Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

Henek Tomson

COMPARISON OF CONTEMPORARY INTENSITY DISTRIBUTION APPROACH AND INCREASED AMOUNT OF HIGH- OR LOW INTENSITY WHEN PROGRESSING TRAINING LOAD IN THE PREPARATION PERIOD OF CROSS-COUNTRY SKIERS.

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ABSTRACT

Background. Successful endurance athletes train a relatively large volume at low intensity endurance training, which is interspersed by relatively low volumes of high intensity training. There is, however, strong indications that an increase in high intensity training load would positively impact physiological determinants of endurance performance.

Purpose. The primary aim of this study was to examine the performance effects of progressing in training load by different training intensity distributions in incremental treadmill roller-ski skating test to voluntary exhaustion. Secondary aim was to investigate the adaptations in laboratory determinants of performance at submaximal and maximal intensity levels in pre- and post-training comparison.

Methods. Following a standardized 8-week baseline-training period, 59 well-trained junior cross-country skiers (male, n = 43; female, n = 16) completed an intervention training period of 8 weeks. The contemporary training model (CG) included athletes who maintained typical training pattern and was compared to load-matched increases in low intensity (LITG) and high intensity training (HITG) by using the training impulse model (TRIMP). Pre- to post changes in endurance performance and physiological performance-determining variables were compared while treadmill roller-ski skating at submaximal stages and during incremental roller-skiing to exhaustion.

Results. The training intensity distribution was 92-4-4%, 85-4-11% and 91-5-4% for LITG, HITG and CG in zone 1-2-3, which present low-, moderate- and high intensity, respectively. The main findings were: **(1)** the covariate-adjusted linear model failed to elicit significant group-differences in performance (i.e. time to exhaustion) and physiological adaptations (e.g. $\dot{V}O_2$peak, blood lactate concentration, gross efficiency); **(2)** within-group improvement in time to exhaustion was observed for HITG (9.7 ± 13.3%) and LITG (5.9 ± 10.4%) ($p < 0.01$, for both), whereas no change was found for CG; **(3)** HITG improved $\dot{V}O_2$peak (L·min^{-1}) significantly by 3.2 ± 5.1%, with values increasing from 4.30 ± 0.74 to 4.43 ± 0.68 L·min^{-1} ($p = 0.01$), while no change was detected in LITG and CG; **(4)** gross efficiency increased for LITG (0.4 ± 0.6%) and HITG (0.4 ± 0.5%) at first submaximal intensity ($p < 0.05$), and no change was evident in CG ($p = 0.19$); at second submaximal intensity improvement was similar for LITG and HITG (increase of 0.3 ± 0.5%, 0.3 ± 0.6%; $p < 0.01$, < 0.05, respectively) and no change was apparent in CG ($p = 0.23$).

Conclusions. This study found that training groups did not differ in time to exhaustion and physiological performance variables after completing a training period of 8 weeks. The within-

group improvements were largest in HITG, as pre- and post-training change in time to exhaustion and $\dot{V}O_2$peak was greater compared to the extent of improvement in two other training groups. In post-test, both HITG and LITG reduced oxygen cost and improved gross efficiency at submaximal intensities with a similar magnitude of change in relation to pre-test, oppositely absolute oxygen demand raised for CG in submaximal workload after the training period.
Key Words: endurance capacity, training intensity, peak oxygen uptake, time to exhaustion, gross efficiency, periodization model, cross-country skiing

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TERMS AND ABBREVIATIONS

XC | Cross-country

$\dot{V}O_2$ | peak Peak oxygen uptake

$\dot{V}O_2max$ | Maximal oxygen uptake

GE | Gross efficiency

HR | Heart rate

TTE | Time to exhaustion

RPE | Rating of perceived exhaustion

V2 or G3 | Ski skating sub-technique

LIT | Low intensity training (zone 1)

MIT | moderate intensity training (zone 2)

HIT | High intensity training (zone 3)

LITG | Low intensity training group

HITG | High intensity training group

CG | Contemporary training group

p | Level of significance

SD | Standard deviation

SE | Standard error

M_{adj} | adjusted mean

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INTRODUCTION

Competitive cross-country (XC) skiing is one of the most challenging endurance events, considering individual physiological responses to varying terrain, duration and intensity require high aerobic power and muscle efficiency to work at or often above lactate threshold (LT) a considerable amount of time, whereas in crucial moments (i.e. accelerating uphill) even exceeding maximal oxygen uptake ($\dot{V}O_2max$) intensity (1, 2). The latter aspect is especially true due to the characteristics of skiing courses that are approximately one third uphill according to international track criteria (3, 4). In addition, necessary propulsion from both active arms and legs raises the oxygen demand to the uppermost levels in endurance sports (3, 5). Accordingly, the $\dot{V}O_2max$ values close to 90 $mL \cdot kg^{-1} \cdot min^{-1}$ have been reported for elite male skiers (1, 6, 7). For female athletes the upper values of approximately 80 $mL \cdot kg^{-1} \cdot min^{-1}$ have been published in literature (8).

Approaching the upper limits of human endurance in terms of aerobic power is not achieved without substantial amounts of training (4, 9). At the highest levels, Norwegian and Swedish XC skiers have reportedly trained 750-950 hours per year for gold medal performance (1). A case study of a top female XC skier has demonstrated a remarkable total annual volume of more than 900h over 5 consecutive years (10). Subsequently, structuring an effective training program – with regards to adequate volume, frequency and intensity of endurance exercise –, is a topic contemplated by researchers, athletes and coaches alike.

Retrospective studies have indicated a tendency for endurance athletes to polarize their training intensity distribution (11-14). Heart-rate based quantification of training load in junor cross-country skiers revealed a 75-8-17% distribution in low, moderate and high intensity zone, respectively (14). Polarized pattern was also observed in the training data of Norwegian elite cross-country skiers and biathletes during the year, when they approached the most successful competition of the career (between 1985-2011), wherein 91% of the training time was accumulated below the first LT, while 9% was above it (15). Despite of this periodization trend, the actual intensity levels are reportedly at or above lactate threshold ($\geq$ 85% of $\dot{V}O_2max$) in all Olympic endurance races (16). In this regard, it is reasonable to question the effectiveness of training ~80% of the time in low intensity zone to enhance aerobic power.

HIT has resulted in large impact on $\dot{V}O_2max$ and peak performance determinants in many experimental studies (17-20). Gaskill et al. (21) demonstrated the effect of training intensification during the 2 year project with 14 XC-skiers. Low responders of the first year reversed their intensity distribution and more than doubled high intensity training hours. Subsequently they improved $\dot{V}O_2max$, lactate threshold and race points significantly over the second year. However, noteworthy is that the control group maintained similar high volume of low intensity and improved performance in the same way. In contrast, modest response has been shown to high intensity in already well-trained athletes (16, 22). For instance, Evertsen et al. (23) did not observe a significant increase in $\dot{V}O_2max$ over the 5-month period in junior XC-skiers who had relatively high baseline values (means ~73 and ~58 $ml \cdot kg^{-1} \cdot min^{-1}$ for male and female, respectively).

Diverse effects of different training intensification models leave substantial space to investigate physiological responses in well-trained athletes. Accordingly, the primary aim of current study was to investigate the effects of progressing training loads by using different intensity distribution on performance in time to exhaustion test. Secondary aim was to compare the laboratory determinants of performance between training groups and investigate the adaptations at submaximal and maximal intensity levels in elite junior cross-country skiers.

METHODS

OVERALL DESIGN

After 8 weeks of baseline training period, XC skiers were randomly allocated to an 8-week intervention, which adopted two distinctly different training intensity distribution models. First group of athletes (LITG) increased the volume of low intensity training and second group (HITG) increased high intensity volume. In parallel arm design, a third group proceeded with a traditional training routine. Study was designed in a way that intervention groups had similar total training load via integration of volume and intensity with training impulse (TRIMP) concept (24). Participants were evaluated on physical performance capacity in incremental treadmill roller-ski skating test.

SUBJECTS

In total, 59 junior-level XC skiers and biathletes (43 males and 16 females) were included in the final analysis. Athletes were recruited from two sport schools in Norway with a specialized program for XC skiing and biathlon. Age ranged from 17 to 19 (more in table 1).

Intervention groups

51 athletes were recruited from Meråker High School (Meråker, Norway). Random allocation was ensured for these athletes. Low intensity training group (LITG) consisted of 26 athletes (male, n = 18; female, n = 8), high intensity training group (HITG) had 25 athletes at the start (male, n = 18; female, n = 7).

Contemporary training group

Third training group, presenting the contemporary periodization approach (CG), was recruited from Heimdal High School (Trondheim, Norway). This parallel cluster was included to study design to compare the effects of specified periodization strategy (intervention) in relation to contemporary training model. CG initially comprised of 30 athletes (male, n = 20; female, n = 10).

Final analysis

A total of 22 participants were not part of the final analysis due to different reasons: sickness or injury (n = 14), withdrawal (n = 4), insufficient data in training diary (n = 4). Those included in final analysis were in the following groups: LITG consisted of 22 (male n = 15; female n = 7), HITG 20 (male, n = 16; female n = 4) and CG 17 (male, n = 12; female n = 5) athletes.

ETHICAL CONSIDERATIONS

The study was approved by the Norwegian Centre for Research Data (NSD) and conducted in accordance with the Declaration of Helsinki. Guidelines for private data collection were respected and potential health risks were assessed before recruitment. All athletes were fully informed with the nature of the experimental study before providing a written informed consent of their participation. The athletes were explicitly informed that they could withdraw from the study at any point in time without providing a reason for doing so. The athletes younger than 18 years of age were asked a parental consent to participate in the study.

DESIGN OF TRAINING PERIODIZATION

Training intensity zone classification

Intensities are analysed based on a 3-zone scale. Anchored to ventilatory (VT_1 or VT_2) and lactate thresholds (LT_1 or LT_2), zone 1 (LIT) is below VT_1/ LT_1; zone 2 (MIT) between VT_1/LT_1 and VT_2/LT_2; zone 3 above VT_2/LT_2 (14, 22, 25). A method described by Sylta et al.(26) is applied to transform 5-zone aerobic intensity scale (by Norwegian Olympic Federation) to three zones for further quantification of training. Based on this classification, zones 1-2 correspond to LIT, zone 3 is MIT, and zones 4-5 are considered HIT (6, 25).

Pre-Intervention Period

Duration of baseline training period was 8 weeks. Both intervention groups followed the same guidelines for training during this timeframe. Baseline periodization model was organized in a way that majority of total volume was performed in zone 1, whereby one session in both zone 2 and zone 3 was instructed weekly. Endurance training was supported by strength and sprint-speed sessions – both implemented 2-3 times per week. Described training structure was a collaboration between study investigators and coaches in the process of finding agreeable standardization for pre-intervention period. Approach was in alignment with how XC skiers and biathletes typically train over the general preparation period. Under the framework of this periodization, training was not strictly standardized for each participant, but rather individual adjustments were managed by coach in accordance with current form and recovery status of the athlete. In contrast, CG was not instructed to change their traditional training method and continued without any supervision from the investigators.

Intervention Period

Objective for HITG was to perform increasing volume of endurance exercise in zone 3. Accordingly, that consisted of 2-3 weekly HIT sessions, which was complemented by 1 long-duration zone 1 session. For a high intensity session, a target heart rate was 90% of maximal heart rate (HR_{max}). LITG aimed to increase volume of zone 1 training. 2-3 long-duration sessions in zone 1 were scheduled every week, which was accompanied by 1 weekly session in both zone 2 and 3 – in respect to maintaining basic stimulus related to higher work rates, which is common in coaching practice. The strength and speed session instructions were identical with the pre-intervention period for HITG and LITG. Similarly to the baseline period, CG did not alter their usual training approach.

QUANTIFICATION OF TRAINING

Online training diary by Norwegian Olympic Federation was used by athletes to report training sessions. In registrating training data, an 85% compliance was necessary for including athlete in the final statistical analysis.

Athletes were instructed to report type of training (e.g., endurance, strength and speed) and duration of the session. Time in zone (TIZ) and session goal (SG) approach was used for training feedback. The advantage of this approach, as described by Sylta et al. (26) is that a combination of TIZ and SG reflects the perceived effort more profoundly. Taking into consideration that session rating of perceived effort (sRPE) corresponds to “modified session goal” approach more than HR recording alone (25).

In reporting platform, endurance training intensity was recorded across 5 zones, which in practice facilitates athletes and coaches to govern more specific heart rate (HR) zones. As covered earlier, this scale was then transformed to three zones in further analysis. Although HR data was not quantified in this study, it was facilitating athletes in targeting the intensities more precisely. In addition, RPE on the 1-10 scale was an indicator of intensity at the individual level for every session. In this model also three zones have been suggested: zone 1, ≤ 4; zone 2 between 4-7; and zone 3, ≥ 7 (14).

For systematization of a single training session, participants were instructed to record warm-up and cool-down separately from the main goal of workout. Interval training was reported from the start of the first exercise bout and ended with the last repetition, together with recovery time. Segment of strength and/or speed was described separately from endurance training, when a mixed session was performed. In that occasion, duration was summarized from onset to completion of that specific part, with rest periods included.

To establish similar baseline for LITG and HITG in terms of total training load, the training impulse (TRIMP) was calculated. By multiplying the duration of exercise within respective intensity zone with a multiplier (1 = zone 1, 2 = zone 2, 3 = zone 3), the TRIMP score indicates a total training load (intensity × volume) (24). This approach allows to compare groups with different intensity distributions.

LABORATORY PROCEDURES AND MEASUREMENTS

Performance tests were integrated into training plans and completed the week after both training period. Standardized treadmill roller-ski skating protocol was conducted. Before baseline laboratory measurements, the participants were informed about the content of the test. Prior to first evaluation all athletes had a session to familiarize with roller-skiing on treadmill employing G3 subtechnique. Same time of day was scheduled for each individual for both pre- and post-test.

Laboratory test locations:

- Meråker High School, Meråker, Norway
- Centre for Elite Sports Research (SenTIF), Granåsen, Trondheim, Norway

The athletes were advised not to perform strenuous exercise within 24 hours preceding the test and prepare for physical evaluation as they would approach a competition. On the day of testing athletes were instructed to avoid caffeine in the last 3 hours prior to test. Food intake was to be normal (no extreme diets, along with a reasonable balance of carbohydrates, fats and protein), with 2-3 hours left between last meal and test. Upon arriving to laboratory subjects filled out a physical readiness form to declare appropriate health condition and fitness status. Measures of height and body mass were collected with medical weights and stadiometers (Seca models 708, 877, 225; GmbH, Hamburg, Germany).

Equipment

Open-circuit ergospirometry apparatus Oxycon Pro gas analyser (Jaeger GmbH, Hoechberg, Germany) with a 30-s sampling time was utilized for respiratory measures in both locations. Calibration in respect to ambient air temperature and humidity was performed. Certified gas mixes were used to calibrate gas sensors (O_2, 15.00% ± 0.04%; CO_2, 5.0% ± 0.1%). The flow transducer (Triple V, Erick Jaeger GmbH, Hoechberg, Germany) was calibrated with a 3-L high-precision calibration syringe (Calibration syringe D, SensorMedics, Yorba Linda, CA, USA). These procedures were performed immediately before each test day and repeated after testing 3 athletes. $\dot{V}O_2$peak tests were performed on a 3.5 x 2.5 m (RL 2500E, Rodby, Södertalje, Sweden) and on a 5 x 3 m treadmill (ForceLink BV, Culemborg, The Netherlands) while employing a G3 skating sub-technique. Subjects used their own ski boots and poles, but identical pairs of skating roller skies (Swenor, Sarpsborg, Norway) and customized carbide tips (Jakobsen V., NIH, Oslo, Norway) were provided for adequate grip on non-slippery rubber belt. Friction tests were applied to notice any changes in resistance for both laboratories and to calculate efficiencies. A safety harness was utilized to reduce the hazards of falling in exhausted condition. Room temperature was regulated to remain 19-21°C and circulation of air was ensured. Blood lactate concentrations were determined by Biosen C-Line lactate analyser (Biosen, EKF Industrial Electronics, Magdeburg, Germany). HR measures were recorded by athletes' own HR-monitors and RPE was obtained by using Borg scale ranging from 6 to 20 (27).

Treadmill roller-ski skating test protocol

Warm-up consisted of running individually 10 minutes in zone 1 (60-72% HR_{max}) on the 5-scale intensity classification by Norwegian Olympic Federation. Briefly after, subject was set ready on the treadmill and a constant incline of 5% was ensured for the whole duration of test protocol. Initial 2 minutes (male at 10 km/h^{-1}; female 8 km/h^{-1}) was used for warming up roller-skies (wheels and bearings) and for athlete to check if equipment requires any minor adjustments (ski-boots, HR monitor, etc.). Subsequently, a nose-clip and a mouthpiece for $\dot{V}O_2$ measurements was implemented.

Submaximal stages

Two stages of 5 minutes were performed at submaximal velocities. For male subjects, first stage was at a constant speed of 12 km/h^{-1}, while female maintained the speed of 10 km/h^{-1}. Respiratory recordings ($\dot{V}O_2$, RER, V_E) were extracted at 3.30 and 4.00 after the start of the stage. An average of these values ($\dot{V}O_2$, RER, V_E) was included for further analysis. HR was noted 30 sec before the end of 5 min stage.

Second 5 min stage was identical in terms of measuring procedures, however velocity for males was 14 km/h^{-1}, and females roller-skied at 12 km/h^{-1}. Between two submaximal tests, 1 minute recovery was implemented. During this break a value of blood lactate concentration $[La^-]_b$ was collected from fingertip immediately after the treadmill stopped. Same procedure was repeated after second stage. In addition, RPE (6-20) was solicited for both 5 min work bouts. After submaximal tests, a 3-5 min recovery period was permitted, whereby athlete was able to hydrate and remove sweat.

$\dot{V}O_2$peak and performance test

Incremental performance test was conducted with a starting speed of 12 km/h^{-1} for female and 14 km/h^{-1} for male. An increase of 2 km/h^{-1} was implemented for each upcoming minute until 18 km/h for women and 20 km/h^{-1} for men; thereafter velocity was accelerated by 1 km/h^{-1} for every proceeding minute until volitional exhaustion. Verbal encouragement was used for the last minutes of test. Heart rate and gas exchange data was continuously recorded. Time to exhaustion was measured from the moment of initiating start button and ended instantly at pushing stop button: last velocity and seconds performed by the athlete were registered. Immediately after, within 1, minute the RPE (6-20) and blood lactate concentration was determined. $\dot{V}O_2$peak was defined at the average of two highest consecutive 30 sec measurements. The term $\dot{V}O_2$peak is used instead of $\dot{V}O_2$max, in regards to a different degree of muscle activation in upper and lower body in XC-skiing (1), and analysis between running and V2-skating has shown ~5% higher peak oxygen consumption for running (28). Highest value of heart rate attained was termed HR_{peak}.

Calculation of gross efficiency

GE is defined as ratio of external work rate to metabolic rate. Equations were in accordance with similar calculations by Sandbakk et al. (29). Work rate (WR) was the sum of power against gravity (P_g) and power against rolling friction (P_f). P_g was the product of mass (body + equipment), gravitational acceleration, the incline (sin α) of treadmill and velocity.

$$P_g = m \cdot g \cdot v \cdot \sin \alpha$$

Rolling friction (P_f) was determined by a towing test. Power against frictional forces (P_f) was determined via mass (body + equipment), friction coefficient of the roller skies (μ), gravitational acceleration and tangential speed at a given incline (α in radians) on the treadmill. Friction coefficient from towing tests resulted to 0.017 for Meråker High School treadmill, and 0.021 in SenTIF laboratory.

$$P_f = m \cdot g \cdot \mu \cdot v \cdot \cos \alpha$$

Metabolic rate (MR) was calculated from the mean $\dot{V}O_2$ (L/min^{-1}) and the O_2 equivalent from respiratory exchange ratio (RER), in which standard conversion table of Lusk (30) is basis for translating RER (≤ 1.00) coefficient to caloric measures. Kilocalories were converted into kilojoules (1 kcal = 4.186 kJ) and correspondingly, kilojoules per second transformed MR to watts (W), which was further used in GE equation. GE is then calculated as a ratio between WR and MR:

$$\text{GE (\%)} = \frac{\text{WR } (W)}{\text{MR } (W)} \cdot 100$$

Statistical analysis

Between-group differences in performance and physiological determinants were compared with a general linear model (GLM) one-way analysis of covariance (ANCOVA) with Bonferroni post hoc tests. A paired samples *t*-test was conducted to compare within subjects physiological and performance variables at pre- and post-tests. Effect sizes (ES) were estimated with Cohen's *d*, and magnitude of effect was classified according to Hopkins et al. (31) as follows: 0.0-0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; >2.0, very large. Training data is analysed with GLM one-way analysis of variance (ANOVA). All data were assessed for normality with Shapiro-Wilk test and visual inspection of QQ-plots. Assumptions to linear model were checked and if violated, further statistical corrections were employed. A level of statistical significance was set to $p < 0.05$, alpha values between 0.05 and 0.1 were considered to indicate trends. All data was analysed with statistical software SPSS 27.0 (SPSS, Inc, Chicago, IL, United States). Statistical graphs were configured in RStudio (version 1.4.1106, RStudio, PBC., Boston, MA, United States). If not stated otherwise, all data is expressed as means $\pm$ standard deviations (SD).

RESULTS

BASELINE CHARACTERISTICS

The groups did not differ significantly in age, body mass and body height pre-intervention. There was no interaction effect of gender in group comparisons, thus both genders were merged in further analysis. The athletes baseline measures are presented in **Table 1**. There was a main effect of group ($F_{(2, 55)}$, $p = 0.02$, $\eta^2 = 0.13$) in body-mass changes. Bonferroni post hoc analysis showed a significant difference between LITG and HITG in body-mass changes ($p < 0.05$). Within groups, HITG and CG increased body mass significantly from pre- to post (HITG 1.7 ± 2.0%, CG 1.2 ± 1.4%, both $p < 0.01$), whereas a non-change was found in LITG (LITG 0.3 ± 1.9%, $p = 0.50$)

Table 1. Baseline characteristics of 59 athletes completing the 8 weeks of training.

	LITG (n = 22)	HITG (n = 20)	CG (n = 17)
Age (yrs)	17.6 ± 0.7	17.6 ± 0.7	17.9 ± 0.8
Body mass (kg)	70.8 ± 7.6	67.7 ± 8.1	66.6 ± 5.7
Height (cm)	177.3 ± 8.8	177.3 ± 8.1	175.7 ± 7.2
Body mass index ($kg{\cdot}m^{-2}$)	22.5 ± 1.6	21.5 ± 1.8	21.6 ± 0.9

Data are presented as mean ± SD. LITG, low intensity training group; HITG, high intensity training group; CG, contemporary training group.

TRAINING CHARACTERISTICS

Baseline training period

Total training hours differed between groups during the 8-week baseline period (LITG 95.7 ± 13.1 h; HITG 96.5 ± 19.2 h; CG 108.6 ± 13.5 h, $p < 0.05$), in which post hoc analysis indicated that CG trained significantly more than than LITG ($p < 0.05$), while no significant difference were apparent for other pairwise comparisons. Total endurance training time was also highest for CG (95.8 ± 11.3 h), compared to LITG (85.7 ± 11.3 h) and HITG (84.7 ± 18.8 h), with a significant effect of goup in one-way ANOVA analysis ($p < 0.05$). However, pairwise comparison did not show any significant differences between groups. There was a significant difference in speed training volume at group level (LITG, 2.3 ± 1.1 h; HITG, 3.3 ± 0.9 h; CG, 3.1 ± 1.6 h; $p < 0.05$), where HITG had trained significantly more speed compared to LITG ($p < 0.05$). Strength training volume was 7.8 ± 3.1 h, 8.5 ± 1.7 h, 9.7 ± 4.4 h in LITG, HITG and CG, respectively, but did not differ significantly between groups.

In terms of training intensity, time in each of three zone did not differ significantly at baseline and percentage distribution of LIT/MIT/HIT was 91/5/4% for both LITG and CG, and 91/4/5% for HITG. Weekly average TRIMP score was 730 ± 93 for LITG, 726 ± 153 for HITG, and 817 ± 90 for CG, which showed a significant group effect (p < 0.05). However, post hoc pairwise comparison demonstrated no significant difference between groups. .

Training intervention period

Training characteristics in the 8-week intervention period is summarized in **Table 2**. Endurance training volume was higher for CG compared to both LITG and HITG (p < 0.05), whereas mean difference between LITG and HITG was not significant (p > 0.05).

The intervention groups were expected to have relatively different proportions of training in zone 1 and 3, which subsequently affects the total endurance volume. At all levels of intensity distribution (LIT/MIT/HIT) significant group-wise differences occurred (p < 0.01). Expressed as percentages, TRIMP training intensity distribution in **Figure 1** indicates a relatively high load of low intensity training (~80%) for both CG and LITG, whereas high intensity contributed ~10% to total – in contrast with HITG that trained ~25% in zone 3.

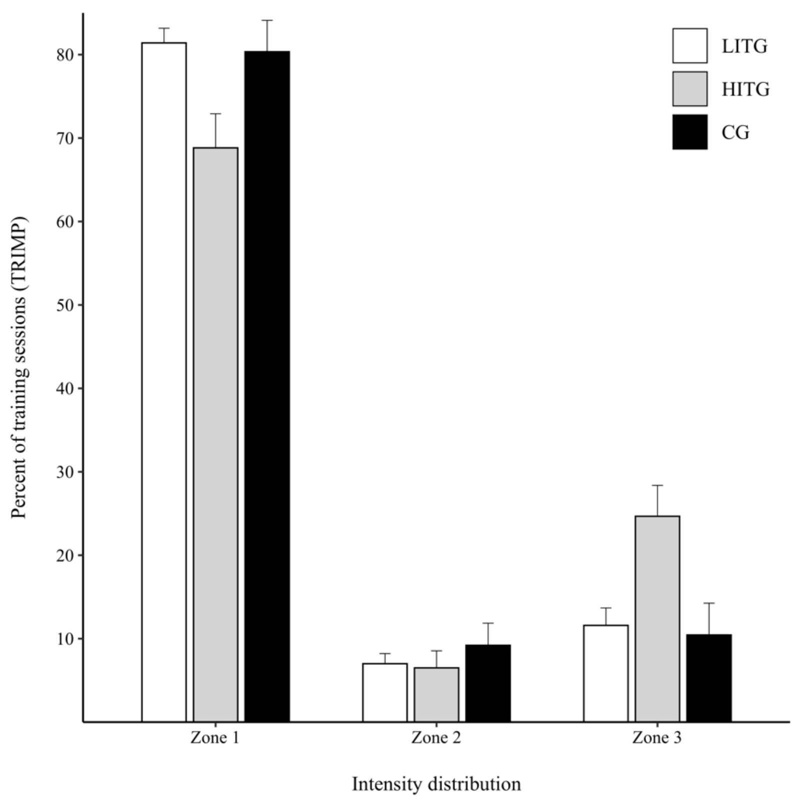

Figure 1. Training intensity distribution during 8-week intervention period. Three basic zones based on TRIMP score.

In zone 1, HITG had significantly lower TRIMP score compared to CG and LITG (both pairwise differences, $p < 0.01$). In low intensity TRIMP, largest increase from pre-intervention was observed in LITG by 8.0 ± 11.7%, whereas CG increased by 7.2 ± 10.7%, and HITG reduced score in zone 1 by 7.1 ± 22.8% (comparison in **Table 2**). Largest TRIMP in low intensity obtained by CG was not below the threshold of significance in comparison to LITG ($p = 0.05$).

In zone 2, TRIMP score observed in CG was larger from both groups ($p < 0.01$); in parallel, no contrast was found between LITG and HITG. Reduction in moderate intensity TRIMP score was 20.7 ± 59.3% for HITG, 12.2 ± 40.0% for LITG, while an increase of 3.3 ± 31.6% was observed in CG.

Table 2. Training characteristics during intervention period (8 weeks).

	LITG (*n* = 22)	**HITG (*n* = 20)**	**CG (*n*= 17)**	*F*-value[a]	*p*-value	η^2
Total training						
Total training (h)	107.3 ± 10.8	94.8 ± 11.0	116.8 ± 15.5	$F_{(2, 56)} = 15.8$	< 0.001	0.36
Number of sessions	67.0 ± 5.7	67.0 ± 7.2	70.4 ± 5.6	$F_{(2, 56)} = 1.8$	0.17	0.06
Training type						
Endurance (h)	94.1 ± 9.6	82.4 ± 10.2	103.8 ± 15.0	$F_{(2, 56)} = 15.9$	< 0.001	0.36
Speed (h)	4.1 ± 2.2	3.6 ± 0.9	2.9 ± 1.9	$F_{(2, 56)} = 2.0$	0.14	0.07
Strength (h)	9.1 ± 2.3	8.9 ± 2.0	10.1 ± 2.5	$F_{(2, 56)} = 1.4$	0.26	0.05
Endurance intensity distribution						
LIT (h)	86.5 ± 9.3	70.4 ± 10.2	94.3 ± 14.5	$F_{(2, 56)} = 22.1$	< 0.001	0.44
MIT (h)	3.6 ± 0.6	3.4 ± 1.0	5.4 ± 1.9	$F_{(2, 56)} = 15.0$	< 0.001	0.35
HIT (h)	4.0 ± 0.7	8.7 ± 1.0	4.0 ± 1.3	$F_{(2, 56)} = 140.2$	< 0.001	0.83
LIT/MIT/HIT (%)	92/4/4	85/4/11	91/5/4			
Endurance session distribution						
LIT (n)	44.9 ± 4.2	37.1 ± 5.7	45.0 ± 5.4	$F_{(2, 56)} = 15.8$	< 0.001	0.36
MIT (n)	4.9 ± 0.8	4.1 ± 1.1	6.3 ± 2.7	$F_{(2, 56)} = 8.0$	< 0.01	0.22
HIT (n)	6.8 ± 1.0	15.6 ± 1.8	10.4 ± 2.9	$F_{(2, 56)} = 110.5$	< 0.001	0.80
LIT/MIT/HIT (%)	79/9/12	65/7/28	73/10/17			
Training load in TRIMP score						
TRIMP (LIT)	5093 ± 600	4303 ± 682	5660 ± 868	$F_{(2, 56)} = 17.0$	<0.001	0.38
TRIMP (MIT)	434 ± 71	403 ± 125	651 ± 226	$F_{(2, 56)} = 15.2$	<0.001	0.35
TRIMP (HIT)	722 ± 136	1523 ± 198	719 ± 234	$F_{(2, 56)} = 118.3$	<0.001	0.81
Mean TRIMP·week^{-1}	781 ± 82	779 ± 89	879 ± 117	$F_{(2, 56)} = 6.5$	< 0.01	0.19

Values are presented as mean ± SD. LITG, low intensity training group; HITG, high intensity training group; CG, contemporary training group. [a] group-wise differences in one-way ANOVA.

Upmost TRIMP load in zone 3 was accumulated by HITG, which differed substantially from LITG and CG ($p < 0.01$). CG and LITG were similar in high intensity TRIMP. Compared to baseline, HITG increased high intensity TRIMP score by 49.7 ± 13.1%, LITG by 2.1 ± 35.0%, and CG had a reduction of 7.3 ± 33.9%.

In weekly TRIMP, CG had higher score compared to intervention groups ($p < 0.01$), whereas statistical difference was not found between LITG and HITG. All groups increased TRIMP (wk^{-1}) score compared to baseline (LITG, 6.0 ± 12.1%; HITG, 6.6 ± 17.9%; CG, 6.4 ± 8.7%), where increase was at a significant level for LITG and CG ($p < 0.05$). A similar amount of rest days was observed during training period (LITG 4.0 ± 2.7; HITG 4.9 ± 2.0; CG 4.6 ± 3.9; $p = 0.69$).

ENDURANCE CAPACITY

Performance

TTE changes from pre- to post revealed no main effect of group ($F_{(2, 55)} = 1.5$, $p = 0.24$, $\eta^2 = 0.05$), nor interaction effect of group and time ($F_{(2, 53)} = 0.9$, $p = 0.42$, $\eta^2 = 0.03$). Adjusted TTE is shown in **Figure 2**. However, TTE improved significantly for LITG and HITG from pre- to post (LITG 5.9 ± 10.4%, HITG 9.7 ± 13.3%; both $p < 0.01$ in paired samples t-test), whereas a non-change was observed in CG (2.2 ± 8.5 %, $p = 0.25$).

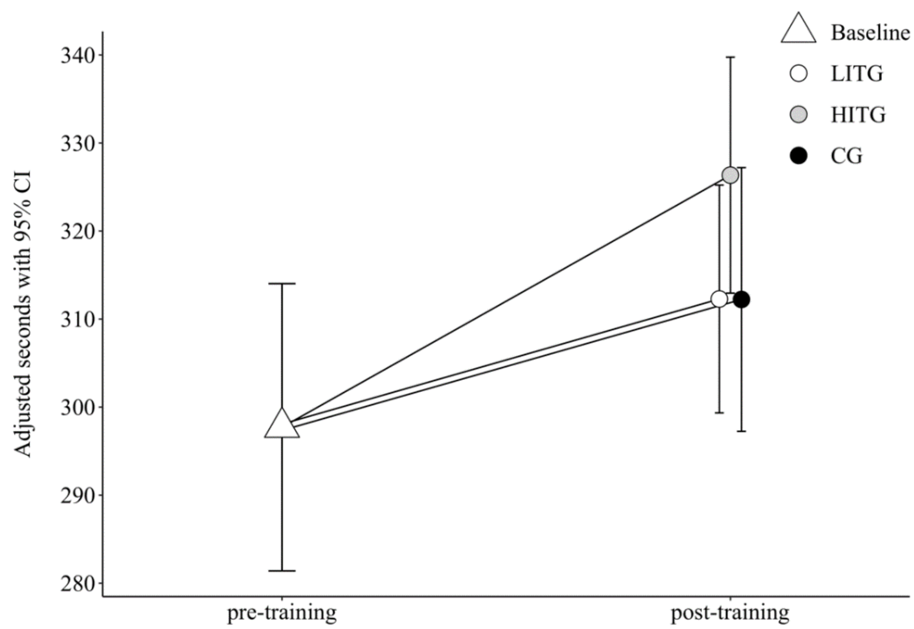

Figure 2. Performance in incremental test to voluntary exhaustion was adjusted with baseline value of 297.7 seconds. No significant differences were found between groups in ANCOVA model with pre-test TTE as a covariate.

Table 3. Physiological responses in submaximal and $\dot{V}O_2$peak test employing V2-skating and double poling technique in treadmill roller-skiing.

		LITG (n = 22)			**HITG (n = 20)**			**CG (n = 17)**		
		Pre-training	Post-training		Pre-training	Post-training		Pre-training	Post-training	
Submaximal intensity I	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	44.8 ± 3.7	43.7 ± 3.40*	0.6	45.0 ± 3.1	43.9 ± 1.9**	0.7	42.9 ± 3.8	43.3 ± 3.0	0.2
	$\dot{V}O_2$ (L·min^{-1})	3.19 ± 0.52	3.12 ± 0.50*	0.5	3.05 ± 0.43	3.03 ± 0.40	0.2	2.87 ± 0.40	2.93 ± 0.41*	0.5
	$\dot{V}O_2$ in % of $\dot{V}O_2$peak	70.8 ± 4.9	69.3 ± 4.8*	0.5	68.9 ± 4.5	68.6 ± 5.1	0.1	67.3 ± 4.6	68.8 ± 3.1	0.5
	$\dot{V}_E$ (L·min^{-1})	85.7 ± 9.4	82.3 ± 9.8*	0.5	87.8 ± 16.9	84.5 ± 13.5	0.3	79.1 ± 10.8	81.5 ± 12.1	0.3
	RER	0.93 ± 0.04	0.91 ± 0.03	0.4	0.95 ± 0.05	0.94 ± 0.03	0.4	0.92 ± 0.04	0.93 ± 0.03	0.2
	$[La^-]_b$ (mmol·L^{-1})	2.72 ± 0.93	2.79 ± 0.78	0.1	3.06 ± 1.25	2.82 ± 0.79	0.3	2.92 ± 1.07	2.86 ± 0.90	0.1
	HR (beat·min^{-1})	173 ± 10	173 ± 10	0.0	170 ± 10	167 ± 9.3**	0.7	172 ± 11	173 ± 10	0.1
	HR (% of peak)	87 ± 4	87 ± 3	0.0	86 ± 4	85 ± 3.5**	0.7	86 ± 5	86 ± 4	0.1
	RPE	11.2 ± 1.9	11.6 ± 1.9	0.3	11.9 ± 1.3	11.8 ± 1.8	0.1	10.9 ± 2.1	10.6 ± 2.2	0.2
	GE_1 (%)	13.8 ± 0.6	14.2 ± 0.7**	0.7	13.9 ± 0.8	14.3 ± 0.6**	0.7	15.6 ± 1.0	15.4 ± 0.6	0.3
Submaximal intensity II	$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})	50.3 ± 3.9	49.4 ± 3.2*	0.5	50.7 ± 3.3	49.6 ± 2.3*	0.5	48.5 ± 3.6	48.9 ± 2.8	0.2
	$\dot{V}O_2$ (L·min^{-1})	3.57 ± 0.56	3.52 ± 0.5	0.4	3.44 ± 0.48	3.42 ± 0.44	0.1	3.23 ± 0.41	3.30 ± 0.40*	0.6
	$\dot{V}O_2$ in % of $\dot{V}O_2$peak	79.5 ± 5.5	78.3 ± 5.3	0.3	77.7 ± 4.9	77.4 ± 5.2	0.1	76.1 ± 4.8	77.7 ± 4.3*	0.5
	V_E (L·min^{-1})	103.2 ± 11.1	99.6 ± 11.4	0.4	107.9 ± 26.7	101.4 ± 14.0	0.3	94.5 ± 11.9	99.1 ± 12.9*	0.6
	RER	0.96 ± 0.04	0.95 ± 0.03	0.2	0.97 ± 0.03	0.96 ± 0.04*	0.5	0.96 ± 0.03	0.96 ± 0.03	0.1
	$[La^-]_b$ (mmol·L^{-1})	4.11 ± 1.41	4.09 ± 1.14	0.0	4.28 ± 2.06	4.17 ± 1.30	0.1	3.91 ± 1.63	4.45 ± 1.45	0.4
	HR (beat·min^{-1})	184 ± 9	183 ± 8	0.2	180 ± 11	178 ± 9.2*	0.5	182 ± 10	184 ± 8	0.4
	HR (% of peak)	92 ± 3	91 ± 2	0.2	91 ± 4	90 ± 3.1*	0.5	91 ± 4	92 ± 3	0.4
	RPE (6-20)	14.4 ± 1.4	14.1 ± 1.4	0.2	14.6 ± 1.2	13.9 ± 1.2*	0.6	13.5 ± 1.8	13.5 ± 2.3	0.0
	GE_2 (%)	14.3 ± 0.6	14.6 ± 0.6**	0.7	14.4 ± 0.7	14.7 ± 0.6*	0.5	16.1 ± 0.9	15.9 ± 0.7	0.3

(Continued)

Table 3. *(Continued)*

		LITG (n = 22)			HITG (n = 20)			CG (n = 17)		
		Pre-training	Post-training	ES	Pre-training	Post-training	ES	Pre-training	Post-training	ES
Incremental test	$\dot{V}O_2$peak (mL·kg^{-1}·min^{-1})	62.8 ± 7.7	62.5 ± 6.6	0.1	63.4 ± 6.8	64.4 ± 6.0	0.4	62.2 ± 5.7	62.1 ± 5.1	0.0
	$\dot{V}O_2$peak (L·min^{-1})	4.48 ± 0.92	4.46 ± 0.86	0.1	4.30 ± 0.74	4.43 ± 0.68*	0.6	4.16 ± 0.66	4.21 ± 0.65	0.2
	V_E (L·min^{-1})	162.3 ± 26.9	161.0 ± 27.9	0.2	165.5 ± 27.0	165.0 ± 26.4	0.1	157.8 ± 25.1	166.6 ± 27.4	0.5
	RER	1.11 ± 0.05	1.11 ± 0.04	0.0	1.11 ± 0.05	1.11 ± 0.05	0.1	1.11 ± 0.03	1.12 ± 0.03	0.3
	$[La^-]_b$ (mmol·L^{-1})	10.84 ± 1.70	11.16 ± 2.23	0.2	10.78 ± 1.64	10.92 ± 1.88	0.1	12.17 ± 1.55	12.77 ± 1.71	0.5
	HRpeak (beat·min^{-1})	198 ± 7	199 ± 7	0.2	196 ± 8	196 ± 7	0.0	200 ± 7	200 ± 6	0.2
	RPE (6-20)	18.7 ± 0.9	19.0 ± 0.8	0.4	18.8 ± 1.3	19.0 ± 0.9	0.2	18.9 ± 1.0	19.2 ± 1.0	0.2
	TTE (s)	280.9 ± 57.7	299.3 ± 57.3**	0.6	291.8 ± 73.1	321.8 ± 59.9**	0.7	326.5 ± 52.9	334.4 ± 50.2	0.3
	*v*TTE (km·h^{-1})	21.0 ± 1.7	21.3 ± 1.7**	0.6	21.4 ± 1.8	21.9 ± 1.7**	0.7	21.9 ± 1.6	22.0 ± 1.7	0.3

Data are presented as mean ± SD. $\dot{V}O_2$, oxygen consumption; $\dot{V}_E$, pulmonary ventilation; RER, respiratory exchange ratio; $[La^-]_b$, blood lactate concentration; HR, heart rate; RPE, rating of perceived effort; *v*TTE, end velocity in time-to-exhaution test; *$p < 0.05$; **$p < 0.01$ significant difference within groups from pre- to post-training. ES, Cohen's *d* effect size: 0–0.2 = trivial, 0.2–0.6 = small, 0.6–1.2 = moderate, 1.2–2.0 = large, and >2 = very large.

Physiological variables

Submaximal workloads

$\dot{V}O_2$ in both absolute (L·min^{-1}) and relative terms (mL·kg^{-1}·min^{-1}) was not different between groups in covariate-adjusted model in post-test comparison ($p > 0.05$, **Table 4**).

In pre- and post-test pairwise comparison, LITG had a 2.3 ± 4.3% reduction and CG had a 2.1 ± 4.3% increase in absolute $\dot{V}O_2$ (in both, $p < 0.05$). HITG reduced $\dot{V}O_2$ non-significantly by 0.7 ± 5.0% ($p = 0.62$) in absolute terms, however reduction was more evident in relative $\dot{V}O_2$ (**Table 3**). At first submaximal intensity both LITG and HITG had a pre- to post-training reduction (2.5 ± 4.4%, 2.4 ± 3.8, respectively; $p < 0.05$) in relative $\dot{V}O_2$ (mL·kg^{-1}·min^{-1}), whereas no change was found in CG (difference 1.0 ± 4.5%, $p = 0.39$).

In $\dot{V}O_2$ (L·min^{-1}) at second submaximal intensity, change was apparent in pre-post comparison for LITG (reduction 1.6 ± 4.2%, $p = 0.09$) and a non-change in HITG (reduction 0.5 ± 5.3%, $p = 0.62$), whereas CG increased absolute oxygen consumption by 2.1 ± 3.8% ($p = 0.04$). Significant within-group differences were found for LITG and CG ($p < 0.05$). The relative $\dot{V}O_2$ (mL·kg^{-1}·min^{-1}) at second submaximal velocity was significantly reduced for LITG (1.2 ± 3.7%, $p = 0.04$) and HITG (2.2 ± 4.2%, $p = 0.03$); whereas there was an increase of consumption in CG (0.9 ± 3.9%, $p = 0.03$).

Table 4. Physiological determinants of endurance performance at incremental treadmill roller-ski test in ANCOVA model.

		Baseline	LITG ($n = 22$)			HITG ($n = 20$)			CG ($n = 17$)			Main effect and interaction		
		$M_{adj.\ (pre)}$	M_{adj}	*SE*	*95% CI* lower-upper bound	M_{adj}	*SE*	*95% CI* lower-upper bound	$M_{adj.}$	*SE*	*95% CI* lower-upper bound	*F*-value	*p*-value	η^2
Maximal	$\dot{V}O_2$peak (mL·kg⁻¹·min⁻¹)	62.8	62.5	0.5	61.5 – 63.5	64.0	0.5	62.9 – 65.0	62.6	0.6	61.5 – 63.8	$F_{(2, 55)} = 2.3^a$	0.11	0.08
												$F_{(2, 53)} = 0.3^b$	0.72	0.01
	$\dot{V}O_2$peak (L·min⁻¹)	4.33	4.32	0.04	4.24 – 4.41	4.46	0.04	4.38 – 4.55	4.36	0.05	4.27 – 4.45	$F_{(2, 55)} = 2.9^a$	0.06	0.10
												$F_{(2, 53)} = 0.1^b$	0.86	0.01
Submaximal I	$\dot{V}O_2$ (mL·kg⁻¹·min⁻¹)	44.3	43.4	0.3	42.8 – 44.0	43.5	0.3	42.8 – 44.1	44.3	0.4	43.6 – 45.0	$F_{(2, 55)} = 1.9^a$	0.16	0.07
												$F_{(2, 53)} = 1.4^b$	0.27	0.05
	$\dot{V}O_2$ (L·min⁻¹)	3.05	2.99	0.03	2.93 – 3.05	3.03	0.03	2.97 – 3.09	3.10	0.03	3.03 – 3.16	$F_{(2, 55)} = 3.1^a$	0.05	0.10
												$F_{(2, 53)} = 0.6^b$	0.56	0.02
	$[La^-]_b$ (mmol·L⁻¹)	2.89	2.88	0.12	2.64 – 3.12	2.73	0.13	2.47 – 2.98	2.84	0.14	2.57 – 3.11	$F_{(2, 55)} = 0.4^a$	0.66	0.02
												$F_{(2, 53)} = 0.3^b$	0.71	0.01
	GE_1 (%)	14.3	14.5	0.1	14.3 – 14.7	14.5	0.1	14.3 – 14.7	14.7	0.2	14.4 – 15.0	$F_{(2, 55)} = 0.3^a$	0.76	0.01
												$F_{(2, 53)} = 0.8^b$	0.46	0.03
Submaximal II	$\dot{V}O_2$ (mL·kg⁻¹·min⁻¹)	49.9	49.1	0.3	48.5 – 49.8	49.1	0.3	48.4 – 49.7	49.8	0.4	49.1 – 50.6	$F_{(2, 55)} = 1.2^a$	0.30	0.04
												$F_{(2, 53)} = 0.7^b$	0.52	0.02
	$\dot{V}O_2$ (L·min⁻¹)	3.43	3.39	0.03	3.33 – 3.45	3.41	0.03	3.35 – 3.48	3.48	0.04	3.41 – 3.55	$F_{(2, 55)} = 1.8^a$	0.18	0.06
												$F_{(2, 53)} = 0.3^b$	0.72	0.01
	$[La^-]_b$ (mmol·L⁻¹)	4.11	4.09	0.19	3.71 – 4.46	4.08	0.2	3.68 – 4.48	4.58	0.22	4.14 – 5.01	$F_{(2, 55)} = 1.8^a$	0.17	0.06
												$F_{(2, 53)} = 0.2^b$	0.85	0.01
	GE_2 (%)	14.9	15.0	0.1	14.7 – 15.2	15.0	0.1	14.8 – 15.2	15.1	0.2	14.8 – 15.5	$F_{(2, 55)} = 0.4^a$	0.71	0.01
												$F_{(2,53)} = 0.5^b$	0.60	0.02

Data are presented as adjusted means (M_{adj}) and standard error (SE) of measurement. Observed means are presented in **Table 3**. [a] Main effect between training groups; [b] Time × training group interactive effect.

Blood lactate at each intensity level did not indicate group differences in covariate-adjusted linear model, nor were there any significant differences in paired samples t-test for pre- to post-test values in any group.

GE at both submaximal speeds was not significantly different between groups (**Table 4**). GE improved significantly ($p < 0.01$) in LITG (0.4 ± 0.6%) and HITG (0.4 ± 0.5%) at first submaximal speed compared to baseline, while non-significant reduction was observed in CG (0.2 ± 0.7%, $p = 0.19$). In second submaximal speed, both LITG and HITG improved GE significantly (0.3 ± 0.5%, 0.3 ± 0.6%; $p < 0.05$, 0.01, respectively), while a reduction in CG did not reach a statistical significance (0.2 ± 0.6%, $p = 0.23$).

Maximal performance

Body-mass-normalized $\dot{V}O_2$peak did not differ significantly between groups when adjusted to baseline values (**Table 4**). In pre- to post comparison, no groups improved relative $\dot{V}O_2$peak ($mL \cdot kg^{-1} \cdot min^{-1}$) significantly, whereby HITG increased by 1.6 ± 0.95% ($p = 0.13$), while no change was noticed in LITG and CG, and reduction in uptake was 0.3 ± 3.2% ($p = 0.49$) and 0.12 ± 5.17% ($p = 0.95$) in these groups, respectively.

$\dot{V}O_2$peak in absolute terms ($L \cdot min^{-1}$) had no significant main effect of group nor interaction effect in covariate adjusted analysis ($p > 0.05$). Absolute $\dot{V}O_2$peak increase from pre- to post-training was highest for HITG by 3.2 ± 5.1% ($p = 0.01$); no change was detected in LITG (reduction in mean uptake 0.2 ± 4.17%, $p = 0.61$) and mean increase was 1.0 ± 5.3% in CG ($p = 0.38$). As seen in **Table 3**, the only group improving absolute oxygen uptake at significant alpha level, was HITG, while effect sizes are trivial for other groups.

DISCUSSION

The present study compared the effects of contemporary intensity distribution and increased amount of high- or low intensity training on endurance capacity in the preparation period of highly trained junior cross-country skiers. The main findings were that: **1)** baseline adjusted linear regression model did not indicate statistically significant differences between training groups in performance (i.e. time to exhaustion) and laboratory determinants of performance (e.g. $\dot{V}O_2$peak, GE, blood lactate concentration, etc.) in incremental treadmill roller-ski skating test; **2)** pre-post improvement in TTE was largest for HITG (~10%) and LITG (~6%) (both $p < 0.05$), compared to no change in CG; **3)** $\dot{V}O_2$peak (L·min^{-1}) improved significantly in HITG (~3%, $p < 0.05$), however no change was apparent in CG and LITG; **4)** shift towards higher GE was observed for LITG (0.4%) and HITG (0.4%) ($p < 0.05$), whereas CG maintained highest overall GE at both submaximal intensities, with no improvement evident.

The underlying complexity in factors that affect XC skiing performance is extensive. A skillful athlete is taking simultaneous advantage from physiological, biomechanical, neuromuscular and anthropometrical components (1, 32). The development of such intrinsic factors is to a large extent determined by the accumulation of ski-specific endurance training (4).

When elaborating on the first main finding, a specificity aspect might be of importance. Since it has been reported that larger proportion of various modes of endurance (running up to ~29% of total) is used in general preparation period and more ski-specific training is undertaken closer to competitive season (33), it could be debated that roller-skiing vs. running might solicit different physiological responses in relation to main training period (September-October) used in current study. A very large correlation ($r = 0.82$, when outlier excluded) between running and V2-skating found by Losnegard et al. 2014 (28) could convince to a certain extent that main findings of this study are reliable. It is acknowledged however that running might differ considerably in terms of upmost $\dot{V}O_2$peak measures (28). In parallel to current thesis, a simultaneous investigation tested performance in running among athletes in intervention groups – therefore stronger evidence is expected to emerge. Among elite XC-skiers ($\dot{V}O_2$max ~79 mL·kg^{-1}·min^{-1}), the seasonal fluctuations in 1,000 m time, O_2-cost and total sums of O_2 deficit were found to be significant between June and October – improving towards competitive period; in contrast $\dot{V}O_2$peak in V2-skating remained basically unchanged (33). Furthermore, other studies with junior XC-skiers have unveiled the $\dot{V}O_2$max improvements over the 8-week training period (34). It was therefore a reasonable expectation that the gains in performance would be exposed during the selected timeframe.

Comparing training groups that emphasize different intensity zones poses several methodological challenges. Merging intensity and duration in modified TRIMP score allowed to measure whether the relative training load was similar between intervention groups. Accordingly, results indicate this objective was achieved (**Table 1**). In this regard, a weekly TRIMP score indicated that a ~11% higher total training load was evident for CG compared to both intervention groups. When seen from the standpoint of total endurance training time, CG trained on average 9% more than LITG and 21% more compared to HITG.

In a similar study that has quantified the training intensity of junior XC-skiers, Seiler & Kjerland (14) found a ~91-6-3% distribution in low, moderate and high intensity zones based on heart rates and blood lactate criteria, whereas simultaneous "session-goal" method diverged to ~75-8-17% in respective zones. Closest to this finding, using a combined session-goal and time-in-zone (SG/TIZ) approach from Sylta et al. (25) in current study, was achieved by HITG (85-4-11%). Training analysis revealed that contemporary periodization model was proportionally similar to intervention group that increased low intensity volume (CG 91-5-4% vs. LITG 92-4-4% in zones 1, 2, 3). In annual training characteristics of Olympic and World champion XC skiers and biathletes, with TIZ quantification 91% of training was performed in low intensity, with remaining 9% in moderate-to-high intensity zone (6). In resemblance, results obtained by Sylta et al. (25), elicited ~95-4-1% distribution in the three zones among elite XC-skiers with SG/TIZ method.

The effectiveness of training approach is reflected in performance and physiological determinants. Despite the superior total endurance training volume in CG, magnitude of improvement appeared larger for intervention groups at both submaximal and maximal level in whilst roller-skiing on treadmill. Plausible explanation might be that a more optimal intensity distribution exists. As examined in review articles (11, 16), the typical pattern for elite endurance athletes is that ~80% of training is performed in low intensity zone, while remaining ~20% is above first lactate threshold (> 2 mmol). One of the first randomized controlled training studies to experimentally assess the effect of different intensity distribution in well-trained endurance athletes concluded that HR-based distribution of 80-12-8% (in zones 1, 2 and 3, respectively) had greater impact on performance compared to a proportion of 67-25-8% in the same zones (22).

In respect to second main finding, the high intensity training is associated with larger effects on cardiovascular transport mechanisms of O_2 (17-19, 35, 36). The increases in cardiac output are closely related to respective increases in stroke volume (SV) for both male and female up to the intensity of $\dot{V}O_2max$ (37, 38). High aerobic capacity is considered a pre-requisite for successful international performance, whereas medal-winning males obtain relative $\dot{V}O2max$ values up to 90 $mL \cdot min^{-1} \cdot kg^{-1}$, and females accordingly approaching 80 $mL \cdot kg^{-1} \cdot min^{-1}$ (8). Thus, endurance training for better performance does indeed need to target the maximal aerobic capacity. In current investigation, greatest improvement in TTE was observed for HITG, which coincided with the largest increase in $\dot{V}O_2peak$. To produce more external power (i.e., increasing speed and intensity) without the limitations of fatigue, efficiency of energy transfer is essential (29). Results also indicated that focusing on high intensity does not hinder the submaximal performance in terms of GE. Quite the opposite appeared in HITG, whereby GE was improved in pre-post comparison with small to large effect sizes present. These findings support the notion that high intensity training might enhance endurance capacity at both submaximal and maximal levels. However, rather than exclusively focusing on intensification or high intensity, the point is to find an optimal balance between low and high intensity. This topic has been addressed extensively in several articles (11, 13, 16) and retrospective analysis of gold medal performers highlights the importance of relatively high volume of low intensity training accompanied with smaller amounts of higher intensities (4, 6, 9, 10). Further evidence suggests the optimal distribution is polarized so that between low- and high intensity zones relatively small amount of training is performed in moderate intensity; accordingly 75-80% of zone 1, 5% of zone 2 and 15-20% of zone 3 training (13). The effectiveness of polarized model was tested experimentally by Stöggl et al. (12), whereby an increase of ~12% was observed for polarized training group in relative $\dot{V}O_2peak$, followed by high intensity interval group (~5% improvement), while smaller effects were present for threshold- and high volume training groups. In contrast, another study that recruited different elite endurance athletes (including XC-skiers) found that high intensity interval (2 weekly sessions of HIT) led to enhanced acute heart rate recovery and improved peak performance ~6% over an 9-week period. Interestingly, the effect of polarized training approach was smaller to that of high intensity interval method, whereas the distributions were 68-6-26% vs. 43-0-57% (zones LIT-MIT-HIT) for those groups, respectively (20).

A unique perspective to top-level endurance program from a case study might bridge the gap between polarized training and high intensity approach to periodization. A highly decorated female XC-skier (8-time Olympic gold medalist) employed two distinctly different periodization models over the professional career (39). First approach was a block periodization, where intensified blocks accommodated increased frequency of HIT. Second model was in essence a high volume of low intensity training interspersed with HIT – approximating polarization to a certain degree. These models were very similar in weekly TRIMP score but differed substantially in intensity distribution. Differently incorporated HIT led to successful performance in both competitive seasons.

The range of impact achieved by HIT is wide – on one side the large performance improvements are often reported (18, 34, 40, 41), at the other end the risk of injuries and overtraining might increase (11, 22). Although the content of high intensity bouts was not extensively analysed in this study, the effectiveness of intensified training strongly depends on frequency, duration and acute intensity of intervals within a single session (42).

A leap to the opposite direction is the question of whether LITG and CG trained enough to overcompensate the relatively small proportion of high intensity with large volume of low intensity. Perhaps the simplest explanation to minor improvements is that the training stimulus was not sufficient? At both submaximal intensities an increased oxygen cost was observed for CG, accompanied with a reduction in GE. Opposite shift was seen within intervention groups.

Sandbakk et al. (29) demonstrated the difference in GE between world class and national level XC-skiers. In that study both aerobic and anaerobic metabolic rate were compared, and a consistently lower anaerobic metabolic rate was determined for world class skiers. Surprisingly however, the CG in this study achieved a high GE (~16%) comparable to world class XC-skiers. Although not presented in the results of this thesis, metabolic rates were ~28-30% lower and work rates ~22-23% lower in comparison to world class and national level athletes pooled. Thus, the actual underlying mechanisms of GE were not matched to those achieved by higher level skiers. In addition, at slightly lower velocity and incline with approximately 6 years older highly trained male XC-skiers, the same roller-ski skating technique elicited a similar result of 16% in GE (28).

Despite the high initial value in CG, a small insignificant reduction was observed in GE at post-test, in contrast to main findings for LITG and HITG. One probable reason for minor reduction of GE in CG was the increased oxygen demand. Higher absolute values of O_2 obtained in both submaximal intensities inflates the metabolic rate and subsequently reduces the GE. No change in absolute O_2 was evident in intervention groups, however in respect to body-mass-normalized $\dot{V}O_2$, a reduction was present in both LITG and HITG. It remains uncertain what caused the elevation of O_2 in CG, but from the direct observations, few athletes were having the signs of fatigue (three athletes with lower RPE in TTE compared to pre-test in combination with nausea or feeling of vomit) during the post-test. Meeusen et al. (43) stated in the position stand article about overtraining syndrome: "Successful training must involve overload, but also must avoid the combination of excessive overload with inadequate recovery." It is thought-provoking to associate current findings with overreaching – yet in this regard, literature cautions more against high intensity training (16, 44). A relatively high dominance of low intensity training (> 90% of time in LIT) does not seem to support such statement in CG. In a study by Seiler et al. (45), parasympathetic recovery was relatively fast from ~120min endurance activity, however when exercising over first ventilatory threshold, a delay was present in autonomic nervous system recovery. The latter investigation also led to the conclusion that highly trained endurance athletes require considerably less time for heart rate variability to recover compared to moderately trained counterparts.

Wenger and Bell (46) highlighted that increases in absolute and relative $\dot{V}O_2$max are inversely related to initial fitness levels. However, this is an unlikely consideration in regard to CG, which obtained lower $\dot{V}O_2$peak values in comparison to both intervention groups (**Table 3**). In a study with elite junior XC-skiers a mean ~4% improvement in $\dot{V}O_2$max was exhibited by the high intensity training group over an 8 week period (34). A substantial increase in relative $\dot{V}O_2$max from 67.5 to 70.2 $mL \cdot kg^{-1} \cdot min^{-1}$ in that study exemplifies the potential for improvements for similar athletes in current investigation.

As elaborated by Peter Wagner (47), O_2 transport ensues via an integrated system of conductance (from the air to the mitochondria), in which central and peripheral factors contribute to metabolize O_2 for ATP generation. It has been proposed that the high volume of low intensity training might be needed to improve peripheral stimulations (e.g., mitochondrial biogenesis, capillary density) (14, 48).

In contrast, muscle biopsies extracted in a study comparing the effect of high or moderate intensity training in elite XC-skiers revealed that the content of specific blood lactate transporter enzymes (specifically MCT_1) did not change significantly for those in HIT group, yet substantial reduction was evident in MIT group (23). Notably, maximal oxygen uptake remained largely the same for both groups over the 5-month period. The overall conclusion was that the high intensity strategy was more effective in improving lactate threshold compared to moderate intensity.

In alignment with the main findings of current work, a tendency for HITG to improve at both submaximal (similarly to LITG) and maximal workloads highlights the effectiveness of this training method. In parallel, low intensity training should not be discarded unproductive. According to Stephen Seiler (16): “One underlying assumption that influences long-term training organization principles in endurance training seems to be that adaptation of peripheral and central components of the respiratory chain are differentially impacted by training intensity and duration, with differing time courses and adaptive scope.” Thus, the generalizability of present results is limited by the fact that long-term training adaptations could deviate remarkably from the conclusions emerged from the short-term study.

Limitations

Firstly, current investigation involved two test locations, which poses some methodological limitations. However, cross-validation with 4 athletes ensured a reliable similarity between measurement instruments. Secondly, the parallel comparison of females and males was not performed, due to the reason that gender, when fitted to factorial ANCOVA, did not elicit a two-way interaction effect with group. Nevertheless, it would be a captivating perspective to evaluate both genders in a similar type of investigation. Thirdly, the analysis of training heart-rate data would ensure higher confidence that the self-reported intensity zones in individual sessions were precise. This could be more feasibly achieved via joint platform that enables to extract heart-rate data in a standardized manner in alignment with the ethical principles of storing sensitive health data.

Practical applications

There is probability of certain degree that one of these athletes that participated in this study will find a path to international podium. As this thesis has circumnavigated around various performance factors and physiological determinants in endurance sport, the complexity of training responses makes it extremely difficult to predict the “winner of tomorrow”. This study demonstrated that by arranging training volume and intensity similarly to the training groups in this study, the overall response, measured by time to exhaustion performance and respective laboratory determinants of performance, might not lead to a difference in adaptive outcomes. There was, however, a tendency for larger improvement in high intensity training group at maximal intensity level, where magnitude of change in pre- to post-test comparison was larger for TTE and absolute $\dot{V}O_2$peak. However, more research is needed to find a training intensity distribution that consistently outperforms other models of training load progression.

CONCLUSIONS

Whilst total endurance volume was highest in CG over the 8 weeks of training load progression, both LITG and CG were found to have a similar training intensity distribution, with more than 90% of endurance training time accumulated in low intensity zone and remainder divided into both moderate and high intensity zones. In contrast, the contribution of high intensity training was approximately two-fold higher in HITG compared to that achieved by other two groups.

Despite this difference in training intensity distribution, the results indicate no difference in performance, expressed by the time to exhaustion in incremental treadmill roller-ski skating test, among the three groups of highly trained endurance athletes. An examination of key adaptations associated with performance (e.g. $\dot{V}O_2$peak, blood lactate concentration, gross efficiency) at both submaximal and maximal intensity levels did not elicit a further statistically significant main effect of group.

Within-group pairwise comparisons revealed the significant improvements of ~6-10% in time to exhaustion for HITG and LITG from pre- to post test, but change was not present in CG. HITG was the only group to enhance absolute $\dot{V}O_2$peak over the timespan of this study, whereby other groups remained unchanged. Gross efficiency improved for LITG and HITG similarly, and no change was detected for CG.

On the basis of these findings it is suggested that optimization of training load by abovementioned intensity distribution patterns induces a similar magnitude of change in performance, determined by the test to voluntary exhaustion and across the adaptations of physiological performance markers, among groups of well-trained cross-country skiers.

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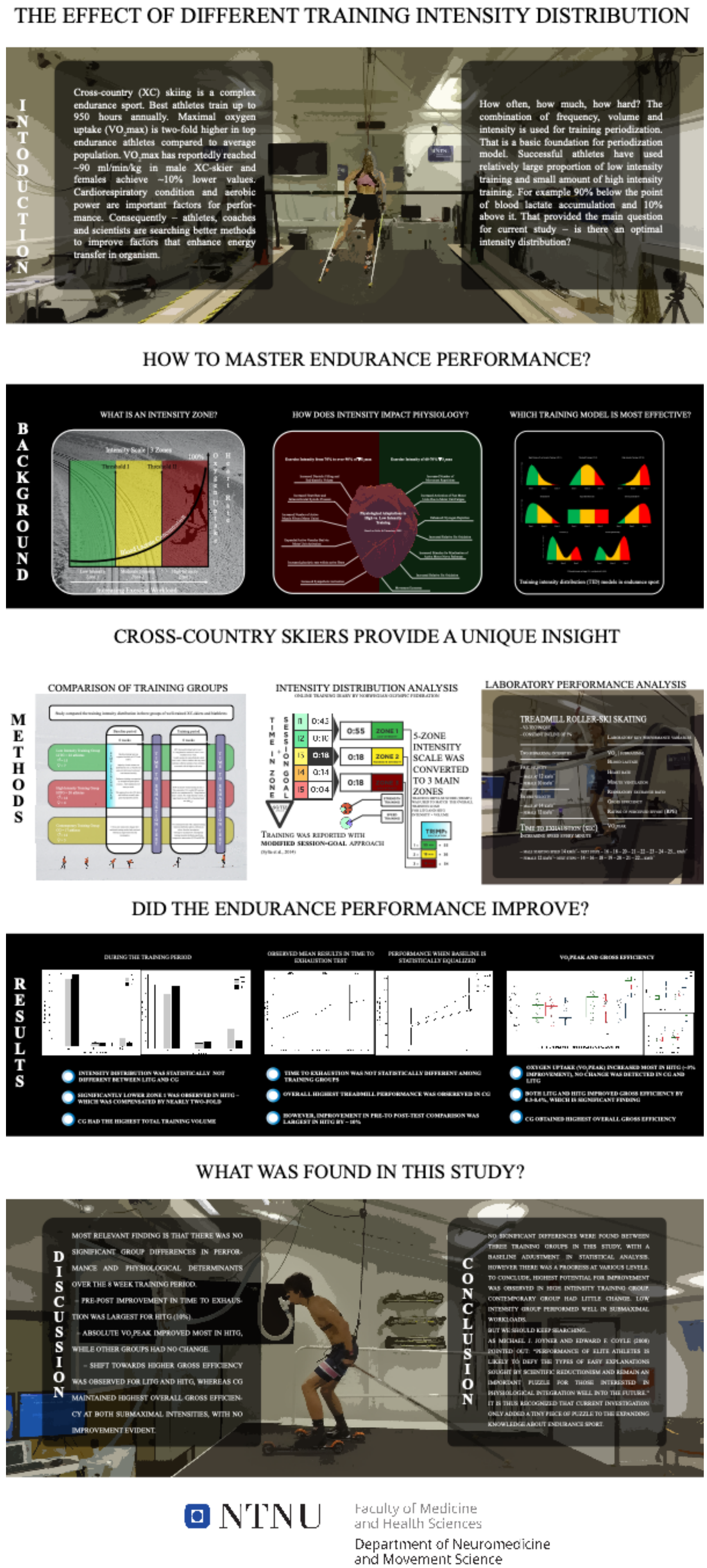
INFOGRAPHIC



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