Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

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Physiological and perceptual effects of a time trial position in submaximal cycling, and the effects of cycling position on transition running performance in well-trained triathletes

Master's thesis in Physical Activity and Health
Specialization: Movement Science
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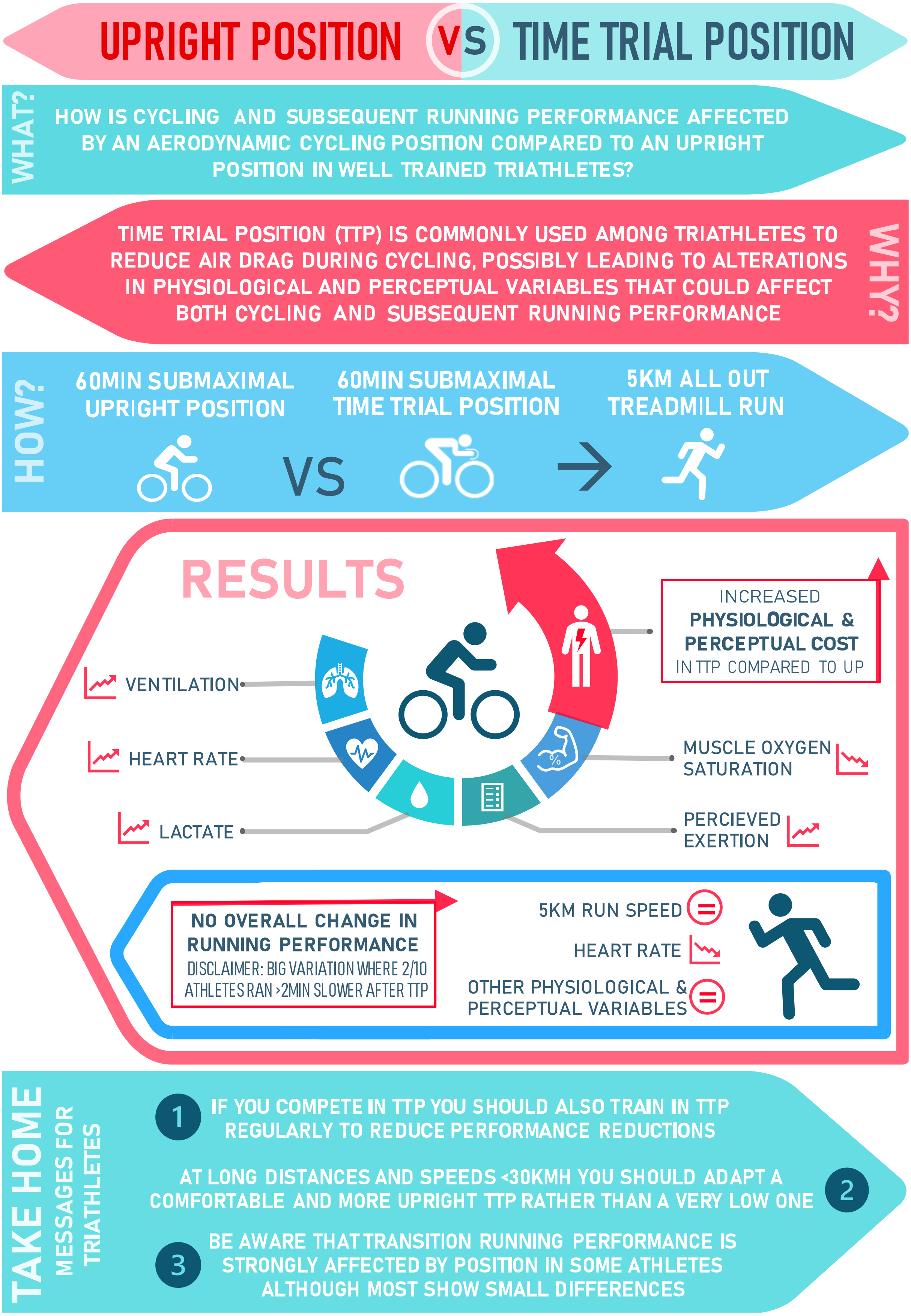
UPRIGHT POSITION VS TIME TRIAL POSITION
WHAT?
HOW IS CYCLING AND SUBSEQUENT RUNNING PERFORMANCE AFFECTED BY AN AERODYNAMIC CYCLING POSITION COMPARED TO AN UPRIGHT POSITION IN WELL TRAINED TRIATHLETES?
WHY?
TIME TRIAL POSITION (TTP) IS COMMONLY USED AMONG TRIATHLETES TO REDUCE AIR DRAG DURING CYCLING, POSSIBLY LEADING TO ALTERATIONS IN PHYSIOLOGICAL AND PERCEPTUAL VARIABLES THAT COULD AFFECT BOTH CYCLING AND SUBSEQUENT RUNNING PERFORMANCE
HOW?
60MIN SUBMAXIMAL UPRIGHT POSITION
VS
60MIN SUBMAXIMAL TIME TRIAL POSITION
5KM ALL OUT TREADMILL RUN
RESULTS
INCREASED PHYSIOLOGICAL & PERCEPTUAL COST IN TTP COMPARED TO UP
VENTILATION
HEART RATE
LACTATE
MUSCLE OXYGEN SATURATION
PERCIEVED EXERTION
NO OVERALL CHANGE IN RUNNING PERFORMANCE
DISCLAIMER: BIG VARIATION WHERE 2/10 ATHLETES RAN >2MIN SLOWER AFTER TTP
5KM RUN SPEED
HEART RATE
OTHER PHYSIOLOGICAL & PERCEPTUAL VARIABLES
TAKE HOME
MESSAGES FOR TRIATHLETES
1
IF YOU COMPETE IN TTP YOU SHOULD ALSO TRAIN IN TTP REGULARLY TO REDUCE PERFORMANCE REDUCTIONS
AT LONG DISTANCES AND SPEEDS <30KMH YOU SHOULD ADAPT A COMFORTABLE AND MORE UPRIGHT TTP RATHER THAN A VERY LOW ONE
2
3
BE AWARE THAT TRANSITION RUNNING PERFORMANCE IS STRONGLY AFFECTED BY POSITION IN SOME ATHLETES ALTHOUGH MOST SHOW SMALL DIFFERENCES

Abstract

Introduction: A time trial position (TTP) is commonly used among triathletes to reduce air drag during cycling, possibly leading to alterations in physiological and perceptual variables that could affect cycling- and subsequent running performance. The aim of this study was to investigate how TTP affects physiological and perceptual performance variables during cycling compared to an upright position (UP), and in addition how TTP and UP differ in affecting subsequent transition running performance in well-trained triathletes.

Method: After a day of baseline testing (lactate profile and VO_2max), 12 well-trained triathletes performed a 60 min cycling protocol initiated by a 15 min ramp up from 50-80% LT, followed by 45 min of bouts at 80, 95 and 105% LT before going straight into a 5km transition run. The protocol was performed once in a TTP and an UP on two separate days separated by a minimum of 48h. Lactate, cardiopulmonary variables, local oxygen saturation and perceived exertion were measured.

Results: Physiological and perceptual cost of cycling increased in the TTP compared to the UP. This included a significant increase of lactate (95% LT: ↑1.2 ± 1.6 mmol/L; 105 LT: ↑1.3 ± 1.7 mmol/L), heart rate (95% LT: ↑4.4 ± 5.2 bpm; 105% LT: ↑5.1 ± 6.9 bpm), breathing frequency (105% LT: ↑3.4 ± 5.3), minute ventilation (95% LT: ↑9.9 ± 13.6 L/min; 105% LT: ↑ 9.9 ± 13.9 L/min) and perceived exertion (105% LT: ↑1.9 ± 1.2 A.U). Muscle oxygen saturation was significantly affected by position in the tibialis anterior (↓) and gastrocnemius (↑) muscles. In the 5km transition run, HR was the only variable that was significantly affected by position, revealing a lower HR during the run after the TTP compared with the run after the UP, however, the total time spent on a 5km run was not significantly affected by position.

Conclusion: The present study demonstrates that there is an increased physiological and perceptual cost of cycling in a TTP compared to an UP. Transition running performance was not significantly affected. Seen in light of existing literature, the potential negative performance effects of using a TTP would most likely be outweighed by the aerodynamic benefit of the position.

Oppsummering

Introduksjon: Tempostilling (TTP) benyttes hyppig av triatleter for å redusere luftmotstand under sykling. Det er mulig at TTP medfører fysiologiske og perseptuelle endringer som kan påvirke sykkel- og påfølgende løpsprestasjon. Målet med denne studien var derfor å undersøke hvordan TTP påvirker fysiologiske og perseptuelle variabler under sykling sammenlignet med en oppreist sittestilling (UP), og i tillegg om det er forskjeller i hvordan TTP og UP påvirker påfølgende overgangsløpsprestasjon hos godt trente triatleter.

Metode: Etter en dag med grunntesting (laktatprofil og VO_2max) utførte 12 godt trente triatleter en 60 min sykkelprotokoll innledet av en 15 min periode med en trinnvis økning i belastning fra 50-80% laktatterskel (LT) etterfulgt av 45 min med drag på 80, 95 og 105% av LT før en direkte overgang til en 5km løpstest. Protokollen ble utført en gang i TTP og en gang i UP på to separate dager atskilt med minimum 48 timer. Laktat, kardiopulmonale variabler, lokal oksygenmetning og opplevd anstrengelse ble målt.

Resultater: Fysiologisk og perseptuell kostnad ved sykling økte i TTP sammenlignet med UP. Dette inkluderte en signifikant økning av laktat (95% LT: ↑1.2 ± 1.6 mmol/L; 105 LT: ↑1.3 ± 1.7 mmol/L), hjertefrekvens (95% LT: ↑4.4 ± 5.2 bpm; 105% LT: ↑5.1 ± 6.9 bpm), pustefrekvens (105% LT: ↑3.4 ± 5.3), minuttventilasjon (95% LT: ↑9.9 ± 13.6 L/min; 105% LT: ↑9.9 ± 13.9L/min) og opplevd anstrengelse (105% LT: ↑1.9 ± 1.2 A.U). Lokal oksygenmetning ble signifikant påvirket av posisjon i tibialis anterior (↓) og gastrocnemius (↑). Under løpstesten var hjertefrekvens signifikant lavere etter TTP sammenlignet med UP. Det var ingen signifikante forskjeller i den totale tiden brukt på 5km løp mellom sittestillingene på sykkel.

Konklusjon: Denne studien viser en økt fysiologisk og perseptuell kostnad ved bruk av TTP sammenlignet med en UP under sykling. Løpsprestasjon direkte etter sykling påvirkes dog ikke av sykkelposisjonene som er undersøkt i denne studien. Sett i lys av eksisterende litteratur vil mulige negative prestasjonseffekter ved bruk av TTP sannsynligvis utlignes av den aerodynamiske fordelen ved å benytte TTP.

Acknowledgements

First of all, I would like to thank my supervisor, Knut Skovereng for his help, guidance and technical assistance. I also have to thank my incredibly knowledgeable co-students Mats Aandahl and Daniel Appelhans for helpful, constructive and insightful discussions throughout the year. Big thank also goes out to my family, friends, and boyfriend for supporting me during a different and sometimes difficult year with home office and social restrictions. Finally, I want to thank everyone who made it possible for me to dig deeper into my favorite sport and research topic by participating in this study, this wouldn't have been possible without your contribution!

The data collection for this master thesis was performed at the core facility NeXt Move, Elite Sports Science Lab, Norwegian University of Science and Technology (NTNU).

Contents

1. Introduction

Triathlon is a multidisciplinary endurance sport uniquely combining a sequential swimming-, cycling- and running part over a variety of distances stretching all the way from the sprint distance (750m swim, 20km bike, 5km run) to the full distance (3,8km swim, 180km bike, 42,2km run) (1). During an Olympic triathlon (1500m swim, 40km bike, 10km run), elite triathletes spend approximately 15% of the total time in swimming, 55% in cycling, and 30% in running, depending on the geographical and climatic conditions of the event. In other words, triathletes spend quite a significant amount of time both on the bike and run during a race, and factors affecting the physiological cost of cycling and transition running in triathlon competition is therefore of great interest.

In endurance sports, such as triathlon, there is a general agreement that three main variables can be considered as crucial for high performance (2). These are maximal oxygen uptake (VO_2max), lactate threshold (LT), and efficiency or work economy (i.e. the energy cost in generating a given cycling power output). Together, VO_2max and LT determine the oxygen uptake (VO_2) that can be sustained for a given period of time. Work economy determines the speed or power that is generated at a specific level of VO_2. In cycling, aerodynamic drag is responsible for up to 90 % of the energy cost at 50 km/h, thus being the markedly most influential component in the forces a cyclist must overcome (3, 4). Considering both the cyclist and the bike, 70 % of the total air drag is due to the cyclist, and 30 % is due to the bike (4). One of the main goals in order to optimize cycling performance is therefore to reduce air drag of the cyclist as much as possible (5). Two of the main strategies in reducing aerodynamic drag is 1) *drafting* (6), and 2) *modifications of body position*, using an aerodynamic time trial position (TTP) to lessen the frontal area, leading to a reduced air drag (5). In sprint and Olympic distance triathlons draft legal cycling is the standard (7). In longer distances, on the other hand, drafting is not allowed, and TTP is therefore commonly used to reduce air drag (7-10). TTP is also common during shorter races when the triathlete is at the front of a group or cycling alone, which happens quite often due to the nature of the sport and the differences in time spent swimming prior to the bike leg.

Several studies have shown a significant reduction in aerodynamic drag between an upright position (UP) and more aerodynamical positions (11-13). Hennekam (11) suggest a reduction in air drag of about 20% when changing from a completely upright and straight arm position to a drop bar position, and another 10-17 % decrease when going from the drop bar position to a fully crutched aero position. In total, Hennekam show a reduction of approximately 30-35% in air drag between the highest and lowest position. Further on, García-López et al. (12) showed a decrease of air drag of 14% only by lowering the height of the time trial handlebars. Adding to this, Chabroux et al. (13) showed that TTP can lead to average reduction of air drag of almost 15 % compared to an UP. The aerodynamic advantage of using a TTP is in other words well established (14).

However, despite being a commonly used tool for reducing air drag, several studies suggest both physiological alterations and a decrease in power output in aerodynamic positions compared to an UP due to differences in the torso angles between the positions (4, 8, 14, 15). The TTP include a lowered torso angle and a more forward leaning and tucked in position of the trunk and arms compared with a more upright body position (10). Fintelman et al. (15) found that peak power output was reduced by 14% when changing from UP to TTP, and that physiological variables such as VO_2, heart rate (HR) and minute ventilation (V'E) increased, and gross efficiency (GE) decreased in TTP compared to UP. Further on, Gnehm et al. (8) estimates that at ~300 W, TTP accounts for a higher metabolic cost of ~37 W, resulting in a ~9 W reduction at the pedal in TTP compared to UP. In addition, Oggiano et al. (4) showed an average of ~22 W saving in power output and 0,75 km/h gain in velocity at 500W for an aerodynamical position compared with UP. Several other authors point towards alterations of physiological cost also at a local muscular level, suggesting that changing the torso angle might affect muscles length and recruitment, and also muscle activation and fatigue (16-20). Due to these local changes, an interesting addition to the literature would be to investigate whether TTP also elicit metabolic changes at a local muscular level, for instance by comparing local oxygen saturation in the working muscles in the TTP and UP. Muscle oxygen saturation (SmO2) can be measured by near-infrared spectroscopy (NIRS), which is a non-invasive technique for continuous measurement of tissue oxygenation and hemodynamic parameters in local tissue (21). In contrast to the aforementioned studies (4), (8), (15-20), there are some studies pointing towards no difference in physiological cost between positions as well (22, 23). All in all, cycling in an aerodynamical position with a smaller torso angle is suggested to increase the physiological cost of cycling, although there are some divergent results in the literature.

Another issue regarding triathlon performance is that cycling and running puts different types of biomechanical and physiological stress on the legs. The transition between cycling and running has therefore been a topic of interest among many researchers (24). Hue et al. (25) suggests that the ability to reduce the biomechanical and physiological alterations and to sustain running performance after completion of the swimming and cycling parts are of especially high importance for overall triathlon performance. Previous studies suggest alterations in physiological variables that could affect running performance after cycling at a submaximal and maximal intensity (24, 26).

Several authors have shown that running economy is significantly decreased in transition running compared to an isolated run (25, 27-31). In example, Guezennec et al. (29) showed an 8% decrease in running efficiency in transition running compared with isolated running. Further on, Hue et al. (25) present several interesting findings regarding the physiological aspects of the transition run. Pulmonary ventilation, VO_2, carbon dioxide (CO2), breathing frequency (BF), and HR were all higher, suggesting an increase in energy cost in transition running compared to isolated running. These finding are supported by Millet et al. (32), who found an increased HR, ventilation and VO_2 of the respiratory muscle.

With all this in mind, a further look into changes in physiological variables during TTP compared to UP is of great interest, including SmO2 that has, to the best of our knowledge, not yet been investigated in a comparison of TTP and UP. In addition, we know that cycling in general might affect transition running performance (TRP) and that TTP might affect different aspects of cycling performance. However, there is still a lack of knowledge in whether the frequently used TTP amplifies the impact of cycling prior to transition running. Hence, the aim of this study was to compare the effects of the TTP and UP on physiological and perceptual performance variables during submaximal cycling. In addition, how the TTP and UP differ in affecting subsequent running performance will be investigated. We hypothesize that the physiological and perceptual cost of cycling in a TTP is greater than in the UP, and that this also has a negative impact on transition running performance.

2. Methods and materials

2.1 Participants

16 healthy, well-trained male (n=13) and female (n=3) triathletes volunteered and gave their written informed consent (Appendix 1) to participate in this study. Four participants were excluded – two of them due to injuries unrelated to this study, one due to lack of time, and one who was not able to complete the cycling protocol at the pre-set workload (day 2 and 3). The testing was conducted during the preparation period of the season (October-February) for all participants. All participants were experienced with the use of TTP in both training and racing. The study was approved by the NSD, Norwegian Centre for Research Data. Subject characteristics are presented in table 1.

Table 1. Characteristics of the 12 included triathletes (mean ± SD)

Sex	Male (n=11), female (n=1)
Age (years)	26.6 ± 7.2
Weight (kg)	74.3 ± 6.3
LT (W/kg)	3.8 ± 0.6
LT (W)	276.9 ± 37.9
VO_2max (mL/min/kg)	67.9 ± 7.6
VO_2max (mL/min)	5.0 ± 0.6
Skinfold thickness TA (mm)	7.9 ± 1.8
Skinfold thickness GAS (mm)	9.9 ± 1.7
Skinfold thickness VL (mm)	13.5 ± 3.2

LT, lactate threshold; VO_2max, maximal oxygen uptake;
TA, tibialis anterior; GAS, gastrocnemius; VL, vastus lateralis.

2.2 Study design and experimental protocol

Using a within-subject study design, each participant came the laboratory on three separate occasions. All participants completed the test days with a minimum of 48h in between, and an average 5 ± 3.2 days in between each day within a standardized time period of the day (within a 3h window). The participants were instructed to abstain from high intensity exercise and alcohol 48h before testing, any exercise 12h before testing, and to have as similar food intake as possible before all tests, including caffeine.

Day one consisted of baseline testing for determining lactate threshold (LT) using the step test and VO_2max using the ramp test. Day two and three consisted of a cycling performance test (CT60) directly followed by a transition run performance test (PTR). Body weight was measured at arrival on each test day. Skinfold thickness was measured on the second day of testing at the sites of the NIRS optodes. The optode sites were shaved prior to attachment if necessary, before the optodes were placed on the muscle belly of the tibialis anterior, gastrocnemius and vastus lateralis muscles. The devices were covered by an opaque cloth to minimize the possibility of external light sources interfering with the signals, before being secured with tape and elastic bandages.

2.2.1 Step test

LT was determined by an incremental step test starting at 100W, 125W or 150W based on body weight and orally provided information on expected LT or recently measured LT if available. The workload increased by 25W every five minutes. Blood lactate (LA) concentrations and rate of perceived exertion (RPE) was reported during the last minute of every step. Cardiopulmonary variables were measured continuously. RPE was determined using the Borg scale (33), and all participants were instructed according to established recommendations. The test was terminated when the LA concentration exceeded 4 mmol/L, or when the participant reported RPE 16 or higher if a LA value of ≥4 mmol/L was not reached at that point.

2.2.2 Ramp test

There was an active break of 10 minutes easy cycling (75-125W) between the step test and ramp test. The ramp test was an incremental test starting at the same workload as the step test, increasing 25W every minute until voluntary exhaustion while given strong verbal encouragement. RPE was reported before and immediately after the test. LA was reported before and ~1 minute after the test. Cardiopulmonary variables were measured continuously.

2.2.3 60 min cycling test (CT60)

The CT60 was a 60 min test starting with a 15 min 3 step ramp up from 50-80% LT, followed by 45 min of submaximal efforts, structured as four bouts, each consisting of 5 min at 95% LT, 3 min at 105% LT and 2 min at 80% LT and an additional 5 min at 95% LT prior to the bike-to-run transition (figure 1). The CT60 was completed once in a time trial position (TTP) using clip on time trial bars, and once in an upright position (UP) with hands on the break hoods. The order of the two cycling positions were randomized between day two and three. The participants were instructed to adjust their bike as preferred before start. All bouts were performed seated and with a freely chosen cadence. The participants were allowed to sit up and drink water during the 2 min sections at 80% LT. SmO2, power, and cardiopulmonary variables were continuously measured, whereas LA and RPE was measured during the last minute of all bouts except from the last 5 min bout of 95% LT due to the subsequent bike-to-run transition.

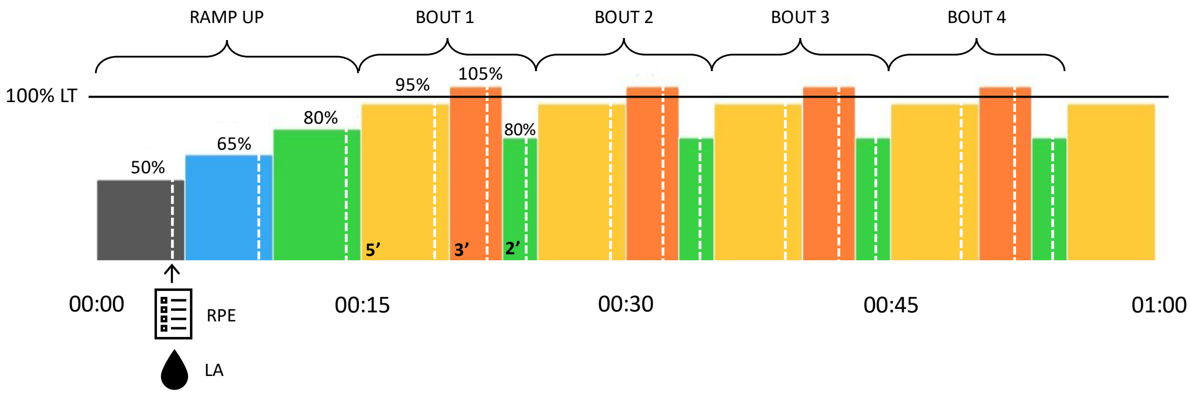

Figure 1: CT60 protocol. After the three first ramp steps of 5 min each, all 95% bouts (yellow) are 5 min, 105% bouts (orange) are 3 min, and 80% bouts (green) are 2 min. White dotted vertical lines marks the measurements of RPE and LA.

2.2.4 Performance test transition run (PTR)

Between CT60 and PTR there was a transition period of 1-2 min with matched duration between tests within each participant where the participant came off the ergometer bike, changed shoes, and went on the treadmill. The PTR was a 5km run where the goal was to have the best time possible. The treadmill was set to 3% incline, and the participant could adjust the speed themselves throughout the whole test. They were blinded from time and speed but had continuous information on distance completed given in meters.

RPE and split times were reported every ~500 m. Cardiopulmonary variables were measured in lap 1+2, lap 4+5+6, and lap 9+10. Between cardiopulmonary measurements the participants were allowed to drink water if desired.

2.3 Equipment and measurements

All cycling tests were performed on a bicycle ergometer (Lode Excalibur Sport, Lode BV, Groningen, The Netherlands). The CT60 in TTP was performed using time trial handlebars (Profile Design T1 Plus, Long Beach, United States). All run tests were performed on a Woodway PPS Med treadmill (Woodway, Foster Ct. Waukesha, United States). Blood lactate was measured in a fingertip using the Biosen C-Line Sport lactate measurement system (EKF Industrial Electronics, Magdeburg, Germany). Heart rate was measured with a chest strap sensor (Polar H10, Polar Electro OY, Kempele, Finland). Cardiopulmonary variables were measured using a computerized metabolic system with a mixing chamber (Vyntus CPX, Vyaire Medical GmbH, Hoechberg, Germany). Prior to all tests, the system was calibrated according to the manufacturers instructions, including an automated gas calibration with gas concentrations of 15% O2 and 5.85% CO2 (Reissner-Gase GmbH & Co, Lichtenfels, Germany) and automated flow calibration. Cardiopulmonary variables include HR, VO_2, respiratory exchange ratio (RER), breathing frequency (BF) and minute ventilation (V'E). Skinfold thickness at the sites of the NIRS optodes was measured using a skinfold caliper (Holtain, Crymych, Wales).

2.3.1 Near infrared spectroscopy (NIRS)

On the second and third day of testing, muscle oxygen saturation of three muscles in the left leg engaged in cycling [i.e., tibialis anterior (TA), gastrocnemius (GAS) and vastus lateralis (VL)] were measured using a continuous wave near-infrared spectrophotometer system (Portamon, Artinis Medical Systems, the Netherlands). Near-infrared spectroscopy (NIRS) is a noninvasive technique that provide valuable information on oxidative metabolism in local tissue (34). Oxyhemoglobin and oxymyoglobin absorb different amounts of light at different wavelengths in the near-infrared spectrum compared to deoxyhemoglobin and deoxymyoglobin. The NIRS devices measures changes in optical density of reflected light at the different wavelengths, and uses a modified Beer-Lambert law to calculate the concentration changes of tissue oxyhemoglobin and oxymyoglobin (O2Hb+O2Mb), deoxyhemoglobin and deoxymyoglobin (HHb+HMb), and total hemoglobin and myoglobin (tHb+tMb). From spatially resolved spectroscopy, tissue oxygen saturation (SmO_2) can be derived and expressed in % by the following formula:

$$SmO_2 = \frac{O_2Hb_{abs} + O_2Mb_{abs}}{O_2Hb_{abs} + HHb_{abs} + O_2Mb_{abs} + HMb_{abs}} \cdot 100\,\%$$

SmO_2 represents the ratio of oxygenated concentration (O2Hb+O2Mb) to total concentration (tHb+tMb), reflecting the dynamic balance between local oxygen supply and consumption in the muscles under investigation.

The NIRS system used in the present study was a dual-wavelength (762 and 841 nm), continuous wave system with one receiver and three transmitters, with inter-optode distances of 30mm, 35mm and 40mm, sampling at a frequency of 10 Hz.

2.4 Data analysis

VO_2max was defined as the highest 1 min average of VO_2 during the ramp test. HR, VO_2, RER, BF and V'E for each workload during the cycling protocol was defined as the average value over the last minute of each bout of intensity throughout the whole protocol. SmO2 was calculated as the average value over 30 sec starting 40 sec prior to every change of workload to minimize the risk of the measurement being affected by potential changes in the pedal pattern prior to the transition to a new workload. SmO2-values were removed if fit factor was below 0.99. The workload corresponding to a LA concentration of ≥4mmol/L was determined through linear interpolation, and used as LT. If 4 mmol/L was not reached by the time the participant reported an RPE of 16, the workload corresponding to an RPE of 16 was used instead. GE for the 95% bouts was calculated by dividing work rate (power output from the ergometer bike) by the metabolic rate (calculated from VO_2 and RER converted to energy expenditure) (35) and reported as percentage. This was done as long as RER was ≤1.00. GE was not calculated at 105% LT since steady state is not expected above LT.

HR and VO_2 during the PTR is defined as the 1 min average of the first minute, one minute in the middle of the test, and the last full minute of the test. Due to technical limitations of the treadmill, 500m±<50m split times were reported in min;sec,hundreds (e.g. 521m in 1;57,5), and calculated into speed in meters per second (m/s). Thereafter, speed was calculated into the time (minutes) each participant would have spent on a 5km run without the deviation of ±<50m to make it possible to compare the tests from day two and day three. The results from the PTR is presented in both time (calculated from avg speed), and in speed in km per hour (km/h). 10 participants are included in the data analysis of the PTR due to measurement errors in the remaining two participants.

The 95% LT and 105% LT bouts are used in the statistical analysis and presented in the results. Measurements from the 2 min sections at 80% LT during the cycling protocol are removed due to variations in sitting positions and missing values in pulmonary variables due to the opportunity to remove the mouthpiece and drink water. The lines in the figures visualizing the differences in the bike variables (figure 2-5) still include the 80% LT sections to better visualize the protocol in total, but no statistical analysis has been done on these time points, and the indicator for these time points are therefore removed in the figures. Indicators for the ramp up are shown in the figures, although they are not statistically analyzed.

2.5 Statistical analysis

A significance level of 95% is used for all statistical analysis. All data were checked for normality using a Shapiro-Wilk test. Raw data for all variables were visually inspected to check for measurement errors prior to further analysis. The main analysis was done using a two-way repeated measures ANOVA (RMANOVA) to investigate main effects of position and time, as well as to check for possible interaction effects. The Greenhouse-Geisser correction was used if the assumption of sphericity was violated. In the case of significant interaction effects during the two-way RMANOVA, simple main effects from a one-way RMANOVA were reported. In the case of significant main effects, repeated within-subject contrasts were used to investigate where these differences were located. The non-parametric equivalent of RMANOVA, the Friedman's test, was carried out to compare the difference in RPE between the two positions throughout the CT60 and PTR due to lack of a normal distribution in RPE. If the Friedman's test was significant, pairwise comparisons was used to locate and explore the differences in RPE between the positions. The data analysis was performed using SPSS 26 (SPSS, Chicago, USA) and Excel 2016 (Microsoft Inc, Redmond, WA, USA). Excel 2016 and Paint 3D (Microsoft Inc, Redmond, WA, USA) was used to create figures.

3. Results

3.1 Cycling performance test

3.1.1 Lactate

The results show a significant main effect of position on LA between UP and TTP at both 95% LT and 105% LT, where LA is higher in TTP compared with UP at both intensities, with a difference of 1.2 ± 1.6 (95% LT) and 1.3 ± 1.7 (105% LT) mmol/L (Table 3, Figure 2). Further on, there is a significant main effect of time at 95% LT, but not at 105% LT, suggesting a significant increase in LA over time throughout the 95% LT bouts only. No significant interaction effect indicates that the change over time is not different between the positions.

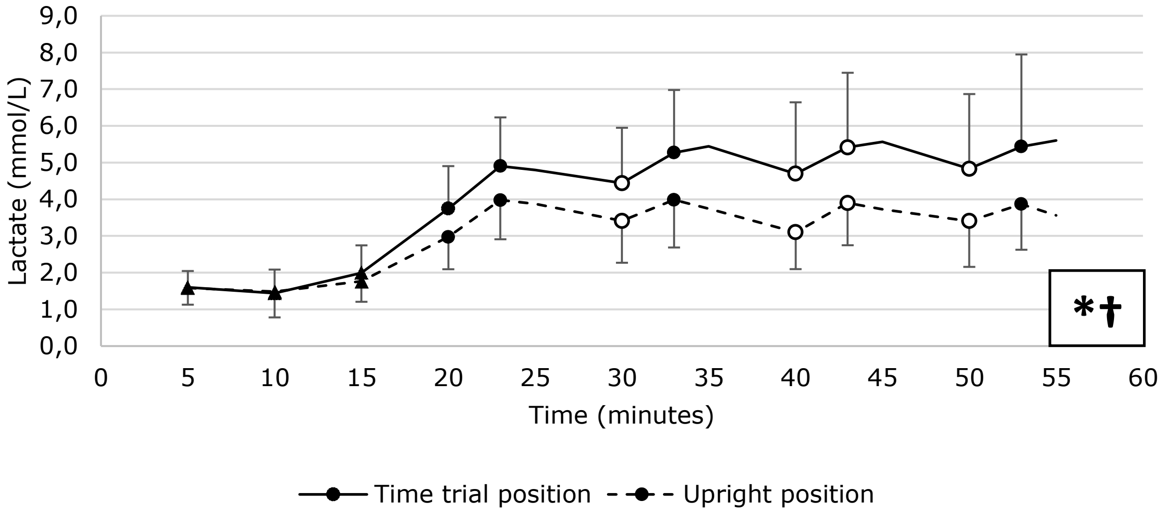

Figure 2: ▲ =Ramp up, not analyzed; *=Sig. main effect of position throughout the protocol at 95% LT; †=Sig. main effect of position throughout the protocol at 105% LT; open circle indicates a sig. main effect of time at this time point compared to the first bout at the corresponding intensity.

3.1.2 Cardiopulmonary variables (VO_2, V'E, BF, HR, RER and GE)

There were no significant interaction effects between position and time in VO_2, V'E, BF and HR. The results show a significant main effect of position on V'E and HR at 95% LT, and V'E, HR and BF at 105% LT, and these variables were all higher in TTP compared with UP (table 2, figure 3 A-D). No significant main effects of position were found in VO_2 at either intensities. Significant main effects of time were seen in all cardiopulmonary variables, meaning they all change significantly over time throughout the cycling protocol, but without an interaction effect, it is shown that the change over time does not differ between the positions.

In addition, RER and GE was investigated, showing no significant interaction effects or main effects of position (table 2). Both had a significant main effect of time, both increasing throughout the protocol.

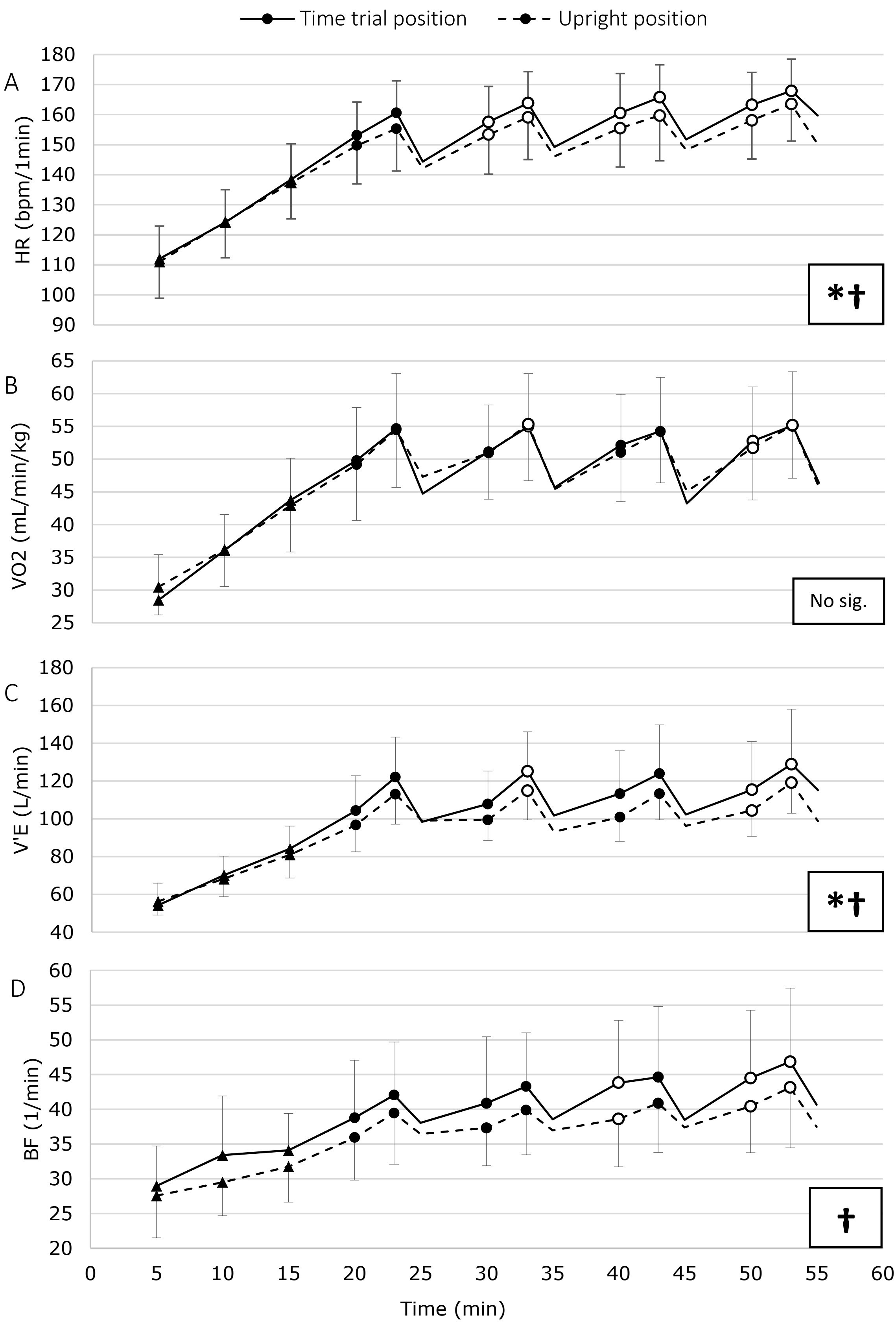

Figure 3 A-D: ▲ =Ramp up, not analyzed; *=Sig. main effect of position throughout the protocol at 95% LT; †=Sig. main effect of position throughout the protocol at 105% LT; open circle indicates a sig. main effect of time at this time point compared to the first bout at the corresponding intensity.

3.1.3 Muscle oxygen saturation

A significant main effect of position was found in SmO2 GAS at both 95% LT and 105% LT, but there were no significant main effects of time in this muscle (table 3, figure 4 B-C). SmO2 VL showed no significant main effects in either position or time, and can therefore be considered quite unaffected by the length of the cycling protocol and change in positions. Both SmO2 GAS and SmO2 VL had no significant interaction effects at either intensities, hence showing that the change over time throughout the cycling protocol does not differ between the positions.

A significant interaction effect between position and time was found in SmO2 TA at both 95% LT and 105% LT ($p=0.045$ and 0.017 respectively), and simple main effects from a one-way RMANOVA are therefore presented (table 3, figure 4 A). Significant simple main effects of position were found in all four bouts at 95% LT, and in bout 3 and 4 at 105% LT. A significant simple main effect of time was only seen in TTP at 95% LT. The significant interaction effect in SmO2 TA for both 95% LT and 105% LT shows that the change in SmO2 TA over time is different between the positions at both intensities.

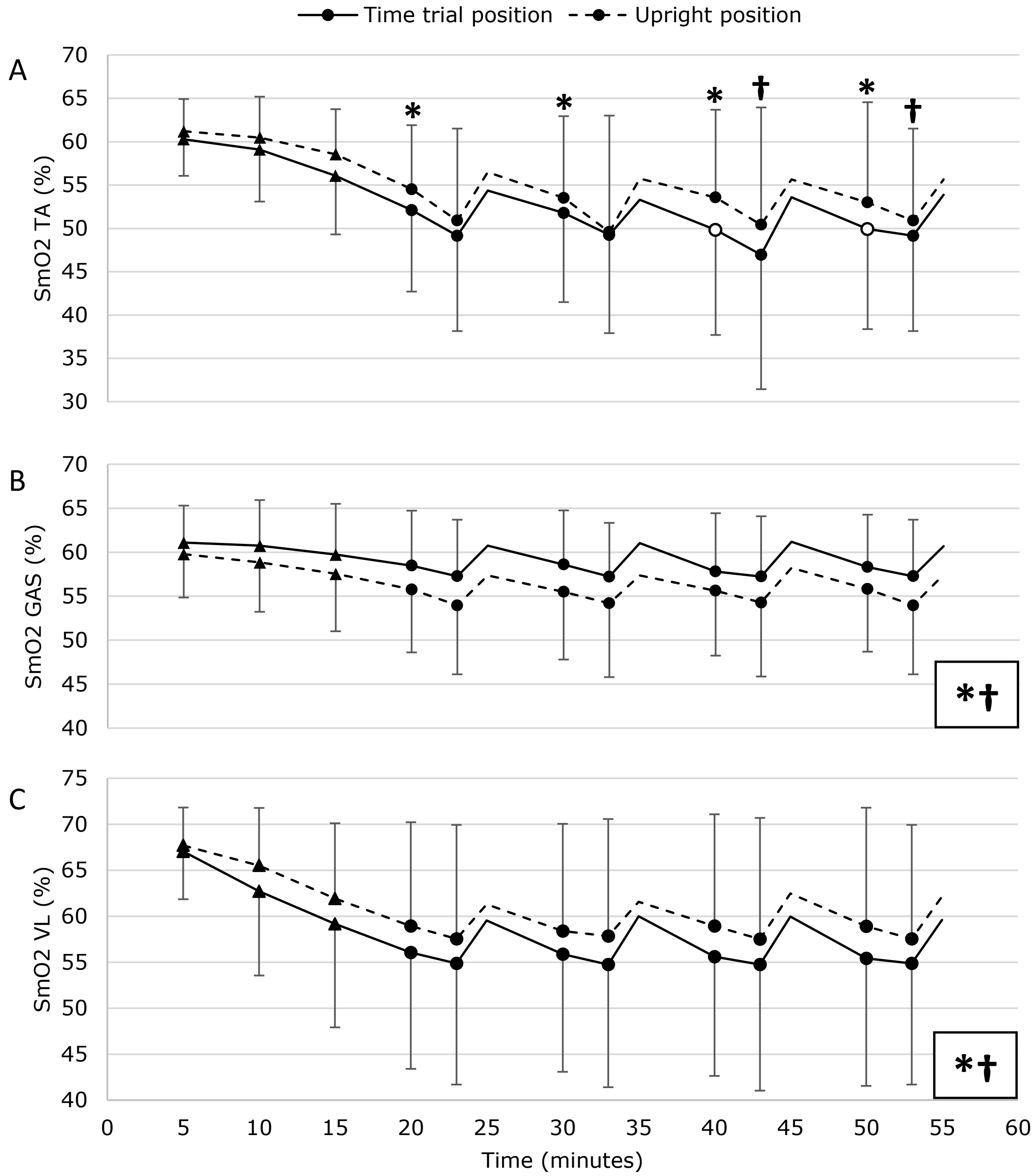

Figure 4 A-C: ▲ =Ramp up, not analyzed; *=Sig. main effect of position throughout the protocol at 95% LT; †=Sig. main effect of position throughout the protocol at 105% LT; open circle indicates a sig. main effect of time at this time point compared to the first bout. In figure 4 A the symbols marking significant difference between position are placed directly above the specific time point since TA is analyzed using a one-way RMANOVA.

Table 3. Mean, SD, differences, main- and interaction effects for all normally distributed bike variables that do not have a significant interaction between position and time.

		UP	TTP	Difference	Position		Time	
Variable	Intensity	*Mean ± SD*	*Mean ± SD*	*Mean ± SD*	Main effect	Partial η2	Main effect	Partial η2
LA (mmol·l^{-1})	95% LT	3.2 ± 1.1	4.4 ± 1.7	1.2 ± 1.6	p=0.016*	0.455	p=0.011*	0.408
	105% LT	3.9 ± 1.2	5.3 ± 1.9	1.3 ± 1.7	p=0.017*	0.45	p=0.420	0.088
HR (bmp)	95% LT	154.2 ± 12.9	158.6 ± 12	4.4 ± 5.2	p=0.008*	0.741	p<0.001*	0.482
	105% LT	159.4 ± 13.8	164.5 ± 10.6	5.1 ± 6.9	p=0.011*	0.456	p<0.001*	0.607
VO_2 (ml/kg^{-1}/min^{-1})	95% LT	50.8 ± 7.6	51.5 ± 7.6	0.7 ± 1.8	p=0.052	0.358	p=0.012*	0.327
	105% LT	54.8 ± 8.1	54.8 ± 7.9	0.0 ± 1.8	p=0.849	0.004	p=0.039*	0.346
RER (CO2/O2)	95% LT	0.91 ± 0.02	0.92 ± 0.03	0.01 ± 0.03	p=0.496	0.053	p<0.001*	0.852
	105% LT	0.95 ± 0.03	0.96 ± 0.03	0.02 ± 0.03	p=0.217	0.164	p<0.001*	0.723
V'E (L/min)	95% LT	100.4 ± 12.7	110.3 ± 21	9.9 ± 13.6	p=0.049*	0.365	p=0.007*	0.353
	105% LT	115.0 ± 15.0	124.9 ± 23.6	9.9 ± 13.9	p=0.044*	0.378	p=0.022*	0.385
BF (1/min)	95% LT	38.1 ± 6.3	42.1 ± 9.2	3.9 ± 6.5	p=0.076	0.308	p=0.001*	0.597
	105% LT	40.8 ± 7.3	44.1 ± 8.9	3.4 ± 5.3	p=0.037*	0.398	p=0.003*	0.394
GE (%)	95% LT	19.5 ± 1.2	19.1 ± 1.0	-0.4 ± 0.8	p=0.069	0.322	p<0.001*	0.561
SmO2 TA (%)	95% LT	53.6 ± 9.4	50.9 ± 10.6	-2.7 ± 2.8	X	X	X	X
	105% LT	50.4 ± 11.8	48.6 ± 12,0	-1.8 ± 3.3	X	X	X	X
SmO2 GAS (%)	95% LT	55.7 ± 7.1	58.3 ± 6.1	2.6 ± 2.2	p=0.001*	0.644	p=0.633	0.034
	105% LT	54.1 ± 7.9	57.3 ± 6.2	3.2 ± 3	p=0.005*	0.525	p=0.507	0.044
SmO2 VL (%)	95% LT	54.3 ± 18.2	51.2 ± 18.8	-3.1 ± 5.3	p=0.124	0.243	p=0.663	0.034
	105% LT	53.0 ± 18.9	50.3 ± 18.9	-2.7 ± 5.4	p=0.172	0.197	p=0.678	0.025

X=Reported as simple main effects in table 4; *=sig. (p>0,05); LA=lactate; HR=heart rate; VO_2=oxygen consumption; RER=respiratory exchange ratio; V'E=minute ventilation; BF=breathing frequency; GE=gross efficiency; SmO2=muscle oxygen saturation; TA=tibialis anterior; GAS=gastrocnemius; VL=vastus lateralis.

Table 4. Simple main effects for bike variables that showed a significant interaction between position and time.

	Position			Time		
Variable	Bout	Significance	Partial η2	Variable	Significance	Partial η2
SmO2 (%) **TA 95%**	Bout 1	p=0.028*	0.366	**SmO2** (%) **TA 95% UP**	p=0.368	0.078
	Bout 2	p=0.012*	0.453			
	Bout 3	p=0.001*	0.64	**SmO2** (%) **TA 95% TTP**	p=0.016*	0.366
	Bout 4	p=0.002*	0.595			
SmO2 (%) **TA 105%**	Bout 1	p=0.068	0.271	**SmO2** (%) **TA 105% UP**	p=0.158	0.176
	Bout 2	p=0.756	0.009			
	Bout 3	p=0.003*	0.556	**SmO2** (%) **TA 105% TTP**	p=0.329	0.101
	Bout 4	p=0.025*	0.409			

*=sig. (p>0,05); SmO2=muscle oxygen saturation; TA=tibialis anterior.

3.1.4 Perceived exertion

The Friedman's test shows a significant effect of position in bout 4 at 95% LT and bout 2, 3 and 4 at 105% LT (table 5, figure 5). Further on, there was a significant effect of time in bout 3 and 4 at 95% LT and bout 4 at 105% LT during the UP, and in bout 2, 3 and 4 at 95% LT and bout 3 and 4 at 105% LT in the TTP. RPE increased with 1.92 and 1.25 at 95% LT and 105% LT respectively in TTP, and 0.75 and 0.83 at 95% LT and 105% LT respectively in UP. Hence, TTP led to a bigger increase compared to UP.

Table 5. Results from RPE bike given in mean ± SD, differences, significance levels for position at each time point, and significance levels for time. Each bout at 95% LT and 105% LT is compared with the first bout at the corresponding intensity.

	UP	**TTP**	**Differences**		**Position**		**Time UP**	**Time TTP**
Variable	*Mean ± SD*	*Mean ± SD*	*Mean ± SD*	Bout	Significance	Bout	Significance	Significance
RPE 95% (A.U)	14.1 ± 1	14.5 ± 1.4	0.1 ± 1.0	Bout 1	p=0.803			
				Bout 2	p=0.211	2 vs. 1	p=0.338	p=0.050*
				Bout 3	p=0.134	3 vs. 1	p=0.050*	p=0.001*
				Bout 4	p=0.016*	4 vs. 1	p=0.041*	p<0.001*
RPE 105% (A.U)	15.5 ± 1	16 ± 1.5	1.0 ± 1.2	Bout 1	p=0.169			
				Bout 2	p=0.030*	2 vs. 1	p=0.505	p=0.145
				Bout 3	p=0.024*	3 vs. 1	p=0.211	p=0.034*
				Bout 4	p=0.041*	4 vs. 1	p=0.020*	p=0.003*

*=sig. (p>0,05); A.U=arbitrary units; RPE=ratio of perceived exertion.

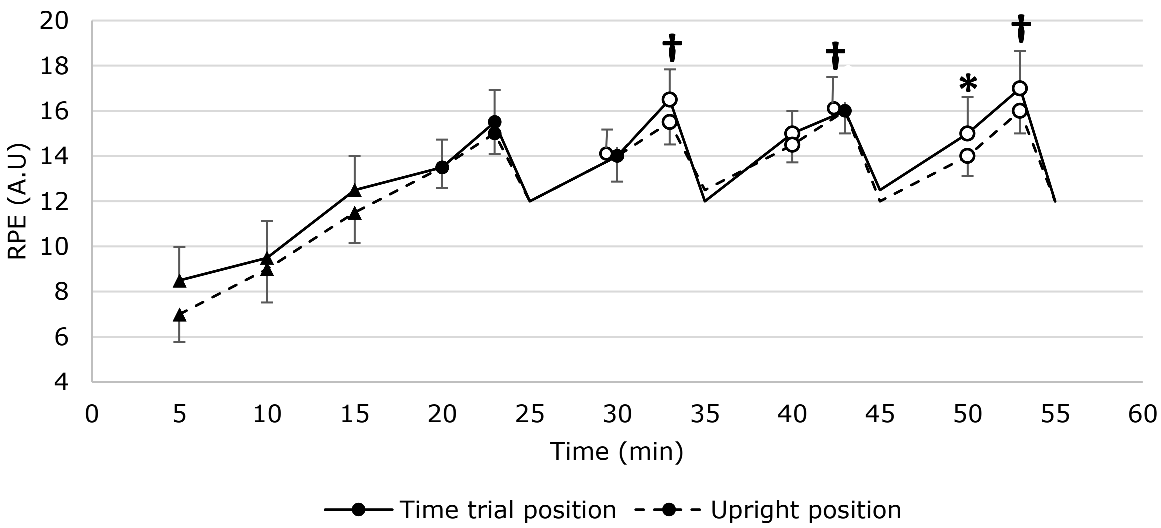

Figure 5: ▲ =Ramp up, not analyzed; *=Sig. effect of position at 95% LT at current time point; †= Sig. effect of position at 105% LT at current time point; open circle indicates a sig. effect of time at this time point compared to the first bout at the corresponding intensity; indicator for TTP at 30 min and 43 min are shifted slightly to the left for clarity; A.U= arbitrary units.

3.2 Run Performance Test

The results from the PTR showed no interaction effects between time and position, and main effects from a two-way RMANOVA are therefore reported for all normally distributed variables (table 6, figure 6 A and 7 A-B). There is a significant main effect of position only on HR, whereas no significant differences are seen between positions on speed and VO_2 during the PTR. Time, one the other hand, showed a significant main effect on all normally distributed variables, and with no interaction effect, there is no difference between the positions in change over time in any of the variables throughout the run.

Furthermore, the Friedman's test showed no significant effect of position in RPE (table 7, figure 6 B). There was however a significant effect of time from lap 5 (UP) and lap 4 (TTP) throughout the run.

Individual differences in running performance after UP and TTP is visually presented in figure 8, showing that only two participants had an increase of >30s in time spent on a 5km run.

Table 6. Mean, SD, differences, main- and interaction effects for all normally distributed run variables.

	UP	**TTP**	**Difference**	**Position**		**Time**	
Variable	*Mean ± SD*	*Mean ± SD*	*Mean ± SD*	Main effect	Partial η2	Main effect	Partial η2
Speed (km/h)	15.1 ± 1.3	14.6 ± 1.1	0.5 ± 1.6	p=0.208	0.17	p=0.014*	0.338
VO2 ($ml/kg^{-1}/min^{-1}$)	62.4 ± 7.0	61.0 ± 5.8	1.3 ± 3.2	p=0.105	0.378	p=<0.001 *	0.836
HR (bmp)	176.3 ± 11.4	174.2 ± 10.1	2.2 ± 3.1	p=0.024*	0.759	p=0.001*	0.843

*=sig. (p>0,05)

Table 7. Results from RPE run given in mean ± SD, differences, and significance levels for position for each 500m lap, and time, where each lap is compared with the first lap.

	UP	**TTP**	**Differences**		**Position**		**Time UP**	**Time TTP**
Variable	*Mean ± SD*	*Mean ± SD*	*Mean ± SD*	Lap	Significance	Lap	Significance	Significance
RPE (A.U)	16.8 ± 1.1	17.2 ± 1.1	0.4 ± 1.4	Lap 1	p=0.605			
				Lap 2	p=0.691	2 vs. 1	p=0.438	p=0.571
				Lap 3	p=0.273	3 vs. 1	p=0.265	p=0.108
				Lap 4	p=0.406	4 vs. 1	p=0.056	p=0.033*
				Lap 5	p=0.307	5 vs. 1	p=0.016*	p=0.005*
				Lap 6	p=0.374	6 vs. 1	p=0.002*	p=0.002*
				Lap 7	p=0.623	7 vs. 1	p=0.001*	p=0.001*
				Lap 8	p=0.970	8 vs. 1	p=<0.001*	p=<0.001*
				Lap 9	p=0.748	9 vs. 1	p=<0.001*	p=<0.001*
				Lap 10	p=0.895	10 vs. 1	p=<0.001*	p=<0.001*

*=sig. (p>0,05); A.U=arbitrary unit; RPE=ratio of perceived exertion.

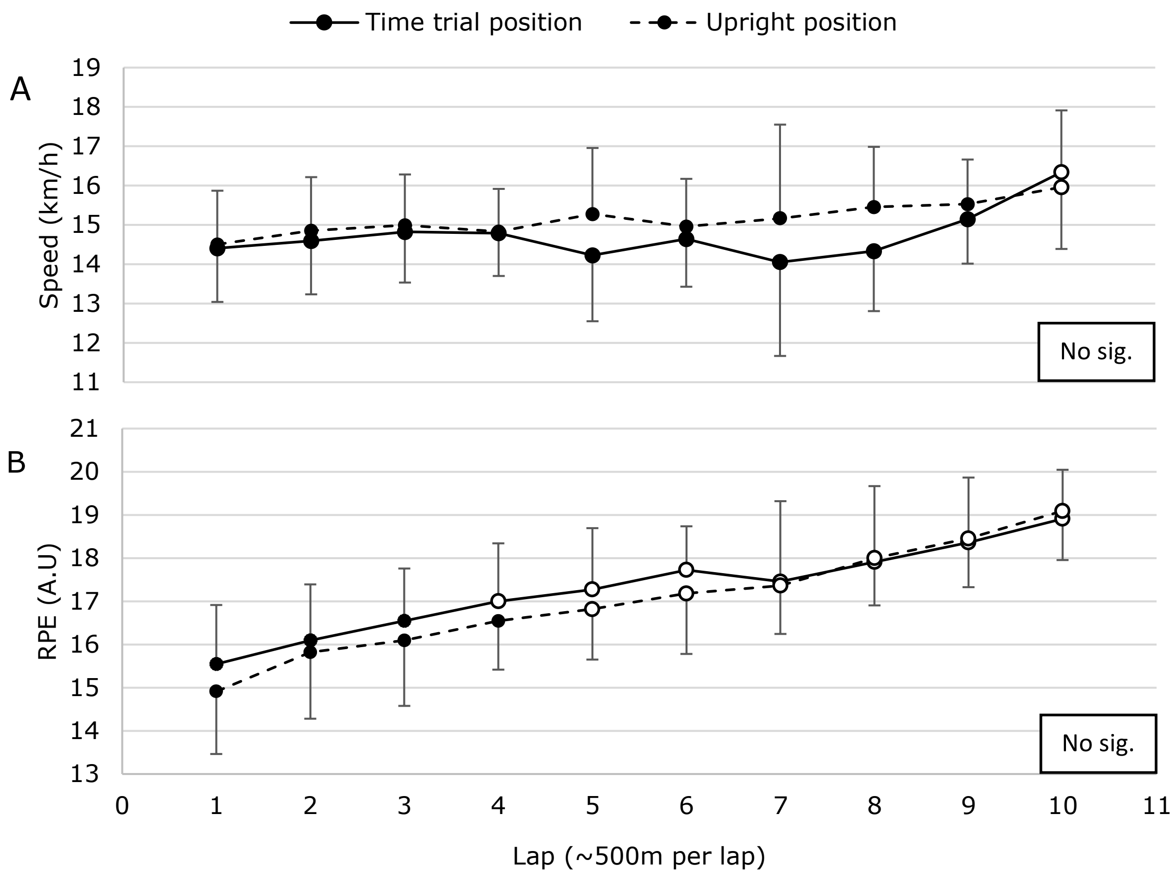

Figure 6 A-B: Open circle indicates a sig. effect of time in this lap compared to the first lap; A.U=arbitrary unit.

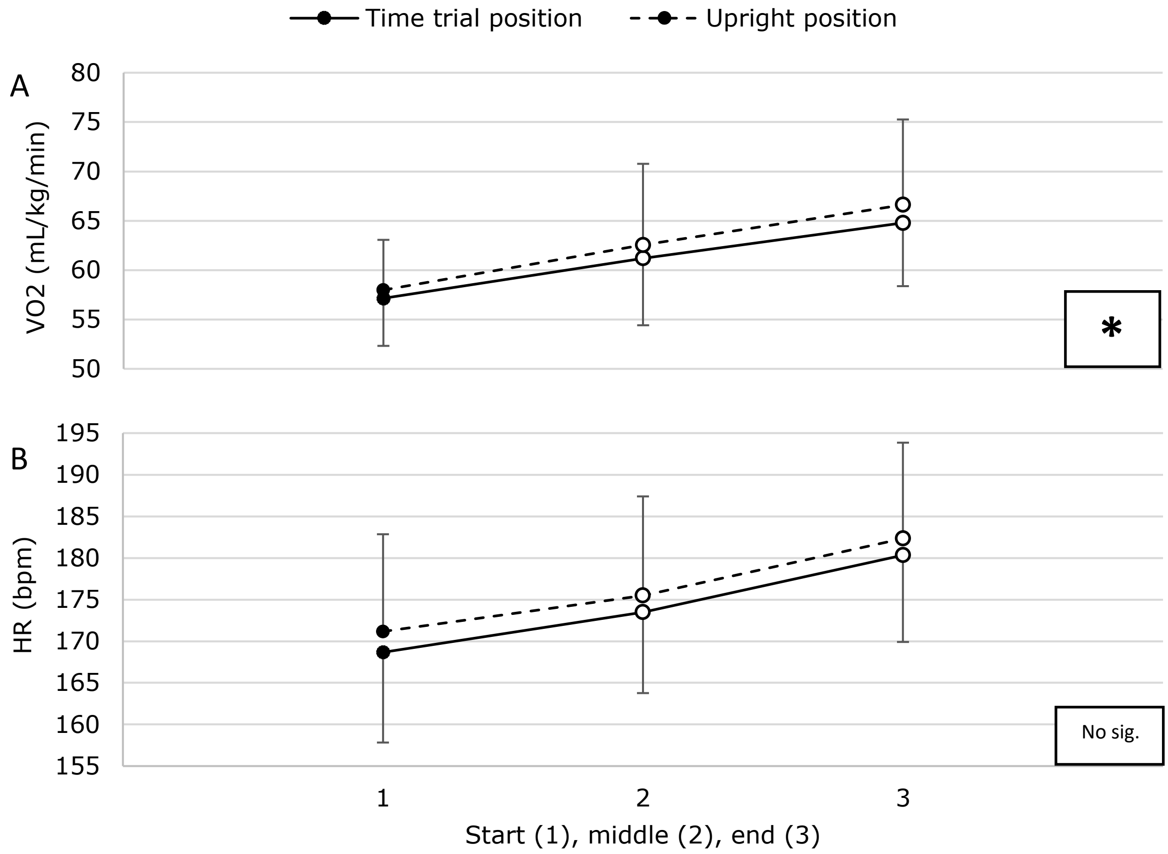

Figure 7 A-B: ***=Sig. main effect of position; open circle indicates a sig. main effect of time at this time point compared to the first time point.

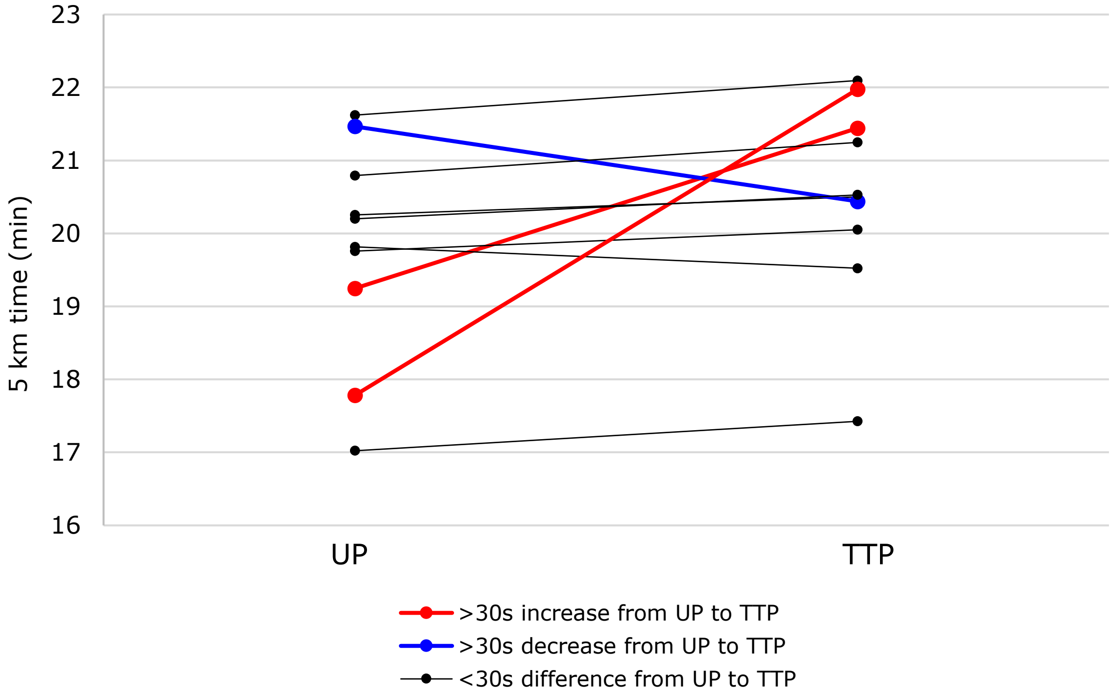

Figure 8: Individual differences in run time after UP and TTP.

4. Discussion

The aim of the present study was to investigate how physiological and perceptual performance variables during cycling were affected by a TTP compared to an UP. In addition, differences in the effect of TTP and UP on subsequent transition running performance was investigated. The main overall findings were that physiological and perceptual cost of cycling increased in the TTP compared to the UP, which is in line with our hypothesis. This included an increase of lactate, heart rate, breathing frequency, minute ventilation and perceived exertion. In the PTR, HR was the only variable that was significantly affected by position, revealing a lower HR during the run after the TTP compared with the run after the UP, however, the total time spent on a 5km run was not affected.

4.1 Physiological cost of cycling in TTP compared to UP

The increased values in HR, LA, BF and V'E without a simultaneously significantly increased VO_2 and decreased GE indicate that the TTP does not lead to increased energy cost. However, TTP still seems to be more demanding compared with the UP given the increase in other physiological variables not directly related to energy cost. The Fick equation could be a useful tool in explaining possible mechanisms behind the increase in HR and SmO2 in TA despite the lack of significant findings in VO_2. The Fick equation state that VO_2 (ml/min) = cardiac output (l/min) · arterio-venous O_2-difference (ml/l) (36). Cardiac output is the blood volume the heart is able to pump out during one minute as the product of stroke volume and heart rate. The arterio-venous O_2-difference is the difference in O_2-concentration in arterial blood and venous blood, which give us a measure of how much oxygen the muscles are able to extract from the blood. Since the oxygen transport is an integrated system (37), changing one of the variables in this equation will lead to changes in the others. In this case, VO_2 stays rather similar between the positions, whereas HR is increased. According to the Fick equation this must mean that either stroke volume, arterio-venous O_2-difference, or both, are reduced. A conceivable mechanism behind a reduced stroke volume could be a more horizontal position of the upper body, or due to limitations imposed by the crutched position. It can also be hypothesized whether the small torso angle might affect blood flow to the legs, and therefore affecting arterio-venous O_2-difference, which alone or in combination with a reduced stroke volume could be the cause of the increased HR.

Further on, the results of the present study show that SmO2 in TA and GAS was significantly affected by the TTP compared with the UP, suggesting physiological differences at a local muscular level. SmO2 in TA was lower during TTP, whereas the opposite was the case in GAS, implying that the lowered torso angle might actually increase oxygen availability in this muscle. In VL there was a difference in SmO2 of -3.1% ± 5.3% and -2.7% ± 5.4% in 95% LT and 105% LT respectively, but unlike TA and GAS, these differences did not reach statistical significance. Skovereng et al. (20) recently found that the decrease in the torso angle occurring when changing from an upright position to a drop bar position led to a simultaneous decrease in the angle of the ankle. This adaptation seen in the ankle counteract the decrease in the hip angle, potentially compensating somewhat for the physiological alterations when lowering the cycling position. The torso angle is therefore shown to elicit changes in other joint angles in the leg, possibly leading to changes in muscle recruitment and oxygen availability in the working muscles, which might be part of the explanation to the changes seen in SmO2 in the present study. This observation is supported by several other authors who suggest that changing the torso angle elicit adaptations in muscles length and recruitment which might affect the physiological cost of cycling (16-19), manifesting the dynamic nature of human movement, in which the current findings in SmO2 substantiates.

Furthermore, LA was higher in TTP compared to UP in the present study. LA generation by working muscle has previously been attributed to intracellular hypoxia, where the assumption has been that an increase in LA must reflect an oxygen limitation to oxidative phosphorylation (38). However, Conley et al. (38) demonstrated that glycolytic flux is independent of oxygenation state, and proportional to muscle activation. Potential changes in muscle activation from lowering the angle of the torso while cycling might therefore explain the higher lactate values seen in TTP compared to UP (16-19).Additionally, an increased muscle length in gluteal muscles induced by the lower torso angle might affect the length-force relationship when pedaling, which might lead to impaired working conditions for these muscles (16). This alteration of muscle activation could have led to a greater degree of glycolysis in this area, which might explain the differences observed in LA between the position (16, 38, 39).

In regard to ventilatory variables, one possible mechanism behind the increased BF might be that the lungs must compensate for a restricted ventilation in the crutched position in order to meet the oxygen demand due to limitations imposed by the crutched position. This suggestion is substantiated by Ashe et al. (19) who proposed that the increase in physiological cost seen in TTP compared to UP, including BF and V'E, could be a result of restricted movement of the diaphragm due to the low and tucked in position of the upper body. In contrast, Berry et al. (22) suggest that ventilatory and pulmonary variables are not limited when cycling in a TTP. They did however find that individuals that were more experienced with aero handlebars showed a smaller difference in time to exhaustion between TTP and UP, suggesting that the tolerance for using the TTP is trainable.

Although the difference between the positions in VO_2, RER and GE did not reach statistical significance, a mean difference of 0.7 ± 1.8 mL/min/kg in VO_2 ($p=0.052$) and -0.4% ± 0.8% in GE ($p=0.069$) at 95% LT still indicate a slightly increased energy cost of TTP compared with UP, which is in accordance with existing literature (4, 15, 16). On the other hand, there are some discrepancies in the findings within this topic, with some studies suggesting no difference in physiological responses between UP and TTP (23). However, these studies investigated time trial positions with a more upright torso angle, which could be the reason why they do not reach conclusions in line with the aforementioned studies (4, 15, 16). This could be applicable to the present study as well since the adjustment of the TTP was self-chosen. Thus, it is likely that the participants chose a position they knew would be comfortable over time. This possibly led to less extreme positions compared to those investigated in other similar studies, as in example Fintelman et al. (16) who investigated a TTP parallel to horizontal. One can argue that investigating the effects of a position that is likely closer to what the practitioners adapt in real life, thus improving ecological validity, is an advantage of the present study, although this might lead to smaller differences between the positions.

4.2 Perceptual cost of cycling in TTP compared to UP

In light of the physiological findings in the present study, the elevated RPE was fully expected partly as a consequence of the increased physiological cost from cycling in a TTP compared to the UP. Additionally, discomfort as a result of increased pressure on the shoulders and neck in the TTP is a mechanism likely to affect RPE (8). It has also been suggested that riding in positions with small torso angles contributes to low back pain in cyclists (40). Further on, sustaining a static riding position at high intensities for prolonged periods may cause gluteal, hamstring and back muscle fatigue that also might contribute to low back pain (41). The protocol needed to be standardized to compare the two positions, hence the athletes were not able to change position during the 95% LT and 105% LT bouts. Thus, the combination of a static position with a small torso angle at high intensities can be considered a likely cause of increased RPE in the TTP at 105% LT, especially in combination with the increased physiological cost.

4.3 Physiological and perceptual cost of transition running after cycling in TTP compared to UP

Several studies show a decrease in performance and an increase in physiological cost of transition running compared to an isolated run (25, 29, 32). The results of the present study suggest that the TTP does not amplify the reductions in running performance beyond the reductions seen after cycling in an UP. Hence, our hypothesis regarding transition running performance being affected by cycling position was not confirmed. No significant effects were found in running performance measured in speed and time spent on a 5km treadmill run. The only significant finding from the PTR was a lower HR after cycling in the TTP compared to the UP (p=0.024). When seen in combination with running speed (figure 8A), one can see that the average speed is somewhat dropped during in the middle of the run after cycling in TTP, whereas the opposite is seen in after the UP. After the UP the general trend is a more even performance, with a small increase in speed throughout the run. This can be considered a sign that the athletes were struggling more with pacing after the TTP compared to the UP. However, there were no significant effects of position in perceived exertion, suggesting that the participants did not experience the PTR after TTP as more exhausting than after cycling in the UP. Even if the speed did not give any statistically significant results, one can see in figure 9 that most athletes had a small reduction in performance on the 5km run. The p-value of differences in speed was p=0.208, but even if the result did not reach statistical significance, the average difference in time spent on the 5km run was ~44s ± 87s. In a sprint or Olympic triathlon, with a 5km or 10km run, a 44s increase in run time would have a major impact on all over performance and chances of getting a good position. However, with a high variation in the results, it is worth looking into the individual performances of the athletes in this small sample to get a better insight into how running performance is affected by position. It becomes clear when looking at figure 8 that most of the athletes perform at a similar level after both positions, and the differences seen in many of them are so small that it cannot be attributed to the cycling position.

Among the 10 participants who are included in the analysis of the PTR, two of them had an increase in time of >2min, which can be considered a severe reduction in performance at this distance. It can be discussed whether or not this was due to position, however, looking into their individual differences in physiological and perceptual variables during the cycling protocol, they were both on the higher end of the scale in regards of differences between the positions in several variables, pointing towards them both being highly affected by the cycling position, especially in the second half of the CT60, suggesting that sitting in a TTP over time affects these two athletes negatively, being a possible explanation for the severe reduction in running performance. On the other hand, it should be emphasized that this was only the case for two athletes, and the differences in their performance and physiological variables could be affected by several other factors such as variations in day-to-day condition, sleep, nutrition, and restitution.

Although attempts have been made to take such factors into account through instructions regarding exercise and nutrition prior to participation, it is not possible to fully eliminate the effects of day-to-day variations in performance. Hence, it cannot be concluded that the differences seen in these two athletes are due to the cycling position. However, performance differences this big could affect the results during competition to such a great extent that it is highly relevant information for the current athletes and their coaches, and something they should investigate further. It is also possible that these differences would be present in more athletes if a larger sample were investigated.

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4.5 Methodological considerations

The results from the literature are difficult to compare due to methodological variations in frequency, intensity, and duration of the protocols. The existing research within the field also varies in quality and outcome variables, making it even more difficult to compare. In addition, no prior studies have, to the best of our knowledge, investigated the effect of how the TTP affects different aspects of transition running performance compared to an UP. The duration and intensity variations of our protocol was therefore primarily based on pilot testing, where the aim was to create a feasible protocol that simulated a competitive situation to the greatest possible extent, but which nevertheless allowed the athletes to reach a steady state at high intensity without too high an element of anaerobic energy turnover. Yet, the short 3 min bouts at 105% LT are included to uncover potential physiological differences between the TTP and the UP also above LT.

Furthermore, defining LT as the workload that corresponds to a LA-value of 4 mmol/L in a step test using 5 minute steps of 25W increments is a widely used and reliable concept within exercise science (42). However, adding a limit of RPE at 16 take into consideration that LA concentration at LT varies between athletes. RPE was therefore used to be certain no athletes ended up cycling at a workload way above what they subjectively perceived as an intensity that was possible to endure throughout the duration of the cycling protocol. When using a within-participant study design, the main focus is to ensure equal conditions between the tests that are compared, hence, the aim was to use the same workload during both tests, and for this purpose, the method used to determine LT in the present study can be considered accurate enough. Only one participant was unable to complete the protocol as planned, and it can therefore be assumed that the workload was appropriate for the purpose of the protocol.

Another methodological consideration in the present study is the use of an ergometer bike, which prevents the athletes from replicating their exact customary position from their personal bike. This could reduce the ecological validity of the study due to potential differences in joint angles, possibly affecting physiological variables. However, there are still clear benefits of using an ergometer bike such as standardizing the equipment and making it more convenient for the athletes to participate, which makes it easier to both recruit and retain participants throughout the study.

Individual aerodynamic properties from the different cycling positions were not obtained in this study. Thus, we cannot make any claims regarding the aerodynamic gains of the time trial positions applied by the participants in this study. However, looking into the literature, Hennekam (11) suggest a reduction in air drag of about 20% when changing from a completely upright and straight arm position to a drop bar position, and another 10-17% decrease when going from the drop bar position to a fully crutched aero position. In total, Hennekam show a reduction of approximately 30-35% in air drag between the highest and lowest position. The equipment and positions these numbers are based on are not fully representative of what we see today due to the development in bikes and positions over the past two decades, although the numbers give a picture of the how much one can potentially save by using a TTP nonetheless. In addition, findings from Fintelman et al. (9) suggest that the aerodynamic losses outweigh the power losses seen when using a TTP when cycling at speeds above 46 km/h, although a fully horizontal position is still not optimal. For speeds below 30 km/h Fintelman et al. (9) recommend using a more upright TTP. In regards of aerodynamic properties, the lack of information on frontal area and torso angles also prevented us from investigating whether the participants adapting a lower TTP was more affected by position compared to those adapting a higher TTP. Future research within this field should consider including these aerodynamic properties in their investigation.

The general performance level and degree of experience with TTP among the participants is another methodological consideration that could possibly affect the results. With a VO_2max of 67.9 ± 7.6 mL/min/kg this is a group of well-trained triathletes in which all are competitive and familiar with the use of TTP. However, information about the degree of experience with TTP was not collected in this study, and it is therefore not possible to determine whether level of experience with the use of TTP has affected our results.

Further on, the unnatural setting of self-pacing on a treadmill without information about speed and duration might have had a negative effect on performance. One possible alternative would be to let the participants run with continuous information on speed and duration, however this could possibly have led to them trying to improve their performance from the first to the second performance test. Hence, a trade-off was made, landing on the conclusion that a blinded performance was necessary to avoid intentional improvement of performance. It should however be mentioned that the problem of self-pacing was the same in both test days, and potential learning effects are minimized by blinding the participants from duration and speed.

4.6 Practical implications

The results of the present study adds to the notion that physiological and perceptual cost of cycling is somewhat increased when using a TTP compared with an UP. However, seen in light of the existing literature, it can be assumed that the aerodynamic gains of using a TTP outweighs the increased physiological and perceptual cost. At speeds below 30 km/h, it is however suggested by Fintelman et al. (9) that one should adapt a higher TTP with a larger torso angle, and avoid staying in a static cycling position over prolonged time periods (41). In regards of transition running performance, the current results point towards an overall insignificant decrease in performance, however there were large individual differences, and some athletes seems to be more affected by the TTP than others. As an athlete or coach, one should do a further investigation to whether this is the case for them/their athletes. If so, prior research has, as mentioned, found that athletes who are more familiar with using the TTP are less affected (22), and it is therefore suggested that the tolerance for TTP might be trainable. In that case it should be possible to mitigate the increased physiological and perceptual cost by frequently incorporating TTP in the daily training.

4.7 Conclusion

In conclusion, this study demonstrates an increased physiological cost of cycling in a TTP compared to an UP in line with our initial hypothesis. Further on, the results indicate that the TTP does not worsen the transition running performance compared to UP, although big variations between participants were present. Seen in light of existing literature, it is suggested that the aerodynamic benefits from cycling in a TTP outweigh the increased physiological cost, although we cannot with certainty draw this conclusion due to lack of information about aerodynamic properties of the positions applied in the present study. Future research should include frontal area and torso angles in their investigation in order to comment on whether the increased physiological cost seen in cycling is outweighed by the aerodynamic gains from the TTP. Further research should also investigate to what degree the increased physiological cost seen in TTP is trainable in order to possibly improve both cycling and transition running performance in triathletes.

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Appendix 1 – Consent form

FORESPØRSEL TIL DELTAKELSE I FORSKNINGSPROSJEKT FOR TRENTE TRIATLETER: EFFEKTEN AV TEMPOSTILLING PÅ ULIKE PRESTASJONSVARIABLER UNDER SYKLING OG PÅFØLGENDE OVERGANGSLØP

Dette er en forespørsel om deltakelse i et forskningsprosjekt som skal undersøke hvordan aerodynamisk tempostilling og tradisjonell oppreist sittestilling på sykkel på ulike måter påvirker prestasjonsbestemmende faktorer under sykling og løping i triatlon.

For å kunne delta må du:

- Være fylt 16 år
- Ha drevet aktivt med triatlon som konkurrerende utøver i minst 2 sesonger
- Være godt kjent med og vant til bruk av tempostilling på sykkel
- Må gjennomføre utholdenhetstrening i form av løping og/eller sykling minst 4 ganger i uken

Du kan ikke delta dersom du:

- Bruker EPO, steroider, eller andre ulovlige prestasjonsfremmende midler
- Har en bevegelseshemning
- Har hjerte- eller lungesykdom eller annen sykdom som medfører økt risiko under fysiske anstrengelser
- Bruker medikamenter som begrenser maksimale utholdenhetsprestasjoner

Du har blitt spurt om deltakelse på grunn av at du trolig utfyller inklusjonskriteriene, altså kravene for å kunne delta i studien. Forskningsprosjektet er et masterprosjekt, og blir ledet av Institutt for nevromedisin og bevegelsesvitenskap og Senter for toppidrettsforskning ved Fakultet for medisin og helsevitenskap ved NTNU i Trondheim.

BAKGRUNN OG HENSIKT MED STUDIEN

Luftmotstand er den største hindringen man må overkomme når man sykler på flatt underlag. Desto høyere fart man har, desto større blir luftmotstanden. Ved en fart på 50 km/t vil hele 90% av kraften man produserer gå til å jobbe mot luftens krefter. I både sykling og triatlon er tempostilling svært vanlig å benytte for å redusere luftmotstand. Studier har vist opptil 35% reduksjon i luftmotstand ved bruk av tempostilling under sykling i høy fart, og selv om forskningen viser at kraftutviklingen reduseres ved tempostilling sammenlignet med en oppreist sittestilling, vil fordelene veie opp for ulempene ved høy fart, som for eksempel i en konkurransesituasjon. Flere studier viser til redusert løpsprestasjon etter sykling, men det er manglende kunnskap om hvorvidt tempostilling påvirker prestasjon på overgangsløp mer enn en oppreist sittestilling, og i så fall hvilke prestasjonsvariabler som påvirkes. I og med at tempostilling er svært utbredt blant triatleter under konkurranse er det av stor interesse å avdekke eventuelle forskjeller i effekten av denne stillingen sammenlignet med en mer tradisjonell oppreist stilling på både sykkel- og løpsprestasjon. Vi planlegger derfor et forskningsprosjekt hvor hensikten er å undersøke og sammenligne hvordan disse sittestillingene på sykkel påvirker ulike prestasjonsvariabler på sykkel- og overgangsløp.

HVA STUDIEN INNEBÆRER FOR DELTAKERNE

Alle deltakere skal møte til 2 testdager på Senter for toppidrettsforskning i Granåsen. Begge testdagene vil bestå av **1)** test av laktatprofil, **2)** test av maksimalt oksygenopptak (VO2maks), **3)** prestasjonstest på opptil 30 min på 75% av peak power output (PPO, høyeste 1 minutt-måling i watt under VO2maks-test) og **4)** prestasjonstest på opptil 5km løp hvor man styrer farten selv. Del 1-3 gjennomføres på egen sykkel på rulle, og del 4 er en løpetest på tredemølle. Oppvarming og aktive pauser mellom de ulike delene (med unntak av overgangen fra del 3-4 som vil skje uten pause) kommer i tillegg.

Forskjellen på de to testdagene vil være at alle tester som gjennomføres på sykkel vil være i oppreist sittestilling (hender plassert på bukkehorn) den ene dagen, og i tempostilling (temposykkel eller tempobøyle) den andre dagen. Rekkefølgen på sittestilling vil være tilfeldig – noen vil starte med oppreist sittestilling den første testdagen, mens andre starter med tempostilling. Dette vil bli informert om i forkant av testdagene.

De to testdagene må ha minimum 48 timers mellomrom, og maksimum 14 dager. Dette er for å passe på at du er godt nok restituert, samt for å påse at du ikke har oppnådd treningseffekter som kan påvirke resultatene mellom de to testdagene.

Begge testdagene vil starte med måling av kroppsvekt og hudfoldtykkelse på lår hvor sensorer for måling av lokal muskulær oksygenmetning (nær-infrarød spektroskopi) skal plasseres.

FYSIOLOGISKE MÅLINGER UNDER TESTPROTOKOLLEN

Oksygenopptak vil måles kontinuerlig under alle deler av testen, med unntak av pausene, hvor man vil ha mulighet til å drikke vann. Hjertefrekvens vil måles kontinuerlig med tildelt pulsbelte. Lokal muskulær oksygenmetning vil måles kontinuerlig med nær-infrarød spektroskopi (sensorer festet på huden to ulike steder på forside lår).

Vi vil måle laktatkonsentrasjon med stikk i fingertupp hvert 5 minutt under laktatprofil, samt på slutten av/umiddelbart etter hver av de resterende delene av testen (Vo2maks-test, prestasjonstest sykkel og prestasjonstest løp).

I tillegg vil opplevd utmattelse registreres med bruk av Borg skala 6-20.

I PROSJEKTET VIL VI HENTE INN OG REGISTRERE OPPLYSNINGER OM DEG

- Kondisjonsdata målt ved oksygenopptak
- Hjertefrekvens
- Laktatverdier
- Lokal muskulær oksygenmetning
- Kraftutvikling (sykling) og løpsprestasjon (målt i tid brukt på 5km)
- Høyde, vekt og hudfoldtykkelse

HVA KAN DU GJØRE/IKKE GJØRE UNDER DELTAKELSE I DETTE PROSJEKTET?

48 timer før testing må du avstå fra høyintensiv trening og alkohol. 12 timer før testing må du avstå fra all trening, både lav- og høyintensiv. Utover dette kan du trene normalt mellom de to testdagene da de vil legges opp med maksimum 14 dagers mellomrom for å unngå eventuelle treningseffekter av endringer i egentrening mellom de to testene.

MULIGE FORDELER OG ULEMPER VED DELTAKELSE

Ved deltakelse vil du få kontakt med kompetente fagpersoner med erfaring fra testing og utholdenhetstrening, særlig rettet mot sykling, løping og triatlon. Du vil få nyttig innsikt i din egen fysiske form og prestasjonsevne gjennom testresultatene, og du vil bidra til økt kunnskap rundt prestasjonsbestemmende faktorer under gjennomførelse av triatlon.

Ulempene antas å være små, da testene er lagt opp slik at den ikke skal overskride de fysiske kravene til konkurranser og høyintensive treningsøkter i det daglige. I og med at det å være en aktiv konkurrerende utøver, samt å være fri fra skade og/eller sykdom som kan øke risiko ved deltakelse er et inklusjonskriterium skal det i utgangspunktet ikke være noen utbredte ulemper ved deltakelse i dette prosjektet. Man må dog regne med at testen i sin helhet vil være anstrengende, og selv om utstyret som brukes til testing ikke er skadelig, kan det oppleves som ubehagelig dersom man ikke har vært med på lignende testing tidligere. Man må avstå fra hard trening i to dager før begge testdagene, og bør også belage seg på et par rolige dager i etterkant av testdagene. Testen er for øvrig lagt opp slik at den kan fungere som en høyintensiv kvalitetsøkt i seg selv, og skal være mulig for deg å legge inn som en del av en helhetlig treningsplan slik at den ikke skal medføre store endringer i treningshverdagen din.

HVA SKJER MED INFORMASJONEN OM DEG?

Personlige opplysninger og testresultater vil utelukkende brukes slik som beskrevet i hensikten med studien. Alle opplysninger vil behandles uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger. En kode knytter deg til dine personlige opplysninger og testresultater gjennom en navneliste. Kun autorisert personell med tilknytning til prosjektet vil ha tilgang til navnelisten som kan knytte deg til dine opplysninger. Du har rett til innsyn i hvilke opplysninger som er registrert om deg, samt rett til å korrigere eventuelle feil i disse opplysningene.

Alle opplysninger vil behandles uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger. Opplysninger knyttet til koden vil bli oppbevart på en egen minnepenn under prosjektperioden, og kun masterstudent og veiledere vil ha tilgang til denne. Forskningsprosjektets varighet er fra 30.august 2020 til 15.juni 2021. datamaterialet vil muligens oppbevares utover denne perioden for bruk i mulige publikasjoner. Dataene vil oppbevares i anonymisert form, og du vil ikke kunne bli gjenkjent fra datamaterialet. All behandling av personlige opplysninger vil baseres på ditt skriftlige samtykke. Prosjektleder har ansvar for forskningsprosjektet og at alle opplysninger om deg blir behandlet på en sikker måte.

DINE RETTIGHETER

Testresultatene vil analyseres, registreres og anonymiseres. Så lenge du kan identifiseres i datamaterialet har du rett til:

- Innsyn i hvilke opplysninger som er registrert om deg,
- Å få rette på personlige opplysninger om deg,
- Å få slettet personlige opplysninger om deg,
- Få utlevert en kopi av dine personopplysninger,
- Å sende inn klage til personvernombudet eller Datatilsynet om behandlingen av dine personopplysninger.

Vårt personvernombud, Thomas Helgesen, kan kontaktes på e-post: thomas.helgesen@ntnu.no eller på telefon: 93079038.

Dersom du har spørsmål knyttet til NSD – Norsk senter for forskningsdata sin vurdering av prosjektet, kan du ta kontakt med på e-post (personverntjenester@nsd.no) eller på telefon: 55 58 21 17.

FRIVILLIG DELTAKELSE OG MULIGHET TIL Å TREKKE DITT SAMTYKKE

Det er frivillig å delta i prosjektet. Dersom du ønsker å delta, skriver du under samtykkeerklæringen på siste side i dette skrivet. Du kan når som helst, uten å oppgi noen grunn, trekke ditt samtykke. Dersom du trekker deg fra prosjektet kan du kreve å få slettet innsamlede resultater og personlige opplysninger, med unntak av anonymisert innsamlet data anvendt i det endelige studiet. Dersom du ønsker å trekke deg, eller har spørsmål om prosjektet, kan du kontakte følgende:

- Møyfrid Kløvning (Masterstudent), moklovni@stud.ntnu.no
- Knut Skovereng (Prosjektleder), knut.skovereng@ntnu.no

FOR FORESATTE TIL DELTAKERE UNDER 18 ÅR

Som foresatt til en deltaker under 18 år er det du som avgjør om barnet ditt skal få delta eller ikke, og du vil ha mulighet til å være med inn i laboratoriet under hele testen dersom du ønsker det. Alle deltakerne som får være med i denne studien er aktivt konkurrerende utøvere, og selv om testprotokollen vil være anstrengende og tung å gjennomføre, vil den, så lenge protokollen gjennomføres etter planen, ikke overskride de fysiske anstrengelsene utøverne opplever under hard trening i det daglige, og triatlonkonkurranser med sprint-distanse (750m svøm, 20km sykkel, 5km løp). Du kan, på samme måte som deltakeren selv, velge å trekke ditt samtykke når som helst og uten å oppgi grunn.

SAMTYKKE TIL DELTAKELSE I STUDIEN

Jeg har mottatt skriftlig informasjon og er villig til å delta i studien. Jeg tillater at mine personopplysninger behandles som beskrevet i dette prosjektet. Jeg er klar over at jeg når som helst, og uten å oppgi grunn, kan trekke meg fra prosjektet uten at det gir noen som helst form for konsekvenser.

Dato/Sted_______________

Skriv under på den linjen som stemmer for deg. Dersom du ikke har fylt 18 år må en foresatt også samtykke til at din deltakelse i prosjektet.

Deltaker over 18 år

_ _

Deltaker under 18 år

_ _

Foresatte til deltaker under 18 år

_ _

Dersom du ønsker å melde din interesse vennligst kontakt en av oss på telefon eller mail og send signert samtykkeerklæring per mail eller ved å levere direkte. På forhånd hjertelig takk for at du vil stille opp – det setter vi stor pris på!

KONTAKTINFORMASJON

- Masterstudent: Møyfrid Kløvning (Masterstudent), tlf: 94486813, e-post: moklovni@stud.ntnu.no
- Prosjektansvarlig og masterveileder: Knut Skovereng (Prosjektveileder), e-post: knut.skovereng@ntnu.no

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