

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

Authors

M. Arkesteijn¹, J. Hopker², S. A. Jobson³, L. Passfield⁴

Affiliations

¹ Department of Sport and Exercise Sciences, Aberystwyth University, Ceredigion, Wales, United Kingdom

² School of Sport and Exercise Sciences, University of Kent, Medway, United Kingdom

³ Department of Sports Studies, University of Winchester, Winchester, United Kingdom

⁴ School of Sport and Exercise Sciences, University of Kent, Chatham Maritime, United Kingdom

Key words

- ergometry
- treadmill
- electromyography
- pedal forces
- muscle activity

Abstract

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Cycling can be performed on the road or indoors on stationary ergometers. The purpose of this study was to investigate differences in cycling efficiency, muscle activity and pedal forces during cycling on a stationary turbo trainer compared with a treadmill. 19 male cyclists cycled on a stationary turbo trainer and on a treadmill at 150, 200 and 250 W. Cycling efficiency was determined using the Douglas bags, muscle activity patterns were determined using surface electromyography and pedal forces were recorded with instrumented pedals. Treadmill cycling induced a larger muscular contribution from Gastrocnemius Lateralis, Biceps Femoris and Gluteus

Maximus of respectively 14%, 19% and 10% compared with turbo trainer cycling ($p < 0.05$). Conversely, Turbo trainer cycling induced larger muscular contribution from Vastus Lateralis, Rectus Femoris and Tibialis Anterior of respectively 7%, 17% and 14% compared with treadmill cycling ($p < 0.05$). The alterations in muscle activity resulted in a better distribution of power during the pedal revolution, as determined by an increased Dead Centre size ($p < 0.05$). Despite the alterations in muscle activity and pedalling technique, no difference in efficiency between treadmill ($18.8 \pm 0.7\%$) and turbo trainer ($18.5 \pm 0.6\%$) cycling was observed. These results suggest that cycling technique and type of ergometer can be altered without affecting cycling efficiency.

Introduction

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Training is a critical aspect of improving performance during competitive events [19]. In particular, training specificity is frequently advocated to optimize training adaptation [26]. Due to the large volume of training required to achieve an elite level [19], many cyclists continue to train during the offseason, i.e., the winter months. During this time, outdoor cycling may be limited by inclement road and weather conditions. Using an indoor turbo trainer provides an alternative training solution in these situations. A turbo trainer applies increased rolling resistance to replace the absent air resistance experienced during road cycling, while maintaining a stationary position. This allows cyclists to perform structured indoor training, to complement or replace a portion of their outdoor training. Comparisons between stationary and road cycling (using a freely moving bicycle) suggest that a turbo trainer changes cycling technique. Bertucci, Grappe and Grosslambert [3] compared cycling on a stationary bicycle (Monark ergom-

eter, Stockholm, Sweden) with road cycling. They [3] found that the stationary ergometer caused an altered distribution of power during the pedal revolution. In particular, this occurred in the region of the dead centres (i.e., where the cranks are positioned vertically), where the power produced by the cyclists is at its minimum. Furthermore, a comparison between an electromagnetic turbo trainer and treadmill cycling has shown that the overall muscle activity is higher when cycling on the turbo trainer [10]. This would suggest an increase in muscular work, which could consequently increase energy expenditure without changes in external work [20,21]. Furthermore, it has recently been shown that muscle activity patterns are related to mechanical efficiency [5], and that this is altered with changing cycling constraints (e.g. gradient, power output) [4]. This suggests that cycling efficiency (the ratio between external work and energy expenditure) can be decreased when cycling on a turbo trainer due to changes in muscle coordination. Leirdal and Ettema [22,23] have presented conflicting results in 2 studies that investigated the

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Bibliography

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Correspondence

Dr. James Hopker
School of Sport and Exercise
Sciences
University of Kent
Chatham Maritime
Medway
United Kingdom
me4 4ag
Tel.: +44/163/4888 814
Fax: +44/163/4888 809
j.hopker@kent.ac.uk

relation between pedalling technique and cycling efficiency. Pedalling technique was quantified by a novel parameter that described the distribution of power during the pedal revolution. The minimum power outputs during the pedal revolution (i.e., the dead centres) were expressed relative to the overall power output and described as 'dead centre size' (DC) [21]. Leirdal and Ettema [22] showed a positive correlation between efficiency and DC and thus pedalling technique. This study was performed on a normal road bicycle positioned on an electromagnetic roller (Taxc, I-magic, The Netherlands). However, when a stationary ergometer with a computer-controlled electromagnetic brake mechanism (Velotron, Racermate Inc., Washington) was employed in a later study [23], the relation between efficiency and DC was not confirmed. This suggests that efficiency is influenced by the kind of ergometer employed, an effect that might be explained by alterations in cycling technique [10]. Alternatively, it has been shown that torso stabilisation increases efficiency [24]. A stationary bicycle does not require active stabilisation of the bicycle and the different ergometers employed could provide an alternative explanation for conflicting findings of Leirdal and Ettema [22,23]. However, no previous research has directly compared the combined effect of different types of ergometers with measures of cycling technique and exercise efficiency.

The aim of the present study was to determine whether cycling efficiency and pedalling technique differ between stationary turbo trainer and treadmill cycling. Participants cycled on a commercially available turbo trainer and on a treadmill to replicate road cycling within a controlled environment. It was hypothesized that DC is increased during treadmill cycling compared with turbo trainer cycling, which would be reflected in muscle activity patterns, but not cycling efficiency. A secondary aim was to identify whether or not DC is related to cycling efficiency and whether or not DC is affected by work rate.

Methods

19 male cyclists (age: 36 ± 10 years, height: 181 ± 6 cm, mass: 77.4 ± 8.4 kg, $\dot{V}O_{2\max}$: 4.6 ± 0.5 L·min⁻¹, Maximal Aerobic Power: 353 ± 45 W) from local cycling clubs participated in the study. All participants trained for 6 h 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 [14].

Experimental design

Participants visited the laboratory on 2 separate occasions. On their first visit, participants were familiarised with the protocol before completing a ramp test to determine $\dot{V}O_{2\max}$ and maximal aerobic power (MAP). During familiarisation participants cycled on standard road bicycle (Specialized Secteur, Specialized, CA, USA) on a treadmill (Saturn, 200×250 cm, HP Cosmos, Nussdorf-Traunstein, Germany) at a power output below 140 W, using their preferred cadence until they were comfortable riding on the treadmill. Subsequently, they completed 6 min of cycling on a computer controlled electromagnetically braked turbo trainer (Tacx Fortius, Wassenaar, The Netherlands). The turbo trainer was positioned on a platform that was placed over the treadmill belt, to minimize movement of equipment due to the presence of cables attached to the participant. On their second visit, par-

ticipants cycled on the treadmill and turbo trainer, completing 6 conditions at 3 work rates (150, 200 and 250 W) on both the treadmill (TR) and turbo trainer (TT) at $90 \text{ rev} \cdot \text{min}^{-1}$. Work rates were administered in a random, counterbalanced design in order to minimise possible fatigue effects due to the length of testing [27]. Thus, TR and TT were performed consecutively at the same work rate. 10 participants started with TR and 9 participants started with TT. All participants switched after the first, third and fifth condition, in order to negate a potential effect of condition order. Cycling efficiency, muscle activity patterns and pedal forces were recorded during the second visit for subsequent analysis. A 10-min warm-up at a work rate of <150 W at $90 \text{ rev} \cdot \text{min}^{-1}$ preceded the experimental conditions. Prior to each test, participants were instructed to refrain from exercise and alcohol for 24 h and from caffeine intake for 4 h.

Cycling tests

An incremental ramp test was performed on a cycle ergometer (Schöberer Rad Messtechnik, Welldorf, Germany). Prior to the test, participants completed a 10-min warm-up at 100 W using a self-selected cadence. The test started at a power output of 100 W for 1 min to allow the participant to reach his preferred cadence. After the first minute, the power output was increased to 150 W. Work rate increased by $20 \text{ W} \cdot \text{min}^{-1}$ until volitional exhaustion. $\dot{V}O_{2\max}$ was calculated as the highest minute average of $\dot{V}O_2$ recorded during the test using a breath-by-breath gas analysis system (Metalyzer 3b, Cortex Biophysik, Germany). MAP was calculated as the highest averaged 1-min power output.

Gross efficiency was measured whilst participants cycled using a standard road bicycle on either the treadmill or the turbo trainer. 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). The participants' own bicycle geometry was measured and replicated using a bicycle scanner (Radlabor, Freiburg, Germany) and participants used their own cleats and pedals. Tyres were inflated to 700 kPa prior to each visit. For safety considerations, cycling speed was kept constant at $17.7 \text{ km} \cdot \text{h}^{-1}$ for both TR and TT and thus gearing was kept constant across conditions. For the TR conditions resistance was provided by a weighted pulley system [8], whereby a basket containing weights is suspended from the rear of the saddle. The weights were increased in order to induce 150, 200 and 250 W at the same cycling speed. Participants rested passively for 3 min between each condition.

Measurements

Each condition commenced with a 1-min period to allow the treadmill speed and cadence to reach required values. The participant cycled for a further 5-min period in the seated position. As power output during TT could decrease due to internal changes in the turbo trainer while cycling [28], power output was monitored continuously using a 30 s average power output (Edge 500, Garmin, USA), to maintain the target power output. Muscle activity patterns were recorded using surface electromyography (Bagnoli-8, Delsys, Boston, MA, USA). Pedal forces tangential and radial to the bicycle crank were captured using instrumented devices that were placed on the right and left cranks (Powerforce, Radlabor, Freiburg, Germany) [31]. Both electromyography and pedal forces recordings were captured at 1000 Hz and were synchronized using a square wave pulse generated when the bicycle crank passed the trigger located on the

bicycle. These signals were then digitized using Imago software (Radlabor, Germany). Power output was continuously recorded at 1 Hz via a rear wheel power measurement device (PowerTap Elite+, Saris, Madison, USA), which has been shown to be valid and reliable [2], allowing the same device to be used during both treadmill and turbo trainer cycling. Expired air was collected in Douglas bags during the final minute of each 5-min period [16]. Participants rested for 3 min 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) [16].

EMG recordings were made on the right lower leg for the Tibialis anterior (TA), Soleus (SOL), Gastrocnemius medialis (GM), Gastrocnemius lateralis (GL), Biceps Femoris (BF), Vastus lateralis (VL), Rectus femoris (RF) and Gluteus maximus (Gmax). Single differential EMG sensors were placed across the muscle belly following the recommendations of the Surface Electromyography for the Non-Invasive Assessment of Muscle function (SENIAM) [15].

Data analysis

Gross efficiency was calculated as the ratio of work done to energy expended during the final minute of each condition. Work done was calculated from the power output during the final minute of each trial. Energy expenditure was determined as the $\dot{V}O_2$ multiplied by the caloric equivalent for the measured RER [29]. The 250 W conditions elicited an RER > 1.00 for several participants and thus invalidated the calculation of efficiency in these cases due to the presence of an anaerobic energy contribution. To facilitate a greater sample size for data analysis at 250 W, efficiency was also calculated regardless of whether the RER > 1.00 (RER = 1.00 was assumed for caloric equivalent). The calculation at 250 W therefore ignored the anaerobic energy contribution; RER was compared across conditions to determine whether the anaerobic energy contribution was equal between TR and TT.

EMG data were analysed offline using custom scripts (MatLab, The Mathworks Inc., MA, USA). From the EMG recording, a 30-s time window was selected for analysis. The time window began at the start of the fifth minute to coincide with the expired gas collection. From the time window, data was rectified and a linear envelope was created using a 4th order, low pass filter with a cut off frequency of 15 Hz. Using the square wave pulse, EMG recordings were linearly interpolated to provide a value for every degree of crank movement, resulting in 360 samples per revolution. The crank trigger was positioned on the bicycle. The top dead centre (TDC) of the pedal revolution was defined as 0°, with the bottom dead centre (BDC) occurring at 180°. After resampling, these data were averaged for each degree of crank angle to create an ensemble average that was representative of the muscle activity for a complete revolution.

The onset and offset of muscle activity were defined as the crank angle where the EMG activity exceeded 20% of the difference between peak and baseline activity [9]. Negative crank angles were used to describe muscle onset that could start prior to TDC (i.e., during the upstroke), but that occurred mainly during the down stroke (e.g. VM, VL, Gmax and RF). As several muscles can display a bi-phasic activity pattern [7], the first onset and second (i.e., final) offset was selected for analysis if 2 bursts of muscle activity occurred. To determine muscle activity amplitude, each muscle's activity level was normalized to the highest value

observed across all conditions for each participant. This provided an indication of the relative amplitude across conditions and provided standardization between participants. The average activity was calculated for the duration of the burst using the normalized values. The product of the burst duration and average activity represented the integrated EMG of the burst, calculated to determine muscle activity level (iEMG) in arbitrary units. The total muscle activity across muscles (iEMG_{total}) was calculated by summation of the iEMG for the 8 muscles. Total force (F_r) was calculated from the effective force (F_e) and ineffective force (F_u) at each degree of crank angle (θ) for the right pedal:

$$F_r(\theta) = \sqrt{F_e(\theta)^2 + F_u(\theta)^2}$$

Subsequently, the index of force effectiveness (IFE) was calculated according to [19]:

$$IFE = \frac{\int_U^{360} F_e(\theta)}{\int_C^{360} F_r(\theta)} \times 100\%$$

DC was calculated by combining the F_e of the right and left side to provide the net power production during each revolution. For each revolution, this produces a sine wave pattern, with the 2 minima in power (around TDC and BDC) being determined and averaged to provide minimum power. The 'dead centre size' (DC) was calculated as the ratio between the minimum power and the average power, as described by Leirdal and Ettema [23]:

$$DC = \frac{(\text{minimum power TDC} + \text{minimum power BDC})/2}{\text{average power}} \times 100\%$$

The overall DC, calculated by averaging the DC across revolutions, described the evenness of power production during the revolution.

Statistical analysis

Changes in gross efficiency, muscle activity onset, offset and iEMG_{burst} and DC were analysed using 3 × 2 factorial ANOVAs with repeated measures for work rate and ergometry. Pairwise comparisons using Bonferroni corrections for multiple comparisons were used to identify significant differences between conditions. All statistical analyses were performed using SPSS 19.0 statistical analysis software (IBM, New York, USA). Results are expressed as mean ± standard deviation (SD). Statistical significance was set at $P < 0.05$. Pearson's correlations between efficiency and DC were compared at 150 and 200 W for TR and TT. Pearson's correlations between economy and DC were compared at 250 W for TR and TT.

Results

No difference between TR and TT was found for power output ($F_{1,16} = 1.523$; $p = 0.235$, TR: 201 ± 2 W, TT: 200 ± 2 W) and cadence ($F_{1,16} = 2.908$; $p = 0.107$, TR: 90 ± 1 rev · min⁻¹, TT: 91 ± 2 rev · min⁻¹).

Efficiency

2 of the 19 participants were unable to complete the 250 W conditions and so their data was excluded from the efficiency analysis. There was no difference in efficiency between TR and TT ($F_{1,8} = 2.202$; $p = 0.176$, TR: $18.8 \pm 0.7\%$, TT: $18.5 \pm 0.6\%$). RER was not different between TR and TT ($F_{1,16} = 2.964$; $p = 0.104$, TR: 0.92 ± 0.04 , TT: 0.93 ± 0.05). Subsequently, it was considered

appropriate to include all 17 participants. There was no difference in efficiency without the RER exclusion criteria ($F_{1,16}=0.760$; $p=0.396$, TR: $18.9\pm 0.7\%$, TT: $18.7\pm 0.6\%$).

Muscle activity timing

Onset

Turbo trainer cycling significantly affected the onset of SOL ($F_{1,15}=5.405$; $p=0.035$) and RF ($F_{1,16}=8.374$; $p=0.011$) compared with treadmill cycling (Table 1). SOL was recruited earlier during the down stroke on the TR, whereas RF was recruited earlier during the upstroke on the TT. GM showed a significant interaction between cycling condition and intensity ($F_{2,34}=10.289$; $p<0.001$). The onset of GM only differed between TR and TT at 150 W (TR: $71\pm 11^\circ$, TT: $75\pm 11^\circ$, $p=0.040$), but not at 200 W and 250 W ($p<0.05$). No other muscle activity onsets were affected by the ergometry mode ($p>0.05$).

Offset

Turbo trainer cycling significantly affected the offset of SOL ($F_{1,15}=6.86$; $p=0.019$), GL ($F_{1,17}=12.933$; $p=0.002$), BF ($F_{1,18}=15.048$; $p=0.001$) and RF ($F_{1,16}=10.299$; $p=0.005$) compared

with treadmill cycling (Table 1). The offset of SOL, GL and BF occurred later for TR. The offset of RF occurred later for TT.

Muscle activity level

iEMG

The iEMG for all muscles is shown in Fig. 1. TR showed significantly more activity in GL ($F_{1,17}=31.054$; $p<0.001$), BF ($F_{1,18}=45.025$; $p<0.001$) and Gmax ($F_{1,10}=10.152$; $p=0.010$) compared with TT. TT showed significantly more activity in TA ($F_{1,18}=7.395$; $p=0.014$), VL ($F_{1,18}=8.333$; $p=0.010$) and RF ($F_{1,16}=11.284$; $p=0.004$) compared with TR.

No differences between TT and TR for iEMG_{total} were observed ($F_{1,9}=0.108$; $p=0.75$).

DC size

Work rate did not influence DC size ($F_{2,36}=2.018$; $p=0.148$). DC was significantly higher in TR than TT ($F_{1,18}=41.723$; $p<0.001$, TR: $27.9\pm 5.0\%$, TT: $23.4\pm 5.8\%$) (Fig. 2). A higher minimum power output was observed for TR compared with TT ($F_{1,18}=51.047$; $p<0.001$, TR: 60.3 ± 11.6 W, TT: 51.6 ± 13.1 W).

IFE

TR decreased the IFE for the complete revolution ($F_{1,18}=24.698$; $p<0.001$) compared with TT (Table 2). This was accompanied by an increased IFE during the down stroke ($F_{1,18}=224.905$; $p<0.001$) and BDC ($F_{1,18}=4.89$; $p=0.040$) for TR compared with TT. In contrast, TT induced a larger IFE during the TDC compared with TR ($F_{1,18}=9.509$; $p=0.006$).

Correlation between efficiency and DC

There was no correlation between efficiency and DC at 150, 200 and 250 W for TR (150 W: $p=0.641$; $r=-0.122$, 200 W: $p=0.303$; $r=-0.265$, 250 W: $p=0.225$; $r=-0.310$) or TT (150 W: $p=0.582$; $r=-0.149$, 200 W: $p=0.632$; $r=-0.125$, 250 W: $p=0.998$; $r=-0.001$).

Table 1 Onset and offset of muscle activity patterns during treadmill and turbo trainer cycling. Values are mean \pm SD averaged across 150, 200 and 250 W. Tibialis anterior (TA), Soleus (SOL), Gastrocnemius medialis (GM), Gastrocnemius lateralis (GL), Biceps Femoris (BF), Vastus lateralis (VL), Rectus femoris (RF) and Gluteus maximus (Gmax). * denotes statistically significantly different from treadmill cycling.

	Onset ($^\circ$)		Offset ($^\circ$)	
	Treadmill	Turbo trainer	Treadmill	Turbo trainer
TA	196 \pm 61	186 \pm 56*	362 \pm 12	361 \pm 15
SOL	21 \pm 13	24 \pm 12	193 \pm 54	172 \pm 51*
GM	77 \pm 12	77 \pm 10	202 \pm 26	199 \pm 28
GL	72 \pm 13	73 \pm 11	240 \pm 24	231 \pm 31*
BF	42 \pm 31	43 \pm 34	183 \pm 23	171 \pm 27*
VL	-32 \pm 9	-32 \pm 10	98 \pm 7	96 \pm 8
RF	-96 \pm 20	-103 \pm 20*	52 \pm 24	58 \pm 24*
Gmax	7 \pm 14	6 \pm 13	110 \pm 10	108 \pm 10

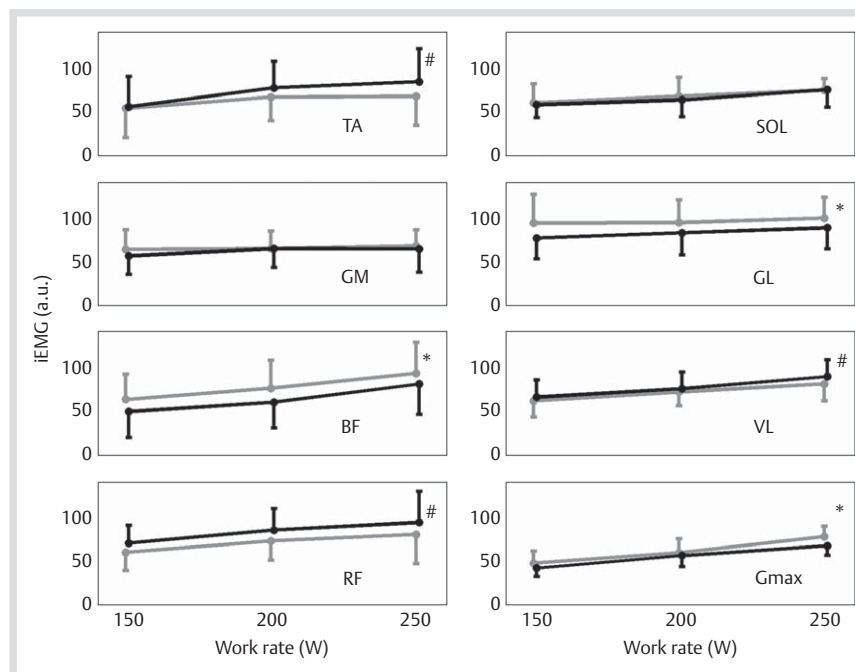


Fig. 1 Muscle activity level (iEMG) for treadmill cycling (grey circles) and turbo trainer cycling (black circles) for the Tibialis anterior (TA), Soleus (SOL), Gastrocnemius medialis (GM), Gastrocnemius lateralis (GL), Biceps Femoris (BF), Vastus lateralis (VL), Rectus femoris (RF) and Gluteus maximus (Gmax) at 150 W, 200 W and 250 W. * denotes significantly ($p<0.05$) higher iEMG for treadmill cycling compared with turbo trainer cycling. # denotes significantly ($p<0.05$) higher iEMG for turbo trainer cycling compared with treadmill cycling.

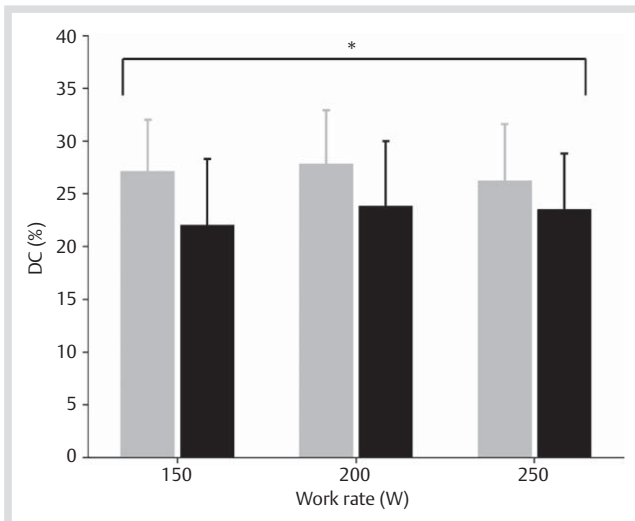


Fig. 2 Dead Centre size (DC) for treadmill cycling (grey) and turbo trainer cycling (black) at 150 W, 200 W and 250 W. * denotes significantly ($p < 0.05$) higher DC for treadmill cycling compared with turbo trainer cycling.

Table 2 Dead Centre size (DC) and index of force effectiveness (IFE) during treadmill and turbo trainer cycling. Values are mean \pm SD averaged across 150, 200 and 250 W. TDC = Top dead centre, BDC = Bottom dead centre.). * denotes statistically significantly different from treadmill cycling.

	Treadmill	Turbo trainer
DC (%)	27.0 \pm 4.6	23.1 \pm 5.3
IFE (%)		
overall (0°–360°)	41.5 \pm 4.5	43.0 \pm 4.4*
TDC (-45°–45°)	49.9 \pm 17.8	54.1 \pm 19*
down stroke (45°–135°)	89.4 \pm 1.6	87.1 \pm 1.5*
BDC (135°–225°)	31.4 \pm 3.6	30.3 \pm 4.5*
upstroke (225°–315°)	-71.7 \pm 5.2	-70.9 \pm 5.1

Discussion

The present study was the first to compare the efficiency between treadmill and turbo trainer cycling and showed no differences exist. As power output, and therefore the amount of work done were controlled between treadmill and turbo trainer conditions, energy expenditure were also similar. Therefore, it is unlikely that any scaling inaccuracies due to the nature of the ratio used in the efficiency calculation would have affected the results [1]. However, muscle activity patterns were different, where VL, RF and TA showed increases in muscle activity level of respectively 7%, 17% and 14% on the turbo trainer compared with treadmill cycling. In contrast, Gmax, BF and GL were more active during treadmill cycling by respectively 10%, 19% and 14%. The change in muscle activity was reflected by a 15% larger DC in treadmill vs. turbo trainer cycling.

The stabilisation of the bicycle during turbo trainer cycling induced a limitation in the movement of the bicycle compared with the free moving bicycle on the treadmill. The additional level of stabilisation could potentially explain the differences in muscle activity and pedalling technique. During treadmill cycling, a large DC generates less intra-revolution oscillation in cycling speed. Although speculative, it could be that cyclists selected a larger DC to maintain a more constant position on the treadmill. In addition, the requirement of balancing the bicycle

during treadmill cycling can affect the magnitude of the lateral sway of the bicycle, with lateral sway being constrained during turbo trainer cycling. Lateral sway is induced by applying force lateral to the bicycle contact points with the ground (i.e., the position of the pedals relative to the wheels). The fixation of the bicycle in the turbo trainer could have allowed the production of more force (and thus power output) during the down stroke, as this would not result in an increased lateral sway. However, subjective reports from the participants indicate that the cycling experience on the turbo trainer was 'unpleasant', with the turbo trainer feeling less 'smooth' compared with treadmill cycling. The mechanical properties of the turbo trainer could thus also have induced alterations in muscle activity and pedal forces (discussed in more detail below).

The increased DC during treadmill cycling was caused by an increased minimum power during the pedal revolution. This reflects greater power production during the dead centres and less power production during the down stroke and/or upstroke. This is in agreement with the increased IFE during the bottom dead centre for treadmill cycling compared with turbo trainer cycling. In addition, turbo trainer cycling induced a less effective down stroke. The exact mechanism behind the alteration in pedalling technique is not clear. Gear ratio was held constant throughout the study to prevent a potential effect of this variable on pedalling technique [13]. Consequently, the average resistance was comparable between turbo trainer and treadmill cycling due to the matched work rates in both conditions using the same gear ratio and cadence. Nevertheless, the turbo trainer generates a constant resistance, due to the properties of the magnetic motor brake. In contrast, the resistance during treadmill cycling can vary due to intra-revolution variations in cycling speed. Resistance increases when moving forwards during phases of high power production (i.e., down stroke) and decreases when moving backwards during phases of low power production (i.e., dead centre). Thus, it is anticipated that crank angular velocity profile would also differ, with larger variations occurring during turbo trainer cycling compared with treadmill cycling. The effect of varying resistance is not accounted for in the calculation of crank inertial load [13]. This provides a potential reason why varying crank inertial load on a stationary ergometer does not induce alterations in cycling technique as encountered during treadmill and turbo trainer cycling.

In contrast to the results of Duc, Bouteille, Bertucci, Pernin and Grappe [10], an increase in total muscle activity was not observed during turbo trainer cycling in the present study. This discrepancy might be explained by differences in the muscles studied and the type of turbo trainer employed. Nevertheless, the absence of an increased overall muscle activity does indicate that the work performed by the 8 main muscles involved in the cycling action [17] is not different between treadmill and turbo trainer cycling. This might explain why the present study did not find an increased metabolic cost and thus lower efficiency during turbo trainer cycling.

Although total muscle activity did not change, a clear difference in the activity level of various muscles was observed between treadmill and turbo trainer cycling. The lower DC during turbo trainer cycling was accompanied by a greater activation of the VL, RF and TA. VL and RF produce power predominantly during the down stroke, via knee extension [11,18]. The increased activity of RF and VL therefore provide a suitable explanation for the increased power output observed in this region of the pedal revolution. The function of TA is complex and it is unclear where

the increase in muscle activity occurred. The present study did not incorporate localised muscle activity patterns and thus TA could have increased during the upstroke or around the dead centres. An increased activity during the upstroke could have led to an increase in DC. However, TA often shows 2 separate bursts around the dead centres at low to moderate work rates [17]. The possible larger variations in crank angular velocity during turbo trainer cycling could have increased the ankle extension velocity. Proprioceptive feedback from the ankle could thus have elicited an increased activity of TA during the bottom dead centre to limit the speed of extension of the ankle [6,25].

The higher DC during treadmill cycling was accompanied by a higher activation of the Gmax, BF and GL. The main period of activity for BF and GL occurred around the latter stages of the down stroke and during the dead centre, consistent with previous literature [17,30]. This matched the increased power production around the dead centre for treadmill cycling. Gmax is mainly active during the down stroke, albeit slightly later than VM and VL [17], and thus increased activity of Gmax in treadmill cycling compared with turbo trainer cycling appears to be inconsistent with the increased DC. Gmax however spans the hip joint and so its increased activity during treadmill cycling may be related to stabilisation of the bicycle and upper body and not power production. Although the overall activity of SOL did not differ between treadmill and turbo trainer cycling, a prolonged period of activity, combined with a lower average activity was apparent, suggestive of a more equally distributed power production.

Recently, conflicting results regarding the relation between DC and efficiency have been reported [22,23]. The present study did not show a relation between DC size and efficiency for either treadmill or turbo trainer cycling. In addition, exercise intensity did not influence DC size. The original positive relation found by Leirdal and Ettema [22] is, therefore, not explained by a variation in intensity with respect to DC. An alternative explanation might be the positive relation between efficiency and intensity [12]. In the present study a significant positive correlation between DC and $\dot{V}O_{2\max}$ ($LO_2 \cdot \min^{-1}$) and MAP (W) (respectively $r=0.497$ and $r=0.463$, $p<0.05$) was found. The results of Leirdal and Ettema [22] might, therefore, be explained by cyclists with a higher MAP were cycling at higher power output, and thus were more efficient [12]. Rather than a correlation between efficiency and DC, Leirdal and Ettema [22] might have been describing a relation between MAP and DC. Future research is required to determine whether or not there is a relation between MAP and DC.

In conclusion, cycling on a turbo trainer altered technique compared with cycling on a treadmill. However, despite this change in technique, cycling efficiency did not differ between treadmill and turbo trainer cycling. The absence of a correlation between efficiency and pedalling technique confirmed that pedalling technique can be altered without affecting cycling efficiency.

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