protocols.

In: *Horm Metab Res* 45 (11), S. 827–833. DOI: 10.1055/s-0033-1347242.

*Abstract:*

In the last years, mainly 2 high-intensity-training (HIT) protocols became common: First, a Wingate-based "all-out" protocol and second, a 4×4 min protocol. However, no direct comparison between these protocols exists, and also a comparison with high-volume-training (HVT) is missing. Therefore, the aim of the present study was to compare these 3 endurance training protocols on metabolic, hormonal, and psychological responses. Twelve subjects performed: 1) HVT [130 min at 55% peak power output (PPO)]; 2) 4×4 min at 95% PPO; 3) 4×30 s all-out. Human growth hormone (hGH), testosterone, and cortisol were determined before (pre) and 0′, 30′, 60′, 180′ after each intervention. Metabolic stimuli and perturbations were characterized by lactate, blood gas (pH, BE, HCO3 −, pO2, PCO2), and spirometric analysis. Furthermore, changes of the person's perceived physical state were determined. The 4×30 s training caused the highest increases in cortisol and hGH, followed by 4 × 4 min and HVT. Testosterone levels were significantly increased by all 3 exercise protocols. Metabolic stress was highest during and after 4×30 s, followed by 4×4 min and HVT. The 4×30 s training was also the most demanding intervention from an athlete's point of view. In conclusion, the results suggest that 4×30 s and 4×4 min promote anabolic processes more than HVT, due to higher increases of hGH, testosterone, and the T/C ratio. It can be speculated that the acute hormonal increase and the metabolic perturbations might play a positive role in optimizing training adaptation and in eliciting health benefits as it has been shown by previous long term training studies using similar exercise protocols.

**Wahl, Schmidt et al. 2013 – Responses of Angiogenic Growth Factors**

Wahl, P.; Schmidt, A.; deMarees, M.; Achtzehn, S.; Bloch, W.; Mester, J. (2013):

## Responses of Angiogenic Growth Factors to Exercise, to Hypoxia and to Exercise under Hypoxic Conditions.

In: *Int J Sports Med* 34 (02), S. 95–100. DOI: 10.1055/s-0032-1314815.

*Abstract:*

The purpose of the present study was to compare the acute hormonal response of angiogenic regulators to a short-term hypoxic exposure at different altitudes with and without exercise. 7 subjects participated in 5 experimental trials. 2 times subjects stayed in a sedentary position for 90 min at 2 000 m or 4 000 m, respectively. The same was carried out again in combination with exercise at the same relative intensity (2 mmol·L − 1 of lactate). The fifth trial consisted of 90 min exercise at sea level. Venous blood samples were taken under resting conditions, 0 and 180 min after each condition to determine VEGF, EPO, IL-6, IL-8 and IGF-1 serum concentrations. EPO, VEGF, and IL-8 showed increases only, when hypoxia was combined with exercise. IL-6 was increased after exercise, independent of altitude. IGF-1 showed no changes in any intervention. The present study suggests that short term hypoxic exposure combined with low intensity exercise is able to up-regulate angiogenic regulators, which might be beneficial to induce angiogenesis and to improve endurance performance. However, in some cases high altitudes are needed, or it can be speculated that exercise intensity needs to be increased.

**Wiedemann, Bosquet 2010 – Anaerobic Work Capacity Derived**

Wiedemann, M. S. F.; Bosquet, L. (2010):

## Anaerobic Work Capacity Derived from Isokinetic and Isoinertial Cycling.

In: *Int J Sports Med* 31 (02), S. 89–94. DOI: 10.1055/s-0029-1233466.

*Abstract:*

The purpose of this study was to compare Anaerobic Work Capacity (AWC) measured on an isoinertial or an isokinetic bicycle ergometer. Twelve male participants completed two randomly ordered exercise testing sessions including a torque-velocity test followed by a 30-s all-out test on an isokinetic ergometer, or a force-velocity test followed by a Wingate Anaerobic Test on an isoinertial ergometer. Optimal load measured during the force-velocity test on the isoinertial ergometer was 1.13±0.11 N.kg−1. Optimal cadence measured during the torque-velocity test on the isokinetic ergometer was 107±13 rpm. Although Ppeak measures were significantly correlated (r=0.77), we found a large difference between them (effect size=2.85) together with wide limits of agreement (bias±95%LOA=24±12%). The same observation was made with Pmean, but with a smaller magnitude of difference (bias±95%LOA=4.2±12%; effect size=0.51; r=0.73). This lack of agreement led us to the conclusion that AWC measures obtained during 30-s all-out tests performed on an isoinertial or an isokinetic bicycle ergometer are not necessarily similar and cannot be used interchangeably.

**Wilson, Lane et al. 2012 – Influence of accurate and inaccurate**

Wilson, Mathew G.; Lane, Andy M.; Beedie, Chris J.; Farooq, Abdulaziz (2012):

## Influence of accurate and inaccurate 'split-time' feedback upon 10-mile time trial cycling performance.

In: *Eur. J. Appl. Physiol.* 112 (1), S. 231–236. DOI: 10.1007/s00421-011-1977-1.

*Abstract:*

The objective of the study is to examine the impact of accurate and inaccurate 'split-time' feedback upon a 10-mile time trial (TT) performance and to quantify power output into a practically meaningful unit of variation. Seven well-trained cyclists completed four randomised bouts of a 10-mile TT on a SRM™ cycle ergometer. TTs were performed with (1) accurate performance feedback, (2) without performance feedback, (3) and (4) false negative and false positive 'split-time' feedback showing performance 5% slower or 5% faster than actual performance. There were no significant differences in completion time, average power output, heart rate or blood lactate between the four feedback conditions. There were significantly lower (p < 0.001) average [Formula: see text] (ml min(-1)) and [Formula: see text] (l min(-1)) scores in the false positive (3,485 ± 596; 119 ± 33) and accurate (3,471 ± 513; 117 ± 22) feedback conditions compared to the false negative (3,753 ± 410; 127 ± 27) and blind (3,772 ± 378; 124 ± 21) feedback conditions. Cyclists spent a greater amount of time in a '20 watt zone' 10 W either side of average power in the negative feedback condition (fastest) than the accurate feedback (slowest) condition (39.3 vs. 32.2%, p < 0.05). There were no significant differences in the 10-mile TT performance time between accurate and inaccurate feedback conditions, despite significantly lower average [Formula: see text] and [Formula: see text] scores in the false positive and accurate feedback conditions. Additionally, cycling with a small variation in power output (10 W either side of average power) produced the fastest TT. Further psycho-physiological research should examine the mechanism(s) why lower

[Formula: see text] and [Formula: see text] scores are observed when cycling in a false positive or accurate feedback condition compared to a false negative or blind feedback condition.

**Wu, Peiffer et al. 2015 – Pacing strategies during the swim**

Wu, Sam Shi Xuan; Peiffer, Jeremiah J.; Brisswalter, Jeanick; Nosaka, Kazunori; Lau, Wing Yin; Abbiss, Chris R. (2015):

## Pacing strategies during the swim, cycle and run disciplines of sprint, Olympic and half-Ironman triathlons.

In: *European journal of applied physiology* 115 (5), S. 1147–1154. DOI: 10.1007/s00421-014-3096-2.

*Abstract:*

PURPOSE: This study investigated the influence of distance on self-selected pacing during the swim, cycle and run disciplines of sprint, Olympic and half-Ironman (HIM) distance triathlon races. METHOD: Eight trained male triathletes performed the three individual races in <2 months. Participants' bikes were fitted with Schoberer Rad Messtechnik to monitor speed, power output and heart rate during the cycle discipline. Global positioning system was worn to determine speed and heart rate during the swim and run disciplines. RESULT: An even swim pacing strategy was adopted across all distances. A more stochastic pacing was observed during the HIM cycle [standard deviation of exposure variation analysis (EVASD) = 3.21 +/- 0.61] when compared with the sprint cycle discipline (EVASD = 3.84 +/- 0.44, p = 0.018). Only 20.9 +/- 4.1 % of the cycling time was spent more than 10 % above the mean power output in the HIM, compared with 43.8 +/- 2.9 % (p = 0.002) and 37.7 +/- 11.1 % (p = 0.039) during the sprint and Olympic distance triathlons, respectively. Conversely, 13.6 +/- 5.1 % of the cycling time was spent 5-10 % below the mean power output during the HIM, compared with 5.9 +/- 1.2 % (p = 0.034) and 8.0 +/- 5.1 % (p = 0.045) during the sprint and Olympic distance triathlons, respectively. A negative pacing strategy was adopted during the sprint distance run, compared with positive pacing strategy during the Olympic and HIM. CONCLUSION: Results of this study suggest that pacing strategies during triathlon are highly influenced by distance and discipline, and highlight the importance of developing pacing strategies based on distance, strengths and individual fitness.