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Morning preconditioning exercise does not increase afternoon performance in competitive runners

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ABSTRACT

Purpose: Preconditioning exercise is a widely used strategy believed to enhance performance later the same day. We examined the influence of preconditioning exercises six hours prior to a time to exhaustion (TTE) test during treadmill running. **Methods:** Ten male competitive runners (26±3 yrs., 184±8 cm, 73±9 kg, $\dot{V}O_{2max}$: 72±7 $mL\cdot kg^{-1}\cdot min^{-1}$) did a preconditioning session of running (RUN), or resistance exercise (RES), or no morning exercise (NoEx) in a randomized order, separated by >72 hours. RUN consisted of 15 min running at a speed corresponding to ~60% of $\dot{V}O_{2max}$ + 4x15s at race pace (21–24 $km\cdot h^{-1}$) on a treadmill; RES involved 5 min running at ~60% of $\dot{V}O_{2max}$ + 2x3 reps of isokinetic one-leg shallow squats with maximal mobilization. Following a six-hour break, electrically evoked force (m. vastus medialis), counter movement jump, running economy and a time to exhaustion (TTE) of ~2 min were examined. **Results:** Relative to NoEx, no difference was seen for RUN or RES in TTE (mean±95CI) (-1.3±3.4% and -0.5±6.0%) or running economy (0.2±1.6% and 1.9±2.7%) (all P>0.05). Jump-height was not different for the RUN condition (1.0±2.7%) but tended to be higher in RES than in the NoEx condition (1.5±1.6%, P=0.07). The electrically evoked force tended to reveal low-frequency fatigue (reduced 20:50 Hz peak force ratio) only after RES compared to NoEx (-4.5±4.6%, P=0.06). **Conclusions:** Preconditioning running or resistance exercise six hours prior to a ~2 min TTE running test did not improve performance in competitive runners.

Key words: *endurance, morning exercise, running economy, strength training, prior exercise, warm-up*

INTRODUCTION

An athlete's level of performance is mainly determined by the training completed in the years, months and weeks leading up to competitions. In addition, preconditioning exercise sessions on competition days have received increasing attention in the past decade and are used by many power athletes in an attempt to optimize performance [1,2]. These exercise sessions typically involve low-volume (3-6 repetitions), high intensity resistance exercise (40-90% of 1 repetition maximum) < 6 hours prior to competition [3,4] with the goal to increase strength and power generation, as well as sprint performance (<60 s) [3-6]. However, whether strength and power preconditioning can improve performance in endurance sports is currently unknown.

In track running, race events are often held in the afternoon or evening. Anecdotal evidence tells us that most middle-distance runners conduct a morning preconditioning session of low-volume running (~20-30 min), interspersed with a few short sprints (~10-15 s), if the competition is held in the afternoon or evening. Such a strategy has been found beneficial for swimming performance [3], but have not been studied in runners. A study with rugby players demonstrated that sprint running (5 x 40 m) did not elicit any preconditioning effects, in contrast to a heavy strength session (squats) [4]. It is, thus, tempting to suggest that heavy strength exercises will be superior to short sprints also in middle-distance runners.

Several mechanisms for increased performance after preconditioning exercises have been suggested, such as psychological effects [6], hormonal processes[7-9], and increased body temperature [3]. An apparent explanation is post activation potentiation (PAP), which is a phenomenon of elevated force and power properties of a muscle after a few high force contractions. PAP has carefully been investigated at the muscle fiber level and explained by altered Ca^{2+}-kinetics and myosin light chain phosphorylation[10]. In sports, PAP appears to explain increased power performances after different "warm-up" strategies, e.g., heavy squats before a vertical jump test [11]. However, the PAP phenomenon lasts less than 20 minutes [12]. Consequently, long-lasting potentiation (observed after hours) has an unknown mechanism(s) and have recently been called post activation performance enhancement (PAPE)[13] – to distinguish it from PAP.

Although several studies have investigated the effect of preconditioning exercise on sprint performance (e.g., anaerobic power) [3,7-9], surprisingly little is known about its effects on endurance performance and related factors. Running economy is an important determinant in distance running performance, and is typically defined as the energy demand for a given velocity of submaximal running and expressed as the submaximal oxygen uptake (VO_2) at a given running velocity[14]. It is established that running economy can be improved by resistance or plyometric training (>8 sessions)[15]. Similarly, a warm-up with a weighted vest (20% of body weight) improved running economy after 10 min of rest, apparently via increased leg-stiffness (and PAP)[14]. Therefore, it is tempting to speculate whether resistance exercise could work as a preconditioning strategy for middle-distance running.

The aim of the present study was to examine the effects of preconditioning exercises on running performance and economy 6 hours later the same day. The preconditioning exercises were a task-specific running exercise (RUN) and a low-volume/high intensity resistance exercise (RES), tested against a no-exercise, control condition (NoEx). Moreover, we investigated the effects of these preconditioning exercises on neuromuscular function, assessed as vertical countermovement jump performance and electrically evoked force.

METHODS

Subjects

Ten male competitive middle- and long-distance runners (26 ± 3 yrs, 184 ± 8 cm, 73 ± 9 kg) were recruited. Their maximal aerobic power ($\dot{V}O_{2max}$) during treadmill uphill (3°) running was tested on a separate day. The mean ± SD was 72 ± 7 $mL \cdot kg^{-1} \cdot min^{-1}$ (range: 60-83 $mL \cdot kg^{-1} \cdot min^{-1}$), with the highest achieved speed of 19 $km \cdot h^{-1}$ (range 18-20 $km \cdot h^{-1}$). Four of the runners were middle distance runners, with an 800-m personal record (PR) of 1:55 ± 0:05 m:s, while five of the runners were long distance runners; 5000-m PR of 15:08 ± 0:34 m:s. The remaining runner had not competed in the previous years. The protocol was approved by the local ethics committee of the Norwegian School of Sport Sciences and registered with the Norwegian Social Science Data Services. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

Design

The main design is shown in Figure 1. In a randomized cross-over design (each runner acted as their own control), the participants underwent an electrically evoked force test of vastus medialis (20 and 50 Hz). Then, they were randomized to a preconditioning session of running exercise (RUN), resistance exercise (RES), or no morning exercise (NoEx) in a counterbalanced fashion. RUN consisted of 15 min running at a speed corresponding to ~60% of $\dot{V}O_{2max}$, followed by 4 x 15 s at race-pace (21–24 $km \cdot h^{-1}$). RES involved 5 min running at a speed corresponding to ~60% of $\dot{V}O_{2max}$, followed by 2 x 3 repetitions with maximal mobilization in an isokinetic one-leg shallow squat exercise. NoEx included no preconditioning exercise. Six hours after the start of the preconditioning exercise, neuromuscular function (counter movement jump; CMJ and electrically evoked force), treadmill running economy and a running time to exhaustion (TTE) test (~110 s) were assessed.

<<Figure 1 near here>>

Methodology

All trials were completed within a two-week period in the off-season (October-December), separated by at least 72 hours. All running exercises were performed on a treadmill. Preconditioning exercises (lasting ~30 minutes) were undertaken at the same time for each runner (07:00-09:00), and the afternoon sessions (lasting ~1.5 hours) started 6 hours later (13:00-15:00).

Familiarization. Familiarization with the experimental protocols and equipment was completed over two days in the week prior to the first testing session. The first familiarization day consisted of 10 min warm-up (1° treadmill inclination and 10 km·h^{-1}), and a submaximal test (4-6 bouts of 5 min) to provide the individual workloads for the running economy test. In addition, $\dot{V}O_{2max}$ was determined at a treadmill inclination of 3° with a starting speed of 15 km·h^{-1}; speed was increased by 1 km·h^{-1} per minute until exhaustion (~5 min). Oxygen uptake was measured continuously, and the highest mean values during 60 s were taken as $\dot{V}O_{2max}$. Thereafter, subjects completed 10 reps (1 min break) of CMJ and 6 x 3 reps in the isokinetic one-leg shallow squat resistance exercise with increasing effort. The second familiarization consisted of an electrically evoked force test (see below) and running on the treadmill with four sprints (15 seconds) at 21-22-23-24 km·h^{-1}, with a 2 min break between sprints. In addition, subjects performed the same procedure for CMJ and resistance exercise as on the first familiarization day.

Electrically evoked force test. Musculus vastus medialis was used to examine the contractile function of the preconditioned muscles as presented in an earlier study from our lab[16]. Subjects were seated with hip and knee joints at 90° in a specially constructed chair for measurement of electrically evoked, isometric knee-extension force **[Figure 2]**. The right leg was attached to a force transducer and self-adhesive multi-use electrodes were attached with a 1 cm gap longitudinally on the muscle belly. The subjects were resting for approximately 5 minutes, before the muscle was stimulated for 200 ms at 20 Hz (5 pulses) and 50 Hz (11 pulses; pulse width: 500 µs; 250 V, constant current 500mA). Average force values from two contractions per stimulation frequency were used to analyze and calculate peak force, 20:50 Hz peak force ratio, 50 Hz contraction time; time for the force to increase from 10-70% of peak force during stimulation (time 10-70% peak force) and relaxation time; time for the force to decrease from peak force to 50% of peak force after the stimulation train is completed (peak force-50% relaxation). We have used this method for a long time in our lab, and have shown that the 20:50 Hz peak force ratio is stable in rested muscle, have good reliability[16], and is sensitive to low frequency muscle fatigue[17,18].

"Day-shape" and perceived readiness. A custom-made category scale of 1-10 (1 = poor, 10 = excellent) was used to assess the subjects' perceived and expected performance level.

Preconditioning sessions. After the electrically evoked force test in the morning, subjects were randomized to one of the preconditioning sessions in a counterbalanced fashion [**Figure 1**]: RUN consisted of 15 min running on the treadmill at a speed corresponding to ~60% of $\dot{V}O_{2max}$ + 4 x 15 s at race pace (21–24 km·h^{-1}) with a 2 min break. RES involved 5 min running on the treadmill at a speed corresponding to ~60% of $\dot{V}O_{2max}$ + 2 x 3 repetition submaximal warm-up and 2 x 3 repetitions with maximal mobilization in a modified one-leg isokinetic shallow (110˚) squat with hip and plantar flexion **[Figure 3]**. The velocity and resistance were set to free speed and 26 kg in the eccentric phase and 0.3 m·s^{-1} with maximal effort (resistance) in the concentric phase. The breaks were 1 min between legs and 2 min between series. NoEx included no preconditioning exercise. In the ~ 5.5-hour break, runners were told to rest and avoid physical exertion. Sleep and caffeine were not permitted.

<<Figure 2 and 3 near here>>

Counter movement jump. Prior to testing, subjects ran for 5 minutes on the treadmill at a speed corresponding to ~ 60% of $\dot{V}O_{2max}$. Subjects then completed two submaximal warm-up jumps and three maximal attempts (with a 1 min rest between attempts), where the average of the two highest jumps was used for further analysis. Subjects were instructed to hold their hands on their hips and elbows turned outwards during the jump, and the depth was self-selected. Jump-height was calculated from the vertical force impulse against the force platform.

Running economy. After the CMJ test, subjects performed three 5 min submaximal bouts on the treadmill (1˚ incline) at increasing speeds, and the last bout (15.0 ± 0.9 $km \cdot h^{-1}$) was used for further analysis. The speed and incline were chosen to induce a competition-relevant technique and to obtain steady-state oxygen uptake. Running economy was determined as the relative average oxygen uptake ($mL \cdot kg^{-1} \cdot min^{-1}$) from the 3rd to 5th minute in the last bout[19], while average heart rate (HR) was registered over the last 30 seconds. Rating of perceived exhaustion (RPE) was reported directly after the bout and was evaluated using a category ratio RPE scale (6–20)[20].

Performance test. Five minutes after the last submaximal bout, all subjects completed three sprints (15-30-15 seconds) at race pace (22-23-24 $km \cdot h^{-1}$, respectively), with a 2 min break between sprints. Then, subjects were given 5 min rest before the start of the TTE-test. Two minutes before the start, subjects reported their perceived readiness to perform, on a category scale from 1-10 ("Readiness prior to test") were 1 = poor and 10 = excellent. The TTE-test was designed to have a duration of ~2 min, similar to a middle-distance race. The speed was fixed at 22 $km \cdot h^{-1}$ during the initial 30 s, at 23 $km \cdot h^{-1}$ from 30–60 s, and thereafter 24 $km \cdot h^{-1}$ until voluntary exhaustion. Subjects ran between two laser beams, and the test was terminated when subjects had two or more consecutive steps behind the rear laser. $\dot{V}O_2$ was measured continuously (5 s epochs) during the test, and $\dot{V}O_{2peak}$ was calculated as the average of the highest values over 30 s epochs due to the short duration of the test. Average $\dot{V}O_2$ (Accumulated $\dot{V}O_2$ / time) was calculated from the same time period for each subject, with a cut-off value $\leq$ 5 s before exhaustion from the test day with the shortest duration. The highest HR value registered over 5 s was regarded as HR_{peak}. RPE was reported directly after the test, and blood lactate was measured 1 min later. Video recording for analysis of contact time and step frequency was conducted at 24 $km \cdot h^{-1}$ (65-75 s). Step frequency and ground contact time were assessed using 2D video captured at 6.6 meters perpendicular to the running direction, using a high-speed camera at 100 frames per/s where the average over 5 consecutive cycles was used. Verbal and/or quantitative feedback (e.g. cheering, jump height, running times) were not given during the tests. Subjects were requested to prepare in an identical manner before each test day with regard to nutrition, sleep and training.

Apparatus
All running tests were performed on a 3 x 4.5 m treadmill (Rodby, Södertalje, Sweden), and the runners were secured with a safety harness connected to an automatic emergency stop. Oxygen consumption was measured using an automatic ergospirometry system with a mixing chamber set-up (Oxycon Pro, Jaeger Instrument, Hoechberg, Germany), as evaluated by Foss and Hallén[21]. Blood lactate concentration [La^{-}_{blood}] was measured directly after the last workload with a Biosen C-Line GP+ lactate analyzer (Biosen C-line, EKF Diagnostic, Cardiff, UK). The lactate analyzer and the Oxycon Pro Jaeger Instrument were calibrated according to the relevant instruction manuals. Heart rate was measured with a Garmin heart rate monitor (Garmin Forerunner 935, Garmin Ltd, Lenexa, KS, USA). Body height and mass were measured on a Seca stadiometer and a Seca Model 708 (Voegel & Halke, Hamburg, Germany). Video recordings were obtained using a high-speed camera at 100 frames per/s (Basler AG, Ahrensberg, Tyskland). The video was captured in SIMI Aktisys (SIMI Reality Motion System GmbH, Unterschleissheim, Germany) and data were analyzed in Tracker (Tracker version 5.0.6, Douglas Brown, Open Source Physics, Davidson, NC, USA). The one-leg shallow (110˚) squat with hip and plantar flexion was performed using a 1080 Quantum Syncro (1080 Motion AB, Lidingö, Sweden). For the electrically evoked force test, a specially constructed chair that allowed the measurement of force by isometric knee-extension was used (Gym2000, Vikersund, Norge) **[Figure 2]**. We used self-adhesive multi-use electrodes for neuromuscular stimulation (PALS, model 896240 5x10 cm, Axelgaard Manufacturing, Lystrup, Denmark) connected to a stimulator (Digitimer DS7AH, Hertfordshire, United Kingdom). Stimulation was verbally pre-informed and manually triggered via a custom-made software controlling the stimulator (Labview, National Instruments, Texas, USA). Force was measured with a load cell (U2A 200 Hottinger Baldwin Mestechnik, Darmstadt, Germany) and recorded and stored on a PC (100Hz) for further analyzes (Labview). Counter movement jumps were measured on a force platform (HUR Labs Oy, Tampere, Finland)

Statistical Analyses

Data are presented as mean ± standard deviation (SD) and the relative differences between NoEx and RUN or NoEx and RES and are presented as mean ± 95 % confidence interval (CI). The "Day-shape" and "Readiness prior to tests" are presented as median ± interquartile range. A one-way ANOVA for repeated measures was used to examine the overall differences between variables (RUN, RES, NoEx). The relative differences between NoEx and RUN and NoEx and RES, respectively, were examined using a T-test. Statistical calculations were performed using Microsoft Office Excel 2013 (Microsoft, Redmond, WA, USA) and IBM SPSS Statistics 24.0 (International Business Machines, New York, NY, USA). A P-value ≤ 0.05 was considered statistically significant and P-values 0.05-0.10 were considered tendencies.

RESULTS

The TTE, VO_{2peak}, average VO_2, [La^- blood], HR and RPE for NoEx, RUN and RES are shown in Table 1. There were no significant differences in TTE (NoEx vs RUN; -1.3 ± 3.4%, P = 0.43 and NoEx vs RES; -0.5 ± 6.0%, P = 0.86) or the other performance-related factors for NoEx, RUN or RES (all $P > 0.05$). There were no differences in step frequency or contact time between NoEx, RUN or RES **[Table 1]**.

The running economy, [La^- blood], HR response and RPE for the three conditions from submaximal tests are shown in Table 2. There were no significant differences in running economy ($mL \cdot kg^{-1} \cdot min^{-1}$) between NoEx and RUN or NoEx and RES (0.2 ± 1.6%, P = 0.83 and 1.9 ± 2.7%, P = 0.16). There were also no significant differences in [La^- blood], HR response or RPE between NoEx, RUN or RES (all $P > 0.05$).

The counter movement jump height was 34.0 ± 3.1 cm for NoEx and was not significantly different in the RUN condition (34.4 ± 3.5 cm; 1.0 ± 2.7%, P = 0.44), but tended to be higher for the RES condition compared to NoEx (34.6 ± 3.2 cm; 1.5 ± 1.6%, $P = 0.07$).

Self-reported ratings of perceived “Day-shape” and “Readiness prior to tests” 5.5 hours after finishing the conditions are presented in Table 3. Here, no significant differences were found between the conditions.

The electrically evoked force response showed no difference in contraction or relaxation time, but the 20:50 Hz peak force ratio tended to be lower between morning and afternoon for RES compared to NoEx (-4.5 ± 4.6%, $P = 0.06$) **[Table 4]**.

<<Table 1-4 and near here>>

DISCUSSION

To the authors’ knowledge, the present study is the first to investigate the effects of preconditioning exercise sessions performed prior to a time to exhaustion test in running. We observed that neither a sport-specific running exercise (15 min easy running + 4 x 15 s at race pace) nor a resistance exercise (2 x 3 reps isokinetic one-leg shallow squats with maximal mobilization) influenced treadmill running economy or time to exhaustion in competitive runners. Neuromuscular function, assessed as countermovement jump height and electrically evoked force, was also unaffected.

The absence of post activation performance enhancement (PAPE) on short term endurance performance in the present study contrasts with the conclusions drawn by McGowan et al[3]; these researchers reported improved 100-m swimming performance (~1 min) after a preconditioning swimming exercise or a combined swimming and resistance exercise in the morning (6 hours prior to testing). The swimmers increased their speed during the first 50 m after both the preconditioning sessions compared to the rest condition, implying a more positive pacing pattern, though the reason for this shift in pacing pattern is not clear. Similar to 100 m swimming, a middle-distance running event (at least 800-m) performance might benefit from a fast starting strategy due to the relatively short duration of the event[22]. However, the present study used a TTE-design with a total time of nearly 2 min to test running performance. In such protocols, the pacing strategy, and thereby increases in speed at the start of exercise, are neglected.

McGowan et al[3] observed increased core-body temperature and PAPE in swimmers six hours after preconditioning exercises in the morning; which point to elevated body temperature as a PAPE mechanism. Unfortunately, we did not measure core-body temperature. However, in the present study the subjects performed an extensive warm-up including 3 short sprints at 22, 23 and 24 $km \cdot h^{-1}$ as these high intensity sprints have been shown to enhance performance in middle distance runners [23], and may thereby have equalized any potential effects of the preconditioning sessions. Consequently, we propose that the extensive warm-up in the present study conducted in a room at a temperature of ~21ºC was sufficient to provide an elevated body temperature, and the warm-up may have equalized any potential preconditioning effects. However, in support to that body-temperature was not a conclusive mechanism for the findings in the present study, we found no difference in jump-performance after just 5 min warm-up at low intensity, which probably was insufficient to result in potentiation per se.

The mechanism(s) behind PAPE is elusive. Fry et al[6] concluded that the response to preconditioning exercise may differ considerably between athletes and that athletes exhibiting high levels of anxiety may experience a beneficial effect from including such strategies. We did not include a questionnaire directly investigating the anxiety levels of our subjects and therefore cannot confirm these findings. However, we found no differences in “psychological factors”, based on the rating of perceived day-shape and readiness prior to test. It should be noted that during an important competition, the stress level is clearly much higher than during our tests, which should be taken into consideration.

A preconditioning performance enhancement may be a kind of delayed neuromuscular potentiation, which apparently can be present up to 48 hours after low volume resistance exercise[2]. In the present study, we used the electrically evoked force of the knee extensor m. vastus medialis to evaluate neuromuscular function in the absence of activation from the central nervous system. There were no changes in contraction time (rate of force development) and relaxation time, which supports the lack of change in jump-height. However, the 20:50 Hz peak force ratio was reduced from the morning to afternoon for the RES condition, indicating low-frequency fatigue. Low-frequency fatigue is associated with compromised calcium release from the sarcoplasmic reticulum and is one indicator of reduced efficacy in the excitation-contraction coupling following strenuous exercise [24]. The indication of low-frequency fatigue suggests that the resistance session (2x3 reps isokinetic squats with maximal mobilization) was too hard and generated a long-lasting fatigue condition. This may have eliminated or masked any type of muscle potentiation. Nevertheless, the changes in 20:50 Hz peak force ratio was not statistically different from the other conditions, indicating a trivial effect or that we were statistically underpowered to detect the effect. Raastad, Hallén [16] reported indications on PAPE by improved jumping performance after strength training with 70% of 3-6RM loads, while the jumping performance was reduced after 100% of 3-6RM loads (knee-extensions and squats). However, the 20:50 Hz peak force ratio was unaffected after the 70% session while decreased after the 100% session. These observations indicate the low-frequency fatigue was part of the performance reductions [17], but it is unclear whether low frequency fatigue somehow suppresses PAPE. Future PAPE studies should investigate these interactions and include other neurophysiological measurements, such as H-reflexes and high-density electromyography.

In most previous studies demonstrating PAPE [4,6,8,25], the participants were power athletes. It seems reasonable to suggest that these power athletes were stronger, possessed a higher proportion of type II fibers[26] , and had more strength training experience than the runners in the present study. As short-term resistance exercise potentiation (PAP) effects seem to be more evident in power athletes than in endurance athletes [27], the training history and sport-specific traits of the athletes might therefore also influence the effects of the preconditioning strategy and PAPE.

Running economy may be improved after a period with strength training, but also during a warm-up with external loading (weighted vest), apparently via increased leg-stiffness (and PAP)[15]. However, we found no indications of PAPE (or detrimental effects) on running economy after either running or resistance exercise preconditioning. We did not measure leg stiffness, but no changes in step frequency and contact time indicate no changes in running mechanics.

Limitations

The low number of subjects (n=10) is a limitation of the present study and could have resulted in a Type II statistical error. Secondly, the tests were performed indoors due to the outdoor conditions in the off-season period (October-December) and not in a "real" performance setting, which limits the ecological validity. Third, we were not able to perform a complete familiarization for the TTE (but included four sprints of 15 seconds at 21-22-23-24 $km \cdot h^{-1}$). This was due to the risk of injuries, strain and the high total training load of performing >3 TTE tests in addition to the other tests. Furthermore, in our protocol, the pacing strategy was neglected, which should be taken into account when transferring the findings to a practical setting. Thus, it remains to be investigated whether self-paced exercise would induce different response. When interpreting the results these issues should be taken into consideration. However, we did not find a significant difference or trend for any of the performance-related factors (e.g., time to exhaustion, running economy or kinematics), which strengthens the conclusion of there being no or trivial effects of morning preconditioning exercise for afternoon running performance in a group of competitive middle-distance runners.

Practical Applications

We found that the preconditioning strategies used in the present study failed to increase time to exhaustion during running. Thus, if our results are representative of preconditioning in middle-distance runners, such exercise sessions are not necessary to optimize performance. In line with others [4], we recommend that athletes systematically explore their individual responses on performance after preconditioning strategies. Furthermore, for athletes who do not experience adverse effects from preconditioning, we suggest that performing low-volume resistance exercise in the morning of competitions or intensive endurance sessions as a strategy for maintaining strength abilities during competition periods [28,29]; when indeed, resistance exercise is in our experience often neglected by endurance athletes. Athletes and coaches should, however, always evaluate the total training load when adding more training.

CONCLUSION

Preconditioning running or resistance exercise performed six hours prior to a treadmill running test did not improve time to exhaustion, running economy or neuromuscular function. Thus, based on the present findings, we do not find such preconditioning exercise necessary for optimal performance in running with durations of ~2 min.

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Figure 1: Schematic of testing session design. Electrically evoked force of m. vastus medialis; Abbreviations: NoEx, no exercise, RUN, running exercise, RES, resistance exercise, TTE, time to exhaustion.

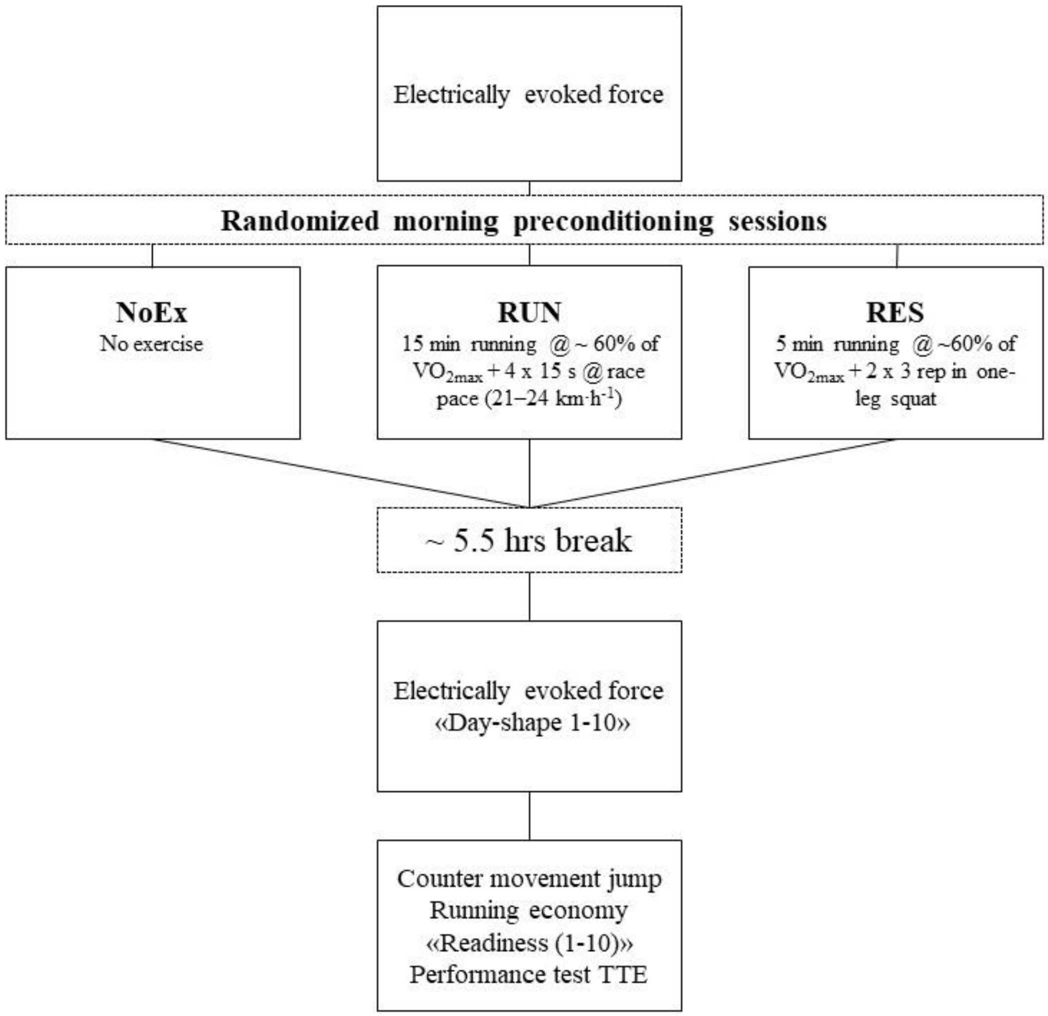

Figure 2: Electrically evoked force of right leg m. vastus medialis.

Figure 3: Resistance exercise performed as isokinetic one-leg shallow squat with maximal mobilization using a 1080 Quantum Syncro.

Table 1: Time to exhaustion (TTE), physiological and kinematical variables during the TTE-test at 1º. The test was performed 5.5 hours after the following conditions: no exercise (NoEx), running (RUN) or resistance exercise (RES).

Variable	**NoEx**	**RUN**	**RES**
TTE (s)	112.1 ± 25.6	110.1 ± 22.0	111.7 ± 24.9
$\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1})	66.7 ± 3.7	66.5 ± 2.5	67.3 ± 2.5
$\dot{V}O_{2AVR}$ (mL·kg^{-1}·min^{-1})	48.7 ± 5.2	48.2 ± 4.2	49.0 ± 4.1
[La^-_{blood}] (mmol·L^{-1})	12.5 ± 1.3	11.5 ± 0.9	11.9 ± 1.0
HR_{peak} (beat·min^{-1})	188 ± 8	188 ± 8	187 ± 8
RPE (6-20)	18.2 ± 1.3	18.3 ± 1.1	18.4 ± 1.0
Step frequency (step·min^{-1})	202 ± 12	201 ± 12	202 ± 13
Contact time (s)	0.16 ± 0.1	0.16 ± 0.1	0.16 ± 0.1

Note: Data are mean±SD. TTE; time to exhaustion, $\dot{V}O_{2peak;}$ peak oxygen uptake over 30 s, $\dot{V}O_{2AVR;}$ average oxygen uptake during test, [La^-_{blod}]; Blood lactate concentration, HR; Heart rate, RPE; rating of perceived exertion, Video recording for analysis of contact time and step frequency was conducted at 24 km·h^{-1} (65-75 s during the test).

Table 2: VO_2, [La^- blood], HR and RPE at a moderate intensity speed (1º, 15.0 ± 0.9 $km{\cdot}h^{-1}$) 5.5 hours after finishing the following conditions: no exercise (NoEx), running exercise (RUN) or resistance exercise (RES).

Variable	**NoEx**	**RUN**	**RES**
$\dot{V}O_2$ ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	50.3 ± 3.0	50.4 ± 3.2	51.3 ± 2.3
[La^-_{blood}] ($mmol{\cdot}L^{-1}$)	1.8 ± 0.5	1.8 ± 0.4	1.8 ± 0.5
HR ($beat{\cdot}min^{-1}$)	163 ± 12	165 ± 10	164 ± 11
RPE (Borg 6-20)	13.1 ± 1.6	13.1 ± 1.5	13.4 ± 1.4

Note: Data are mean±SD [La^-_{blood}]; Blood lactate concentration, $\dot{V}O_2$; oxygen uptake, HR; Heart rate, RPE; rating of perceived exertion

Table 3: Self-reported rating of perceived "Day-shape" and "Readiness prior to tests" 5.5 hours after finishing the conditions; no exercise (NoEx), running exercise (RUN) or resistance exercise (RES).

Variable	NoEx	RUN	RES
Day-shape (1-10)	7 ± 1	7 ± 2	7 ± 2
Readiness prior to tests (1-10)	7 ± 1	7 ± 2	7 ± 2

Note: Data are median±IQR.

Table 4: Electrically evoked force of right leg m. vastus medialis conducted in the morning and the afternoon for no exercise (NoEx), running exercise (RUN) and resistance exercise (RES). * Significant lower in afternoon compared to morning (*P*=0.04); # Tendency to be lower for RES compared to NoEx in the afternoon (*P*=0.06).

	Morning			Afternoon		
	NoEx	**RUN**	**RES**	**NoEx**	**RUN**	**RES**
20 Hz peak force (N)	90 ± 41	78 ± 33	76 ± 40	88 ± 44	70 ± 36	61 ± 38
50 Hz peak force (N)	108 ± 46	98 ± 45	90 ± 47	105 ± 49	98 ± 45	76 ± 45
20:50 Hz peak force ratio (%)	82 ± 5	82 ± 6	86 ± 3	82 ± 5	82 ± 5	81 ± 5*#
Time 10-70% peak force (ms)	73 ± 12	77 ± 9	76 ± 11	75 ± 11	73 ± 10	77 ± 8
Peak force-50% relaxation (ms)	103 ± 10	108 ± 9	108 ± 12	99 ± 13	101 ± 14	103 ± 8