The Effect of Cycling Intensity on Cycling Economy During Seated and Standing Cycling

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Abstract

Background. Previous research has shown that cycling in a standing position reduces cycling economy compared with seated cycling. It is unknown whether the cycling intensity moderates the reduction in cycling economy while standing.

Purpose. ~~It is unknown whether the cycling intensity moderates the reduction in cycling economy while standing. It was hypothesized thatt~~ The aim was to determine whether~~ at a higher intensity,~~ the negative effect of standing on cycling economy would be decreased at a higher intensity.

Methods. Ten cyclists cycled in 8 different conditions. Each condition was either at an intensity of 50% or 70% of maximal aerobic power, at a gradient of 4% or 8% and in the seated or standing cycling position. Cycling economy and muscle activation level of 8 leg muscles were recorded.

Results. There was an interaction between cycling intensity and position for cycling economy ($P = 0.03$), the overall activation of the leg muscles ($P = 0.02$) and the activation of the lower leg muscles ($P = 0.05$). The interaction showed decreased cycling economy when standing compared with seated cycling, but the difference was reduced at higher intensity. The overall activation of the leg muscles and the lower leg muscles respectively increased and decreased, but the differences between standing and seated cycling were reduced at higher intensity. ~~Overall leg muscle activation increased, whereas activation of the lower leg muscles decreased, when standing compared with seated cycling, while the difference was reduced at higher intensity for both overall and lower leg muscles.~~

Conclusions. Cycling economy was lower during standing cycling than seated cycling, but the difference in economy diminishes when cycling intensity increases. Activation of the lower leg muscles ~~does~~ did not explain the lower cycling economy while standing. The increased overall activation therefore suggests~~, suggesting~~ that increased activation of the upper leg muscles explains part of the lower cycling economy while standing.

Introduction

During uphill cycling, cyclists regularly opt to change from a seated to a standing position when the gradient increases[1] . Previous studies have found that cycling economy is decreased during a standing position at low and moderate exercise intensities (<70% of maximal oxygen consumption [$\dot{V}O_{2max}$])[2,3]. However, at higher intensities, above 70% $\dot{V}O_{2max}$, the negative effect of standing on cycling economy seems to disappear[4–6]. Thus, it appears that cycling intensity could influence the metabolic cost of uphill standing cycling, although this has not been determined in a single study. In addition, the gradient during uphill cycling -has recently been shown to influence cycling economy[~~12~~7], and could also influence the comparison between seated and standing cycling.

The transition from seated to standing cycling changes body position on the bicycle, ~~effectively~~ allowing the cyclist to shift their centre of mass forward[~~7~~8], ~~and~~ which increases the degrees of freedom[~~8,~~9,10]. Both of these actions require a reorganisation of the muscular recruitment pattern[10-12~~9–11~~]. For example, standing has been shown to increase the level of activity in individual (proximal) upper leg muscles as well as overall~~, total~~ muscle activation, and to alter~~ation in~~ the timing of muscle activation[1~~0~~1]. Interestingly, comparable changes have not been seen in muscles of the lower leg[1~~0~~1].

The increase in overall muscle activation ~~with~~ while standing could increase metabolic cost and thus reduce cycling economy compared with a seated position.~~ In addition, gradient has recently been shown to influence cycling economy[12].~~ Therefore, the aim of this study was to determine the effect of intensity ~~in~~ during seated and standing cycling ~~positions~~ on cycling economy during treadmill cycling. Subjects cycled at two exercise intensities and two gradients in both seated and standing positions~~Two cycling intensities at two gradients were performed in both the seated and standing positions~~. It was hypothesized that cycling intensity would interact with cycling position to impact on ~~both~~ cycling economy and muscle activation. It was hypothesized that cycling economy would be reduced by a greater amount during standing cycling at a low exercise intensity compared with a high exercise intensity. In conjunction, it was hypothesized that muscle activation would be increased by a greater amount at a low exercise intensity compared with a high exercise intensity.

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Methods

Participants

Ten male cyclists (age: 31 ± 9 years, height: 182 ± 5 cm, mass: 74.7 ± 5.4 kg, $\dot{V}O_{2peak}$: 4.8 ± 0.4 $L \cdot min^{-1}$, Maximal Aerobic Power: 367 ± 40 W) from local cycling clubs participated in the study. All participants trained for 6 hours or more per week and were free of medical issues that could restrict lower limb movement. All participants provided written informed consent to participate in the study that was approved by the institution's ethics committee, in accordance with the Declaration of Helsinki. Prior to each test, participants were instructed to refrain from exercise and alcohol for 24 hours and from caffeine intake for 4 hours.

Experimental design

Participants visited the laboratory on two separate occasions. On their first visit, participants were familiarized with the protocol before completing a ramp test to determine peak oxygen consumption ($\dot{V}O_{2peak}$) and Maximal Aerobic Power (MAP). During familiarization participants cycled at a power output below 140 W, using their preferred cadence until they were comfortable riding on the treadmill (Saturn, 200 x 250 cm, HP Cosmos, Nussdorf-Traunstein, Germany). On their second visit, participants cycled on the treadmill completing 8 conditions, which are outlined below.

Methodology

Visit 1

An incremental ramp test was performed on a cycle ergometer (Schöberer Rad Messtechnic, Weldorf, Germany). Prior to the test, a 10-min warm-up at 100 W, using a self-selected cadence was allowed. The test started at a power output of 100 W for 1 minute to allow the participants to reach his preferred cadence. After the first minute, the power output was increased to 150 W and the test continued increasing by 20 W·min^{-1} until volitional exhaustion. $\dot{V}O_{2peak}$ was calculated as the highest minute average of $\dot{V}O_2$ recorded during the test (Metalyzer 3b, Cortex Biophysik, Germany). MAP was calculated as the highest averaged 1-minute power.

Visit 2

During visit 2, participants cycled on a treadmill using a standard road bicycle (Specialized Secteur, Specialized, CA, USA). The bicycle was fitted with an adjustable stem (Look ergo stem, Look, Nevers, France) and an adjustable seat post (I-beam, SDG Components, CA, USA). Tyres were inflated to 700 kPa prior to each visit. A 10-min warm-up at the participant's preferred power and cadence was performed prior to testing, with power being increased to the target intensity during the final 120 s. Treadmill speed was calculated using equations proposed by Coleman et al. [13] with a correction for rolling resistance[14].

Cycling conditions consisted of 5 minutes of cycling at a power output of 50% MAP (low intensity) or 70% MAP (high intensity), at either a 4% or 8% gradient in the seated and standing position. Intensity and gradient were administered in a random, counterbalanced design. Body position (Seated, Standing) was altered in a randomized order within each combination of gradient and intensity. Based on Harnish et al.[4], cadence was specified at 60-70 rev·min^{-1}, depending on individual preferred standing uphill cycling cadence, and was constant across conditions for each participant.

Expired air was collected using the Douglas bag technique, during the final minute of each 5-minute period[15]), and is described in detail in Arkesteijn et al.[~~12~~7]. During the standing conditions, participants breathed through the mouth piece for the full duration, while for the seated conditions, participants inserted the mouth piece after two minutes. Participants rested for three minutes between conditions, during which Douglas bag contents were analysed for oxygen consumption and carbon dioxide production using a high precision offline gas analyser (Servoflex MiniMP, Servomex, UK) and dry gas volume meter (Harvard Apparatus Ltd., Edenbridge, UK). Prior to use, equipment was calibrated for each visit according to manufacturers' recommendations.

Mean power output was calculated from the power output provided via a rear wheel power measurement device (PowerTap Elite+, Saris, USA) during the final minute of each condition. Cycling economy was defined as the mean power output produced relative to the volume of oxygen consumed~~ during the final minute~~.

Muscle activation was determined on the right leg for the Tibialis anterior (TA), Soleus (SOL), Gastrocnemius medialis (GM), Gastrocnemius lateralis (GL), Vastus medialis (VM), Vastus lateralis (VL), Rectus femoris (RF) and Gluteus maximus (Gmax). Single differential EMG sensors (Delsys Bagnoli, Delsys Inc., USA) were placed across the muscle belly following the recommendation provided by the Surface Electromyography for the Non-Invasive Assessment of Muscle function (SENIAM)[16]. Muscle activation was recorded for the final minute of each condition with a sampling frequency of 1000 Hz (Imago, Radlabor, Germany). A linear envelope was created using a fourth-order, low-pass filter with a cutoff frequency of 15 Hz. The envelope was aligned with the crank orientation using a square wave pulse generated each revolution to indicate the top dead centre.

Muscle activation level was normalized to the highest value observed across all conditions for each participant [17]. This provided an indication of the relative amplitude across conditions and provided standardization between participants while allowing intra-subject comparisons. Burst duration was defined as the period where EMG activity exceeded 20% of the difference between peak and baseline activity above baseline activity. The mean activity was calculated for the duration of the burst using the normalized activity level. The product of the burst duration and mean activity determined the overall muscle activation and quantified the integrated EMG activity (iEMG) in arbitrary units. Overall muscle activation level was determined from the iEMG of all leg muscles, while muscle activation of the lower leg (iEMG$_{LL}$) was determined from the iEMG of TA, SOL, GM and GL. Muscle activation of the upper leg muscles was not combined, as no hamstring muscles were recorded.

Statistical analysis

The ability to adequately control the independent variables of power output and pedalling rate was evaluated using factorial ANOVAs with repeated measures for intensity, gradient and body position. ~~Subsequently, changes in c~~Cycling economy, muscle activation onset, offset and iEMG were analysed using~~ factorial~~ ANOVAs with ~~repeated measures for ~~intensity, gradient and body position as within subject factors.~~.~~ Pairwise comparisons using Bonferroni corrections for multiple comparisons were used to identify significant differences between conditions. To determine interactions between intensity and position, differences between the seated and standing positions for each dependent variable (DV: economy and iEMG) at low and high intensity were calculated as the mean across gradients, according to:

$$\Delta \mathrm{DV}_{\mathrm{low}} = \frac{\left(\mathrm{DV}_{\mathrm{standing\ 4\%\ low}} + \mathrm{DV}_{\mathrm{standing\ 8\%\ low}}\right)}{2} - \frac{\left(\mathrm{DV}_{\mathrm{seated\ 4\%\ low}} + \mathrm{DV}_{\mathrm{seated\ 8\%\ low}}\right)}{2}$$

and

$$\Delta \mathrm{DV}_{\mathrm{high}} = \frac{\left(\mathrm{DV}_{\mathrm{standing\ 4\%\ high}} + \mathrm{DV}_{\mathrm{standing\ 8\%\ high}}\right)}{2} - \frac{\left(\mathrm{DV}_{\mathrm{seated\ 4\%\ high}} + \mathrm{DV}_{\mathrm{seated\ 8\%\ high}}\right)}{2}$$

Post hoc testing for interactions between intensity and position was performed using paired samples t-tests, comparing $\Delta \mathrm{DV}_{\mathrm{low}}$ and $\Delta \mathrm{DV}_{\mathrm{high}}$. Post hoc testing for interactions between intensity, position and gradient were not performed. All statistical analyses were performed using SPSS 17.0 statistical analysis software (SPSS, Inc, Chicago, IL, USA). Results are expressed as mean ± standard deviation (SD). Statistical significance was set at $P < 0.05$.

Results

An interaction between gradient, intensity and position was found for power output ($F_{1,9}$ = 6.807; $P = 0.03$). Position significantly affected the mean power output ($F_{1,9}$ = 7.62; $P = 0.02$, Seated: 228 ± 20 W, Standing: 232 ± 22 W) ~~independently of changes in gradient. The interaction effect indicated that~~, but the magnitude of the difference ~~in power output~~ depended on the actual combination of gradient and intensity. Paired samples t-tests indicated that mean power output was different between seated and standing positions at 4% at high intensity (t(9) = -2.324, $P = 0.05$, Seated: 266 ± 25 W, Standing: 275 ± 30 W) and at 8% at low intensity (t(9) = -3.022, $P = 0.01$, Seated: 187 ± 17 W, Standing: 192 ± 17 W). No differences were found in power output between seated and standing positions for 4% at low intensity and 8% at high intensity ($P > 0.05$).

Cycling economy

An interaction between intensity and position was found for economy ($F_{1,9}$ = 6.326; $P = 0.03$) (Figure 1). Standing elicited a lower economy compared with seated (F(1,9) = 43.903; p < 0.001, Seated: 71.4 ± 2 $\mathrm{W{\cdot}LO_2^{-1}}$, Standing 64.7 ± 3.5 $\mathrm{W{\cdot}LO_2^{-1}}$). The difference between seated and standing was larger at low intensity compared with high intensity (t(9) = 2.449, $P = 0.03$, $\Delta\mathrm{Economy}_{\mathrm{low}}$: 9.1 ± 5.7 $\mathrm{W{\cdot}LO_2^{-1}}$, $\Delta\mathrm{Economy}_{\mathrm{high}}$: 4.4 ± 2.4$\mathrm{W{\cdot}LO_2^{-1}}$). Economy increased by a greater amount between low and high intensities in the standing compared with the seated position (t(9) = 2.449, $P = 0.03$, ΔSeated: 2.9 ± 4.4 $\mathrm{W{\cdot}LO_2^{-1}}$, ΔStanding: 7.6 ± 3.3$\mathrm{W{\cdot}LO_2^{-1}}$). Oxygen consumption and respiratory exchange ratio (RER) for each condition are provided in table 1. RER was higher at high intensity compared with low intensity ($F_{1,9}$ = 28.853; $P < 0.001$) and for the standing position compared with the seated position (($F_{1,9}$ = 11.552; $P = 0.008$).

Muscle activation level

Overall iEMG showed a main interaction between intensity and position ($F_{1,6}$ = 10.285; P = 0.02) but no overall effect of position ($F_{1,6}$ = 1.182; $P = 0.319$). The difference between seated and standing was greater at low intensity compared with high intensity (t(6) = 3.207, $P = 0.018$, $\Delta\mathrm{iOverall}_{\mathrm{low}}$: 73 ± 103, $\Delta\mathrm{iOverall}_{\mathrm{high}}$: 24 ± 135). Only the $\mathrm{iEMG_{LL}}$ of the lower leg muscles (iEMG of TA, SOL, GM, GL) demonstrated an interaction between intensity and position ($F_{1,6}$ = 5.963 , P = 0.05). The difference between seated and standing positions for the $iEMG_{LL}$ was smaller at low intensity compared with high intensity (t(6) = 2.442, P = 0.05, $\Delta iEMG_{LL\ low}$: -47 ± 63, $\Delta iEMG_{LL\ high}$: -71 ± 79)

An example of the ~~muscle activity~~ muscle activation patterns for a representative participant at low and high intensities ~~with~~ at an 8% gradient in seated and standing positions is shown in Figure 2. An interaction effect of intensity, gradient and position was found for the iEMG of RF ($F_{1,9}$ = 9.248; P = 0.01). Intensity, gradient and position also independently affected the iEMG of RF ($P < 0.05$).

An interaction effect of intensity and position was found on the iEMG for VM ($F_{1,8}$ = 16.945; P = 0.003). VL demonstrated a similar interaction as VM, but was not significant ($F_{1,9}$ = 4.695; P = 0.06). The difference in iEMG between seated and standing was larger at low intensity compared with high intensity for VM (t(8) = 4.116, P = 0.003, ΔiVM_{low}: 37.6 ± 9.9, ΔiVM_{high}: 29.6 ± 12.5), with VL demonstrating a similar trend (t(9) = 2.167, P = 0.06, ΔiVL_{low}: 41.8 ± 18.5 , ΔiVL_{high}: 36.7 ± 19.1).

A main effect of cycling position was found on the iEMG for GL ($F_{1,8}$ = 9.254; P = 0.02) and SOL ($F_{1,7}$ = 25.288; P = 0.002). An increased iEMG was found for standing for SOL (Seated: 50.2 ± 11.2, Standing: 72.8 ± 10.2), whereas a decreased iEMG was found for GL in the standing position (Seated: 102.5 ± 22.6, Standing: 65.1 ± 19). TA, Gmax and GM were not affected by intensity, position or gradient ($P > 0.05$)

Discussion

The present study aimed to determine the effect of cycling intensity and cycling position on cycling economy and muscle activation. The main findings of the present study are that the standing position reduced cycling economy more during low intensity cycling than during high intensity cycling compared with the seated position. These same changes were evident in the ~~O~~overall muscle activation, which ~~-~~showed a similar ~~effect of~~response to changes in cycling intensity and cycling position as ~~to~~ the cycling economy data. Muscle activation levels of upper leg muscles VM and VL were higher in the standing position compared with the seated position, with the difference being larger at low intensity compared with high intensity. However, the lower leg muscles showed reduced activity levels in the standing position compared with the seated position, with the difference between positions increasing at high intensity

The present study is the first to compare seated and standing cycling at various intensities and gradients while maintaining a constant cadence. Previous studies have either only considered a single intensity[2,5,6], a single gradient whilst incorporating various intensities[3], or allowed

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Formatted: Font: (Default) Times New Roman, 12 pt use of preferred cadence[4]. Allowing participants to select their preferred cadence unfortunately has been shown to induce a lower cadence when cycling in the standing position compared with the seated position[4]. Although the present study has thus a lower ecological validity, a reduction in cadence at the same exercise intensity subsequently improves cycling economy due to the positive relationship between the cadence and cycling economy[18]. The present study is the first single study to show that cycling intensity impacts on the effect of cycling position when factors such as cadence are controlled. Although standing still impairs economy at an intensity of 70% MAP, the difference is much smaller compared with 50% MAP.

The present study largely supports the findings of Duc et al.[1~~0~~1] and Li and Caldwell[10~~9~~] by demonstrating increased activity of the knee extensor muscles when cycling in the standing position. The role of RF, a bi-articular muscle inducing knee extension and hip flexion appears to be very complex in cycling as the activity level depends on intensity, gradient and position. This complexity is in line with previous suggestions that RF functions to stabilize joints, transfer energy and generate force[19–21]. More importantly, the present study suggests that the magnitude of the increase in muscle activation for VM and VL in the standing position (compared with the seated position) depends on the exercise intensity. At 50% MAP, muscle activation level in the standing position was increased by 60% to that during the seated position, which decreased to 40% when cycling at 70% MAP. Duc et al.[11~~0~~] reported a difference of 20% in the same muscles during cycling at 80% MAP. Assuming a continuing trend at intensities >80% MAP, this could potentially result in lower knee extension activity in the standing position compared with the seated position at intensities above 100% MAP, delaying fatigue in these muscles. This would be in line with the results of Hansen and Waldeland[1] where, at intensities above 94% MAP, the standing position resulted in the best performance in a time to exhaustion task.

Contrary to the findings of Duc et al.[1~~0~~1] and Li and Caldwell[~~9~~10], the present study demonstrated a decrease in activity of muscles that cross the ankle joint (TA, GL and SOL) when standing compared with seated cycling. A few explanations can be provided for the divergent results. The study by Li and Caldwell[~~9~~10] was performed by tilting the bicycle, rather than by actually replicating uphill cycling, which could influence a cyclist's pedalling technique differently[22]. In addition, exercise intensities were different between the current study, and that of Duc et al.[1~~0~~1] (70% MAP versus 80% MAP respectively). It is proposed that muscle activation of TA, GL and SOL is affected by cycling position because, when standing, body mass is no longer supported by the saddle, leading to increased ankle dorsiflexion due to a forward shift of the body's centre of mass[1~~1~~2]. As exercise intensity increases (i.e. 70–80% MAP), increased resistive force is encountered at the pedal, whereas the gravitational force (i.e. body weight) exerted on the pedal remains constant as a consequence of the unsupported body mass. Ultimately, the lower resistive force at low intensity would likely increase the dorsiflexion moment of the ankle and increase the activity of the plantar flexor, SOL (as found in the present study), to counteract this moment. The accompanying absence of activity for TA indicates that the function of TA in the seated position might be to prevent plantar flexion and reduce ankle extension velocity. The lower activity of GL (and to a lesser extent GM) during the standing position indicates that the function of this bi-articular muscle is not necessarily to stabilize the ankle, but to transfer power generated across the knee joint to the ankle[23].

The interaction between intensity and position for VM and VL was reflected in the whole body measure of economy. The knee extensor muscles are considered to be the primary power producing muscles in cycling[24]. The present study thus suggests that the primary power producing muscles (i.e. VM and VL) play a dominant role in the overall metabolic cost during cycling. However, contrary to the knee extensor muscles, the overall lower leg muscle activation (TA, SOL, GM and GL combined) showed decreased activity during the standing position compared with seated cycling at low intensity. Furthermore, at high intensity, this decreased lower leg muscle activation was even greater. This indicates a greater effort for the lower leg muscles at high intensity in the seated position compared with low intensity in the same position, but that a standing position reduced this, in particular at a high intensity.

Practical Applications

The activity of the lower leg muscles appears to impact minimally on the overall metabolic cost, as the standing position decreased activity levels for these muscles, which cannot explain the observed decrease in economy. This suggests that the upper leg muscles are most likely dominant in relation to the metabolic cost, as these muscles increased their muscle activation while standing, in line with the increased metabolic cost and subsequent decreased cycling economy.

The present study shows that the standing position could alleviate the strain on the lower leg muscles, even at moderate intensities. It should be noted that the cadence selected in the present study was relatively low for the seated condition, where a cadence above 80 rev·min^{-1} is generally preferred[4]. Although this could potentially influence the generalizability of the present study, previous research indicates that cadence has limited effect on muscle activation levels[25]. More importantly, a down side is that the standing position leads to an increase in knee extensor activity compared with seated cycling. ~~Thus~~ Therefore prolonged standing is likely to impair performance at 70% of MAP, as also suggested by the decreased cycling economy~~,~~. Thus a seated position during prolonged uphill cycling would be recommended for cyclists.

The difference in power output between seated and standing cycling observed in the present study and the RER exceeding 1.00 for the standing positions at high intensity provide potential limitations. Firstly, the present data on seated cycling are similar to those reported by Hansen et al[26], who used similar intensities and reported gross efficiency, indicating RER was below 1. The rationale for determined cycling economy in the present study is that cycling economy does not rely on the RER to remain below 1.00, as opposed to cycling efficiency[27]. Secondly, the overall difference of 4 Watts is thus unlikely to explain the results, in particular because the positive correlation is minimal at intensities above 200 W[18].

Nevertheless, for cyclists it does indicate that standing uphill cycling during competitive events could be made more effective by minimizing the increase in power output compared with seated cycling as found in the present study. Potentially, an increased lateral sway in the standing condition has caused cyclists to require more effort to stabilize the bicycle in the standing position, increasing the activation of leg and arm muscles[1~~0~~1]. Future research sh~~c~~ould aim to determine the cause of the increased power output, without increasing cycling velocity, in a standing position compared with seated cycling

Conclusions

In conclusion, cycling in the standing position elicits a lower cycling economy for moderate intensities. The difference in cycling economy between the standing and seated position however is reduced with increasing intensity. Standing cycling increased the overall muscle activation level, which is the result of increased upper leg muscle activation, while muscle activation was reduced for lower leg muscles. The decreased cycling economy when cycling in the standing position appears largely to be the result of the increased activity of the knee extensor muscles.

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References

1. Hansen EA, Waldeland H. Seated versus standing position for maximization of performance during intense uphill cycling. *J Sports Sci*. 2008;26(9):977-984. doi:10.1080/02640410801910277.

2. Ryschon TW, Stray-Gundersen J. The effect of body position on the energy cost of cycling. *Med Sci Sport Exerc*. 1991;23(8):949-953.

3. Tanaka H, Bassett DR, Best SK, Baker KR. Seated versus standing cycling in competitive road cyclists: uphill climbing and maximal oxygen uptake. *Can J Appl Physiol*. 1996;21(2):149-154.

4. Harnish C, King D, Swensen T. Effect of cycling position on oxygen uptake and preferred cadence in trained cyclists during hill climbing at various power outputs. *Eur J Appl Physiol*. 2007;99(4):387-391. doi:10.1007/s00421-006-0358-7.

5. Millet GP, Tronche C, Fuster N, Candau R. Level ground and uphill cycling efficiency in seated and standing positions. *Med Sci Sport Exerc*. 2002;34(10):1645-1652. doi:10.1249/01.MSS.0000031482.14781.D7.

6. Swain DP, Wilcox JP. Effect of cadence on the economy of uphill cycling. *Med Sci Sport Exerc*. 1992;24(10):1123-1127.

7. Arkesteijn M, Jobson S, Hopker JG, Passfield L. The Effect of Gradient on Cycling Gross Efficiency and Technique. *Med Sci Sports Exerc*. 2012;45(5):920-926.

8. Caldwell GE, Li L, McCole S, Hagberg J. Pedal and crank kinetics in uphill cycling. *J Appl Biomech*. 1998;14(3):245–259.

~~8~~9. Bernstein N. *The Co-Ordination and Regulation of Movements*. Pergamon Press, Oxford; 1967.

~~9~~10. Li L, Caldwell GE. Muscle coordination in cycling: effect of surface incline and posture. *J Appl Physiol*. 1998;85(3):927-934.

1~~0~~1. Duc S, Bertucci W, Pernin JN, Grappe F. Muscular activity during uphill cycling: effect of slope, posture, hand grip position and constrained bicycle lateral sways. *J Electromyogr Kinesiol*. 2008;18(1):116-127.

12~~1~~. Li L, Caldwell GE. Task Specific Coordination of Leg Muscles during Cycling. *Int Res Sport Biomech*. 2002;(1984):241.

~~12.~~ ~~Arkesteijn M, Jobson S, Hopker JG, Passfield L. The Effect of Gradient on Cycling Gross Efficiency and Technique. *Med Sci Sports Exerc*. 2012;45(5):920-926.~~

13. Coleman DA, Wiles JD, Davison R, Smith MF, Swaine IL. Power output measurement during treadmill cycling. *Int J Sports Med*. 2007;28(6):525-530. doi:10.1055/s-2006-955888.

14. Henchoz Y, Crivelli G, Borrani F, Millet GP. A new method to measure rolling resistance in treadmill cycling. *J Sports Sci*. 2010;28(10):1043-1046. doi:10.1080/02640414.2010.498483.

15. Hopker JG, Jobson SA, Gregson H, Coleman DA, Passfield L. The Reliability of Cycling Gross Efficiency Using the Douglas Bag Method. *Med Sci Sport Exerc*. 2012;44(2):290-296. doi:10.1249/MSS.0b013e31822cb0d2.

16. Hermens H, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol*. 2000;10(5):361-374.

17. Burden A. How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. *J Electromyogr Kinesiol*. 2010;20(6):1023-1035. doi:10.1016/j.jelekin.2010.07.004.

18. Ettema G, Lorås HW. Efficiency in cycling: a review. *Eur J Appl Physiol*. 2009;106(1):1-14. doi:10.1007/s00421-009-1008-7.

19. Hug F, Dorel S. Electromyographic analysis of pedaling: a review. *J Electromyogr Kinesiol*. 2009;19(2):182–198.

20. Hug F, Turpin NA, Couturier A, Dorel S. Consistency of muscle synergies during pedaling across different mechanical constraints. *J Neurophysiol*. 2011;106(1):91-103. doi:10.1152/jn.01096.2010.

21. Neptune RR, Herzog W. Adaptation of muscle coordination to altered task mechanics during steady-state cycling. *J Biomech*. 2000;33(2):165–172.

22. Arkesteijn M, Hopker J, Jobson SA, Passfield L. The Effect of Turbo Trainer Cycling on Pedalling Technique and Cycling Efficiency. *Int J Sports Med*. 2013;34(6):520-525. doi:10.1055/s-0032-1327658.

23. Van Ingen Schenau GJ, Bobbert MF, Rozendal RH. The unique action of bi-articular muscles in complex movements. *J Anat*. 1987;155:1-5.

24. Raasch CC, Zajac FEE. Locomotor strategy for pedaling: muscle groups and biomechanical functions. *J Neurophysiol*. 1999;82(2):515–525.

25. Marsh AP, Martin PE. The relationship between cadence and lower extremity EMG in cyclists and noncyclists. *Med Sci Sport Exerc*. 1995;27(2):217-225.

26. Hansen EA, Andersen JL, Nielsen JS, Sjøgaard G. Muscle fibre type, efficiency, and mechanical optima affect freely chosen pedal rate during cycling. *Acta Physiol Scand*. 2002;176(3):185-194. doi:10.1046/j.1365-201X.2002.01032.x.

27. Lucía A, Hoyos J, Pérez M, Santalla A, Chicharro JL. Inverse relationship between VO2max and economy/efficiency in world-class cyclists. *Med Sci Sport Exerc*. 2002;34(12):2079-2084. doi:10.1249/01.MSS.0000039306.92778.DF.

Figure captions

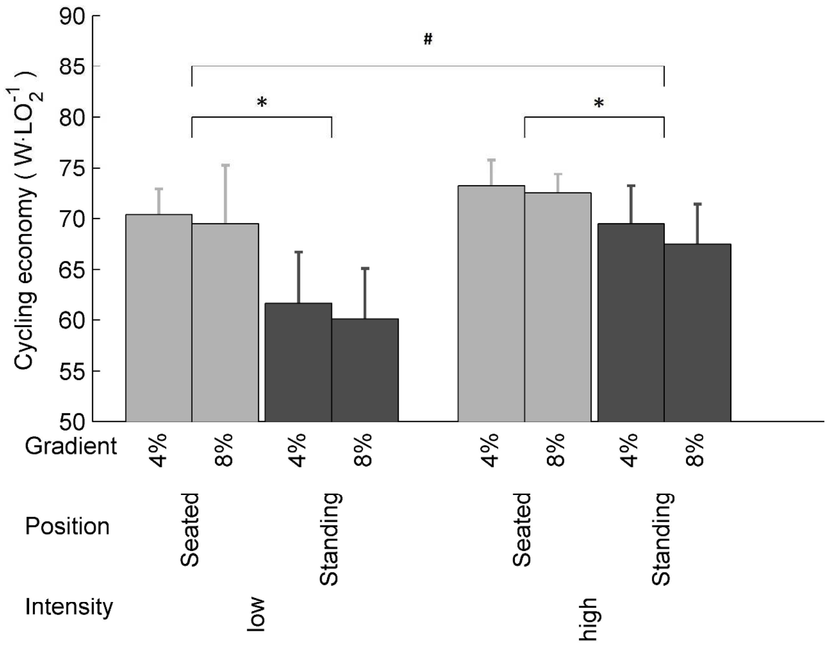
FIGURE 1. Cycling economy (Mean ± SD) at low and high intensity in the seated and standing position at 4% and 8% gradients. # indicates an interaction effect between intensity and position. * indicates a difference between the seated and the standing position.

FIGURE 2. Example of the muscle activation patterns during cycling in a standing position (solid lines) and a seated position (dotted lines) at low intensity (black) and high intensity (grey) for one participant. Top dead centre is represented by 0° and the down stroke is between 0°–180°. Tibialis anterior (TA), soleus (SOL), gastrocnemius medialis (GM), gastrocnemius lateralis (GL), vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), and gluteus maximus (Gmax).

Table 1. Mean ± standard deviation of oxygen consumption, oxygen consumption relative to the peak oxygen consumption attained during an incremental test, and respiratory exchange ratio during submaximal cycling conditions.

Intensity	50% MAP				70% MAP			
Position	Seated		Standing		Seated		Standing	
Gradient	4%	8%	4%	8%	4%	8%	4%	8%
Oxygen Consumption ($LO_2 \cdot min^{-1}$)	2.7 ± 0.2	2.7 ± 0.3	3.2 ± 0.3	3.2 ± 0.2	3.6 ± 0.2	3.7 ± 0.3	4.0 ± 0.3	3.9 ± 0.3
Relative Oxygen consumption ($LO_2 \cdot min^{-1} \cdot kg^{-1}$)	56.5 ± 4.4	56.4 ± 4.8	66.7 ± 8.3	67.4 ± 8	76.1 ± 6.9	77.1 ± 5.8	82.8 ± 7.2	82.5 ± 7.1
Respiratory Exchange Ratio	0.89 ± 0.06	0.87 ± 0.05	0.93 ± 0.05	0.93 ± 0.03	0.93 ± 0.03	0.94 ± 0.04	1.0 ± 0.05	1.01 ± 0.06

MAP: Maximal Aerobic Power



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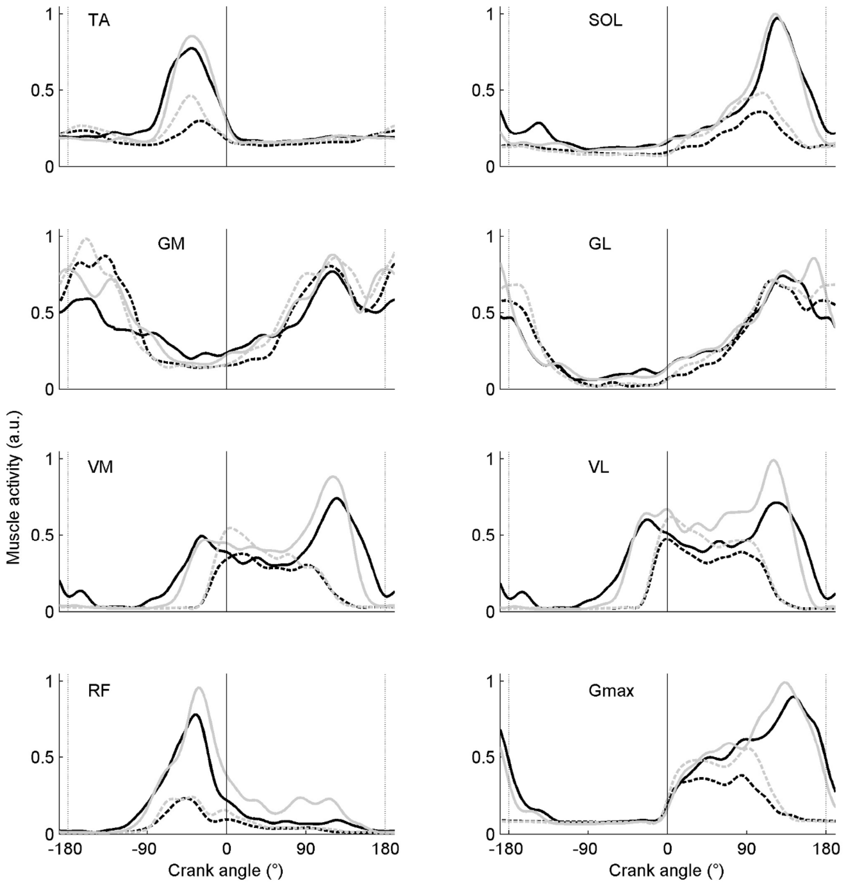

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