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Exercise-induced trunk fatigue decreases double poling performance substantially in well-trained cross-country skiers

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Abstract

Purpose: To examine the effects of exercise-induced trunk fatigue on double poling performance, physiological responses and trunk strength in cross-country skiers. ***Methods:*** Sixteen well-trained male cross-country skiers (mean±SD; age = 19.1±2.6 y, body height = 177±6 cm, body mass = 68.8±7.3 kg, running VO_{2max} = 62.2±6.9 $mL \cdot min^{-1} \cdot kg^{-1}$, annual training = 567±96 h) completed two identical pre- and post- performance tests, separated by either a 25-min trunk fatiguing exercise sequence or rest period in a randomized, controlled cross-over design. Performance tests consisted of maximal trunk flexion and extension tests, followed by a 3-min double poling (DP) test on a ski ergometer. ***Results:*** Peak torque during isometric trunk flexion (-66%, p<.001) and extension (-7.4%, p=.03) decreased in the fatigue relative to the control condition. Mean external power output during DP decreased by 14% (p<.001) and could be attributed both to reduced work per cycle (-9%, p=.019) and a reduced cycle rate (-6%, p=.06). Coinciding physiological changes in peak oxygen uptake (-6%, p<.001) and peak ventilation (-7%, p<.001) could be observed. Pacing analysis revealed a larger performance difference between fatigue and control during the first two minutes of the test. ***Conclusions:*** In well-trained cross-country skiers, exercise-induced trunk fatigue led to a substantial decrease in DP performance, caused by both by decreased work per cycle and cycle rate and accompanied by reduced aerobic power. Hence, improved fatigue resistance of the trunk may therefore be of particularly importance for high-intensity DP in cross-country skiing.

Keywords: core, ergometer, ski, power output, technique

Introduction

Cross-country skiing is a demanding endurance sport involving various skiing techniques where skiers load the upper-body, trunk and lower-body to different extents on the varying racing terrain. In classical style cross-country skiing, double poling (DP) is a main sub-technique with particularly large contribution from the upper-body and trunk since all propulsion comes through the poles.[1,2] DP has gained high scientific interest over the last two decades. The technique is nowadays more frequently used in competitions since better trained upper-bodies of skiers, higher competitive speeds and harder snow surfaces make poling highly efficient. Many events, such as sprint and mass start races, are decided in the final sprint, where skiers almost exclusively employ the DP technique. In some male races, solely DP is used throughout the entire race.[3,4]

To exhibit effective propulsion in DP, the involved muscles are working in a sequential order.[2] Initially, the legs generate potential and rotational energy that can subsequently be transferred to power by efficient stabilization of the trunk and arms.[5] At the same time, the trunk and arms muscles produce propulsion directly by activating trunk and hip flexors, followed by the shoulder and elbow extensors.[2] In all parts of this chain, the trunk segment of the body plays a crucial role, both in the direct power production[1] and in the transfer of body energy to propulsion during DP.[5]

Research suggests that higher maximal strength[6] and lean and muscle mass located in the trunk[7] appears to be advantageous for producing high power in DP. In addition, technical aspects of the trunk movement are of importance in DP, e.g. hip flexion velocity is associated with DP performance[2] and locomotor and respiratory movements in the corresponding trunk musculature are also closely linked.[8] Altogether, reduced trunk function, due to limited physical or technical capacities or induced by fatigue, is therefore hypothesized to have a large influence on power production in DP.

While fatigue is a complex phenomenon, encompassing reduced physiological, biomechanical and psychological capacities,[9] its presence would rationally influence performance in a physically and technically complex endurance sports such as cross-country skiing.[10] A previous study looking at the effects of whole-body fatigue on DP performance demonstrated lower peak speed as well as reduced hip flexion and hip flexion velocity after several 3-min maximal exercise bouts in the classical technique.[11] However, while intense whole-body exercise may fatigue many inter-related aspects that potentially limit performance, the isolated effects of each component of the muscle chains of relevance for DP is not well understood.

Therefore, this study aimed to investigate the acute effects of exercise-induced trunk fatigue on DP performance in competitive cross-country skiers. In order to explain the possible mechanisms coupled with possible changes in DP performance, we examined the corresponding changes in trunk strength as well as technical and physiological responses during DP.

Methods

Subjects

Sixteen male cross-country skiers (mean±SD; age=19.1±2.6 y, body height=177±6.0 cm, body mass=68.8±7.3 kg, body fat=8.4±1.8%, running VO_{2max}=62.2±6.9 $mL \cdot min^{-1} \cdot kg^{-1}$, annual training=567±96 h) volunteered to participate in this study. Athletes were required to compete at the national level with a minimum of five years of ski specific training. Skiers agreed to refrain from high-intensity training within 48 h prior to testing and not to consume caffeine on test days. The regional ethics committee (Ethikkommission Nordwest- und Zentralschweiz) approved the study (approval number 2015/201).

Design

This randomized, controlled cross-over study was performed in spring, shortly after the competitive cross-country ski season. On the first day, participants were familiarized with equipment and test protocols and performed a running VO_{2max}-test. On the second and third day, skiers performed either an experimental fatigue (FAT) or control (CON) protocol in randomized order. Pre- and post-intervention assessments on both days included an isometric and isokinetic trunk strength and a 3-min DP test (3MT), performed identically before and after a trunk fatiguing exercise sequence in FAT, or a rest period in CON. Athletes completed all three measurements at approximately the same time of the day, separated by at least 48 h between measurements within 14 days.

Methodology

Familiarization day. On the first day, the anthropometric assessment was followed by a 10-min warm-up on a cycle ergometer at Borg RPE 3 (Borg 1-10). One repetition maximum (1RM) was determined for both trunk flexion and extension on a Cybex Abdominal and Cybex Back Extension strength machine (Cybex International, Inc., Medway, MA, USA) according to NSCA guidelines.[12] 1RM measures determined the load for the fatigue protocol. Athletes then practiced three additional core exercises for the trunk fatigue sequence. Participants then performed the trunk strength tests described below. After another 30 min break, VO_{2max} was determined using a running-protocol on a treadmill according to previously published procedures for cross-country skiers.[13]

Trunk strength. Isometric and isokinetic maximal trunk strength was assessed in an identical manner on the first day and during both pre- and post-tests on the second and third day. Ventral and dorsal trunk strength was determined in a seated position (IsoMed 2000 backmodule dynamometer, D&R Ferstl GmbH, Hemau, Germany). Athletes performed two voluntary isometric contractions in both hip flexion and extension, separated by 30 seconds. Contractions were performed at 85° hip angle and lasted five seconds each. After another 1-min break, maximal isokinetic trunk flexion and extension were measured during five consecutive repetitions at 60°/s in a range between -30° and +30°, with the neutral zero position being at 85° hip angle. Participants were given no visual feedback but a test instructor provided strong verbal encouragement. Data was recorded at a sampling rate of 200 Hz and exported to an Excel spreadsheet (Microsoft, Redmond, WA, USA). Movement artifacts were processed using a second-order zero-lag low-pass Butterworth filter with a cut-off frequency of 1.5 Hz using a customized Matlab script (MathWorks, Natick, MA, USA). For the two maximal isometric contractions, the highest peak torque was retained. For the five isokinetic contractions, the highest peak torque during the entire range of motion for both flexion and extension was used for further analysis. Reliability of these measurements in our laboratory are excellent (coefficient of variation (CV) $\leq 9.4\%$, intra-class-correlation coefficient (ICC) ≥ 0.91 for all measures assessed in this study).[14]

3-min test (3MT). Following a 5-min break after the trunk strength test, skiers performed a 3-min self-paced test on a modified ski ergometer (SkiErg, Concept2, Morrisville, VT, USA) with cross-country ski straps (Leki, Kirchheim, Germany) attached to the pulling cords. For standardization, the drag factor setting was adjusted according to the skier's body mass as described by Faiss and colleagues.[15] Based on pilot tests, the drag factor was set at 100% of individual's body mass for all 3MTs. Skiers were familiar with 3-min efforts, encountered regularly in sprint races and interval training. Power production and cycle rate data were continuously measured stroke by stroke by the ergometer's internal software, extracted with a Microsoft ActiveX® software component and recorded in an Excel spreadsheet (Microsoft

Corporation, Redmond, WA, USA) as previously reported.[15] The ergometer's internal power measurement was validated[5] and a test-retest reliability analysis for 3MT power output with the current data demonstrated a CV=3.9% and an ICC=0.96. The average power production and cycle rate over 3 min were calculated and 20-s segments were used for pacing analysis. The performance monitor was purposely displayed during tests and skiers were instructed to attain maximal average power output, with a test instructor providing verbal encouragement throughout the test.

Respiratory air was continuously sampled and analyzed breath-by-breath (Metalyzer 3B, Cortex Biophysik GmbH, Leipzig, Germany). Respiratory test equipment was calibrated before each test in accordance with manufacturer's instructions. Peak oxygen uptake (VO_{2peak}) and peak ventilation (VE_{peak}) were determined as the three highest consecutive 10-s samples, measured during the last minute. The respiratory locomotion relationship was determined by dividing the synchronized measures of cycle rate and breathing frequency. Heart rate was measured continuously with Polar Wearlink (Polar Electro Oy, Kempele, Finland) and synchronized with the gas analysis equipment. Peak heart rate (HR_{peak}) was determined as the highest 5-s recording. Capillary blood samples (20 µL) were obtained from the ear lobe before, 1, 3 and 5 min after the test and blood lactate concentration in hemolyzed samples were analyzed using a stationary Super GL2 lactate analyzer (Hitado GmbH, Möhnesee, Germany).

Fatigue protocol. In the FAT, participants completed an exercise sequence targeting both ventral and dorsal trunk musculature to induce trunk fatigue. Participants completed three sets of five exercises within a timeframe of 23.1 ± 0.8 min. This duration is similar to workouts previously used to induce trunk fatigue.[16,17] Core exercises consisted of a medicine ball Russian Twist, Cybex Abdominal, Cybex Back Extension, Bug Crunch, and inclined Back Extension. In order to achieve an equal level of fatigue and time under load among participants, exercise load was based on either percentage 1RM or maximal repetitions during 1 min. Participants completed the exercise sequence without extra rest period besides changing to the next exercise and were accompanied by a test instructor. A video appendix of the exercise standardization is available at: (https://www.youtube.com/watch?v=e0sDkWGUMxM&feature=youtu.be).

Statistical Analysis

All data were checked for normality using the Shapiro-Wilk test and are presented as mean and standard deviation (mean ± SD). A two-way repeated-measures ANOVA (condition x time) was performed to detect overall effects of treatment (FAT vs. CON) and time (pre vs. post), as well as to identify possible interaction. The relationships between 3MT performance and trunk strength were calculated using Pearson product-moment correlation with pooled CON and FAT pre-test variables. ANOVA and correlation statistics were analyzed in SPSS v.22.0 (IBM, Chicago, IL, USA).

Absolute, percentage and standardized mean differences in change scores between FAT and CON from pre- to post-test were calculated together with 90% confidence intervals for each variable and pacing segments, using the pre-test as a covariate, according to the magnitude-based inference approach.[18] The effect sizes (ES) are classified as trivial (<0.2), small (>0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0), and very large (>2.0) according to Batterham and Hopkins.[18] In addition, we determined the likelihood of the true effect being harmful, trivial, or beneficial by means of a published Excel spreadsheet for pre-post crossover designs.[19] A practically relevant change was assumed when the difference score was at least 0.2 of the between-subject standard deviation.[20]

Results

Differences in mean change between FAT and CON from pre- to post-test showed very large, most likely decreases in isometric (66%) and isokinetic (37%) peak torque during trunk flexion (both p<.001), while only small and moderate decreases were found for extension (7 and 17%, respectively; p=.03 and p=0.002) (Table 1 and 2). 3MT power output was positively correlated with isometric and isokinetic trunk flexion and extension (r=0.59-0.69; p<.001).

For power output, a moderate, most likely decrease (14%) was observed (p<.001), explained primarily by a reduction in work per cycle (9%; p=.02), as well as a reduced cycle rate (6%; p=.06) (Table 1 and 2). In addition, coinciding decreases in peak oxygen uptake (6%) and peak ventilation (7%) were found in FAT (both p<.001), but not in CON.

Table 1 about here
Table 2 about here

The difference in performance change from pre- to post-test between FAT and CON gradually decreased with the duration of the test (see Figure 1). Differences in pre-post change regarding cycle rate remained constant across all segments (range= -7.1 to -9.7%). At the same time, differences in pre-post change scores for work per cycle decreased from 20 to 1.6%. Mean differences in pre-post change scores between FAT and CON are presented for 20-s segments in Table 3.

Figure 1 about here
Table 3 about here

Discussion

In well-trained cross-country skiers, exercise-induced fatigue of the trunk led to a large reduction in isometric and isokinetic trunk strength during flexion (66 and 37%) and to a smaller extent also during extension (7 and 17%). During 3-min maximal DP, a 14% performance decrease arising from a 9% reduction in work per cycle and a 6% reduction in cycle rate was accompanied by a decrease in peak oxygen uptake (6%) and peak ventilation (7%). In addition, skiers altered their pacing strategy when fatigued, and used a more conservative pacing strategy indicated by a performance reduction particularly during the first two minutes of the 3-min DP test.

Trunk strength. We observed a large reduction in isometric and isokinetic trunk strength during flexion (66 and 37%) and to a smaller extent during extension (7 and 17%) after the exercise-induced fatigue sequence. DP relevant muscle groups, especially those contributing to trunk flexion, were clearly fatigued. This is in accordance with other studies, where the abdominal musculature demonstrated a larger fatigue susceptibility compared with the muscle groups of the back extensors.[21,22] In our study, this phenomenon was most prominent during isometric measurements, where the relative decrease in trunk strength during flexion was six fold that of extension. Although isokinetic compared to isometric strength can be considered more functional, DP performance decreased substantially despite a smaller decline in isokinetic compared to isometric trunk strength in the current testing. The high fatigue susceptibility of the musculature responsible for trunk and hip flexion is likely to have implications for the DP movement, where the trunk flexors contribute to a great extent in the power generation,[1] being the first link of the muscle activation chain during the distinct muscle sequencing.[2]

Performance. Exercise-induced trunk muscle fatigue led to a substantial performance decrease, explained by both reduced work per cycle (9%) and cycle rate (6%), while pre- and post-test performance in CON was similar. Further, we found large correlations between all trunk strength variables and DP performance. These findings highlight the importance of maintaining strength of the trunk muscles for performance during short-duration, high-intensity DP. Few studies investigated the influence of trunk muscle fatigue on exercise performance. In running, a 39% performance decline was demonstrated in a time-to-exhaustion test following a 24-min core muscle workout comparable to the current study.[16] Another study reported changed kinematics during running resulting from trunk fatigue.[23] Neuromuscular performance such as jumping[24] and balance tasks[25] were also shown to be negatively affected by exercise-induced trunk fatigue. However, this study is the first to demonstrate the negative effect of trunk fatigue in an upper-body dominant exercise mode.

Since trunk muscles are highly involved in power production during DP,[2] exercise-induced trunk fatigue potentially led to an increase in neuromuscular activation of active trunk muscles during high-intensity DP. This is especially relevant in DP, due to the repetitive flexion and extension of the upper body during the poling and recovery phase, with high contribution of the trunk muscles especially during high-intensity.[2,26] The reduced force potential of the ventral trunk muscles, demonstrated by the large decreases in peak torque during hip flexion, might have led to the alternative poling strategy used in FAT, with reduced cycle rate and slower repositioning after each stroke.

As the DP movement is characterized by a sequential muscle activation chain, initiated by the hip flexors,[2] fatigued trunk muscles possibly interfered with the effective beginning of this muscle activation chain. As athletic performance during complex movement-tasks require a well-coordinated activation of body segments,[27,28] DP performance might be simultaneously affected by impaired timing and reduced muscle activation. Furthermore, the reduction in proximal stability caused by trunk muscle fatigue might have hindered the proximal to distal force generation pathway,[27] which is expected to be especially important in DP, involving the transfer of force through poles.

The 20-25-min break between subsequent 3-min exercise-bouts employed for CON in the current study is comparable with sprint cross-country skiing competitions. There was unchanged pre- and post-test performance in CON, which supports studies showing no or only small performance changes within and between successive cross-country ski sprint heats of similar length.[29-32] Overall, this strengthens the relevance of the negative performance changes following the FAT condition, which were significant when compared to CON. Whether fatigue-resistance training for trunk flexors and/or respiratory muscles may affect repetitive DP sprint performance is currently unclear and should be subject of future investigations.

Pacing analysis revealed that the performance difference appeared most prominently during the first two minutes of the test, with a relative difference in pre-post change of 40-55 Watts during the first two minutes and a 20-30 Watts difference during the last minute between FAT and CON. The positive pacing strategy found here, with a fast start and a successive decline in velocity, is typical for sprint cross-country skiing events of 2-4 min duration.[29,33] However, trunk muscle fatigue appeared to interfere with the positive pacing strategy, leading to a lower, but more steady power output in the post-test at the FAT condition compared to the pre-test in FAT and both tests for CON.

Cardiorespiratory responses. Trunk fatigue affected physiological processes during DP. In FAT, skiers demonstrated lower VO_{2peak} (-6%), VE_{peak} (-7%) and RER. At the same time, HR_{peak}, peak blood lactate concentration and RPE remained relatively unaffected, indicating that skiers pushed themselves with the same effort to exhaustion in both conditions. Since VO_{2peak} and VE_{peak} tended to increase in CON, it is likely that several processes along the way of respiration, oxygen transport and oxygen extraction were negatively affected by the fatigued trunk musculature. As power output is lower in the post-test in FAT, a smaller fraction of maximal aerobic power is utilized and required. However, fatigued trunk muscles may also have a negative influence on respiratory muscle function, technique and body posture, all contributing to worse conditions for breathing during exercise and thereby reducing VO_{2peak} and VE_{peak}. In simulated sprint skiing using roller skis on a treadmill[29] or on a tartan track,[31] VO_{2peak} did not differ between successive sprint heats with either 45 min,[29] or 20 min breaks[31] in between trials, whereas Stöggl et al.[10] reported lower peak oxygen uptake in subsequent sprint heats when separated by 20-25 min. Unchanged physiological responses in consecutive maximal sprint heats have been found in roller ski skating.[31]

Although it is unclear whether trunk fatigue negatively affected exercise efficiency in the 3MT, high-intensity exercise led to impaired efficiency during subsequent submaximal exercise in cross-country skiers.[34] Due to the technical complex movements utilized in skiing, effects of trunk fatigue on efficiency during submaximal double poling should be examined in future studies. Since the fatiguing exercise sequence likely affected the respiratory muscles, respiratory muscle fatigue might be one of the main explanations for the decrease in VO_{2peak} and VE_{peak}, as both inspiratory[35] and expiratory[36,37] muscle fatigue have shown to impair exercise performance. When comparing consecutive classical ski sprint heats, respiratory muscle fatigue has been suggested as an explanation for decreased VO_{2peak}[10] and was observed after high-intensity exercise in runners.[16]

The propulsion phase in DP coincides with expiration, similar to rowing[38,39] Since expiratory abdominal muscles are thought to be more prone to fatigue due to their lower oxidative capacity[36] and contribute substantially to the power production during DP,[1] performance is expected to be particularly compromised by fatigued trunk muscles. With a 66% decrease in peak torque performance between pre- and post-test, a significant level of fatigue was achieved in trunk flexors through our protocol, potentially leading to a negative impact on expiratory flow by a loss in contractile function as previously suggested.[40] Fatigued abdominal muscles may further be responsible for an increased sensation of dyspnea and therefore impaired exercise performance as suggested by Taylor and co-workers.[40] In order to evaluate the occurrence of respiratory muscle fatigue during DP, measures of maximal voluntary inspiratory and expiratory mouth pressures should be included in future investigations. The relationship between locomotion and respiration did not seem to be affected by trunk fatigue in the current study. The characteristic stroke-to-breathing frequency ratio of 1:1 during high-intensity DP was unaltered and in agreement with previous studies.[8,41] In our experiment, trunk muscle fatigue appeared to limit both performance and respiratory capacity, underlining the important role of trunk muscles during DP, where these muscles contribute to both propulsion and respiration.

Limitations. Standardizing the application of fatigue across participants was challenging, as several different methods exist to induce fatigue and fatigue may vary inter-individually. Based on pilot testing, a mix of both repetition- and time-based exercises were used to minimize the variation in workload between subjects. The exhaustive fatiguing sequence potentially affected other muscle groups and could have led to a certain level of non-local muscle fatigue and cross-over fatigue.[42,43] Unintentional, collateral fatigue in the two-jointed hip flexors and in the elbow flexors and extensors might have negatively affected successive DP performance. A reason for the more conservative pacing approach in the post 3MT in FAT is certainly the collateral fatigue in addition to the fatigued trunk muscles that originated from the exercise sequence.

Conclusions. Exercise-induced trunk fatigue in well-trained cross-country skiers led to substantial performance decreases during DP, caused by both decreased work per cycle and cycle rate and accompanied by reduced aerobic power. Since the trunk muscles are simultaneously involved in both respiration and high force-generating propulsion during DP, improved fatigue resistance of the trunk may be of particular importance in this technique.

Further investigations should examine how trunk fatigue occur and subsequently influence performance during cross-country skiing competitions, in particular during long distance events where DP is of high importance.

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Table 1. Peak Torque during Isometric and Isokinetic Trunk Flexion and Extension, as well as Performance Characteristics and Physiological Responses during the 3-Min Self-Paced Double Poling in Pre- and Post-tests in the Fatigue (FAT) and Control (CON) Condition, Mean ± Standard Deviation

	FAT		**CON**		**ANOVA**
	Pre	**Post**	**Pre**	**Post**	**Time x Condition**
Isometric peak torque flexion (Nm)	135 ± 36	49 ± 23	132 ± 31	134 ± 30	< .001
Isometric peak torque extension (Nm)	280 ± 80	250 ± 76	262 ± 53	255 ± 66	.03
Isokinetic 60°/s peak torque flexion (Nm)	129 ± 27	78 ± 20	129 ± 24	125 ± 24	< .001
Isokinetic 60°/s peak torque extension (Nm)	301 ± 86	240 ± 71	289 ± 66	283 ± 83	.002
Mean external power output (W)	248 ± 45	216 ± 40	242 ± 43	247 ± 43	< .001
Cycle rate (Hz)	1.10 ± 0.13	0.99 ± 0.13	1.14 ± 0.13	1.08 ± 0.12	.06
Work per cycle (J)	226 ± 50	217 ± 41	216 ± 50	231 ± 49	.02
HR$_{peak}$ (bpm)	183 ± 4.1	181 ± 5	180 ± 6	183 ± 6	< .001
VO$_{2peak}$ (L·min^{-1})	3.67 ± 0.50	3.54 ± 0.49	3.61 ± 0.59	3.73 ± 0.62	< .001
VO$_{2peak}$ (mL·kg^{-1}·min^{-1})	54 ± 5.8	52 ± 5.8	53 ± 6.8	54 ± 6.1	< .001
VE$_{peak}$ (L·min^{-1})	150 ± 19	138 ± 17	147 ± 20	148 ± 22	< .001
RER (VCO$_2$/VO$_2$)	1.29 ± 0.09	1.11 ± 0.07	1.32 ± 0.11	1.26 ± 0.11	< .001
Breathing frequency (b·min^{-1})	64 ± 6.5	59 ± 9	65 ± 8	63 ± 7	.11
Cycle rate/breathing frequency	1.00 ± 0.06	0.99 ± 0.10	1.02 ± 0.07	1.00 ± 0.06	.43
BLa pre-test (mmol)	2.2 ± 0.8	9.4 ± 2.2	2.0 ± 0.6	4.3 ± 1.5	< .001
Peak BLa (mmol·L^{-1})	11.6 ± 1.7	11.5 ± 1.4	11.8 ± 1.6	11.5 ± 1.6	.64
Δ BLa (mmol·L^{-1})	9.4 ± 1.5	2.1 ± 1.2	9.8 ± 1.5	7.3 ± 1.2	< .001
RPE pre-test (0-10)	1.2 ± 1.2	5.1 ± 2.0	0.9 ± 1.0	1.7 ± 1.1	< .001
RPE post-test (0-10)	8.4 ± 1.2	8.5 ± 1.2	7.8 ± 1.5	8.4 ± 1.4	.15

Peak heart rate (HR$_{peak}$), peak oxygen consumption (VO$_{2peak}$), peak ventilation (VE$_{peak}$), respiratory exchange ratio (RER), rating of perceived exertion (RPE), blood lactate (BLa), delta blood lactate (Δ BLa) derived from subtracting pre-test BLa from peak post-test BLa concentration.

Table 2. Differences in Mean Changes from Pre- to Post Fatigue in FAT and CON for Trunk Strength and 3-Min Double Poling, Mean [90% Confidence Interval]

	Differences in Mean Change			**Magnitude Based Inferences**		
	Absolute	**Percentage**	**Standardized**	**Harmful**	**Trivial**	**Beneficial**
Isometric peak torque flexion (Nm)	-87 [-96;-78]	-66 [-72;-60]	-4.0 [-4.7;-3.4]	100 most likely	0 most unlikely	0 most unlikely
Isometric peak torque extension (Nm)	-24 [-42;-5.8]	-7.4 [-14;-0.46]	-0.27 [-0.53;-002]	83 likely	17 unlikely	0 most unlikely
Isokinetic 60°/s peak torque flexion (Nm)	-46 [-53;-39]	-37 [-42;33]	-2.0 [-2.4;-1.7]	100 most likely	0 most unlikely	0 most unlikely
Isokinetic 60°/s peak torque extension (Nm)	-55 [-77;-33]	-17 [-23;-11]	-0.64 [-0.87;-0.40]	100 most likely	0 most unlikely	0 most unlikely
Mean external power output (W)	-36 [-45;-27]	-14 [-18;-11]	-0.81 [-1.0;-0.59]	100 most likely	0 most unlikely	0 most unlikely
Cycle rate (Hz)	-0.06 [-0.11;-0.01]	-5.9 [10;-1.5]	-0.50 [-0.87;-0.13]	88 likely	11 unlikely	0 most unlikely
Work per cycle (J)	-22 [-38;-6.7]	-9.3 [-15;-3.3]	-0.42 [-0.70;-0.15]	91 likely	9 unlikely	0 most unlikely
HR$_{peak}$ (bpm)	-4.0 [-5.9;-2.0]	-2.2 [-3.2;-1.1]	-0.71 [-1.1;-0.36]	99 very likely	1 very unlikely	0 most unlikely
VO$_{2peak}$ (L·min^{-1})	-0.23 [-0.32;-0.14]	-6.1 [-8.6;-3.5]	-0.40 [-0.57;-0.23]	98 very likely	2 very unlikely	0 most unlikely
VE$_{peak}$ (L·min^{-1})	-11 [-16;-6.7]	-7.3 [-11;-3.9]	-0.50 [-0.74;-0.26]	99 very likely	1 very unlikely	0 most unlikely
RER (VCO$_2$/VO$_2$)	-0.13 [-0.16;-0.10]	-11 [-13;-8.1]	-1.4 [-1.7;-1.1]	100 most likely	0 most unlikely	0 most unlikely
Breathing frequency (b·min^{-1})	-2.7 [-5.6;0.10]	-5.0 [-9.4;-0.28]	-0.45 [-0.88;-0.02]	78 likely	21 unlikely	1 very unlikely
Cycle rate/breathing freq.	-0.05 [-0.17;0.07]	1.0 [-2.4;4.5]	0.16 [-0.38;0.69]	71 possibly	11 unlikely	18 unlikely
Pre-test BLa (mmol·L^{-1})	4.8 [4.2;5.5]	120 [94;148]	2.2 [1.8;2.5]	0 most unlikely	0 most unlikely	100 most likely
Peak BLa (mmol·L^{-1})	0.12 [-0.52;0.77]	1.4 [-4.2;7.3]	0.09 [-0.29;0.48]	12 unlikely	59 possibly	29 possibly
Δ BLa (mmol·L^{-1})	-7.0 [-7.9;-6.2]	-76 [-82;-66]	-8.9 [-11;-6.9]	100 most likely	0 most unlikely	0 most unlikely
RPE (0-10)	-0.25 [-0.85;0.36]	-2.3 [-10;6.1]	-0.12 [-0.53;0.30]	45 possibly	48 possibly	7 unlikely

Negative values indicating lower values in the fatigue condition compared to the control condition. The probabilities of an effect being harmful/trivial/beneficial are expressed as percentage values. Peak heart rate (HR$_{peak}$), peak oxygen consumption (VO$_{2peak}$), peak ventilation (VE$_{peak}$), respiratory exchange ratio (RER), rating of perceived exertion (RPE), blood lactate (BLa). Delta blood lactate (Δ BLa) derived from subtracting pre-test BLa from peak post-test BLa concentration.

Table 3. Pacing Analysis with Pre-Post Change between FAT and CON for 20-s Segments during the 3-Min Double Poling Test, Mean Difference [90% Confidence Interval]

	Change	**20s**	**40s**	**60s**	**80s**	**100s**	**120s**	**140s**	**160s**	**180s**
Power output (W)	ABS	-56 [-84;-28]	-47 [-76;-17]	-43 [-70;-17]	-42 [-66;-17]	-39 [-61;-16]	-33 [-54;-12]	-29 [-50;-8]	-26 [-48;-4]	-20 [-46;6]
	%	-26 [-35;-15]	-18 [-27;-8]	-17 [-25;7]	-17 [-25;-7]	-16 [-24;-7]	-14 [-22;-5]	-13 [-21;-4]	-11 [-20;-2]	-8 [-18;2]
	SMD	-1.32 [-1.93;-0.72]	-1.01 [-1.62;-0.41]	-1.03 [-1.64;-0.43]	-1.05 [-1.66;-0.45]	-1.06 [-1.67;-0.46]	-0.95 [-1.55;-0.34]	-0.86 [-1.46;-0.25]	-0.73 [-1.34;-0.13]	-0.49 [-1.09;0.12]
Cycle rate (Hz)	ABS	-0.09 [-0.17;0.00]	-0.07 [-0.15;0.01]	-0.09 [-0.17;-0.02]	-0.10 [-0.17;-0.02]	-0.10 [-0.17;-0.02]	-0.10 [-0.18;-0.02]	-0.09 [-0.17;0.00]	-0.09 [-0.19;0.01]	-0.10 [-0.21;0.01]
	%	-8.1 [-15;-0.6]	-7.1 [-14;0.5]	-9.3 [-16;-2.2]	-9.7 [-16;-2.6]	-9.5 [-16;-2.4]	-9.5 [-16;-2.2]	-8.3 [-16;-0.4]	-8.3 [-17;1.1]	-8.7 [-18;1.8]
	SMD	-0.64 [-1.24;-0.04]	-0.56 [-1.16;0.03]	-0.77 [-1.3;-0.17]	-0.81 [-1.41;-0.21]	-0.79 [-1.39;-0.19]	-0.77 [-1.37;-0.17]	-0.63 [-1.22;-0.03]	-0.53 [-1.12;0.07]	-0.50 [-1.09;0.10]
Work per cycle (J)	ABS	-42 [-67;-17]	-32 [-60;-2.7]	-21 [-49;7.6]	-18 [-46;11]	-16 [-44;11]	-12 [-37;13]	-12 [-39;16]	-10 [-39;19]	-1.1 [-35;33]
	%	-20.0 [-29;-9.3]	-12.0 [-22;-1.0]	-8.5 [-19;2.9]	-7.8 [-18;3.8]	-7.4 [-18;4.2]	-5.7 [-16;5.3]	-5.6 [-16;6.4]	-4.5 [-16;8.4]	-1.6 [-15;14.0]
	SMD	-1.07 [-1.68;-0.47]	-0.66 [-1.26;-0.05]	-0.46 [-1.06;0.15]	-0.41 [-1.02;0.19]	-0.39 [-1.00;0.21]	-0.32 [-0.93;0.28]	-0.29 [-0.90;0.31]	-0.22 [-0.83;0.38]	-0.06 [-0.67;0.54]

Absolute change (ABS), percentage change (%) and standardized mean difference (SMD).

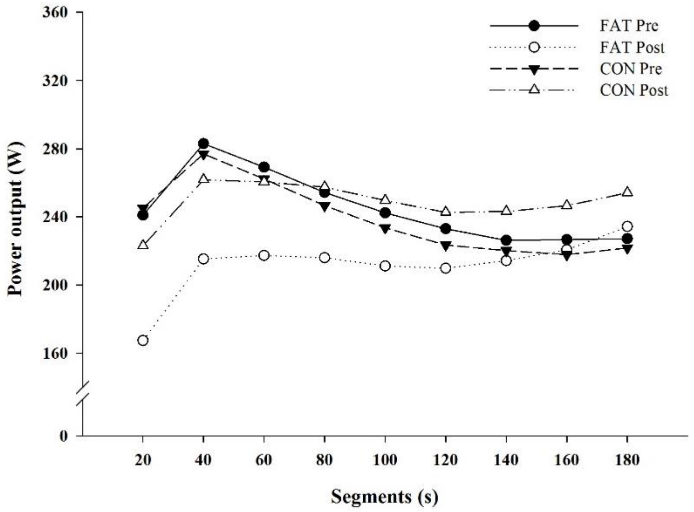
FAT Pre
FAT Post
CON Pre
CON Post
Power output (W)
360
320
280
240
200
160
0
20
40
60
80
100
120
140
160
180
Segments (s)

Figure 1 - Pacing strategy during pre and post double poling test in fatigue (FAT) and control (CON) condition. Data presented as means for nine consecutive 20-s segments.