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Increasing Oxygen Uptake in Well-Trained Cross-Country Skiers During Work Intervals With a Fast Start

Running head: Optimizing high-intensity intervals

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Abstract

Purpose: Accumulated time at a high percentage of peak oxygen consumption (VO_{2peak}) is important for improving performance in endurance athletes. The present study compared the acute effect of a roller-ski skating session containing work intervals with a fast start followed by decreasing speed (DEC) with a traditional session where the work intervals had a constant speed (similar to the mean speed of DEC; TRAD) on physiological responses, rate of perceived exertion (RPE) and leg press peak power (LPPP). ***Methods:*** Eleven well-trained cross-country skiers performed DEC and TRAD in a randomized order (5x5-min work intervals, 3 min relief). Each 5-min work interval in the DEC protocol started with 1.5 min at 100% of maximal aerobic speed (MAS) followed by 3.5 min at 85% of MAS, while the TRAD protocol had a constant speed at 90% of MAS. ***Results:*** DEC induced a higher VO_2 than TRAD, measured as both peak and average of all work intervals during the session (98.2 ± 2.1 vs. 95.4 ± 3.1% VO_{2peak}, respectively and 87.6 ± 1.9 vs. 86.1 ± 3.2% VO_{2peak}, respectively) with a lower mean RPE after DEC compared to TRAD (16.1 ± 1.0 vs. 16.5 ± 0.7, respectively) (all $p<0.05$). There were no differences between sessions for mean heart rate, blood lactate concentration or LPPP. ***Conclusion:*** DEC induced a higher mean VO_2 and a lower RPE compared with TRAD, despite similar mean speed, indicating that DEC can be a good strategy for interval sessions aiming to accumulate more time at a high percentage of VO_{2peak}.

KEY WORDS

Endurance training, High-intensity aerobic training, Intense exercise, Roller-skiing

INTRODUCTION

Performance in cross-country (XC) skiing is highly related to maximal oxygen consumption (VO_{2max}).[1,2] The high VO_{2max} values in XC skiers could be related to numerous factors like genetics, training volume, training periodization and amount of high-intensity aerobic interval training (HIT). To the best of our knowledge, there is only one previous study focusing on optimizing a single HIT session for well-trained XC skiers. This study observed that longer intervals (5-10 min) were more effective than shorter intervals (2-4 min) in improving endurance performance after 8 weeks.[3] The importance of optimizing the HIT session for XC skiers is emphasized in a recent review paper where Sandbakk and Holmberg[4] suggested that well-trained XC skiers could benefit from increasing the quality of HIT sessions. In this context, the quality of a HIT session can be defined by mean VO_2 or accumulated training time ≥ 90% VO_{2max}[5-7] possibly due to the large stimulus for myocardial morphological adaptations that increases maximal cardiac stroke volume and also more peripheral skeletal muscle adaptations.[6]

In order to optimize exercise time ≥ 90% VO_{2max}, a speed between 90 to 100% of maximal aerobic speed (MAS) is recommended.[8] However, continuous work at MAS can only be sustained for ~6 minutes in well-trained runners and cyclists.[9,10] Therefore, there is a quest for developing HIT sessions that optimize time ≥ 90% VO_{2max} by balancing work and recovery durations and intensities.[11] It has been recognized that a fast-start strategy might speed the VO_2 kinetics during both running and kayaking.[12,13] Furthermore, by using cycling in untrained to moderately-trained participants, it has been observed that fast start intervals acutely increase VO_2.[14-16] To the best of our knowledge, the VO_2 in roller-ski skating intervals, involving four active limbs with a large muscle mass, have not been investigated. Given the differences in VO_2 kinetics during exercise with a large muscle mass (i.e., running) compared with a smaller muscle mass (i.e., cycling),[17,18] it would be of interest to investigate the effects of a fast start strategy while roller-ski skating on time ≥ 90% VO_{2max}. Furthermore, acute physiological effects of a fast start with a subsequent speed reduction during work intervals in a HIT session has not yet been investigated in well-trained endurance athletes.

Therefore, the primary purpose of the present study was to compare the acute effects of a HIT session containing work intervals with a fast start and subsequent reduction in speed with a traditional HIT session with similar mean speed during the work intervals but performed at a constant speed on physiological responses during roller-ski skating in well-trained XC skiers.

METHODS

Subjects

Eleven well-trained[19] male skiers (age 23.5±3.5 years, height 184±6 cm, body mass 77.9±7.2 kg, peak oxygen consumption (VO_{2peak}) 70.6± 5.7 $mL \cdot min^{-1} \cdot kg^{-1}$) competing in XC skiing or biathlon volunteered for the study, which was performed according to the ethical standards established by the Helsinki Declaration of 1975 and approved by the local ethical committee of the Department of Sports Science, Lillehammer University College. All participants provided informed consent. The self-reported amount of endurance training hours during the year preceding the experiment was 579±85 h. These hours were categorized into a three-zone model,[20] of which 89±3%, 6±2% and 5±1% was performed in heart rate (HR) zone 1 (60%-82% of HR_{max}), zone 2 (83%-87% of HR_{max}) and zone 3 (88%-100% of HR_{max}). The mean weekly endurance training time during the three months preceding the start of the experiment was 14.0 ± 1.8 h with an intensity distribution similar to the mean values of the entire year. The experiment was performed in the last half of the skiers' preparatory period (September).

Experimental design

The participants visited the test laboratory on five separate occasions and roller-ski skating was the exercise mode performed throughout. The first test session was a preliminary test to determine MAS, VO_{2peak} and HR_{peak}.On the subsequent four visits, two different 5x5-min HIT sessions were performed twice. One HIT session consisted of work intervals with a fast start followed by decreasing speed (DEC) and the other HIT session employed work-matched (± 0.1 $km \cdot h^{-1}$) intervals with a constant speed (TRAD). After performing DEC and TRAD once each in a randomized order, the two sessions were both repeated once more, again in a randomized order. The HIT session with the highest mean VO_2 from the two repeated days of testing (within condition) was used in statistical analyses. The recovery demand of neuromuscular function was assessed by measuring peak power output during a seated leg press before and after the HIT sessions.

Preliminary testing

Preliminary roller-ski testing and all HIT sessions (including the warm-up) were performed while skating on a treadmill (Lode Valiant Special, Lode B.V. Groningen, the Netherlands) using the same roller-skis (IDT Skate Elite RM2, IDT Solutions AS, Lena, Norway), the same poles (SWIX Triac 2.0, Swix Sport AS, Lillehammer, Norway, length between 160 and 177.5 cm), and under similar environmental conditions (17–20 °C) with a fan ensuring circulating air. The athletes used their own ski boots and could freely choose between the two predominant uphill skating techniques (V1, where the skiers use their poles on every second leg push-off and V2, where the poles are used on every leg push-off).

After a 10-min warm-up on the treadmill at an inclination of 3% and a velocity of 12 $km \cdot h^{-1}$ (68 ± 5% of HR_{peak}) the test started, using a constant inclination of 9%. The first 5-min bout started at a velocity of 7 $km \cdot h^{-1}$ and increased by 1 $km \cdot h^{-1}$ for each 5-min bout until a blood lactate concentration ($[La^{-}]$) above 4.0 $mmol \cdot L^{-1}$ was measured (4.5 ± 1 bouts). Capillary blood samples were taken from a fingertip during a 1-min break in between each 5-min bout, and analyzed for whole blood $[La^{-}]$ (Biosen C-line, EKF Diagnostics, Barleben, Germany). The average VO_2 from the two last minutes of each 5-min bout was used for a subsequent calculation of MAS based on the relationship between VO_2 and workload. VO_2 was measured with a sampling time of 30 s, using a computerized metabolic system with mixing chamber (Oxycon Pro, Erich Jaeger, Hoechberg, Germany). The flow turbine (Triple V, Erich Jeger) was calibrated with a 3L, 5530 series, calibration syringe (Hans Rudolph, Kansas City, Missouri, USA). The same metabolic system with identical calibration routines was used during the subsequent HIT sessions. The speed at 4.0 $mmol \cdot L^{-1}$ $[La^{-}]$ was calculated from the relationship between $[La^{-}]$ and speed using linear regression between the closest workload below and above 4.0 $mmol \cdot L^{-1}$ from the preliminary testing.

Ten minutes after the submaximal test an incremental test was performed, starting at a 9% inclination and a speed of 7 $km \cdot h^{-1}$ which increased by 1 $km \cdot h^{-1}$ every minute until exhaustion (average duration of 9.1 ± 0.8 minutes). VO_{2peak} was calculated as the average of the two highest 30-s measurements and HR_{peak} was the highest 1-s value recorded (Polar RCX5, Polar, Kempele, Finland). MAS was defined as the speed where the horizontal line representing VO_{2peak} met the extrapolated linear regression representing the submaximal VO_2/speed relationship. Work rates at 4.0 $mmol \cdot L^{-1}$ $[La^{-}]$ and MAS were calculated as the sum of the power against gravity and the power against rolling friction (friction coefficient = 0.0237) at the respective velocities as described previously.[21]

HIT sessions

The HIT sessions were performed at a fixed time of day (± 1 h) interspersed with 3-5 days containing only easy training. The participants were instructed to consume the same meal before each visit to the lab and were not allowed to eat during the hour preceding a session or to consume coffee or other products containing caffeine during the three hours preceding the tests. The roller-ski warm-up and the subsequent HIT sessions were performed on a constant treadmill inclination of 9%. The first 5 min of the warm-up was performed at a speed of 7 $km \cdot h^{-1}$, followed by a 5-min gradual increase in speed, based on individual preferences, towards the speed at 4.0 $mmol \cdot L^{-1}$ [La⁻]. The speed at 4.0 $mmol \cdot L^{-1}$ [La⁻] was maintained for 4 min, before a new increase in speed towards the starting velocity of the first work interval was reached (after ~3 s) and maintained for 1.5 min. A 5-min active recovery period (3% inclination and 10 $km \cdot h^{-1}$) concluded the warm-up. This means that there was a difference in the warm-up protocol, where DEC involved exercise at 12.6±0.9 $km \cdot h^{-1}$ and TRAD involved exercise at 11.3±0.8 $km \cdot h^{-1}$ for the final 1.5 min. The rationale for this difference is that anecdotally there is a common practice amongst XC-skiers to include efforts of the start pace of their work intervals during the warm-up, and that it has been recommended to perform at least one race-pace effort during the warm-up for middle-distance runners[22] (which is comparable with the present exercise setting). Furthermore, the 5-min active recovery period before starting the first work interval is likely to minimize any potential physiological difference induced by the intensity difference in the warm-up. However, to verify that the different warm-up procedures did not affect data collection in the first 5-min work interval, seven XC skiers performed the present warm-up protocol in two different sessions within one week. The only difference was 1.5 min at either 12.6 $km \cdot h^{-1}$ or 11.3 $km \cdot h^{-1}$ followed by the 5-min active recovery before they performed the first 5-min TRAD work interval at a velocity of 11.3 $km \cdot h^{-1}$. The order was randomized and there were no differences between using 12.6 and 11.3 $km \cdot h^{-1}$ during the warm-up protocol on mean VO_2 during the first 1.5 min (3414±120 vs. 3417±237 $mL \cdot min^{-1}$, respectively, $p=0.98$) or mean VO_2 during the entire 5-min work interval (4129±212 vs. 4127±197 $mL \cdot min^{-1}$, respectively, $p=0.96$).

The athletes could freely choose between V1 and V2 skating techniques during all sessions, as there appears to be no difference in work economy or performance at these speeds and inclines.[23] Anecdotally, the individual skier was quite consistent in the choice of skating technique from session to session, but there were individual differences between the skiers.

Between the 5-min work intervals there was a 3-min relief period where the two first minutes were passive and the last minute was performed at 7 km·h^{-1} and an incline of 9%. The speed was increased to the starting velocity over the final 5 s of each rest period. Each 5-min work interval in the DEC protocol started with 1.5 min at 100% of MAS followed by 3.5 min at 85% of MAS. This protocol was based on a previous study indicating that exercise for 1-1.5 min at MAS is needed before cyclists reach 90-95% of VO_{2max}.[14] It was therefore anticipated that this exercise intensity and duration would speed the VO_2 kinetics during the DEC session without resulting in too much fatigue. Furthermore, it has also been indicated that this high VO_2 can be maintained for ~16 min even after reducing exercise intensity to ~80% of MAS.[14] Each work interval in the TRAD protocol was performed with a constant speed at 90% of MAS, resulting in a similar mean speed as in DEC (11.34 and 11.28 km·h^{-1}). Continuous running to exhaustion and intermittent running, both at an exercise intensity of 92% of MAS, have previously elicited a substantial time spent at 90% of VO_{2max}[24], which was the rationale for selecting a mean intensity of 90% of MAS for DEC and TRAD in the current study. Other reasons for this choice were that, anecdotally, XC-skiers do not usually perform HIT sessions to exhaustion and it was important that all participants were able to complete the HIT sessions.

VO_2 and HR during the work intervals were recorded at 15-s intervals. The highest 15-s measurement across all intervals was used as maximum VO_2 and HR during each HIT session. Time $\geq$ 90% VO_{2peak} was calculated as the sum of VO_2 values (averaged over 15 s) that were superior or equal to 90% of the reference value for VO_{2peak} obtained from the incremental exercise test to exhaustion. The same procedure was used for determination of time $\geq$ 90% HR_{peak}. Immediately after each work interval a capillary blood sample was collected from the fingertip and analyzed for [La^-] (Biosen C-line, EKF Diagnostics, Barleben, Germany) and rate of perceived exertion (RPE) was recorded using Borg's 6-20 scale.[25] Mean VO_2 during each HIT session was calculated as the mean value across all work intervals. To evaluate the development of VO_2 in the work intervals, the mean values of all five intervals were used. This was calculated as the mean percentage of VO_{2peak} during the first two minutes, the third minute and the last two minutes.

Leg press peak power

Lower-body peak power was measured before and after the HIT sessions using a pneumatic bilateral seated leg press machine (Keiser A420, Keiser Sports Health Equipment Inc, Fresno, California, USA). This equipment has been described previously and has been found to have a high level of reproducibility.[26] Testing before the HIT session was performed after a 10-min cycling warm-up at a RPE of 11-12 on the 6-20 Borg scale and was repeated 5 min after the last work interval (without any physical activity during this 5-min period). The participants sat with knees flexed at 90° to 96° and the hips flexed at approximately 45° with the individual seating position being identical for all tests. Following the 10-min cycling warm-up, two warm-up repetitions were performed at 44 kg. The power testing consisted of a single trial of ten increasingly heavy lifts with standardized recovery periods (gradually increasing from 5 to 45 s) and loads starting at 44 kg and ending at 279 kg. During all lifts the participants were instructed to exert force "as fast as possible". Average concentric mechanical power of each lift was calculated in the manufacturer's software and based on these calculations peak power output was calculated and used for statistical analysis. Two warm-up repetitions at 44 kg were performed for the testing after the HIT sessions. Familiarization to this test procedure was provided both before and after the preliminary testing on test day 1.

Statistics

All values presented in the text and tables are mean±SD. Two-way repeated measures ANOVA with Bonferroni post hoc tests were performed to evaluate differences between DEC and TRAD in the mean percentage of VO_{2peak} during the first two minutes, the third minute and during the two last minutes of all work intervals (time vs. condition). Student`s two-tailed paired t-tests were used to evaluate potential differences between DEC and TRAD in RPE and physiological responses. The initial statistical significance level was set to $p \leq 0.05$, however, Holm-Bonferroni sequential adjustments were applied when evaluating physiological responses due to multiple comparisons.[27] ANOVA analyses were performed in GraphPad Prism 7 (GraphPad Software Inc., CA, USA) and Student's t-tests were performed in Excel 2010 (Microsoft Corporation, Redmond, WA, USA). Effect size (ES) of DEC was calculated when there were significant differences between DEC and TRAD with the following formula: ([DEC mean – TRAD mean]/ SD). The scale proposed by Rhea[28] for well-trained subjects was used to interpret the magnitude of the treatment effect; 0.0-0.24 trivial, 0.25-0.49 small, 0.5-1.0 moderate, >1.0 large.

Results

The submaximal test on the first test day showed that the mean velocity at 4 mmol·L^{-1} [La^{-}] was 10.1±0.8 km·h^{-1}, equal to an external workload of 250±32 W, while the calculated MAS was 12.6±0.9 km·h^{-1}, equal to an external workload of 311±30 W. Responses during DEC and TRAD are shown in Table 1 and individual data for maximum and mean VO_2 across all work intervals are presented in Figure 1. Maximum VO_2 was higher during DEC compared with TRAD (p=0.0003, Table 1), with a moderate ES. DEC also induced a higher mean VO_2 than TRAD (p=0.0293) and again ES was moderate. As shown in Figure 2, mean VO_2, expressed as percentage of VO_{2peak}, across all work intervals was higher during the two first minutes of DEC compared to TRAD (83.6±4.4% vs. 79.6±5.1%, respectively, p<0.0001; ES=0.78). There was no difference between DEC and TRAD during the third minute (87.7±4.7% vs. 87.6±5.5%, respectively), while TRAD was higher than DEC during the last two minutes (88.8±5.3% vs. 86.6±4.6%, respectively, p=0.0015; ES=0.44). Both the maximum and mean RPE for all work intervals were lower in DEC than TRAD (p=0.036 and p=0.045, respectively; Table 1) and ES values were small ES. There was no statistical difference between DEC and TRAD in time ≥ 90% of VO_{2peak}, time ≥ 90% of HR_{peak}, maximum HR measurement, maximum or mean [La^{-}] (Table 1). Furthermore, there were no differences between DEC and TRAD in changes in leg press peak power from before (773 ± 104 and 776 ± 112 W, respectively) to after (788 ± 107 and 801 ± 113 W, respectively) the HIT sessions.

(Insert Table 1 approximately here)
(Insert Figure 1 approximately here)
(Insert Figure 2 approximately here)

Discussion

The main finding of the present study was that DEC induced higher maximum and average VO values, and a lower RPE, than TRAD. In addition, the ES analyses showed a moderate practical effect of DEC on VO_2 and a small practical effect on RPE, despite having similar mean speed during all work intervals as TRAD.

In DEC the work intervals commenced with 1.5 min at a higher speed than TRAD and this resulted in a larger mean VO_2 during the two first minutes (measured as mean values for all work intervals). This is in agreement with the observation that starting a 2-5-min exercise with a higher power output increases the overall VO_2 compared with a more even intensity distribution.[13,29] During the third minute of all work intervals there was no difference between DEC and TRAD in mean VO_2, despite a higher speed during TRAD. This higher speed during TRAD eventually led to a higher mean VO_2 during the last two minutes of all work intervals. Interestingly, the ES showed that DEC had a moderate practical effect on VO_2 during the first two minutes of the work intervals, while TRAD only had a small practical effect during the two last minutes. To the best of our knowledge, this is the first study to demonstrate this potential advantage of DEC vs. TRAD by using similar mean speed and exercise duration in roller-ski skating intervals. In agreement with the present findings, previous studies utilizing only lower-body exercise through cycling have observed longer times spent at a VO_2 >85% of VO_{2max} when starting the exercise with a high power followed by reduced power in untrained to moderately-trained participants.[14-16] However, in two of these studies the sessions differed in duration and mean exercise intensity, making the findings somewhat challenging to interpret.[14,15] Since the present study utilized a similar mean speed for both DEC and TRAD, it can be suggested that starting the work interval with a higher speed, followed by a subsequent reduction in speed, may lead to a higher mean VO_2 and thus a better stimulus on central and peripheral factors involved in VO_2 than using similar mean intensity in a flat distribution. In agreement with our findings, Zadow et al.[16] used trained cyclists and observed longer time above 85% of VO_{2max} when using a 15-s all-out strategy in the beginning of 3-min work intervals compared to a more even distribution of the power output.

The larger VO_2 response in DEC might be related to the quicker rise in VO_2 with a fast start compared to a slower start.[30] The absolute rate at which VO_2 rises at the onset of exercise is a positive function of the difference between the current and the required steady-state VO_2 in the working muscle.[31] Therefore, the larger difference between current and required VO_2 in the working muscles during the beginning of the work intervals in DEC is likely to speed the VO_2 response. Additionally, in later intervals slow VO_2 kinetics of the initially recruited type II fibers, reduced contractile efficiency, and a gradual increase in O_2 demand from the recovery processes in fatigued fibers[32] might contribute to explain the higher mean VO_2 in DEC than TRAD. The present study may be limited by the choice of increasing the ecological validity by finalizing the warm-up with 1.5-min at the starting velocity of the work interval, which induced a difference in the lead-in to the first work interval. This higher exercise intensity in DEC may have sped up the VO_2 kinetic response compared to TRAD. However, the 5-min active recovery period before starting the first work interval can be suggested to minimize any potential physiological difference induced by the intensity difference in the warm-up. This is supported by the subsequent preliminary study showing no effect of the two warm-up procedures on mean VO_2 during the first 1.5-min or mean VO_2 during the 5-min work interval. In addition, any potential difference in physiological response due to the difference in warm-up should mainly be localized to the beginning of the first interval, while the present statistics are based on mean values from all 5 work intervals.

The time ≥ 90% VO_{2peak} in DEC and TRAD was 12.0 min and 10.8 min, respectively. To the best of our knowledge no previous study has used a similar protocol focusing on time ≥ 90% VO_{2peak}. The study with the closest approach was performed on sub-elite runners who performed ~5 intervals with a duration of ~5 min with ~3 min of recovery in between.[24] Interestingly, their values were in the same range as our TRAD group in time ≥ 90% VO_{2peak} (10.5 vs. 10.8 min), indicating similar responses in the cardiovascular system in the exercise mode of running and skating on roller-skis.In the present study, there was no statistical difference between DEC and TRAD on time ≥ 90% VO_{2peak}. However, the mean value showed an advantage of ~70 s more time ≥ 90% VO_{2peak} for DEC compared to TRAD. The smallest worthwhile enhancement in performance time for elite skiers is 0.4%[33], and therefore it can be hypothesized that in elite sport, this could be a relevant advantage in training stimulus. Indeed, recreationally-trained cyclists that spent ~100 s more time above ~90% VO_{2max} per training session achieved the largest improvement in VO_{2max} and power output at the lactate threshold.[7] The explanation for a higher mean VO_2 in DEC vs. TRAD with no significant difference between sessions in time ≥ 90% VO_{2peak} remains speculative. It could be that the reduction in speed to 85% of MAS during the last 3.5 min of each DEC work interval was too low to support a substantial time ≥ 90% VO_{2peak}, but sufficient to give a higher mean VO_2 than the TRAD session. Individual differences in fractional utilization of VO_{2peak} at lactate threshold could in theory contribute to the large variation in time ≥ 90% VO_{2peak} despite all participants exercising at the same percentage of MAS.[34,35] Indeed, a previous study has also observed large individual variations in time ≥ 90% VO_{2peak} even though a similar percentage of MAS was used.[10] In order to optimize the DEC session to induce the longest possible time ≥ 90% VO_{2peak}, the individual athlete should probably test different speeds in the different phases of the work interval. Furthermore, maybe future studies should consider taking into account individual differences in fractional utilization of VO_{2peak} at lactate threshold.

Both the peak and mean RPE was lower in DEC than TRAD, indicating that the athletes perceived the DEC protocol to be less demanding than the TRAD protocol, despite similar mean speed and a higher VO_2 during the work intervals. This was somewhat unexpected, since RPE during interval exercise is typically associated with HR and $[La^-]$[36], and there were no differences between DEC and TRAD in these variables. A reduction in RPE by using a fast start strategy has been observed previously[12], but contrasting findings exists.[16] Billat et al.[14] suggested that RPE is directly related to the power output at any instant of the exercise. Therefore, it can be suggested that the assumed higher perceived effort induced by the higher speed during the first 1.5 min in DEC is counteracted by the lower speed during the last 3.5 min, leading to a lower RPE overall. The reduced RPE can be linked to previous observations of improved exercise tolerance[30] and performance[13,29,37] with a fast start strategy compared to a more even distribution strategy. Consequently, we can hypothesize that the higher VO_2 in the first 2 min saves the limited anaerobic capacity and therefore the athletes are further away from exhaustion when finishing the work intervals and thus experience a lower exertion. Furthermore, changing the exercise intensity and breaking up a monotonous exercise can increase the rate of perceived enjoyment[38] and may thus also contribute to explain the lower RPE in DEC vs. TRAD. The lower RPE after DEC is likely to be an important practical finding since we know that well-trained trained XC skiers perform a high training volume (usually from 12 to 25 weekly training hours) including ~ two weekly HIT sessions.[2,39] When performing such a high training volume year after year with regular HIT sessions, it could be hypothesized that a lower RPE of the DEC protocol may be beneficial in terms of mental wellbeing, and avoiding overtraining.[40] Importantly, the latter has yet to be investigated in longitudinal studies.

It has been shown that a HIT session can acutely impair neuromuscular function.[41] Power output in the lower-body has been found to be a valid tool to measure both fatigue and recovery of neuromuscular function following HIT sessions.[42] A decline in leg press peak power was expected from before to after the HIT session, but this was not observed in any of the sessions. It could be speculated that the warm-up to the leg press before the HIT session was insufficient and thus limited the leg press performance. However, the similar warm-up in DEC and TRAD and no differences between them in changes in leg press peak power from before to after the HIT session indicates no differences between sessions in recovery demand of the contractile function in the lower-body muscles. It also indicates that if earlier recruitment and fatigue of type II fibers contributes to the increased mean VO_2 in DEC, then the type II fibers involved in leg press peak power had recovered during the 5-min break between the HIT session and the peak power test. The present study did not perform any measurement of upper-body recovery and did not investigate other important factors that need recovery, like the glycogen stores.

Practical application

The DEC strategy may be a good alternative to TRAD if the main aim of the HIT session is to accumulate more time at a high percentage of VO_{2peak}. However, whether this culminates into superior long-term adaptations needs to be investigated in longitudinal studies. Importantly, a lower RPE was noted after DEC compared to TRAD, which can be important to consider in terms of mental wellbeing. In terms of recovery of the contractile function in the lower body, there seems to be no difference between DEC and TRAD. However, the long-term demands of recovery are uncertain, so it is important to carefully monitor the training response and recovery needs. The present DEC protocol utilized a similar approach for all athletes where all work intervals started with 1.5 min at 100% of MAS followed by 3.5 min at 85% of MAS. This approach did not take into account differences in fractional utilization of VO_{2peak} at lactate threshold and was likely not optimal for all athletes. Therefore, if a coach or athlete plans to test out this principle of organizing the HIT session, the exact exercise intensities and durations during the DEC work interval should be individualized in order to achieve the desired stimulus.

Conclusion

DEC induced higher maximum and average VO_2 values during the session, as well as lower RPE, than TRAD. This was supported by the ES showing a moderate practical effect of DEC on both maximum and average VO_2 and a small practical effect on the RPE. Finally, there was no difference between DEC and TRAD in leg press peak power output after the HIT sessions.

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FIGURES

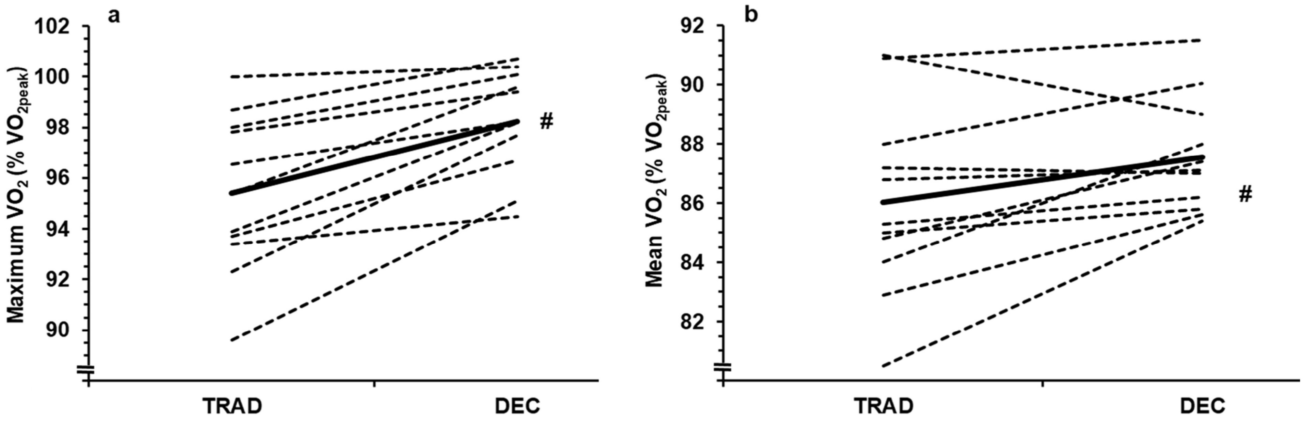

Figure 1 Individual data points (dotted lines) and mean value (solid line) for maximum oxygen consumption (percent of peak oxygen consumption (VO_{2peak}); panel a) and mean oxygen consumption (percent of VO_{2peak}; panel b) during a 5x5-min HIT session with a fast start and declining speed (DEC) or a more traditional evenly-distributed speed with the same mean speed as DEC (TRAD). # Significant difference between sessions ($p < 0.05$).

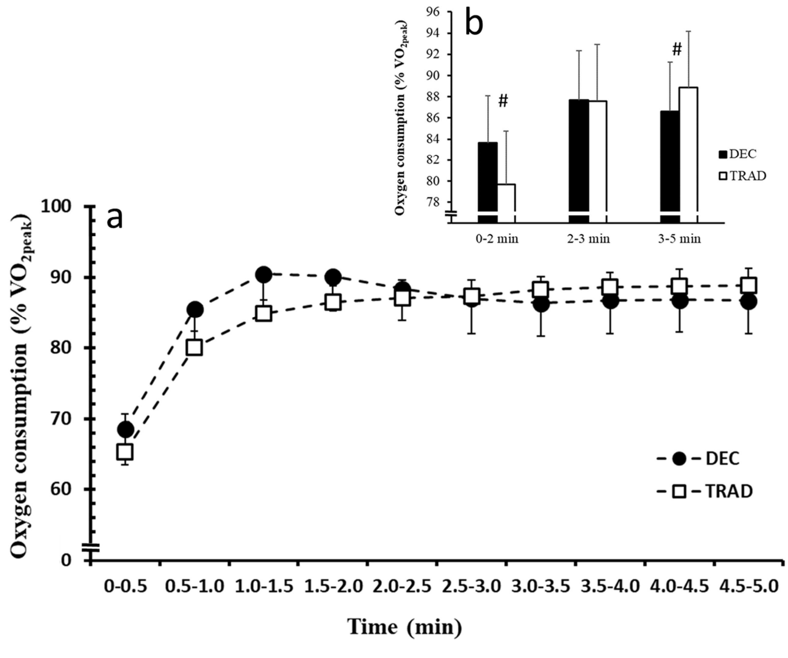

Figure 2 Average VO_2 for all 5 work intervals during the HIT session with a fast start and declining speed (DEC) or a more traditional evenly-distributed speed with the same mean speed as DEC (TRAD; panel a). The statistical analyses were performed by comparing mean values during the first two minutes, the third minute and during the two last minutes of all work intervals (panel b).

Significant difference between sessions for mean values during the first and last 2-min periods ($p < 0.05$).

Table 1 Data from the 5x5-min HIT sessions with a fast start and declining speed (DEC) or a more traditional evenly-distributed speed with the same mean speed as DEC (TRAD).

	DEC	TRAD	Effect size
Mean velocity ($km \cdot h^{-1}$)	11.3 ± 0.8	11.3 ± 0.8	
External workload (W)	278 ± 31	280 ± 27	
Maximum VO_2 measure (% VO_{2peak})	98.2 ± 2.1#	95.4 ± 3.1	0.95
Mean VO_2 (% VO_{2peak})	87.6 ± 1.9#	86.1 ± 3.2	0.56
Time ≥90% of VO_{2peak} (min)	11.95 ± 4.08	10.84 ± 5.72	
Maximum HR measure (% HR_{peak})	97.7 ± 2.2	97.2 ± 1.8	
Mean HR (% HR_{peak})	92.9 ± 2.2	92.5 ± 1.5	
Time ≥90% of HR_{peak} (min)	20.32 ± 2.52	19.75 ± 1.84	
Maximum $[La^-]$ measure ($mmol \cdot L^{-1}$)	9.25 ± 3.76	8.87 ± 2.86	
Mean $[La^-]$ ($mmol \cdot L^{-1}$)	7.84 ± 2.78	7.62 ± 2.16	
Maximum RPE measure	17.5 ± 1.4#	18.1 ± 0.8	0.48
Mean RPE	16.1 ± 1.0#	16.5 ± 0.7	0.41

VO_{2peak}: peak oxygen consumption during the incremental VO_{2peak} test; HR_{peak}: peak heart rate during the incremental VO_{2peak} test; $[La^-]$: blood lactate concentration after the work intervals; RPE: rate of perceived exertion after the work intervals. Values are mean±SD.
#Different from TRAD (p<0.05).