Master's thesis

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

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Acute physiological responses to external versus internal intensity control during a standard "threshold" training session in well trained endurance athletes

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Supervisor: Jørgen Danielsen
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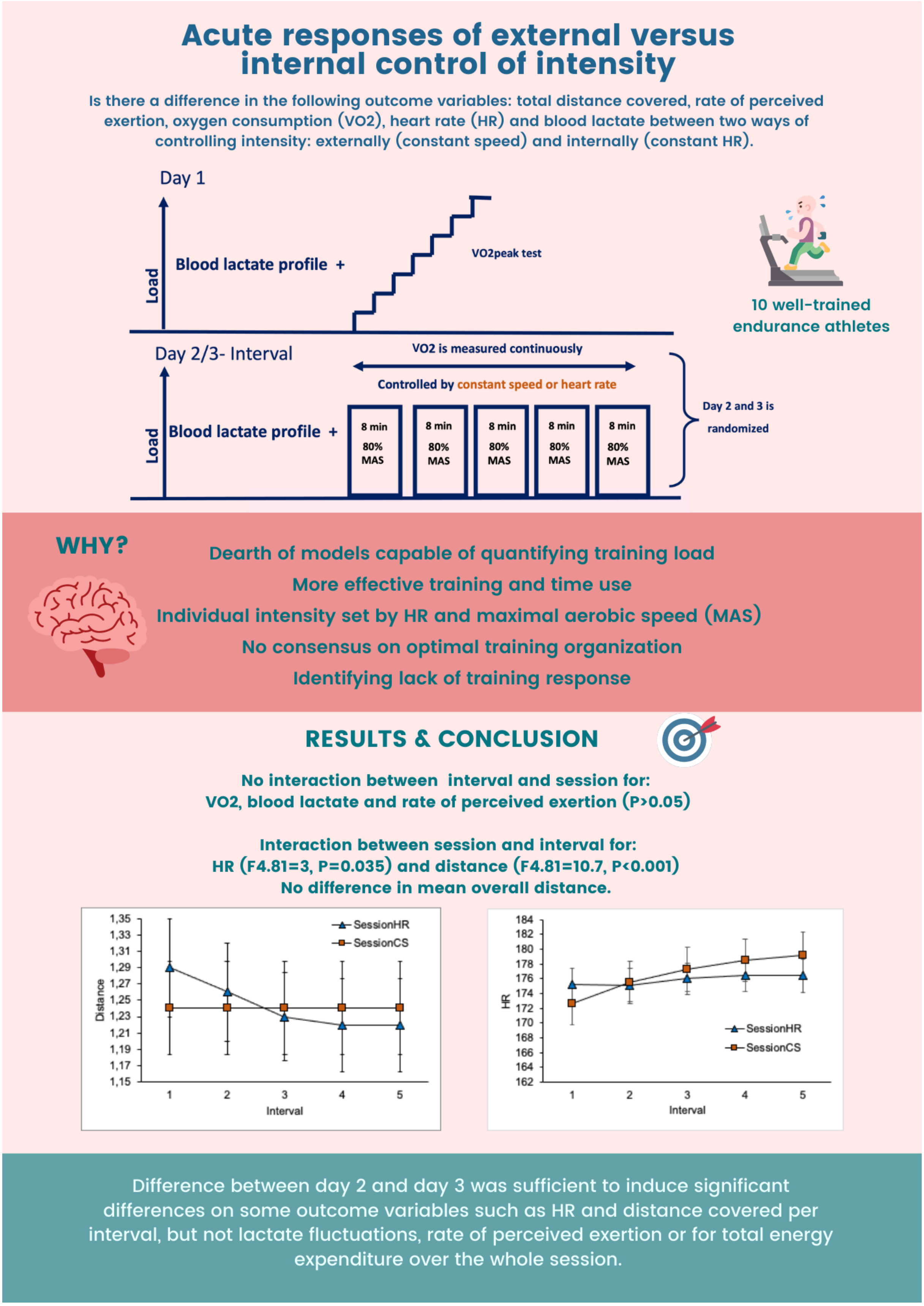
Infographic



Abstract

Background: Endurance athletes utilize a variety of strategies to control the overall and acute exercise intensity. Two often used methods for acute control of intensity are i) externally (speed) and ii) internally (heart rate (HR)). It is believed that one cannot keep both constant over time, since constant HR likely demands decrease in speed, and constant speed demands increased HR. However, the extent to how such sessions differ regarding distance covered, oxygen consumption (VO_2), rate of perceived exertion (RPE) and blood lactate concentration (BLa) fluctuations is not well documented.

Purpose: To investigate if there is a difference in the following outcome variables: total distance covered, RPE, VO_2, heart rate and BLa between two ways of controlling intensity: externally (constant speed) and internally (constant HR).

Methods: 10 well trained endurance athletes (age 21.6 ±4.56 years, body weight 65.01 ±9.18 kg, body height 177.8 ±8.37 cm and VO_{2peak} 63.6 ± 8.3 ml/kg/min) came to the lab three separate days. Day1 consisted of a blood lactate-profile and VO_{2peak} test, from which speed corresponding to 80% of maximal aerobic speed (MAS) was calculated. Day2 and Day3 consisted of interval sessions performed as 5 * 8 min efforts, where intensity was controlled either internally: referred to as sessionHR, keeping HR approximately constant corresponding to 80%MAS by adjusting speed, or externally: referred to as sessionCS, speed constant at 80%MAS. Respiratory variables, HR, BLa, RPE and total distance covered was collected and compared.

Results: For HR and distance covered, there was a significant interaction between interval and session ($p<0.05$). SessionCS induced a lower HR than sessionHR during interval1. Thereafter HR increased gradually per interval during sessionCS and remained stable during sessionHR. Distance covered per interval showed the opposite pattern. For mean VO_2 there was no significant interaction, and for participants individually the differences induced appears to be minimal. For RPE and BLa there was no significant interaction. There was no difference in mean between sessions in any of the outcome variables.

Conclusion: Difference between sessionHR and sessionCS was sufficient to induce significant differences on some outcome variables such as HR and distance covered per interval, but not BLa fluctuations, RPE or for VO_2 over the whole session.

Key words: training load, endurance athletes, heart rate, constant speed, blood lactate, oxygen consumption, rate of perceived exertion

Sammendrag

Bakgrunn: Utholdenhetsutøvere bruker en rekke ulike strategier for å kontrollere overordnet og akutt treningsintensitet. To ofte brukte metoder for akutt intensitetskontroll i en økt er i) ekstern (fart) og ii) intern (puls). Det antas at en ikke kan holde begge konstant over tid, siden konstant puls sannsynligvis krever nedgang i fart, og konstant fart krever en økning i puls. Derimot, i hvilken grad distanse løpt, oksygenopptak (VO_2), opplevd anstrengelse (RPE) og konsentrasjon av blodlaktat (BLa) fluktuerer mellom øktene er ikke godt dokumentert.
Formål: Å undersøke om det er en forskjell i følgende utfallsvariabler: total distanse, RPE, VO_2, puls og BLa basert på to ulike måter å kontrollere intensitet: eksternt (konstant fart) og internt (konstant puls).
Metode: 10 veltrente utholdenhetsutøvere (alder 21.6 ($\pm$4.56) år, kroppsvekt 65.01 ($\pm$9.18) kg, høyde 177.8 ($\pm$8.37) cm og VO_{2peak} 63.6 $\pm$ 8.3 ml/kg/min) kom til laben tre ulike dager. Dag1 besto av blodlaktat-profil og en VO_{2peak}-test, hvor fart tilsvarende 80% maksimal aerob hastighet (MAS) ble kalkulert. Dag2 og Dag3 besto av intervalløkter utført som 5 x 8-minutter, hvor intensitet ble kontrollert enten internt: referert til som sessionHR, jevn puls tilsvarende 80%MAS ved å justere fart, eller eksternt: referert til som sessionCS, fart konstant på 80% MAS. Respiratoriske variabler, puls, BLa, RPE og total distanse løpt ble målt og sammenlignet.
Resultater: For puls og distanse løpt var det en signifikant interaksjon mellom interval og økt ($p<0.05$). SessionCS induserte en lavere puls enn sessionHR for interval1. Etter dette økte puls gradvis per interval for sessionCS, og holdt seg stabil for sessionHR. Distanse løpt per interval viste motsatt mønster. For gjennomsnittlig VO_2 var det ingen signifikant interaksjon, og for deltakerne individuelt ser det ut til at forskjellene indusert er minimale. For RPE og BLa var det ingen interaksjon. Det var ingen forskjell i gjennomsnitt mellom øktene for noen av utfallsvariablene.
Konklusjon: Forskjellen mellom sessionHR og sessionCS var tilstrekkelig til å indusere signifikante forskjeller på noen av utfallsvariablene, puls og distanse løpt per interval, men ikke for fluktuering i BLa, RPE eller for VO_2 over hele økten.
Nøkkelord: Treningsbelastning, utholdenhetsatleter, puls, konstant fart, blodlaktat, oksygenopptak, opplevd anstrengelse

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1. Introduction

Exercise may, depending on factors such as intensity, frequency, volume, and type of exercise, lead to physiological and technical adaptations that can improve performance. Endurance performance is dependent on several determinants, where maximal oxygen uptake (VO_{2max}), lactate threshold (LT) and efficiency are most influential (Joyner & Coyle, 2008). Often, a description of the totality of endurance training involves a more or less clear separation of exercise into different intensity zones. Typically, one may use the 5-level zone or the 3-level zone. Grossly, these zones are based on (theoretical as well as practical) thresholds, for example LT, some percentage of heart rate max ($HR_{max)}$ or VO_{2max} (Losnegard et al., 2021). Overall, a proper amount of and combination of exercise at difference intensities and recovery lead to enhancing endurance performance. The individual response to standardized programs may vary considerably and are dependent on many factors, such as genetics, sleep, type of exercise etc. (Jacques et al., 2022).

Soligard et al. (2016) defines training (or exercise) load as *«the cumulative amount of stress placed on an individual from a single or multiple training sessions (structured or unstructured) over a period of time»*. Endurance athletes utilize a variety of strategies to describe their load, where methods typically build on both or either *internal* or *external* load. Bourdon et al. (2017) defines internal load as *"biological stressors inflicted on an athlete during the sport, among them are heart rate, blood lactate, oxygen consumption and rate of perceived exertion",* and external load as "*objective measures of work (power output, speed)*. However, to quantify both heart rate (HR) and blood lactate concentration (BLa) together with VO_2 as internal load is complicated. This is because VO_2 (indirect measure of metabolic energy input) is strongly and linearly related to external load such as speed (useful external energy output) (Ingen Schenau & Cavanagh, 1990) . On the other hand, HR and BLa cannot be predicted from speed because these measures are more dependent on the fitness level of an individual. The relationship between HR and external load is also much linear, but not directly casual. For example, running at 17 km/h will demand approximately 55 ml/kg/min (given some incline and variation in running economy) for any individual (Jones et al., 2021). For a well-trained athlete this external load (17 km/h, 55 ml/kg/min) may correspond to a relative HR of 60% and BLa of 1 $mmol{\cdot}L^{-1}$. However, for a less trained athlete this same external load may correspond to a relative HR of 90% and BLa of 5 $mmol{\cdot}L^{-1}$.

Several studies have tried to explore some methods of quantification of load, including session-goal, time-in-zone (heart rate-scales), and session rate of perceived exertion (RPE) (Wallace et al., 2014). Control of intensity is one of the most important aspects regarding the training load in endurance athletes and is one of the most used approaches by several sports. The better and more professional the athlete, that is, the more time spent exercising, the more important does control of intensity become. For example, to avoid overreaching and overtraining and to induce the appropriate stimulus for performance improvements, control of intensity per session (and overall) is more important for individuals exercising 10 sessions (10+ hours) per week than for individuals that exercise 2 sessions (1 hour) per week. According to reviews by Stöggl & Sperlich (2015) and Seiler & Kjerland (2006), it appears that optimal training volume and organization of training for performance improvement is yet to reach a consensus. A review by Borresen & Lambert (2009) discovered a dearth of models capable of quantifying training load and their impact on performance at individual level.

Typically, some common ways of controlling session intensity used in practice is HR, speed/power output, RPE or BLa, or a combination of these. Blood lactate (BL)- approaches, however, are more invasive. Also, often it is not trivial to define the "correct" LT (Jamnick et al., 2018). Adjusting speed to HR is often used, for example by staying within some target HR relative to maximal HR (Seiler, 2010). However, during exercise, HR may drift quite considerably, especially at higher intensities (Coyle & González-Alonso, 2001). Although VO_2 may also drift (slow component), this drift is usually of a smaller magnitude and occurs at higher intensities than for HR drift. Thus, in order to stay within some pre-defined HR range, one must often decrease external load progressively throughout the session because of this drift. Because of the causal and predictive relationship between VO_2 and load, a decrease in load (power, speed) should mean that VO_2 also decreases, despite a remaining higher HR. HR has a day-to-day variation (Lamberts & Lambert, 2009), and in practice, one often sees that HR has a larger day-to-day variability than VO_2.

Another method of controlling session intensity is to prescribe load according to some percentage of maximal aerobic speed (MAS). It is defined as the minimal speed associated with obtained VO_{2max}, and determines and prescribes intensity individually, based on a subjects VO_{2max} and energy consumption at a defined speed (Gheorghiu & Onet, 2013). Quantification of how these different ways of controlling intensity may lead to variations in session outcome, may be important knowledge for coaches and athletes. It is critical to identify potential causes of athletes' subpar training response, and potential connections to performance development or lack thereof. Training periods consists of several single sessions, where individuals may perform the same external load during a training session or over a period, but the internal load may be very different and different adaptations to same training stimuli is produced (Mujika, 2017). To perform well in e.g., half-marathon, a steady high speed is needed, where this speed is as high as possible. If an athlete trains according to HR, in theory, speed must be adjusted up and down in a session, where VO_2 also will fluctuate. Over time, this may lead to less specific training, that is, training at too high or too low speed within sessions compared to performance speed (Joyner & Coyle, 2008). While training at steady pace (estimated from BLa or %MAS), internal measures as HR, RPE and BLa may drift, but in theory one will train more specifically for performance (steady high speed).

To what degree this pattern is correct, comparison of the two and the acute responses of the sessions remains to be examined. Therefore, the purpose of the current study was to further investigate this. In this present study, the aim was to investigate if there is a difference in the following outcome variables: total distance moved, VO_2, HR, RPE and BLa based on how two different sessions are quantified, internal (HR) vs. external load (speed). It is hypothesized that the internally controlled session will demand a progressive lower speed and VO_2. Which in sum may give lower total distance covered and energy expenditure. The externally controlled session will yield a progressive increase in HR, which may indicate higher than prescribed intensities (based on BL-profile and peak oxygen uptake (VO_{2peak})-tests), but where actual load and VO_2 remains constant.

2. Methods

2.1 Participants

10 experienced Norwegian endurance athletes (5 male and 5 female) with VO_{2peak} 63.6 ± 8.3 ml/kg/min, took part in the study. *Demographics found in table 1*. The participants were actively competing endurance athletes, including orienteers, cross country skiers and middle-distance runners. Participation was voluntary, and all participants signed a form of written consent. Prior to this, they were also verbally informed about the procedures and possible following risks and advantages. They all had the right to withdraw their participation at any time without any reason given. The present study has been approved by Norwegian Social Science Data Services. For the ethical statement of this current study, testing is done on healthy athletes who are familiar with testing. Testing is done according to strict routines and executed by trained personnel only.

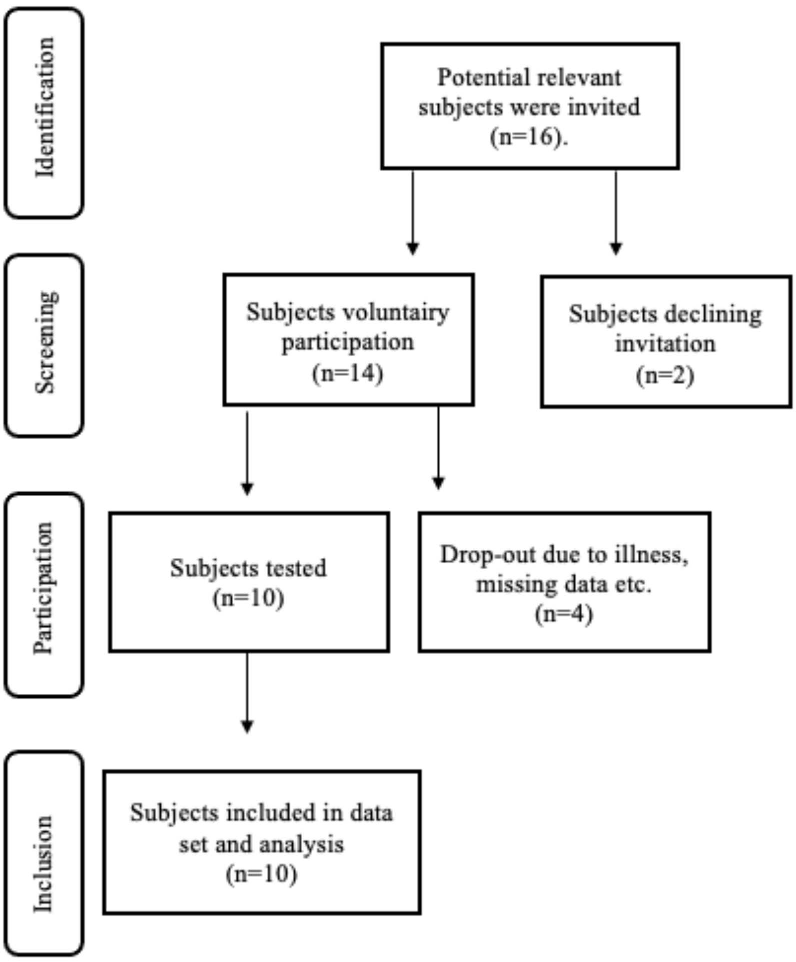


Figure 1. Flowchart of recruitment and inclusion of participants**.**

Table 1. Mean, standard deviation (SD) and range of descriptive statistics of participants.

	Age (year)	**Height (cm)**	**Weight (kg)**	**VO_{2peak} (ml/kg/min)**
Mean (±SD)	21.6 (4.56)	177.8 (8.37)	65.01 (9.18)	63.6 (8.3)
Range	17-33	167-189	53.9-79	50.1-75.2

Abbreviation: VO_{2peak}= peak oxygen uptake.

2.2 Outline of the study

In this cross-sectional study with an explorative approach, a total of three sessions was performed. Day1 was a combined BL-profile and incremental test to find VO_{2peak}, used to prescribe a given intensity for testing day2 and 3. Day2 and Day3 consisted of two different ways of controlling intensity, at a pre-defined experimental protocol running on treadmill with interval sessions performed as 5 * 8 min efforts with 2 min breaks, where intensity was controlled either i) internally: sessionHR, keeping HR approximately constant corresponding to 80%MAS by adjusting speed, or ii) externally: sessionCS, keeping speed constant at 80%MAS. The order of the sessions was counter balanced. All days involved running at 10.5% incline. The three sessions were separated by a minimum of 1 day in between, preferably no more than two weeks. Data was collected in the period from November 2022-February 2023.

2.3 Experimental design and instrumentation

Preparation

All participants maintained their usual training schedule during the testing period. To minimize differences and give same prerequisites to all participants, all tests were supervised by one well trained and experienced test-leader. All tests were performed on the same Woodway PPS Med 55 treadmill ergometer (Woodway GmbH, Deutschland), with a standardized incline in all sessions to avoid changes and differences in environmental factors. All participants were instructed to bring indoor running shoes and suitable clothing. Additionally, they were instructed to abstain from strength training the day prior to all test-days, and only do light training. All three tests were set to start at approximately the same time of the day and participants were instructed to eat and drink as similar as possible. Temperature in the lab was maintained at 19°C-21°C with 22-38 % relative humidity. During sessionHR and sessionCS, participants had the option to either drink water or they could abstain fully from water intake. Intake was standardized in both interval sessions.

Body height was measured prior to all tests, and body weight was measured using an electronic body mass scale (Seca model nr:877; Seca GmbH & Co. KG., Hamburg, Germany) before and after all tests.

Test day 1: BL-profile and VO_{2peak} testing.

Before starting the test, all participants were orally informed about the procedure and the use of RPE measurements using the Borg-scale (6-20) (Borg, 1998). Following, all participants started a combined familiarization period and warmup with running. The warmup period consisted of 5 minutes easy running at self-chosen speed. Thereafter a BL-profile test was conducted, with 5-minute intervals in series. Starting speed was set to 6,6 and 7,5 km/h for women and men respectively, with speed increasing with 0,9 km/h per interval, and the test was terminated when participants reached approximately 4 $mmol \cdot L^{-1}$ BLa, or if RPE exceeded 16.

HR was continuously recorded using HR-belt by Garmin (Garmin HRM-Pro) with a compatible Garmin watch (Garmin Forerunner 920 XT). Between intervals, participants had a 2-minute rest. During the 2-minute rest periods, immediately after all 5-minute intervals, BLa was taken from the fingertip, collecting 20 µL blood and analyzed using Biosen C-line sport lactate analyzer (EKF Diagnostic BmbH, Magdeburg, Germany) to record BLa. The Biosen System was calibrated automatically every 60 minutes using a concentration of 12-mmol µL. RPE was also noted.

Respiratory variables were measured continuously for each interval with 30-second averages, using an open circuit indirect calorimetry Vyntus CPXTM with a mixing chamber (Vyaire medical GmbH, Hoechberg, Germany). The mean over the last 2 minutes of each submaximal interval defined steady state respiratory variabels. The system was calibrated according to user manual before all tests. Calibration was done against ambient air and gas with known concentrations: 15% O2 and 5 % CO2 and using built in automatic pump for the flow transducer.

Thereafter, participants performed a 5-minute active recovery at slow pace. After this, participants did an incremental exercise test to determine VO_{2peak}. The starting speed was 1 km/h lower than the speed the participants finished at in the BL-profile test, whereafter speed increased with 1 km/h every minute until voluntary exhaustion. Respiratory variables and HR were recorded continuously through the incremental test using the same instruments as formerly described. The 2 highest 30-s rolling average values defined $VO_{2peak,}$ if the following criterias for VO_{2peak} was met:

1. Plateau in VO_2, despite an increase in speed or
2. Respiratory exchange ratio (RER) ≤ 1.0

Criterias was met by all participants. The highest speed achieved was defined as peak treadmill speed (V_{peak}). Highest RER during the test was noted. HR_{max} was noted directly after test termination, which was the highest HR lasting for 5 seconds and added 3. 1 minute after finishing the test, BLa was measured, and RPE using Borg-value was noted.

Test day2 & 3: sessionHR and sessionCS

All tests were performed on the same time of the day to minimize differences in liquid intake, meals, and possible effects of daily fluctuations in hormones etc. Figure 2. shows a schematic overview of the two sessions performed at day2 and day3. SessionCS and sessionHR consisted of 20 minutes with a combined warm-up and BL profile, with following 5 x 8-minute intervals, with a standardized 10.5 % inclination. The warmup was 5 minutes of running at a self-chosen speed, thereafter bouts of 5 minutes BL-profile, using a similar protocol as described in day 1. However, for sessionHR and sessionCS, there was 3 bouts, where the first bout was set to start at 2,3 km/h slower than MAS calculated from day 1. Then, speed increased with 0,9 km/h per bout. This was to ensure equal difference in speed between the last 5-minute bout and the first interval, for both sessions and all participants.

After warm-up, participants got a 5-minute break before starting the first 8-minute intervals. For sessionCS, speed was constant through all intervals, set to 80% of MAS calculated from test day 1. The 80% MAS was chosen based on pilot tests and MAS was defined as the lowest speed where the VO_{2peak} occurred. MAS was calculated from test day 1: MAS = a + Bx. Where x is the obtained VO_{2peak}, a and B is the offset and regression coefficient from linear regression analysis on VO_2 and speed from submaximal test. In the present study, 80% MAS was used for all intervals. MAS was chosen due to high variation in BL-response. Additionally, it was found challenging to set the right speed corresponding to a given LT, which has also been found in other studies (Jamnick et al., 2018).

For sessionHR, starting speed was set to 80% MAS, and thereafter set to adjust up and down after HR to stay approximately equivalent corresponding to 80% MAS. Heart rate was set to stay within a pre-determined range calculated from day1, 2%points lower - 2%points higher relative to the %HR_{max} corresponding to speed at 80%MAS. Speed was adjusted up or down 0,3 km/h accordingly for each adjustment needed to stay within the HR-range. 0.3 km/h was chosen because at 10.5% incline, linear regression analysis between HR and VO_2 versus speed gave an increase of 8 beats per minute (HR) and 4.5 ml/kg/min (VO_2) per 1 km/h increase in speed. Thus, a change of 0.3 is approximately equal to a HR and VO_2 change of 2.7 beats per minute and 1.5 ml/kg/min. For both sessions HR and respiratory variables were measured continuously after warm up to the end of the test, using the same instruments as described in day1. There was a 2-minute break between intervals, with BLa- and RPE collected immediately after all intervals. Total running distance was calculated afterwards in both sessions. For sessionCS and sessionHR, mean VO_2 was calculated as the mean value of all 30-second measurements in each interval (8-minute average). Additionally, mean values was presented in % of VO_{2peak}.

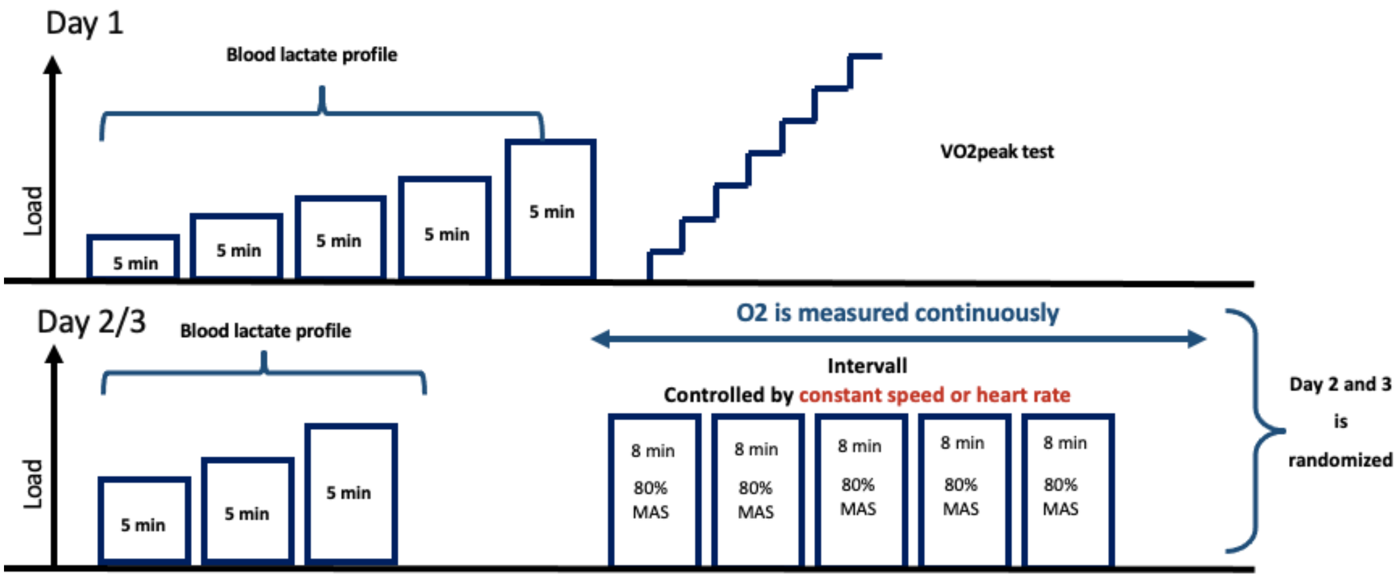


Figure 2. Visualization of study protocol.

2.4 Statistical analysis
Microsoft Excel for Mac (version: 16.52; Microsoft Corp; Redmond, WA, USA) and IBM Statistical Package for the Social Sciences (SPSS 25.0; IBM Corp; Armonk, NY, USA) were programs used for statistical analysis. Descriptive statistics are presented in mean values ± standard deviation (SD).

To evaluate the effect of interval and session on the outcome variables, a linear mixed model (LMM) was used. VO_2, BLa, RPE, distance, and HR was defined as dependent variables in separate analyses. Interval number and session (both categorical) were fixed factors, while participant number were random factors (random intercept model), approximately equivalent to a repeated measure analysis of variance. In the presence of significant interaction between interval and session, follow-up interaction contrasts were used to examine at which interval possible differences between session occurred and to examine the effect of interval for each session separately. Bonferroni corrections was used for this post-hoc analysis. If no interaction was found, the interaction term was removed, and main effects were reported. Effect size (ES) was calculated using Hedges g calculations due to small sample size ($n<20$) in the study. Calculation for Hedges g for dependent samples was used. Magnitude interpretation was trivial <0.1, small = 0.2, medium = 0.5, large = 0.8 and very large = 1.3. Raw values and Hedges g was used to see if there was an effect and eventually where the effect could be found, even though no interaction was found.

3. Results

3.1 Physiological parameters

Distance

Mean distance covered for each interval and session are shown in Fig. 3D and Table 2. For distance covered, there was a significant interaction between session and interval ($F_{4.81}=10.7$, $p<0.001$). There was a significant effect of interval for sessionHR ($F_{4.81}=21$, $p<0.001$) but not for sessionCS ($F_{4.81}<0$, $p=1$). Total mean distance in both sessions was 1.24 km, and no difference between sessions was found. For the effect of session at each interval, bonferroni corrected tests revealed differences between days for interval 1, 4 and 5 ($p<0.05$). For sessionHR and sessionCS, respectively, distance decreased with 0.07 km (range: -0.1-0) and 0 km from interval1 to interval5 (Hedges g= 3.3).

Rate of perceived exertion

Mean RPE response for each interval and session are shown in Fig. 3E and Table 2. For RPE, there was no significant interaction between session and interval ($F_{4.81}=1.7$, $p=0.161$). There was also no difference between sessions ($F_{1.85}=0.2$, $p=0.644$), however there was a significant difference between intervals (Mean range: 13.9-15.3, $F_{4.85}=12.1$, $p<0.001$). For sessionHR and sessionCS, respectively, RPE increased with 0.9 (range: -1-4.) and 2 on Borg-scale (range 0-4) from interval1 to interval5 (Hedges g= 0.8).

Heart rate

HR-responses for each interval and session are shown in Fig. 3B and Table 2. For HR, there was a statistically significant interaction between session and interval ($F_{4.81}=3$, $p=0.035$). For sessionHR, there was no effect of interval ($F_{4.81}=0.5$, $p=0.704$), but for sessionCS there was a significant effect of interval ($F_{4.81}=8.8$, $p<0.001$), with HR increasing mainly from interval1 to interval2 (ref. Table 2). For the effect of session at each interval, Bonferroni corrected pairwise t-tests revealed a statistically significant difference between days at interval 1 and 5 ($p<0.05$). Here, the difference in HR flipped from interval1 to interval5. For sessionHR and sessionCS, respectively, HR increased with 1.2 beats (range: 2-4) and 6.6 beats (range 4-11) from interval1 to interval5 (Hedges g = 2.6). Overall mean HR was similar in both sessions.

Oxygen uptake

Mean VO_2 response for each interval and session are shown in Fig. 3A and Table 2. The mean VO_2 for all intervals showed no significant interaction (F4.81=0.5, p=0.738) between session and interval. There was also no difference between sessions (F1.85=0.2, p= 0.639) nor between intervals (F4.85=1.4, p=0.239). For sessionCS and sessionHR, respectively, VO_2 increased with 0.8 mL/kg/min (range: -2-4.4) and decreased with 0.8 mL/kg/min (range -1.3-3.1) from interval1 to interval5 (Hedges g= 0.5).

Blood lactate

Mean BL-responses for each interval and session are shown in figure 3C and table 2. For BLa, no significant interaction was detected between session and interval (F4.81=0.8, p=0.510). There was also no difference between session (F1.85=0.3, p=0.562) nor interval (F4.85=0.1, p=0.984), although visually BLa appears to have a small increase in sessionCS and decrease with interval during sessionHR. For sessionHR, BLa decreased with 0.5 $mmol \cdot L^{-1}$ (range: -2.54-1.78) and for sessionCS, BLa increased with 0.5 $mmol \cdot L^{-1}$ (range: -0.55-2.99) from interval1 to interval 5 (Hedges g= 1.1).

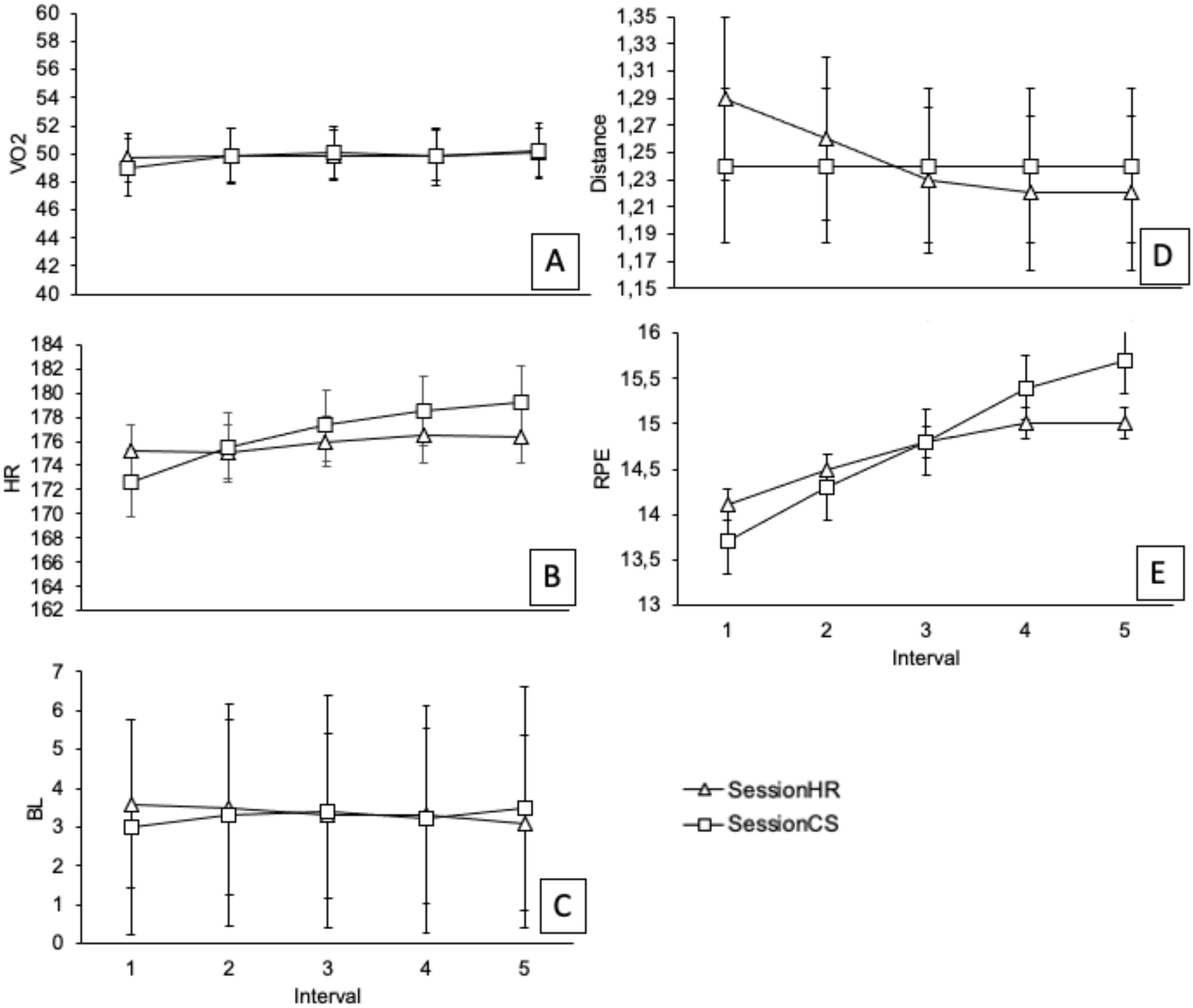


Figure 3. Mean effect of interval and session for all main outcome variables. Oxygen consumption (VO_2), heart rate (HR), BLa (blood lactate concentration), distance covered and rate of perceived exertion (RPE) respectively, is presented in ml/kg/min, BPM, $mmol \cdot L^{-1}$, kilometers, and Borg scale (6-20).

Table 2. Mean effect of interval and session for all main outcome variables presented with standard deviation (SD). Oxygen consumption (VO_2), heart rate (HR), BLa (blood lactate concentration), distance covered and rate of perceived exertion respectively, is presented in ml/kg/min, BPM, mmol·L^{-1}, km/h, and Borg scale (6-20).

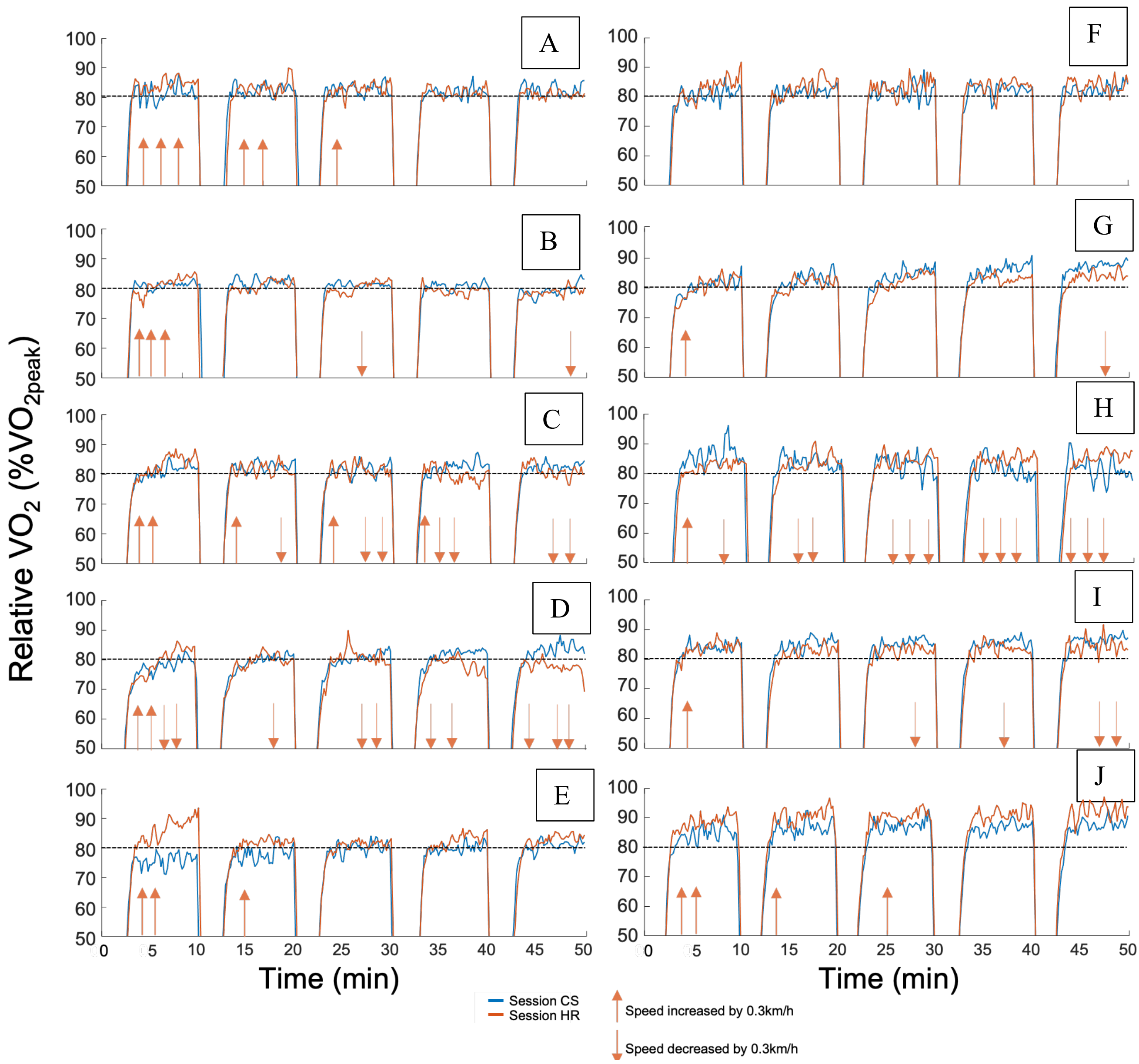
PARAMETER	**Interval**	**1**	**2**	**3**	**4**	**5**
HR	**sessionHR**	175.2 (±6.8)	175.1 (±7.1)	176.0 (±6.7)	176.5 (±7.1)	176.4 (±7.1)
	sessionCS	172.6 (±8.8)[* ,3,4,5]	175.5 (±9)[5]	177.3 (±9.5)[1]	178.5 (±9.2)[1]	179.2 (±9.8)[*1,2]
	ES	0.33	0.04	0.16	0.24	0.32
VO_2	**sessionHR**	49.7 (±5.5)	49.9 (±6)	49.9 (±5.8)	49.9 (±5.5)	50.1 (±5.4)
	sessionCS	49 (±6.4)	49.8 (±6.2)	50.1 (±5.9)	49.8 (±6.4)	50.2(±6.1)
	ES	0.11	0.01	0.03	0.02	0.02
DISTANCE	**sessionHR**	1.29 (±0.19)[2,3,4,5]	1.26 (±0.19)[1,3,4,5]	1.23 (±0.17)[1,2]	1.22 (±0.18)[1,2]	1.22 (±0.18)[1,2]
	sessionCS	1.24 (±0.18)[*]	1.24 (±0.18)	1.24 (±0.18)	1.24 (±0.18)[*]	1.24 (±0.18)[*]
	ES	0.27	0.10	0.05	0.11	0.11
BLA	**sessionHR**	3.6 (±2)	3.5 (±2.9)	3.3 (±1.9)	3.3 (±2.3)	3.1 (±1.9)
	sessionCS	3.0 (±1.4)	3.3 (±1.9)	3.4 (±2.1)	3.2 (±1.6)	3.5 (±2.1)
	ES	0.35	0.08	0.05	0.05	0.20
RPE	**sessionHR**	14.1 (±1.7)[3,4,5]	14.5 (±2.1)[4,5]	14.8 (±2.0)[1]	15 (±1.9)[1,2]	15 (±2.1)[1,2]
	sessionCS	13.7 (±1.9)[3,4,5]	14.3 (±2.3)[4,5]	14.8 (±2.1)[1]	15.4 (±2.0)[1,2]	15.7 (±2.3)[1,2]
	ES	0.22	0.09	0.00	0.2	0.32

**=Indicates different from sessionHR (P<0.05). 1,2,3,4,5=indicates different from compared interval (P<0.05). Abbreviation: ES= effect size.*

3.2 Individual oxygen uptake in percentage of peak

Figure 4 shows, for all participants, VO_2 as a function of time for all intervals and both sessions. From this data it appears as if the two sessions induced minimal differences in VO_2. However, multiple speed decreases coinciding with approximately constant VO_2-values could indicate the occurrence of VO_2 slow component (drift). Speed had to be adjusted for HR to stay within range in 9 of 10 participants.

Figure 4. Rate of oxygen uptake (VO_2) in % of peak oxygen uptake (VO_{2peak}) for all intervals and both sessions, for all individuals. Orange arrows indicate at what time point speed was either increased or decreased by the test leader. The VO_2-data was sampled at 0.1 Hz and a 30s moving average was applied to smoothen the signal. VO_2 is presented in ml/kg/min.



4. Discussion

The purpose of the current study was to compare the acute physiological effects of external versus internal control of intensity during a typically performed threshold interval session. The main findings were that for HR and distance covered, there was a significant interaction effects between session and interval ($p<0.05$). HR increased gradually per interval during sessionCS and remained stable during sessionHR. Distance covered per interval showed the opposite pattern, with distance decreasing with interval in sessionHR. Mean distance (over all intervals) did not differ between session. However, contrary to the hypothesis, there was no effect of session or interval for VO_2, BLa and RPE. For mean VO_2 there was no significant interaction, and for participants individually the differences induced appears to be minimal. For RPE and BLa there was no significant interaction, while RPE increased throughout both sessions.

4.1 Task execution and overall method

The current study had an explorative approach looking at the immediate responses and eventual differences to the sessions. All participants were endurance trained and familiar with running and managed to complete all sessions. However, sport-specific parameters might be apparent, as seen in a formerly conducted study who found that runners would have a higher capacity of adjusting to increased speed and achieving a higher MAS (Casado et al., 2022). When 80% MAS is prescribed, this may for some correspond to above LT, while for others below LT. While using LT, this may correspond to 90% MAS and 60% MAS for others. A study by Jamnik et al. (2018) found that estimating true threshold speed/power can be challenging. One benefit of using MAS is that some athletes have low BLa overall, with peak BLa of 6 $mmol·L^{-1}$ and threshold of approximately 1.4 $mmol·L^{-1}$. For other athletes in our data, peak BLa was 19 $mmol·L^{-1}$ and threshold around 7 $mmol·L^{-1}$. To match the intensity for these, a percentage of MAS may work better. However, other measures such as a pre-defined or even individual set LT (e.g baseline BLa + 2 $mmol·L^{-1}$), or session-RPE could have been used and needs to be compared to the findings of using HR versus %MAS of this study to further disentangle the effects of different ways of intensity control.

If the overall goal is to perform at a half marathon, some mean (high) speed must be performed over time, with minimal fluctuations. Cross-country skiers or orienteers on the other hand, must perform well with more fluctuations. Thus, the two sessions might have different practical value. Specificity wise, it might be beneficial to perform training sessions close to, and just below or above this speed, especially considering the mechanics of muscle contractions. However, if, for any reason, the body is struggling with something, indicated by increased/decreased HR or BLa, it may be smart to adjust the overall intensity of that specific session accordingly. In any case, this study shows, independent on whether session intensity is externally or internally controlled, that variation over time occurs. Thus, this fact may itself suggest that a combination of internally and externally measures to control intensity is the best way.

Often, in practice, one max-session is conducted to set load for training sessions over a period. Research has shown that MAS provides individualization of training with accuracy due to a precise intensity defined and a measurement of change in physical fitness (Bellenger et al., 2015). However, some participants can be uneconomical in terms of VO_2, running at a high speed with high energy cost. This can result in a high MAS prescription. On the other hand, some can run at the same speed at a lower energy cost. Efficiency is greater with low energy consumption at a set speed (Bellenger et al., 2015). When exploring participants individually in the current study, a tendency was found towards too easy or too hard load for some participants in the sessions. E.g., one participant ran (see fig. 3E), for most part of sessionCS at VO_2 below 80%, with BLa lower than BLa corresponding to 80% MAS. On the other hand, another participant ran at higher BLa and had VO_2 higher than 80% of MAS (see fig. 3J). Thus, indicating that load can be too high or low. Additionally, using one session to set load for other sessions may be affected by day-to-day variations in measurements. Thus prescribing 80% MAS from one day may result in difference in VO_2 at same speed. Furthermore, if these sessions were repeated over time (say 2 times per week for months), the question is then: is it best to control intensity within each interval within each session, or to control intensity per session? This study does not answer this question. For reasons such as the relationship between muscle contraction dynamics required for a given speed, and the relationship between energy in and energy out required to sustain this speed over time, one could argue that adjusting intensity over sessions is more beneficial and less susceptible to rather large day-to-day variations in HR, for example. On the other hand, these day-to-day variations in HR may include variation that may indicate start of sickness; thus, it may be beneficial to adapt immediately within the session.

According to the study´s findings, running at 80% MAS linked to varying percentage of HR_{max}. Highly trained athletes can train at higher percentage of their maximum capacity, coinciding with results from studies on elite athletes (Joyner & Coyle, 2008). Also, highly trained athletes can sustain high speed without reaching their threshold for a longer time, which has been shown positive for results in running races (Mclaughlin et al., 2010). This may caracterize the difference in the different parameters for running at 80% MAS.

4.2 Physiological parameters

Overall, effects for HR and distance were found. HR went up when speed and distance was constant, due to HR-drift, as expected. However, no such effect occurred for VO_2, somewhat surprising. But VO_2 drift is "slower" response than HR and may occur at higher intensities than the present one. On the other hand, for some of the participants in which speed was decreased considerably (Figure 3D and H), the fact that VO_2 does not decrease could indicate that VO_2 slow component is occurring. A study by Bassett & Howley (1997) found a linear increase in VO_2 with increasing speed, showing the Fenn-effect (Fenn, 1924). For one participant (see figure 3, panel G), there was a larger VO_2-drift and then one can see similar effects as for HR. This is important to remember in practice: HR drifts more and faster than VO_2, highlighting the much more predictive and causal relationship between VO_2 and external load versus HR and external load. Indicating that, for sessions of this or higher intensities, relying solely on HR likely will lead to only larger differences than observed in this study.

For HR, the difference between days was biggest for interval1, then the difference was flipped. Possible reasons behind this are that for most participants, speed was adjusted up in the first interval of sessionHR due to a low HR at the start of the session, then adjusting speed down due to an increase in HR throughout. This also kept HR constant, as was given by the protocol. In sessionCS, HR drifted, however distance was kept constant in all intervals and there was an interaction between interval and session.

% of HR_{max} was used to define HR-range for sessionHR. This was done by first finding the $\%HR_{max}$ corresponding to the speed at 80%MAS. Then, 2 %-points was added below and above, to avoid too rapid speed adjustments. There are individual differences in HR-response, where some participants have a faster increase in HR, some slower (Stöggl & Sperlich, 2015). Thus, that can affect how much adjustments in speed are needed. HR can vary due to internal factors as genetics or training status, or environmental factors as temperature and humidity. Awareness on those factors may reduce possible differences and day to day variations (Halson, 2014). HR response can be different between subjects, or even within a subject during a session. Those factors, in addition to e.g. measurement errors are some considerations to be aware of connected to the use of HR (Ludwig et al., 2018). Runners often use total volume as a measure of training load and may be measured in total distance over a period, e.g., a week. The results showed interaction between session and interval for distance, and thus may indicate different use, however no difference in mean total distance was found between sessions. One interesting finding was that in sessionHR, speed had to be adjusted up and down several times due to HR-drift. For example, interval1 may have a higher covered distance compared to interval5. This, however, may in total, give similar total distance covered in both sessions as observed in the results. SessionHR varies after HR on the current day, on the other hand sessionCS had a pre-determined distance.

ES was trivial (<0.1) for mean VO_2 in both sessions and intervals, and no effect of interval nor session was found. At workloads below a critical threshold, VO_2 reaches a level at where uptake can be sustained over a longer time (Ferretti et al., 2017). At this level, BLa does not accumulate. There was no interaction between interval and session for BLa nor RPE. For RPE however, there was a statistically significant difference between intervals. Eston (2012) stated that duration and exercise intensity are two important factors affecting RPE. Changes in RPE due to changes in speed are also seen in sessionHR by inspecting participants individually. In both sessions, RPE increased with increase in interval, thus increased with duration. No such effect was found for BLa. This is important to note, as RPE is another way often used to adjust or set intensity. Both RPE per interval, over time, or per session.

In performance of increasingly higher speed and increase in workload, there has been observed an increase in BLa (Ghosh, 2004). By increasing, or lowering, speed due to an increased or too low heart rate, BLa can follow accordingly. The data indicate the current intensity was below BL accumulation for some of the athletes, thus a higher change in speed or higher intensity may have produced a higher effect. However, an important aspect was not to provoke too much fatigue, which is practically relevant in such “threshold” sessions. Other possible reasons behind findings can be changes in speed both up and down in sessionHR, which in total results in no mean difference. Factors that can affect accumulation is temperature, hydration status and type of exercise prior (Halson, 2014), however all factors were accounted for and may have aided to reduce differences.

There was no difference between intervals nor sessions, however differences in BL response between participants was observed when examining and compared separately. This might be explained by difference in fitness level, training experience and the fact that there is a variability in response to training (Stöggl & Sperlich, 2015). Research has shown that well trained subjects can work at a higher percent of their VO_{2max} at submaximal workloads with low BL accumulation (Ghosh, 2004). In sessionHR, a difference was expected because of a change in speed. However, in sessionCS, an approximately constant BLa was assumed. This is because that if the prescribed 80% MAS speed was correlating to a threshold speed lower than the onset of blood lactate accumulation (OBLA), concentration should stay constant or have a low increase (Ghosh, 2004).

4.3 Methodological considerations

Overall, while the present study provides some valuable insights into the effects of different training sessions on physiological variables, there are several considerations to be aware of. These include the lack of information about pre-training status (time of season, periodization) and only one BL-profile and VO_{2peak}-test was conducted to map current fitness. Additionally, the present study focusses only on running, which may limit the use of the quantification approach to the chosen, or similar locomotor disciplines. In the current study Hedges g was trivial-small for all intervals between days. Hedges g for mean change from interval1 to interval5 in the two sessions was medium-very large in all parameters even though p-values was non-significant, indicating effects that may be of relevance although not statistically significant.

The study included elite endurance athletes (VO_{2peak}>70 ml/kg/min) and recreational athletes. In the results, there is a tendency towards similarity between the two sessions in the most well-trained athletes. For recreational athletes, difference in type of session might be more crucial. Also, the steep incline in the experimental protocol was chosen to reduce mechanical muscle load, particularly due to different background in running. For example, participants were more or less familiar with level running over time. Running at steep incline may reduce demands of running technique and skill.

In the current study, MAS was prescribed from submaximal data VO_2 and the incremental VO_{2peak} test. One study found that MAS can be estimated using different approaches, e.g., % of max speed in a graded exercise test (GTX), due to a true V_{peak} (Cerezuela-Espejo et al., 2018). In the current study, determining MAS was based on the linearity between VO_2 and speed from submaximal steady-state bouts and one VO_{2peak} test. Quantifying training load by current method requires well trained personnel, is time consuming and stationary equipment of high cost; thus, the method may not be feasible for all coaches and athletes and is currently not feasible as a field test. Future research should aim to address the current considerations.

Monitoring training load can be advantageous because it will provide grounds for looking into the relationship between training load and changes in performance. Toleration of training load is affected by several components such as training history, age, aerobic fitness etc. Monitoring training load correctly can help adjust for those factors (Gabbett, 2020). This will aid in further tailoring and planning of training, especially for coaches. Additionally, adjusting and monitoring load can help reduce the risk of overtraining, injury, and fatigue. This can set better prerequisites for good performance by getting a better insight into and better understanding of training (Halson, 2014).

There are several methods and approaches to finding «thresholds», or HR- or speed ranges, that are typically used for endurance training, and a commonly used method is LT approaches, such as OBLA of 4 $mmol \cdot L^{-1}$ or baseline + absolute values etc. Ghosh (2004) found that speed at LT is the most appropriate physiological indicator of running performance. However, a study conducted by Jamnick et al. (2018) found that LT cannot be decided from only one GTX. They also found that the OBLA of 4 $mmol \cdot L^{-1}$ and other traditional LT methods was insufficient for estimation of maximal lactate steady state (MLSS) and showed insufficient validity. In this study, MAS was chosen. However, it may well be that using individually set LT or MLSS protocols would have been better. Future studies should examine this further.

4.4 Practical implications and future research

Balancing training and recovery is crucial to avoid fatigue, injury, and illness. Monitoring training load and using methods from the current study can help athletes make better training prescriptions and avoid negative consequences. A great load of training is performed by athletes, and it is valuable to spend time more efficient. Using methods from the current study can aid in this by monitoring training load closely and provide information on several aspects on current fitness, both subjective and objective. Future research should aim to include some elements that were absent from this present, and other earlier studies. The relationship between quantification of training load in combination with recovery/fatigue markers can give valuable information. Training response and adaptation is affected not only by the training itself, but non-sports related factors as nutrition and sleep (Nuuttila et al., 2022), which was lacking from the current study and should receive more focus in future research.

The present study has limited number of sessions and duration of the study, and only gives a snapshot of the difference between sessions. Future studies should compare similar sessions, perhaps where intensity is prescribed using LT in addition. And possibly, the long-term effects, if any method of quantification is more advantageous. In a such study, it may be useful to explore total load and fatigue, to see if recovery can be adjusted accordingly over time. An evidence-based strategy for maximizing the beneficial training adaptations can be provided by taking into account these factors and seeing difference over time (Gabbett, 2020). According to pioneering studies, including Bourdon et al. (2017), a single marker to assess and quantify response to training remains unpublished. It is proposed, however, that a combination of both internally and externally controlled (both subjective and objective measurements) training load can provide valuable information in assessment of a training period or a single session. Uncoupling of training loads can be useful in determining an athletes training status, which could provide indications of fatigue and insufficient rest (Bourdon et al., 2017). This can be reflected in e.g., same external load in two similar sessions, with a change in HR- or BL response.

4.6 Conclusion

The present findings displayed that one internally- and one externally controlled session induced interaction between session and interval for HR and distance, however no mean difference over sessions was found. This, to high extend, supports the hypothesis that type of session would affect outcome variables differently, due to different relationship between external load (speed, power) and different measures of internal load (HR, BLa, VO_2 and RPE). It also indicates that change in speed in sessionHR was insufficient to induce a difference for RPE, BLa nor VO_2 due to no interaction. Hedges g for mean change from interval1-5 for days was medium-very large in all parameters, indicating effects that may be of relevance although not statistically significant. Further research is needed to support or disprove the current results and use of the current method to eventually aid in planning of training load and adjust load consequently to increase athlete performance. Additionally, long-term studies should investigate if these two, or perhaps additional ways of controlling intensity matters in the long run.

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