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Title:
Competitive cross-country skiers have longer time to exhaustion than recreational cross-country skiers during intermittent work intervals normalized to their maximal aerobic power.

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ABSTRACT

Purpose: To investigate differences in time to exhaustion (TTE), O_2 uptake ($\dot{V}O_2$) and accumulated O_2 deficit (O_2^{def}) between competitive and recreational cross-country (XC) skiers during an intermittent interval protocol standardized for maximal aerobic power (MAP). ***Methods:*** Twelve competitive (maximal $\dot{V}O_2$; $\dot{V}O_{2max}$=76.5±3.8 mL·kg^{-1}·min^{-1}) and ten recreational ($\dot{V}O_{2max}$=63.5±6.3 mL·kg^{-1}·min^{-1}) male XC skiers participated. All tests were performed on a rollerski treadmill in the V2 ski skating technique. To quantify MAP and maximal accumulated oxygen deficit (MAOD), the skiers performed a steady state sub-maximal test followed by a 1000-meter time-trial (1000-m TT). After a 60 min break, TTE, $\dot{V}O_2$ and accumulated O_2^{def} was measured during an intermittent interval protocol (40 s work and 20 s recovery), which was individually tailored to 120 and 60% of each subject's MAP. ***Results:*** During the 1000-m TT, the competitive skiers had 21% (95%CI=12-30%) shorter finish time and 24% (95%CI=14-34%) higher MAP (all P<0.01) than the recreational skiers. No difference was observed in relative exercise intensity (average power/MAP) (P=0.28), MAOD (P=0.18) or fractional utilization of $\dot{V}O_{2max}$. During the intermittent interval protocol, the competitive skiers had 34% (95%CI=3-65%) longer TTE (P=0.03) and accumulated 61% (95%CI=27-95%) more O_2^{def} (P=0.001) than the recreational skiers during work phases. ***Conclusion:*** Competitive XC skiers have longer TTE and accumulate more O_2^{def} than recreational XC skiers during an intermittent interval protocol at similar intensity relative to MAP. This implies that performance in intermittent endurance sports is related to the ability to repeatedly recharge fractions of MAOD.

Endurance, performance, supra-maximal intensity, oxygen-deficit, oxygen-uptake

INTRODUCTION

Endurance sports performance is generally dependent on performance oxygen uptake ($\dot{V}O_2$) and gross efficiency (GE). Some endurance sports, like cross-country (XC) skiing and road cycling, are characterized by large fluctuations in intensity due to both environmental factors and equipment used [1-4]. Research has demonstrated that an athlete's ability to maintain a high mean power output, repeat high-intensity efforts, and perform an all-out sprint to the finish line while avoiding a strong positive pacing, even as fatigue develops, is critical for optimal performance in these types of endurance sports [5-7]. Athletes who engage in these sports must therefore frequently transition between sub- and supra-maximal (e.g., exceed the maximal aerobic turnover rate) efforts during a race, and thereby repeatedly derive energy from anaerobic pathways [1,2,8]. This results in frequent accumulation and recovery of O_2 deficit (O_2^{def}) when racing. During a simulated XC skiing distance race (15 km, ~30-35 min), Gløersen, et al. [1] reported O_2^{def} on average to be accumulated in bulks of < 20% of the maximal accumulated oxygen deficit (MAOD), and no more than 50% of MAOD. The total accumulated O_2^{def} was, however, approximately four times larger than MAOD, suggesting significant recovery of O_2^{def}. Therefore, it appears that it is not simply the capacity of MAOD that matters to the specific endurance ability, but also the ability to repeatedly recharge fractions of MAOD, and thereby accumulate a large total of O_2^{def} during a race.
Several studies have investigated intermittent exercise performance in untrained to highly trained subjects. Some studies focus on the critical power concept and consider the ability to work above critical power to be of significance [9-11]. They conclude that this ability is dependent on oxidative processes. A greater aerobic power could therefore possibly enhance an intermittent exercise performance, allowing not only to work at a higher intensity at any given rate of O_2^{def} accumulation, but also to recover more accumulated O_2^{def} during sub-maximal intensities. Furthermore, the increased recovery could allow for a larger total of O_2^{def} to be accumulated before exhaustion. It is, however, not known to which degree the ability to accumulate a larger total of O_2^{def} is related to the performance level of XC skiers.
The purpose of the present study was therefore to investigate differences in time to exhaustion (TTE), $\dot{V}O_2$ and O_2^{def} accumulated between recreational and competitive XC skiers during an intermittent interval protocol standardized for maximal aerobic power (MAP). We hypothesized that the ability to repeatedly accumulate and recover O_2^{def} would be related to performance level. If true, this could provide novel and valuable practical information for coaches and athletes alike, helping to clarify the physical demands of the sport and guide the specificity of physical training.

METHODS

Participants

Twelve competitive and ten recreational male XC skiers were recruited. According to McKay, et al. [12] the participants within the competitive group should be classified as highly trained and elite XC skiers that regularly participated in national and international races, while the recreational XC skiers should be classified as trained and highly trained. All participants were familiar with rollerski on treadmill prior to the experiment. There were no differences between the two groups with regards to age (24 ± 5 vs. 26 ± 3 yrs, $P = 0.322$), height (183 ± 7 vs. 181 ± 6 cm, $P = 0.552$), or bodyweight (76.2 ± 4.5 vs. 79.1 ± 6.9 kg, $P = 0.258$). All participants gave their written, informed consent. The study was approved by the ethics committee of the Norwegian School of Sport Sciences (138-180620) and registered by the Norwegian Center for Research Data. The research was conducted according to the Declaration of Helsinki.

Design

This study consisted of three different protocols conducted on a rollerski treadmill within a single session lasting 2.5 h. The first part consisted of two baseline protocols determining the individualized intensity applied in the third and main protocol performed in the second part of the study. All testing was performed with the V2 ski skating technique (also referred to as "G3" or "double dance"), a technique utilized at moderate to high velocities involving a synchronized double poling thrust for each ski push-off.

Methodology

Sub-maximal Test and 1000-meter Time-Trial

A detailed description of the first part is presented in Losnegard, et al. [13] and is only briefly summarized here. After a ten min warm-up consisting of low-intensity skiing, participants completed three to four sub-maximal bouts lasting five min each to measure individual gross efficiency (GE). The intensity of each load was increased by adjusting incline (range 2.5-7.0°) in increments of 0.5° while keeping velocity constant at 3 $m{\cdot}s^{-1}$. Then, the participants performed 15 min low-intensity skiing (< 70% of max heart rate; HR_{max}) followed by a 20 s burst at the start pace of the succeeding 1000-m time-trial (1000-m TT). Thereafter, they rested in a stationary standing position for two min, before completing the approximately 4-6 min long 1000-m TT to measure maximal O_2 uptake ($\dot{V}O_{2max}$) and maximal accumulated oxygen deficit (MAOD).

Intermittent Interval Protocol

After the 1000-m TT, participants had a 45 min passive recovery followed by a warm-up consisting of 15 min low-intensity skiing, which culminated in a 20 s burst at the pace selected for the high-intensity phases of the succeeding TTE intermittent interval protocol. After standing still for 2 min, all participants completed the intermittent interval protocol at the same intensity relative to MAP. The intermittent interval protocol consisted of two types of phases repeating in cycles; recovery phases lasting 20 s at 60% MAP, followed by work phases lasting 40 s at 120% MAP, resulting in each 60 s cycle averaging an intensity of 100% MAP. The intensity was tailored to each participant's MAP by adjusting the incline (range 2.6-5.1 °) while keeping the velocity of the two phases at 2.75 and 5.50 $m{\cdot}s^{-1}$, respectively. Velocity was kept within this range so that it would be suited for the V2 ski skating technique. The test was concluded when the participant was no longer able to keep the front wheels of the skis in front of a laser beam placed 130 cm from the front of the treadmill. Participants were verbally informed about the time remaining of the current phase, usually after having completed ½ and ¾ of the phase. Additionally, the final three seconds of the phase were counted out loud. Participants were also able to see the remaining time of the current phase on a screen in front of them. Participants were otherwise, neither verbally nor in any other way, intentionally encouraged or motivated to endure during the protocol by testing personal. $\dot{V}O_2$ was measured during the entire protocol. Heart rate (HR), rate of perceived exertion (RPE; 6-20 scale [14]) and blood plasma lactate concentration ($[La^-]$) were monitored to evaluate individual effort.

Apparatus

All tests were performed on a 3 × 4.5 m treadmill (Rodby, Södertalje, Sweden). $\dot{V}O_2$ was measured using an automatic ergo-spirometry system with a mixing chamber setup (Oxycon Pro; Jaeger Instruments, Höchberg, Germany), as previously validated for steady state exercise by Foss, Hallén [15]. $[La^-]$ was measured using a Biosen C-Line GP+ lactate analyzer (Biosen C-line; EKF Diagnostic, Cardiff, United Kingdom). All participants wore the same pair of Swenor Skate Long (Sarpsborg, Norway) rollerskis with wheel type 1 (coefficient of rolling resistance; $C_{rr} = 0.014$) and NNN ski binding (Rottefella, Lier, Norway). The participants used pole type Swix Triac 3.0 (Swix Sport, Lillehammer, Norway) with a pole length of 90 ± 1% of body height. The participants wore their personal ski boots and HR monitor. Body mass was measured using an electronic body mass scale (Seca model nr: 877; Seca GmbH & Co., Hamburg, Germany).

Calculations

$\dot{V}O_{2max}$ was defined as the highest 60 s average during the 1000-m TT. MAP was defined as the propulsive power output (P_{prop}) corresponding to $\dot{V}O_{2max}$, based on the assumption of a constant $\dot{V}O_2$ to P_{prop} ratio. P_{prop} was defined as the mechanical energy needed to overcome gravity and friction, calculated using the following equation:

$$P_{prop} = m_{BW+E} \cdot g \cdot v \cdot (sin(\theta) + C_{rr} \cdot cos(\theta)) \qquad (1)$$

where m_{BW+E} is the combined mass of the subject and equipment, $g = 9.81 m \cdot s^{-2}$ is the acceleration due to gravity, v is the velocity of the treadmill, $C_{rr} = 0.014$ is the coefficient of rolling resistance, and θ is the treadmill inclination angle.

Calculating MAP, we assumed a constant $\dot{V}O_2$ to P_{prop} ratio which was determined for each of the sub-maximal bouts, and the average ratio was termed Eco. MAP was then calculated using the following relation:

$$MAP = \frac{\dot{V}O_{2max}}{Eco} \qquad (2)$$

Since the intermittent interval protocol used identical velocities (2.75 and 5.50 $m \cdot s^{-1}$) for all participants, the treadmill incline was calculated individually to ensure that P_{prop} was 120% MAP during the work phases and 60% MAP during the recovery phases. This was done by applying the first order Taylor approximation and solving Equation 1 for θ, resulting in Equation 3:

$$\theta_{IP}\ [\text{rad}] = \frac{x \cdot MAP}{m_{BW+E} \cdot g \cdot v} - C_{rr} \qquad (3)$$

where θ_{IP} (in radians) yields the incline for the work phases by inserting x = 1.2 and v = 5.5, and for the recovery phases by inserting x = 0.6 and v = 2.75 (within a small error margin introduced by the first order Taylor approximation).

Gross efficiency was defined as P_{prop} divided by metabolic rate, which was calculated in accordance with the procedure of Garby, Astrup [16]. Regarding MOAD, it is independent of duration for maximal trials lasting two min or longer [17], and we therefore calculated it as previously done by Losnegard, et al. [18], subtracting the average $\dot{V}O_2$ from the average O_2 demand (O_2^{dem}) of the 1000-m TT. The highest 30 s average $\dot{V}O_2$ of the intermittent interval protocol was termed $\dot{V}O_{2peak}$.

The overall O_2^{dem} of the 1000-m TT was calculated from the average P_{prop} during the test. For the intermittent interval protocol, P_{prop} and O_2^{dem} were calculated for every second. $O2^{dem}$ was calculated by the following relation:

$$O_2^{dem} = \frac{P_{prop} \times Eco}{m_{BW+E}} \qquad (4)$$

The O_2^{def} accumulated and recovered was calculated by subtracting the O_2^{dem} from the $\dot{V}O_2$.

Statistical Analysis

Normality of data distribution was checked using a Shapiro-Wilk Test. Generally, for normally distributed data, group differences were analyzed with independent-samples t-test, while skewed data were analyzed with a non-parametric Mann-Whitney test. Due to the nature of the intermittent interval protocol with repeated measures, and the fact that not all participants conducted the same number of intervals, group differences in subsequent and cumulative O_2^{def} were analyzed using a mixed-effects model (REML), followed by a Bonferroni's post-hoc correction for multiple comparisons. Sample averages are reported with sample standard deviation (SD). Group differences are reported in relative values with 95% confidence intervals (95%CI). The threshold for statistical significance was defined as $\alpha = 0.05$. In tables and figures, $P < 0.05$ is indicated by a single asterisk, while $P < 0.01$ is indicated by a double asterisk. Figures are constructed using GraphPad Prism version 9.1.0

(GraphPad Software, San Diego, CA) and statistic using SPSS version 24.0.0.2 (IBM Corp., Armonk, NY) and GraphPad Prism 9 (San Diego, CA, USA).

RESULTS

Sub-maximal Test and 1000-meter Time-Trial

The 1000-m TT time, relative exercise intensity (average power / MAP), $\dot{V}O_{2max}$, GE, MAP and MAOD are shown in Table 1 for both groups. The competitive skiers had shorter 1000-m TT time than the recreational skiers, with no difference in relative exercise intensity or MAOD during the test. The competitive skiers also had higher GE and $\dot{V}O_{2max}$, which resulted in higher MAP compared to the recreational skiers. The competitive skiers reported lower RPE after the 1000-m TT (18.1 ± 1.0 vs. 19.1 ± 1.0, $P = 0.027$), while HR_{peak} (189 ± 9 vs. 192 ± 12 bpm, $P = 0.476$) and $[La^{-}]_{peak}$ (11.6 ± 1.7 vs. 12.9 ± 3.2 mmol·L^{-1}, $P = 0.232$) were not different between groups.

Intermittent Interval Protocol

The competitive skiers had 34% (95%CI = 3.2-65%) longer TTE than the recreational skiers (473 ± 141 vs. 353 ± 94 s, $P = 0.032$) (Figure 1). The recreational group averaged six cycles of recovery and work phases, while the competitive group averaged eight. No difference between the two groups was observed in RPE (18.4 ± 1.0 vs. 18.3 ± 1.3, $P = 0.810$), $[La^{-}]_{peak}$ (11.4 ± 2.2 vs. 11.5 ± 2.1 mmol·L^{-1}, $P = 0.943$) or HR_{peak} (191 ± 9 vs. 192 ± 10 beat per minute, $P = 0.734$).

Average $\dot{V}O_2$ and O_2^{dem}, along with the number of participants remaining for both groups, is shown in Figure 2. Relative to $\dot{V}O_{2max}$, $\dot{V}O_2$ for the competitive skiers was 8% (95%CI = 3-13%) lower during the first minute (43 ± 2 vs. 47 ± 3% of $\dot{V}O_{2max}$, $P = 0.005$), and 3% (95%CI = 0-6%) lower the second minute (86 ± 3 vs. 89 ± 3% of $\dot{V}O_{2max}$, $P = 0.028$) compared to the recreational skiers. However, there was no difference in $\dot{V}O_2$ after the second minute, nor in $\dot{V}O_{2peak}$ relative to $\dot{V}O_{2max}$ (99 ± 3 vs. 101 ± 3% of $\dot{V}O_{2max}$, $P = 0.113$) between the two groups. The average O_2^{dem} relative to $\dot{V}O_{2max}$ was not different between groups during TTE (100.0 ± 0.5 vs. 100.0 ± 0.8%, $P = 0.494$).

The O_2^{def} accumulated and recovered for each phase, along with the cumulative O_2^{def} from phase to phase, is shown in both absolute values (Figure 3a) and relative to MAOD (Figure 3b). For absolute O_2^{def}, there was an interaction effect and a main effect of group (both $P < 0.001$). O_2^{def} relative to MAOD showed no interaction effect ($P = 0.182$) but a main effect ($P < 0.001$). There was also an interaction effect and a main effect of group for cumulative O_2^{def}, both in absolute values and relative to MAOD (both $P < 0.001$). Post-hoc tests showed a group difference after each of the first six recovery and work phases, except for the very first recovery phase (W1 and R2; $P < 0.05$, W2-W6 and R3-R6; $P < 0.001$). The competitive group's larger accumulation of O_2^{def} occurred in recovery phase R1 and work phase W1-W4 (all $P < 0.001$) (Figure 3a). Relative to MAOD, a group difference was only present after the first work phase ($P < 0.001$).

The competitive group accumulated 61% (95%CI = 27-95%) larger total of O_2^{def} during work phases ($P = 0.001$) and recovered 63% (95%CI = 5-121%) larger total of O_2^{def} during recovery phases ($P = 0.035$) than the recreational skiers. In total, this resulted in 60% (95%CI = 24-96%) larger net accumulation of O_2^{def} after TTE ($P = 0.002$) for the competitive group (Figure 4a).

<<Table 1 and Figure 1-4 near here>>

DISCUSSION

The present study showed that competitive XC skiers had longer TTE and accumulated more O_2^{def} than recreational XC skiers, when normalizing an intermittent interval protocol to MAP.

Thus, this "endurance ability" is likely a key determinant of performance in intermittent endurance sports that to date is not well elucidated.
Although we found the competitive skiers to have longer TTE during the intermittent interval protocol, we found the fractional utilization of $\dot{V}O_{2max}$ to be mostly similar for both groups during TTE (Figure 2b). This implies they both had a similar relative energy contribution from aerobic and anaerobic energy sources during the intermittent interval protocol, while also having a similar MAOD (Table 1). Because the competitive group had higher MAP, yet performed the intermittent interval protocol at the same relative intensity as the recreational group, their absolute intensity was higher. Similar fractional utilization of $\dot{V}O_{2max}$ at a higher absolute intensity would result in both higher absolute aerobic and utilized a larger portion of their anaerobic capacity during each work phase, yet they still were able to achieve a longer TTE. Thus, it could be they were able to compensate by also recovering more accumulated O_2^{def} during each recovery phase (higher rate of recovery). Our results were, however, not able to demonstrate this (Figure 4c and 4d). Furthermore, according to our results, the competitive group accumulated 11% more O_2^{def} during the intermittent interval protocol than during the continuous 1000-m TT (total net O_2^{def} accumulated > MAOD), while the recreational group seemingly did not, as their total net O_2^{def} accumulated was 23% lower than their MAOD (Figure 4b). These inconsistencies may be due to an underestimation of the true O_2^{dem} throughout the test, as our applied methods did not allow for continuous measuring of GE, and the dynamic nature of GE could therefore not be accounted for. It has been demonstrated that GE is negatively affected by high-intensity work, and that the recovery of GE after such work is relatively slow.[19-21] Grasaas, et al. [19] showed that GE in male XC skiers they classified as elite was reduced after exercise to exhaustion with an intensity similar to the intermittent interval protocol in the present study. It is possible that our recreational skiers were more susceptible to a severe decrease in GE because of an earlier onset of muscular fatigue and/or struggling more with their form at the high velocity, thus were exposed to a higher O_2^{dem} in reality than estimated. This would invalidate our measurements of the O_2^{def} accumulated and recovered, allowing the possibility of the competitive group recovering more accumulated O_2^{def} during each recovery phase than the recreational group, and also the possibility that the recreational skiers might in reality have accumulated a larger total net O_2^{def} than estimated; equal to, or even greater than, their MAOD. Due to these uncertainties, we would recommend interpreting these results with caution.
The specific mechanisms related to recovering accumulated O_2^{def} were beyond the scope of the present study, as the mixing chamber setup (due to the high ventilation rates of our participants, see methods) denied us detailed analysis of $\dot{V}O_2$-kinetics. However, in future research, the mechanics could possibly be examined using the framework provided by the critical power (CP) concept; a currently developing theory, attempting to model the hyperbolic relationship between the power output and the tolerable duration within the domain of severe intensity [22]. Because the capacity to perform work above the critical power (W') depends on aerobically replenished intra-muscular energy substrates [23] and fatiguing metabolites [24-26], it can be recovered through oxidative processes determined by aerobic characteristics, such as $\dot{V}O_{2max}$ [10,27] and $\dot{V}O_2$ kinetics [28]. The inter-individual variability of the bi-exponential recovery course of W' [27] is, however, shown be quite large [9,29-32], and might therefore to some degree explain the difference in TTE.

Practical Applications

First, the present study shows that competitive skiers can repeat more work bouts than recreational skiers when performing at a similar intensity relative to MAP. Thus, to increase performance level, athletes should not only improve their physical capacity to match higher performance level athletes' relative intensity, but also their ability to repeat high-intensity efforts at the required relative intensity. Second, training load within a single session can be managed by adjusting intensity, duration and/or breaks, and the present findings support the notion that the duration of work and recovery phases during high-intensity intermittent exercise should be different between performance levels of athletes to obtain similar relative training load. Higher performance level athletes should therefore train at higher intensity and/or longer duration than lower performance level athletes, and/or shorten the breaks to achieve an appropriate training load. Finally, valid performance tests in the lab are mandatory for researchers and practitioners to determine physiological abilities of skiers. Moreover, because specific performance tests seem important to predict intensified training changes in elite athletes with stable $\dot{V}O_{2max}$ [13], the intermittent interval protocol utilized in the present study might serve as an alternative method to regularly test high level skiers.

CONCLUSION

Competitive XC skiers have longer TTE and accumulate more O_2^{def} than recreational XC skiers during an intermittent interval protocol at similar intensity relative to MAP. This implies that performance in intermittent endurance sports is related to the ability to repeatedly recharge fractions of MAOD.

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Author Contributions
EH, MLH, ØG and TL conceived and designed research. EH and MLH conducted experiments. EH, ØG and TL analyzed data. EH, ØG and TL wrote the manuscript. All authors read and approved the manuscript.

Statements and Declarations
The authors declare no conflict of interest and have no financial stakes in the products used in the study.

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Figure 1: Time to exhaustion during the intermittent interval protocol. COM: competitive skiers. REC: recreational skiers. Large vertical line: group average. Pair of smaller vertical lines: SD.

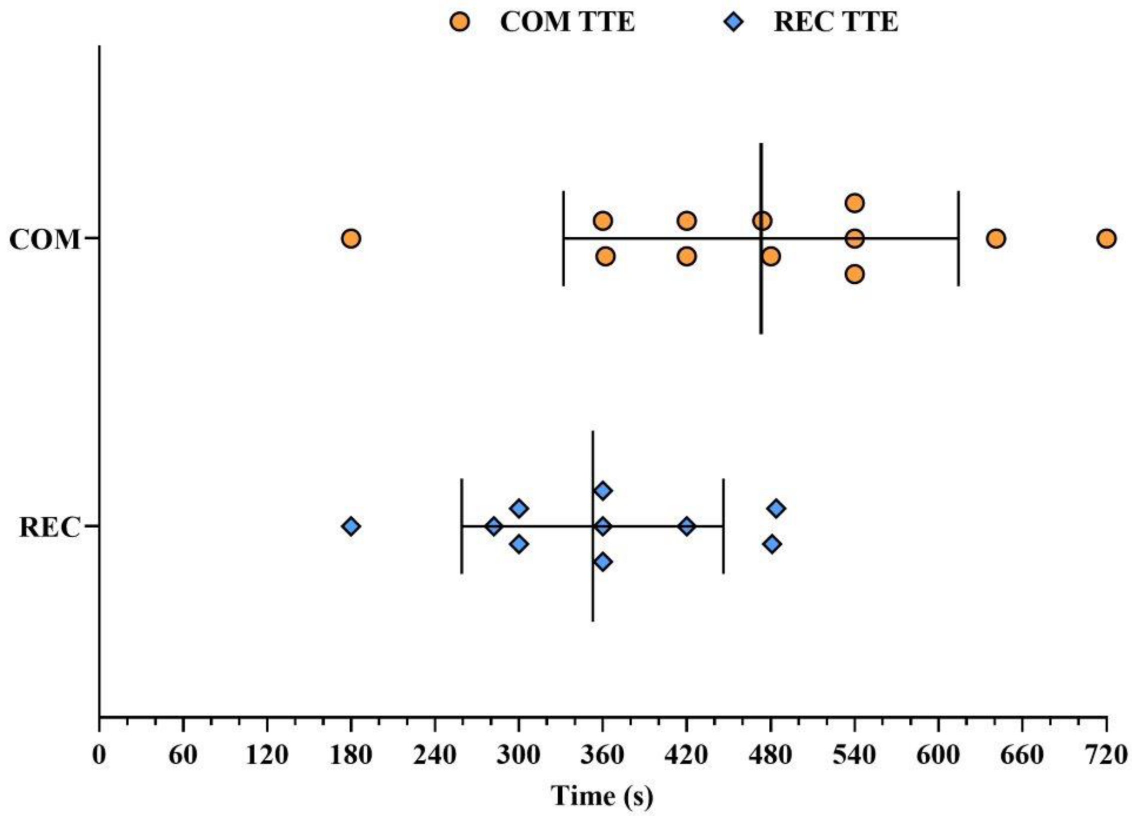

Figure 2: Average O_2 uptake ($\dot{V}O_2$) and O_2 demand (O_2^{dem}) per time, along with number of participants remaining during the average time to exhaustion (TTE) of the intermittent interval protocol. COM: competitive skiers. REC: recreational skiers. Vertical semi-transparent dotted lines: TTE for individuals (only those with a shorter TTE than average). a) $\dot{V}O_2$ and O_2^{dem} are both expressed in ml·kg^{-1}. b) $\dot{V}O_2$ and O_2^{dem} are both expressed relative to the maximal O_2 uptake (%VO_{2max}). c) Number of participants remaining. $\dot{V}O_2$ and O_2^{dem} are plotted every five and every single second, respectively.

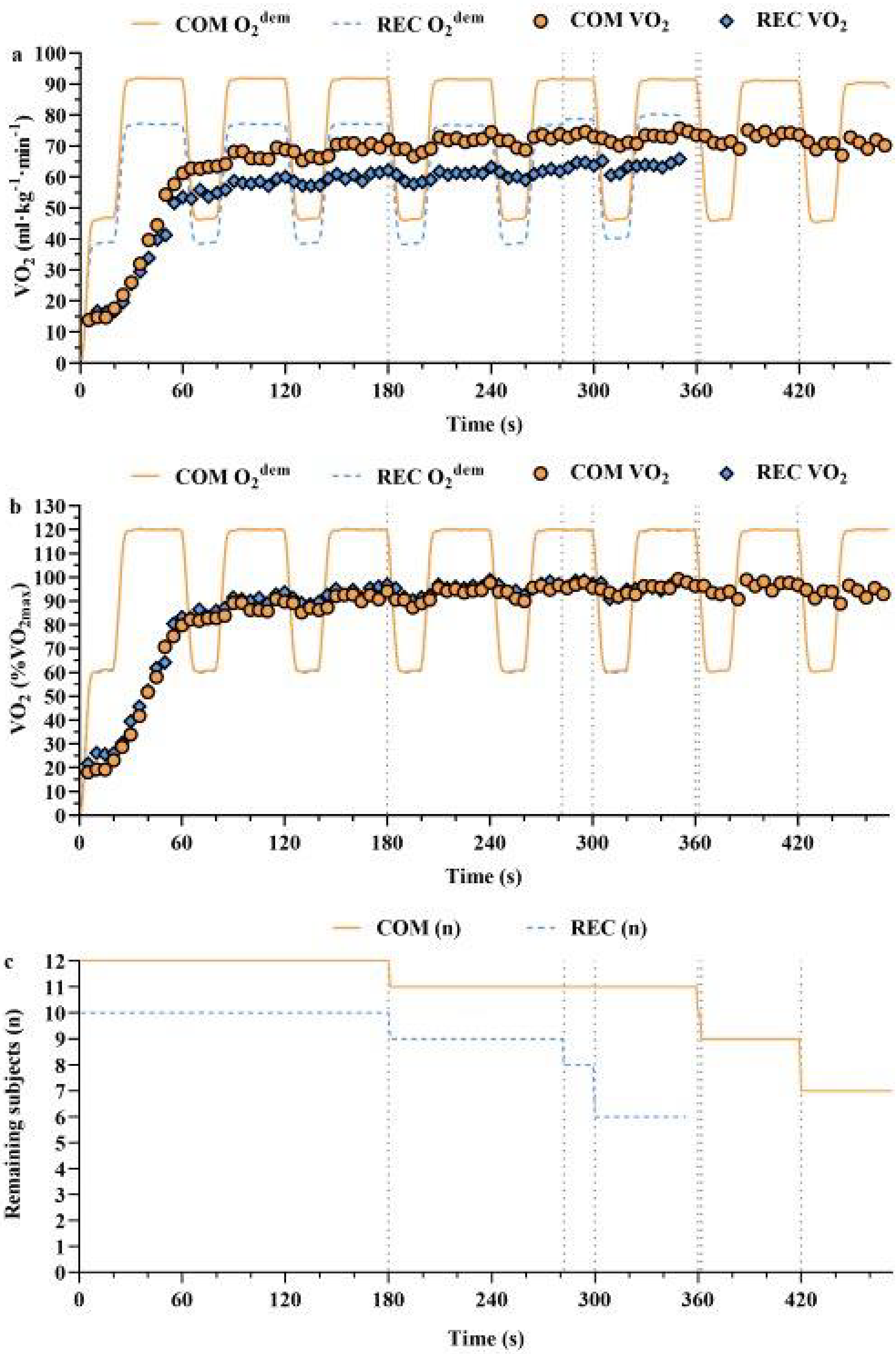

Figure 3: O_2 deficit (O_2^{def}) per time during the average time to exhaustion (TTE) of the intermittent interval protocol. COM: competitive skiers. REC: recreational skiers. Positive O_2^{def}: accumulated. Negative O_2^{def}: recovered. a) O_2^{def} is expressed in ml·kg^{-1}. b) O_2^{def} is expressed relative to the maximal accumulated oxygen deficit (%MAOD). Statistical significance is indicated at the bottom for O_2^{def} (*) and cumulative O_2^{def} (#). Single mark indicates $P < 0.05$, double mark indicates $P < 0.01$. Calculations for each phase only include participants who completed the respective phase. The treadmill save file for one recreational skier was lacking. Thus, neither O_2^{dem} nor O_2^{def} could be calculated for this subject, and the subject's data are entirely excluded from this figure.

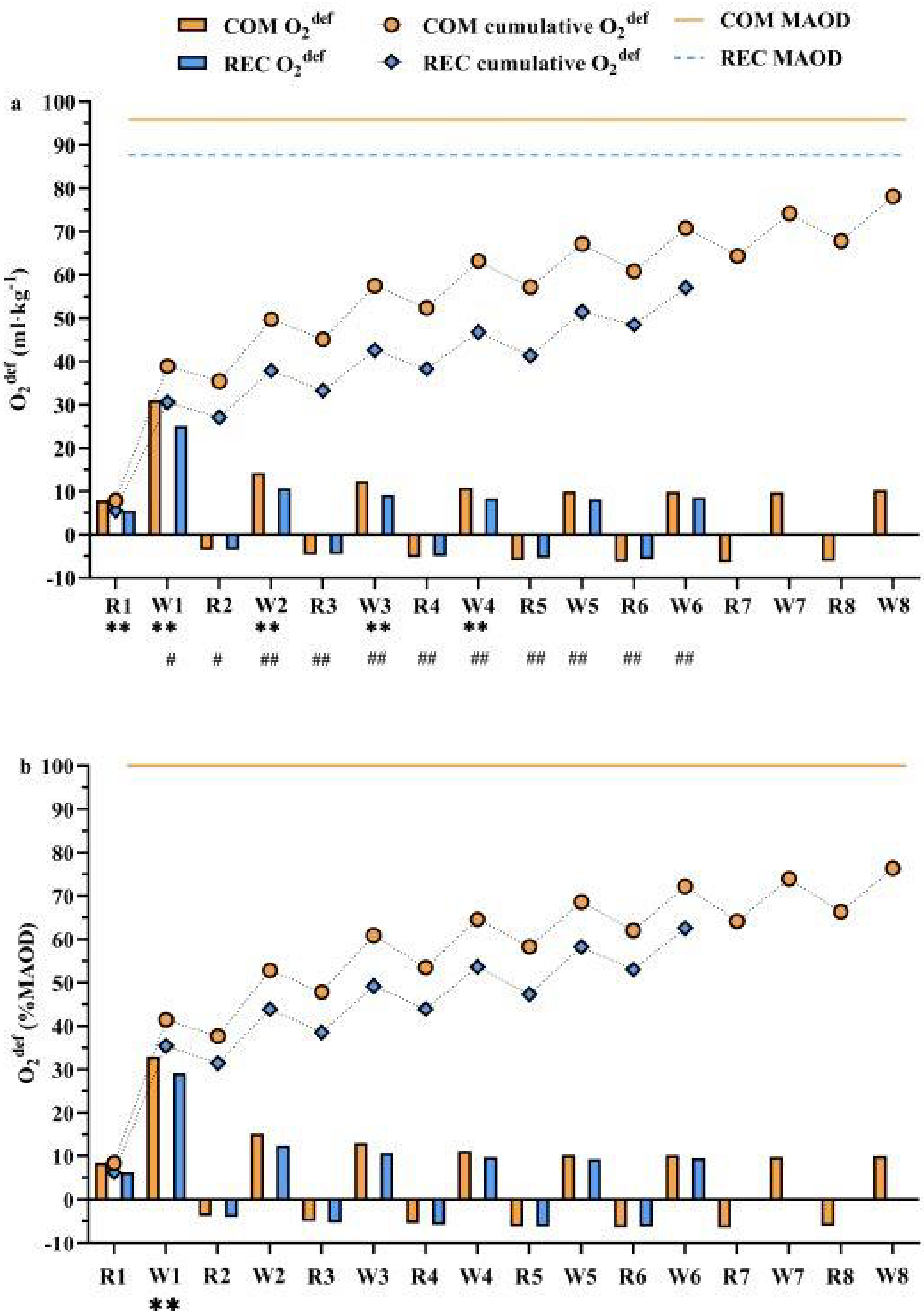

Figure 4: O_2 deficit (O_2^{def}), both total and average, during recovery and work phases, as well as net accumulation. COM: competitive skiers. REC: recreational skiers. Positive O_2^{def}: accumulated. Negative O_2^{def}: recovered. Large horizontal line: group average. Pair of smaller horizontal lines: SD. a) total O_2^{def} in ml·kg^{-1}. b) total O_2^{def} relative to the maximal accumulated oxygen deficit (%MAOD). c) average O_2^{def} in ml·kg^{-1}. d) average O_2^{def} in %MAOD. Single asterisk indicates $P < 0.05$, double asterisk indicates $P < 0.01$. The first cycle ($R_1 + W_1$) was excluded when calculating average O_2^{def}, due to the latency of $\dot{V}O_2$ in response to the onset of exercise. The treadmill save file for one recreational skier was lacking data. Thus, neither O_2^{dem} nor O_2^{def} could be calculated for this subject, and the subject's data are entirely excluded from this figure.

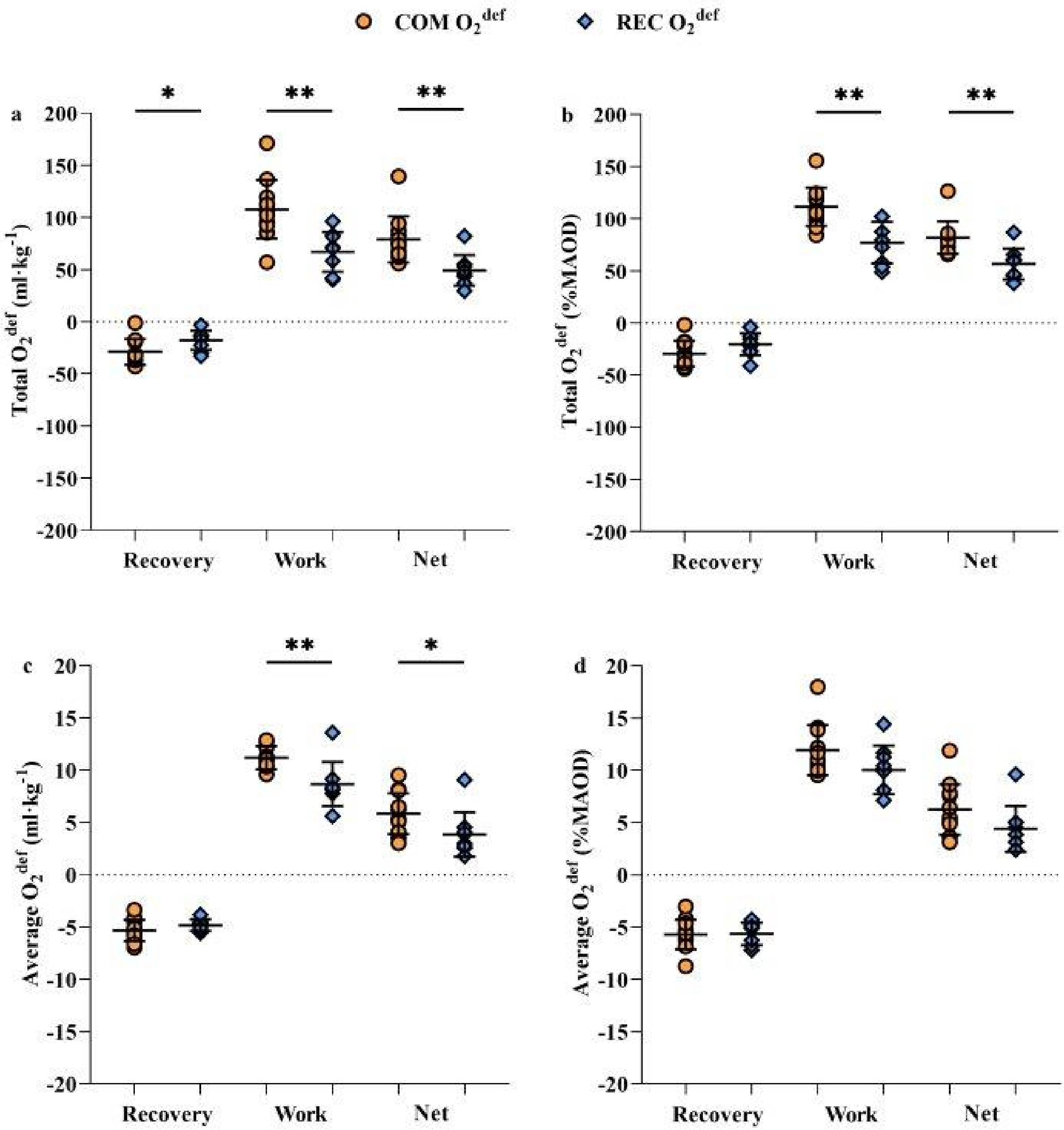

Table 1: Physiological comparison between the competitive and recreational group.

	Competitive (n = 12)	Recreational (n = 10)	Difference (%) [95%CI]
1000-m TT Time (s)	254 ± 18	321 ± 42	−21 [−30, −12] *
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	76.5 ± 3.8	63.5 ± 6.3	20 [13, 28] *
MAOD (ml·kg^{-1})	96 ± 13	88 ± 13	9 [−5, 23]
GE (%)	16.6 ± 0.9	15.5 ± 0.6	7 [2, 11] *
MAP (W)	330 ± 31	267 ± 25	24 [14, 34] *
1000-m TT Power (%MAP)	111 ± 5	114 ± 4	−2 [−5, 2]

1000-m TT Time = Time to finish during the 1000-meter time-trial. $\dot{V}O_{2max}$ = maximal O_2 uptake measured across 60 consecutive seconds during the 1000-m TT. MAOD = maximal accumulated oxygen deficit during the 1000-meter time-trial. GE = gross efficiency measured as average ratio between mechanical and metabolic power output during the sub-maximal test. MAP = maximal aerobic power calculated as the lowest mechanical power output yielding $\dot{V}O_{2max}$ according to the estimated skiing economy. 1000-m TT Power = average mechanical power output during the 1000-meter TT. Group values are reported in average ± standard deviation. Group difference is reported in percentage with 95% confidence interval [95%CI]. Asterisk (*) = significant difference between groups ($P < 0.05$).