Endurance training organization in elite endurance athletes

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Endurance training organization in elite endurance athletes

From description of best practice towards individualized prescription

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Table of contents

Papers

Paper I   Do elite endurance athletes report their training accurately?

Paper II   From heart-rate data to training quantification: A comparison of 3 methods of training-intensity analysis.

Paper III   The road to gold: Training and peaking characteristics in the year prior to a gold medal endurance performance.

Paper IV   The effect of different high intensity periodization models on endurance adaptions.

Paper V   Effects of HIT on physiological and hormonal adaptations in well-trained cyclists.

Appendices

Appendix I   Index describing all collected data, *study III*

Appendix II   Informed consent, *study I*

Appendix III   Informed consent, *study III*

Appendix IV   Informed consent, *study II*

Appendix V   Confirmation of research clearance from NSD, *studies I-III*

Appendix VI   Confirmation of research clearance from REK, *study III*

Appendix VII   Confirmation of research clearance from NSD, *study III*

Acknowledgements

I

List of papers

This dissertation is based on the following original research papers, which are referred to in the text by their Roman numerals.

I.   Sylta Ø, Tønnessen E, Seiler S. Do elite endurance athletes report their training accurately? *Int J Sport Physiol Perform.* 2014; 9: 85-92.

II. Sylta Ø, Tønnessen E, Seiler S. From heart-rate data to training quantification: A comparison of 3 methods of training-intensity analysis. *Int J Sport Physiol Perform.* 2014; 9: 100-107.

III. Tønnessen E, Sylta Ø, Haugen TA, Hem E, Svendsen IS, Seiler S. The road to gold: Training and peaking characteristics in the year prior to a gold medal endurance performance. *PloS one.* 2014; 9(7): e101796.

IV. Sylta Ø, Tønnessen E, Hammarström D, Danielsen J, Skovereng K, Ravn T, Rønnestad BR, Sandbakk Ø, Seiler S. The effect of different high intensity periodization models on endurance adaptions. *Med Sci Sports Exerc.* 2016; 48(11): 2165-2174.

V.   Sylta Ø, Tønnessen E, Sandbakk Ø, Hammarström D, Danielsen J, Skovereng K, Rønnestad BR, Seiler S. Effects of HIT on physiological and hormonal adaptations in well-trained cyclists. *Med Sci Sports Exerc.* 2016, *in review.*

Abbreviations

C	Cortisol
CP	Competition period
DEC	Decreasing HIT group
ES	Effect size
FT	Free testosterone
FTCR	Free testosterone-cortisol ratio
GE	Gross efficiency
GP	General preparation
HIT	High intensity training
HIIT	High intensity interval training
HR	Heart rate
HR_{max}	Maximal heart rate
IGF	Insulin-like growth factor
INC	Increasing HIT group
$[la^-]$	Venous blood lactate concentration
LIT	Low intensity training
LT	Lactate threshold
MAP	Maximal aerobic power
MIT	Moderate intensity training
MIX	Mixed HIT group
MLSS	Maximal lactate steady state
OLT	The Norwegian Olympic Sports Centre
$Power_{30s}$	Mean power during a 30 s all-out test (Wingate)
$Power_{40min}$	Mean power during a 40 min all-out trial
$Power_{4mM}$	Power corresponding to 4 $mMol^{.}L^{-1}$ blood lactate concentration
PPO	Peak power output
RPE	Rating of perceived exertion (BORG scale, 6-20)
SG	Session goal
SG/TIZ	A hybrid session goal/time in zone approach
SP	Specific preparation
SR	Self-report
sRPE	Session rating of perceived exertion (1-10)
TID	Training intensity distribution
TIZ	Time in zone
TT	Total testosterone

$\%\dot{V}O_{2peak}@4mM$	Percent peak oxygen uptake corresponding to 4 mMol·L^{-1} lactate
$\dot{V}O_2$	Oxygen uptake
$\dot{V}O_{2max}$	Maximal oxygen uptake
$\dot{V}O_{2peak}$	Peak oxygen uptake
VT	Ventilatory threshold
XC	Cross-country (skiers)

Abstract

Purpose: The overall objective of this thesis is to contribute to a more detailed understanding of the relationship between endurance training organization and adaptive responses. Three independent studies, and five original papers, have been published towards this objective. Peer-reviewed studies describing training characteristics in elite endurance athletes have been published since the 1980's. In these studies, different methods of quantifying training patterns during longer time frames have been used, with athlete self-report (SR) in training diaries being the most common. While extensively used, athlete SR diary data has not been evaluated for accuracy and validity. In addition, there are several pitfalls concerning quantification of training intensity distribution (TID). The aims of *papers I* and *II* were therefore 1) to validate the accuracy of SR training duration and intensity distribution in elite endurance athletes, and 2) compare three methods of TID quantification employed by elite endurance athletes. Results from these two methodological papers secured a fundamental platform for analysis of further training-characteristic in studies including reliable methodological interpretations, during an annual cycle in World-Class athletes. The aim of *paper III* was to describe training characteristics across the annual cycle in Olympic and World Champion endurance athletes. Through observations of high intensity training (HIT) organization patterns in *paper III*, we formulated hypotheses to be tested experimentally. The aim of *paper IV* was to compare the effects of different intensity zone periodization models during 12 weeks on endurance adaptions in well-trained cyclists. Finally, the aim of *paper V* was to quantify the time-course of development of performance, physiological and hormonal responses during a 12-week HIT period in groups prescribed different interval training prescriptions.

Methods: In *papers I* and *II*, 29 elite cross-country (XC) skiers from the Norwegian national team (mean maximal oxygen uptake ($\dot{V}O_{2max}$) ♂ 80±5 and ♀ 70±5 mL·kg^{-1}·min^{-1}) performed, in total, 570 training sessions during a ~14 day altitude camp. *Paper I* compared SR training duration with recorded training duration from heart rate (HR) monitors, and compared SR intensity distribution with the intensity distribution derived from summated expert analyses of all session data. In *paper II*, the proportion of training in the zones of low intensity training (LIT), moderate intensity training (MIT) and HIT was quantified using total training time or frequency of sessions, and compared through a time in zone (TIZ), session goal (SG) or a hybrid session goal/time in zone (SG/TIZ) approach. Simple conversion factors across different methods were calculated. In *paper III*, 11 Olympic or World Champion XC skiers and

biathletes (mean $\dot{V}O_{2max}$ ♂ 85±5 and ♀ 73±3 mL·kg⁻¹·min⁻¹) SR one year of day-to-day training leading up to the most successful competition of their career. Training data were quantified and divided in phases and distributed into training forms, activity forms and intensity zones.

Papers IV and *V* are derived from a randomized controlled experimental trial executed as a coordinated multicenter study involving three test centers. Sixty-nine well-trained male cyclists (mean $\dot{V}O_{2max}$ 61±6 mL·kg⁻¹·min⁻¹) were randomly assigned to one of three training groups, all of whom performed a 12-week intervention consisting of 2-3 prescribed HIT sessions per week in addition to *ad libitum* LIT. Groups were matched for total training load, but **increasing HIT (INC)** group (*n*=23) performed interval training as 4x16 min in cycle 1 (week 1-4), 4x8 min in cycle 2 (week 5-8) and 4x4 min in cycle 3 (week 9-12). **Decreasing HIT (DEC)** group (*n*=20) performed interval sessions in the opposite cycle order as INC, and **mixed HIT (MIX)** group (*n*=20) performed all three interval prescriptions in a mixed distribution during each cycle. Interval sessions were prescribed as maximal session efforts. Laboratory exercise tests and measures of resting blood hormones were conducted pre, and at the end of weeks 4, 8 and 12 of the intervention.

Main results: In *paper I*, SR training was nearly perfectly correlated with recorded training duration ($r = .99$), but SR training was 1.7% lower than recorded training duration ($P<0.001$). No significant differences were observed in intensity distribution in the LIT area between SR and expert analysis comparisons, but small discrepancies were found in the MIT and HIT area ($P<0.001$). In *paper II*, comparing TIZ, SG/TIZ and SG methods, 96.1, 95.5 and 86.6% of total training time or frequency of sessions was spent in zone 1 ($P<0.001$), 2.9, 3.6 and 11.1% in zone 2 ($P<0.001$), and 1.1, 0.8 and 2.4% in zone 3 ($P<0.001$), respectively. Estimated conversion factor from TIZ or SG/TIZ to SG was three (x 3) in the MIT/HIT range. *Paper III* demonstrated that gold medal winning XC skiers trained ~800 h·yr⁻¹ (of this ~500 h sport-specific), of which 94% endurance training (90% LIT and 10% HIT). Total training volume progressively increased during the general preparation (GP) and decreased 32% (mainly aerobic cross-training) from GP to competition period (CP). Absolute volume of HIT remained stable across all phases, although HIT patterns became more polarized in CP.

Paper IV demonstrated a 5-10% improvement in key components of endurance performance among already well-trained cyclists completing the training intervention.

However, no significant adaptation differences were observed among the three training groups differing in sequencing of prescribed HIT sessions ($P>0.05$). An individual response analysis indicated similar likelihood of either large, moderate or non-responses in each training group ($P>0.05$). Of the total change in power output corresponding to 4 $mMol^.L^{-1}$ blood lactate concentration ($Power_{4mM}$) and peak oxygen uptake ($\dot{V}O_{2peak}$) during 12 weeks, INC achieved 98 and 70%, and MIX 149 and 92%, respectively, whilst DEC achieved only 34 and 38%, during the first 4 weeks of intensified training (*paper V*). However, changes in PPO during cycle 1 accounted for 77, 64 and 89% in INC, MIX and DEC groups, respectively, of total change. INC (4x16 min) revealed a moderate effect size (ES) compared to DEC (4x4 min) when comparing delta changes in $Power_{4mM}$ (ES: 0.7) and $\dot{V}O_{2peak}$ (ES: 0.7) during cycle 1. Pooling the three training groups, total- (TT), free-testosterone (FT) and free testosterone-cortisol ratio (FTCR) decreased significantly by 22, 13 and 14% (all $P<0.05$), respectively by the end of the first 4-week training cycle. Insulin-like growth factor-1 (IGF-1) increased significantly by 10% ($P<0.05$).

Conclusions: The present thesis demonstrates that daily SR training is a valid method of quantifying training duration and intensity distribution in elite endurance athletes, although additional common reporting guidelines would further enhance accuracy. Our evaluation of three common HR based TID approaches provide practical and useful tools to compare and convert different methods used by athletes. A one year, day-to-day description of the training to Olympic- and World champion XC skiers shows annual training patterns that can provide a valuable reference for upcoming athletes. However, we questioned if training patterns where TID became more polarized in CP were an appropriate tradition based on best practice. Our experimental approach suggests that different HIT organization patterns have little or no effect on training adaptation when the overall training load is the same. However, we found that most of the progression in specific performance outcomes was achieved already during the initial 4 weeks of training, though dependent on interval training prescription. Hence, a 4x16 min interval prescription 2-3 times per week appears to induce greater adaptions in $Power_{4mM}$ and $\dot{V}O_{2peak}$ compared to a 4x4 min interval prescription. Resting levels of anabolic hormones were found to first decline and then rebound over 12 weeks, with the period of decline associated with greater adaption.

Introduction

Rationale for the thesis

The training organization of elite endurance athletes has been debated over several decades (82, 145). Historically, athletes or coaches associated with outstanding performances have tended to be trendsetters for training principles (21, 76, 92). Interval training became popular in the 1920s and 1930s thanks to successful Finnish and German runners (21). The importance of high training volume was emphasized through the examples of outstanding runners and coaches such as Zatopek and Lydiard, respectively, in the 1950s and 1960s (76, 92). In the mid-1980s and early 90s, the first empirical descriptions of training intensity distribution in well-trained athletes were published in the sport science literature (3, 115). Since then, several retrospective training-studies have emerged in different sport disciplines (Table 1), providing some useful information regarding general common training organization patterns. However, when the present thesis was planned, we still saw a need to further examine this topic. The Norwegian Olympic Sports Centre (OLT) had been closely involved in the training and testing of hundreds of elite athletes in endurance disciplines over the last 20 years. That database represented a huge, untapped research resource internationally, and an important tool for institutional learning within OLT and Norwegian sport. Unfortunately, OLT had not yet been systematic in using this source of information to better understand the training process. In addition, methodological considerations raised questions about the validity and interpretation of existing training data reported from elite endurance athletes. Consequently, there was a need for common methodological tools as well as supplementary detailed annual training descriptions of elite endurance athletes.

In parallel, over the last decades, scientists have designed and implemented a number of short-term experimental approaches which provide us with fragmented insight into the effects of different types and methods of training on performance (23, 97, 134). In particular, the effects of training in the HIT-range has been widely investigated, giving us a deeper understanding of the adaptive role of integrating different HIT prescriptions into an endurance training program e.g. (12, 83, 122, 137, 143). However, surprisingly few studies have been carried out on well-trained to elite athletes. In addition, our observations in *paper III* of the long-term periodization and HIT organization employed by internationally successful athletes gave us a unique foundation for generating experimentally testable hypotheses.

Therefore, the overall objective of the present thesis was to present new and accurately nuanced aspects of training organization patterns in elite endurance athletes through a combination of methodology development, descriptive and experimental studies.

The purpose of this introduction is to summarize the body of relevant scientific literature available at the time point when the present thesis was initiated (year 2012 for *paper I-III* and 2014 for *paper IV-V*) and highlight specific areas that we identified as requiring more detailed investigation regarding methodological considerations, training characteristics and experimental approaches in elite endurance athletes.

Literature search

To identify all relevant retrospective studies describing the training characteristics of well-trained to elite endurance athletes, a systematic search was conducted in sports and medicine databases using methods described by Pope et al. (112). The PubMed and SPORTDiscus databases were used, in addition to searches within specific sport journals and sport literature books. In addition, relevant articles were included by "cherry picking". That is, after the initial search, each included study was checked for citations by copying them to Google Scholar and/or SCOPUS. Cited articles were screened and some of them included.

The selections of keywords were based on the aim of the study. This thesis is intended to provide a systematic review of descriptive studies or long-term intervention studies regarding "best practice" in terms of quantifiable training characteristics among well-trained to elite athletes in different endurance sports. Therefore, four search categories were chosen: 1) Training description, 2) Quantifiable training data, 3) Sports and 4) Level of athletes. The initial search strategy was: (training characteristics) OR (training organization) OR (training analysis) OR (training diary) OR (principles of training) AND duration OR volume OR intensity OR (training zones) OR (exercise intensity) OR (heart beat) OR (heart rate) OR lactate OR distribution AND endurance OR running OR swimming OR cycling OR ski* OR rowing OR kayak OR triathlon OR marathon AND elite OR top OR high OR well-trained.

The systematic search described here were limited to "training characteristic studies". In total, 42 studies were included and analyzed (Table 1).

Methodological considerations

Since the first empirical descriptions of TID in well-trained athletes appeared back in the 1980-1990's (3, 115), descriptive studies have been conducted across almost every endurance discipline. These studies have primarily quantified basic aspects of training volume and intensity distribution over timeframes from weeks to an entire season, using a number of different analysis methods (Table 1). An increasing number of studies have raised a need for common guidelines and methods to be able to compare findings across studies.

In the scientific literature, it is possible to identify several methods for quantifying general training characteristics in endurance athletes. The most common objective method is daily SR data obtained from diaries (35, 47, 52, 61, 115, 126, 132, 150, 152). Retrospective summary methods such as questionnaires and surveys (3, 40, 77), or analysis of data that are in part or completely derived from training plans (9, 11, 131, 140, 141) have also been employed. In addition, some studies have relied entirely on objective data obtained from e.g. HR monitors (37, 162), or have used a combination of different methods (10, 52, 132, 150). All of these training quantification methods have specific strengths and weaknesses. Quantification of training, alongside performance data, may be used to examine the relationship between training dose and training adaptation, and serve as a basis for mechanistic hypothesis generation. This, however, requires that SR from diaries, questionnaires, or other methods is accurate and valid, particularly with regard to training volume and intensity distribution.

When the present thesis was planned, we could only identify two studies exploring the validity of SR training volume or frequency data (17, 52). In a validation study of SR training volume in recreational athletes, Borresen and Lambert (17) concluded that quantification of an athlete's actual training volume may be inaccurate when relying exclusively on SR data. However, this study was not conducted with elite athletes, and it is reasonable to assume that there may be differences between elite and recreational athletes in SR quality. Later, Guellic et al (52) evaluated the reliability of the training documentation of elite junior rowers. SR training data reported directly to the national coach were compared with postal survey data reported directly to a research group. Reported data deviated from those in the postal survey by 4% in training frequency and -10% in training volume. The results from Guellic et al (52) indicate that questionnaires may be inaccurate and could account for as much as 100 h/year over-

reported training volume in elite athletes. Despite quantification of training volume (e.g. hours trained or distance covered) or frequency (number of sessions) being relatively straight forward, it may still be associated with substantial large inaccuracies. However, we hypothesized that SR in diaries is a valid and reliable training quantification method in elite athletes, but were not able to identify any studies on the topic.

Quantification of intensity distribution is challenging, both conceptually and practically. The basic idea is to divide and quantify training time or distance into different intensity zones, over timeframes from single sessions, to a few weeks to years. Focusing on endurance athletes, training dose can be measured in terms of external work executed (power, velocity) (10, 11) or internal physiological responses elicited by that work (HR, blood lactate concentration ([la⁻]), oxygen uptake ($\dot{V}O_2$)) (36, 37, 87, 90, 104, 115, 126, 132, 152). Training dose can also be measured by how the stimulus was perceived (session rating of perceived exertion (sRPE)) (43-45, 132, 142). Describing and comparing TID across different studies requires a common intensity scale to make comparisons between different methods.

In the 1960's, Wasserman and colleagues introduced the term "anaerobic threshold", initially based on changes in the respiratory exchange ratio as a function of workload (135). Their breath-by-breath ventilatory threshold (VT) method provided the methodological foundation and physiological framework for identifying two distinct and reproducible intensity thresholds, VT_1 and VT_2. Later, numerous studies have used a "two threshold" model for interpreting lactate threshold (LT) and VT tests, as well as demarcating intensity ranges (87, 90). For practical purposes, a 3-zone model where three zones are separated by two physiologically defined and reproducible anchor points may be the best suited method to create a basic picture of a general TID comparable across multiple sport disciplines. The three intensity zones are also often titled LIT (defined as work eliciting a stable [la⁻] of less than approximately 2 mMol·L⁻¹), MIT (2-4 mMol·L⁻¹ [la⁻]) and HIT (training above maximum lactate steady state (MLSS) intensity and/or >4 mMol·L⁻¹ [la⁻]) (Figure 1, (134)). While the 3-zone scale is physiologically validated, it may be inadequate for correctly interpreting the subtle intensity variations that elite athletes use in their training. More comprehensive methods, such as a 5- to 8-zone scale, divided for example by physiological anchors, HR, [la⁻] or speed, may be useful to describe TID in detail within a specific sport. OLT has developed a 5-zone scale which is well established among Norwegian elite endurance athletes and more practically applicable. Studies where intensity

distribution are based on VT-derived zones are not directly comparable with the OLT model, but for practical purposes, the 3-zone model and the OLT model have common intensity anchor points around LT. In addition to the OLT model, similar 5-zone scales have been developed in cycling, based on power output sustained over a given duration (110), and in running related to running speed (35). There may be advantages to using a 5-zone scale instead of a 3-zone scale. For example, the greater zone precision could enable athletes to control their training load more accurately and coaches to give more precise training prescriptions to their athletes. However, there is no study comparing these two prescription approaches, and there is a need for more studies utilizing and comparing the results of different prescriptive approaches in young, recreational and elite athletes. In the present work, we have primarily used a 5-zone model in keeping with the most common practice of Norwegian endurance athletes, but results are also presented as a 3-zone or binary model.
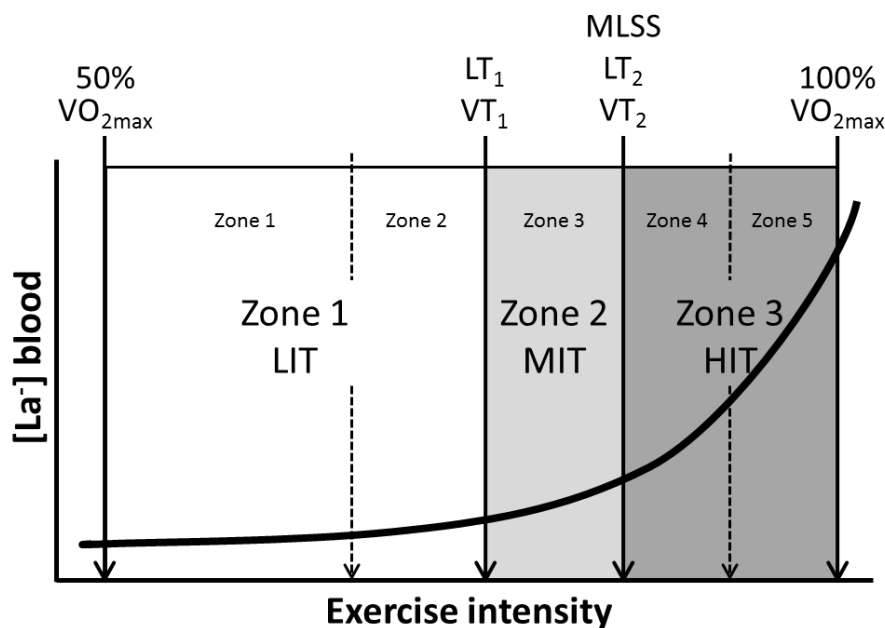
Figure 1: A 3-zone intensity model based on identification of lactate- and ventilatory thresholds (solid lines), and OLT's 5-zone model (dashed lines). Relative width of intensity zones requires individual adjustments. Redrawn after permission, Seiler 2010 (134).

It is important to point out that the use of HR or blood lactate measurements to demarcate standardized intensity zones raises several concerns, as the approach fails to account for individual variation in the relationship between HR and [la⁻] across the intensity continuum. For example, HR may be influenced by day-to-day variability, cardiovascular drift, hydration status, temperature, altitude as well as training status and activity form (1). In addition, [la⁻] is sensitive to activity-specific variation ([la⁻] at

MLSS is higher in activities activating less muscle mass (6, 7)), or other factors such as nutritional status (39, 95, 114, 161). Therefore, using absolute limits as for example zone 1: <2 mMol·L^{-1}, zone 2: 2-4 mMol·L^{-1} and zone 3: >4 mMol·L^{-1} [la$^-$], may induce meaningful errors in the interpretation of training intensity distribution at the individual level.

Searching the literature, we have identified three basic approaches for quantifying endurance training sessions based on HR response (Figure 2).
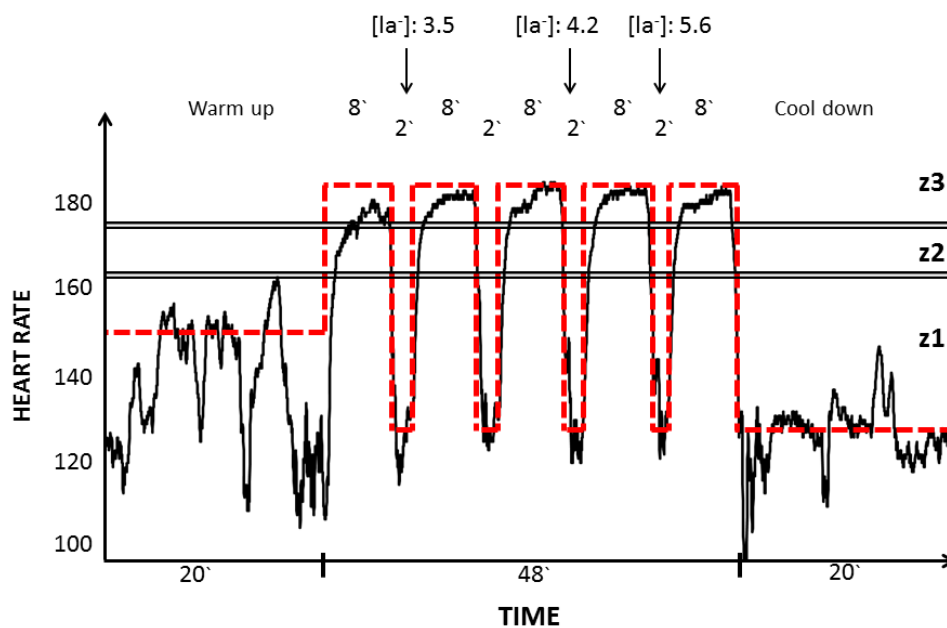
Figure 2: Illustration of intensity distribution using three different heart rate (HR) methods allocated in three basic intensity zones. The example illustrates a typical endurance session lasting ~90 min, organized as interval training including 5 x 8 min work periods with 2 min recoveries, in addition to warm-up and cool-down period. This session-example was prescribed as a zone 3 interval session based on the 3-zone model. The athlete's maximal HR is 200 beat·min^{-1}. The time in zone (TIZ) method uses the HR curve (solid line) as the basis for allocating time in different zones. Thirty-five minutes are distributed in zone 3, plus 48 min in zone 1 and 5 min in zone 2. The modified session goal method (SG/TIZ) uses the dotted line in combination with lactate values. Forty minutes are distributed in zone 3 and 48 min in zone 1. The session goal (SG) approach is based on the intensity during the core section of the session in combination with [la$^-$] values, and defines this example as a session in zone 3.

First, TIZ is a technologically simple and straightforward method, where continuous HR monitor registration data (often aggregated over 5 or 15 s time intervals) are allocated to pre-defined intensity zones from HR cut-offs registered in the software. Esteve-Lanao et al (37) was the first to report data based on the TIZ method in a descriptive study of training characteristics in eight distance runners collected over a 6-month period. This approach has later been used by others (36, 104, 132) and is the

basic methodology used by heart monitor manufacturers in their proprietary software. The TIZ method has also been used to quantify intensity distribution during multistage cycling competitions (87, 90). However, doubts have been raised as to whether this method gives a realistic picture of the total training load over longer timeframes, due to underestimation of the time spent working at high intensity (e.g. HR lag time during intervals). In addition, TIZ distribution does not seem to correspond well with perceived effort for a given workout (132). A second SG method is a categorical approach where entire sessions are assigned into intensity zones based on which physiological stress the main-portion of the session reflects. Seiler & Kjerland (132) introduced this method and argued that a categorical approach likely gives a realistic picture of the total TID over the long term, as its matches well with intensity categorization based on sRPE (45). The third, and maybe most common method used by elite endurance athletes keeping daily training diaries, is a hybrid combination of SG and TIZ, often termed a *modified SG approach* (SG/TIZ) in the literature (126, 132, 152). The goal of a session's different parts (e.g. warm-up, intervals, cool-down) is used to aid in allocating training time to intensity zones, based on a combination of actual HR registration, [la$^-$] measurements and external workloads applied. Critically, the validity of all three methods for investigating TID and performance development depends on consistent and comparable interpretation of training data. Seiler & Kjerland (132) compared SG, TIZ and sRPE, and found agreement between SG and sRPE, and disagreement with TIZ in the HIT range. However that was not the primary focus of the study, and simple algorithms to convert data across methods were found to be lacking in the literature review.

Training characteristics in elite athletes

The optimization of endurance training remains a frequently discussed topic among athletes, coaches and scientists (81, 82, 134, 145). The training stimulus emerges from an interaction among activity form, duration, intensity and frequency, as well as the recovery in between training sessions (81, 82, 97, 134, 138). Importantly, the impact of different components in the training stimulus appears to be modified by training status, making results from untrained or moderately trained subjects of marginal relevance for understanding the long-term training of competitive elite athletes. One method to approach a best practice model for endurance training organization is to accurately describe the training of successful athletes from different disciplines and examine potential commonalities and differences. Therefore, retrospective training analyses of elite athletes serves as an appropriate starting point for aggregating information towards a best practice summary. At the time point when the present thesis were planned (2012), we saw a huge potential in systematizing and exploiting already existing training data from numerous highly successful endurance athletes collected as a part of the OLT's daily work. Although such studies had already emerged in the literature over the previous two or three decades (Table 1), methodological weaknesses and limited data on the long-term training of elite athletes highlighted the need to further explore this topic. Available descriptive studies typically only presented data over a shorter timeframe (10, 11, 142), at a sub-elite level (37, 52, 104, 132, 162) or as single case studies (66, 152). However, the thesis monograph by Tønnessen (152) (limited to only Norwegian language) represented an innovative contribution and informed the digital training diary methodology used in subsequent studies, both because of highly detailed descriptions of successful elite athletes during a whole career and solid methodological interpretations. The weakness of Tønnessen's work was that it was based on individual case studies of only three female athletes.

Training volume

Retrospective studies describing training volume in senior elite athletes (up to 2012) support a consensus that high total training volume is required for elite success (Table 1). However, there appear to be substantial differences in both annual and typical monthly training volumes (measured as training hours) across sport-disciplines, despite all being top performers in their sport. This can likely be attributed to differing degrees of eccentric or ballistic stress of the sport movement, as well as differences in muscle contraction duty cycles (strike frequencies) (138). Table 1 shows reported

training volume in several studies. Converting these numbers to annual training hours, a rough estimate indicates that distance runners (9-11, 35, 77, 142, 152) and orienteering runner's (152) train 500-600 hours annually, XC skiers (126, 152) 800-900 hours, while rowers (40), cyclists (131), swimmers (139) and tri-athletes (99) train from 1000 and up to 1300 hours annually. Athletes from speed-skating (61) and kayak (48) are reported to train 600-700 $h^{.}yr^{-1}$. Converting these training hours to training frequency in different intensity zones in elite athletes over longer timeframes, we find that an athlete training 10-13 sessions per week is likely to dedicate, on average, 1-3 sessions weekly to training at intensities at or above MLSS. The athlete's recovery response after training determines in part their capacity for frequent doses of MIT or HIT, and higher frequency of HIT does not necessarily further increase performance (12). However, all these numbers must be interpreted with caution due to methodological considerations, and hence there is a need to further describe this topic.

Although the importance of high total training volume had been highlighted through retrospective observations in elite athletes, there was still an ongoing discussion in the beginning of the 2000's regarding the efficacy of adding more volume (mainly LIT) to stimulate enhanced physiological adaptations in already well trained athletes. Laursen & Jenkins (82) reviewed the scientific basis for high-intensity interval training (HIIT), and argued that an additional increase in submaximal training (i.e. volume) in highly trained individuals did not appear to further enhance either endurance performance or associated physiological variables. They concluded that further incremental improvements in endurance performance could only be achieved through HIIT. That conclusion was in stark contrast to some retrospective observations. Steinacker et al (141) investigated this issue as early as the 1990's in international level rowers. For example, he compared the development of rowing power and $\dot{V}O_{2max}$ in Danish and Norwegian rowers during a summer of training associated with their training protocol. A decrease in $\dot{V}O_{2max}$ was found in the Danish group when the total training volume decreased. A few years later Billat et al (11) compared top-class vs. high-class marathon runners during a 12-week training period before an Olympic trial. The only difference observed in training patterns was that the top-class runners, on average, ran more km each week. Further, Fiskerstrand and Seiler (40) found that positive development of performance level among international medal winners over three decades was associated with increased training volume in Norwegian rowers. By the end of the 2000's three reviews appeared which all agreed on the importance of high total volume, predominance of low-intensity, long-duration training, in combination

with fewer, high-intensity bouts in an appropriately composed training program for elite athletes (81, 134, 138). To sum up, although the topic has been open to some debate, the discussion has moved from focus on either volume *or* intensity as a stimulus for an adaptation, to focus on optimization of the overall intensity distribution and interaction between volume *and* intensity.

Training intensity distribution models

Although there are differences in the methods for quantifying training intensity, we find remarkable consistency in the basic TID patterns selected by successful endurance athletes. This has provided the literature with a couple of accepted terms regarding general training models. Fiskerstrand & Seiler (40) presented the training of international level rowers during three decades, and based on that study and other sources of descriptive data at the time, argued that the optimal TID for maximal performance was a model with about 75% of training performed well below LT and 15-20% well above that intensity. After that a simple dichotomous *80/20-rule* of training intensity distribution was popularized, recommending that 80% of training sessions be performed as LIT while the remaining 20% of sessions are distributed between training at or near LT (or MIT), and training at intensities in the HIT range. The *80/20-rule* has later been described in detail (138), and even emerged in a popular science book by Fitzgerald (41).

Other training-models have also appeared to better nuance the training patterns, especially in the MIT/HIT range. The term *polarized training model* was also introduced in the sport science literature for the first time by Fiskerstrand & Seiler (40). However, the concept received more attention a few years later when a polarized TID model was contrasted with a *threshold training model*, and illustrated through the training of junior XC skiers (132). The polarized model emerged from observations of elite athletes (11, 131, 141), suggesting that athletes generally train either below LT (perhaps 75-80% of endurance sessions) or clearly above the threshold intensity (15-20%), while training at or near LT is performed infrequently. Later, Esteve-Lanao and colleagues (36) published a randomized, controlled training study exploring the effects of increasing or decreasing the contribution of LIT vs. MIT on performance. During a 5-month period, a TID (TIZ-method) of 80% LIT, 12% MIT and 8% HIT elicited greater performance improvements than a program where time spent as MIT was doubled to 25%, while the amount of HIT was held constant. As of 2012 we could also identify two retrospective studies supporting a polarized training model, including a

two year TID analysis of an elite level 1500m runner (66) and elite sprint speed skaters (61). However, although the threshold training model, which favors training in the LT area, has not obtained the same international acceptance as the polarized model during the last decade, principles from the model have been used by highly successful runners (35, 150), as well as tested experimentally with a small degree of positive results (38). Future experimental studies should explore the potential benefits of a training model where 20-40% of total training volume is focused around the LT area in elite athletes.

Intensity distribution – retrospective descriptions

When the present thesis was planned, we could only identify a small number of studies that had quantified TID in elite athletes using appropriate methods. Lucia et al (87) evaluated the HR response of eight professional cyclists during the 3-week Tour de France as an indicator of exercise intensity during a competition. Their results showed that the relative contribution in each intensity zone (3-zone model) was 70%, 23% and 7%, respectively. The same scientists found similar results in Vuelta a Espana, despite that the total duration was shorter in the Spanish 3-week grand tour (90). These were two of a small number of studies (10, 11, 126, 152) drawing on elite athletes (Table 1), but Lucia and colleagues (87, 90) did not examine the intensity distribution during the athletes' *training process*.

At the beginning of the 00's, Billat and colleagues (10, 11) published two well-cited studies quantifying intensity distribution (based on running speed) during 8-10 weeks in elite marathoners and Kenyan long-distance (5-10 km) elite runners. The focus of these papers was high intensity training. However, a less emphasized aspect of the published data was the finding that the marathoners distributed their training in a clearly polarized 3-zone model (78%, 4%, 18%), a distribution which was identical in both high-level (♂: <2 h 16 min or ♀: <2 h 38 min) and "elite" performers (♂: <2 h 11 min or ♀: <2 h 32 min) (11). Observations of the Kenyan 5-10 km runners also went very much in the same direction regarding TID, but some discrepancies where found. The runners were divided in groups based on different training patterns, and the "high-speed" groups followed a polarized model (♂: 84%, 7%, 9% and ♀: 88%, 0%, 12%). However, the "low-speed" group, distributed their intensity in a different pattern (♂: 84%, 14%, 2%), and still produced outstanding results (10). The latter pattern has later been classified as a *pyramidal model* (145). The quantification of intensity in these studies were probably not 100% valid due to deficient training diaries from some of the runners, with some data based on training plans and not actual training diaries.

Similar pyramidal TID patterns were also found in a study on elite XC sprint skiers during a six month pre-season period. The World-Class skiers in that study had an intensity distribution in their training of 88% LIT, 7% MIT and 5% HIT (SG/TIZ method) (126). Using a direct HR-based TIZ quantification method we could also identify a few studies (37, 132, 162) that gave insight into the primary distribution of training intensity self-selected by endurance athletes. In all these studies, 70-80% of total duration was performed as LIT. However, there was substantial variation in the intensity distribution of work performed at or above LT intensity. In addition, subjects in these studies were not elite athletes.

To our knowledge, there was only one study that quantified the endurance training of athletes with medals from Olympics or World Championships by using a 5-zone intensity scale (152) at the time of this literature review (2012). The previously mentioned case series from Tønnessen showed a mean total LIT (zone 1-2) volume of ~85% during the whole year for all three athletes. In the MIT/HIT-range (>2 mMol$^.$L^{-1}) the distribution showed an average of 5% zone 3, 8% zone 4 and only 1% zone 5. However, when the distribution of intensity across all 5-zones was considered, there was substantial variation among athletes. For example, one World Champion athlete reported "never" training in intensity zone 5 and almost never training in zone 1. As mentioned before, successful endurance athletes are consistently characterized by performing a high total training volume, and by self-selecting an intensity distribution where ~70-90% of total training time is performed as LIT (zone 1 & 2). Interestingly though, the relative contribution of LIT is higher in those studies that include elite athletes when compared to "national-level" athletes, probably due to higher total volume (126, 152). Perhaps more importantly than general long-term TID patterns, Tønnessen reported subtle TID variations across different seasonal cycles. For example, there was a pattern that athletes performed generic aerobic development in the initial phase of the pre-season, and sport-specific and more anaerobic-like HIT sessions towards the start of the competitive season. In other words, an *increased HIT intensity* and decreased HIT duration from GP to CP. A similar pattern of HIT sessions is also observed in retrospective descriptive studies of elite junior rowers (52) and elite junior runners (150). However, anecdotal evidence also shows that some successful athletes utilize a "reversed" model, with *decreased HIT intensity* and increased HIT duration, or a "mixed" model with larger micro-variation of various HIT sessions (e.g. interval sessions) throughout a macro training-cycle. The results from Tønnessen (152) represented still an important starting point for better understanding the training

process of elite athletes as well as hypothesis generation for experimental approaches. This was however, an in-depth study built on a case series including only three female athletes. It was also never published in a peer-reviewed international journal. There was therefore a need for more research in this area.

In summary, based on data from retrospective descriptions in elite athletes as of 2012, we found some common TID patterns. Seventy to >90% of total training time is performed as LIT, depending on total volume and activity form. There is relatively strong evidence that incorporating the remaining ~10-30% in the HIT-range (also including LT-intensity) gives excellent long-term results among elite endurance athletes. On average, approximately two HIT sessions per week appears sufficient to induce performance and physiological adaptations without overreaching during the long term. However, numerous questions related to training organization in the HIT-range are still unclear, and therefore an area for future research.

High intensity – duration complexity, experimental approaches

Already back in the 1960's, the famous physiologists Per-Olof Åstrand and Kåre Rodahl questioned which type of training is most effective; *"to maintain a level representing 90% of $\dot{V}O_{2max}$ capacity for 40 min, or to tax 100% for 16 min"* (165). Fifty years later, surprisingly few studies have answered these questions using well-trained or elite athletes.

Experimental observations indicate that relatively small changes in exercise intensity are associated with large changes in tolerable accumulated exercise duration during HIIT sessions (128, 137, 143). Likewise, based on data from the present thesis, *papers IV & V,* we observed that maximal heart rate (HR_{max}) (average values during all four interval bouts) at ~94, 91 and 89% resulted in a tolerable accumulated duration of 16, 32 and 64 min when sessions were performed as long intervals at *isoeffort* (all-out) prescription (Figure 3). The range 85-95% HR_{max} crosses zones 3, 4 and 5 in a 5-zone intensity scale (Table 3 – method section). Our data and other studies raise important questions about how work intensity and accumulated duration of HIT interact to signal physiological adaptations as well as perceptual responses.

It has been suggested that HIT protocols that elicit $\dot{V}O_{2max}$, or at least near $\dot{V}O_{2max}$, severely stress the oxygen transport and utilization systems and may therefore provide the most effective stimulus for enhancing $\dot{V}O_{2max}$ in elite athletes (23, 82, 97). For
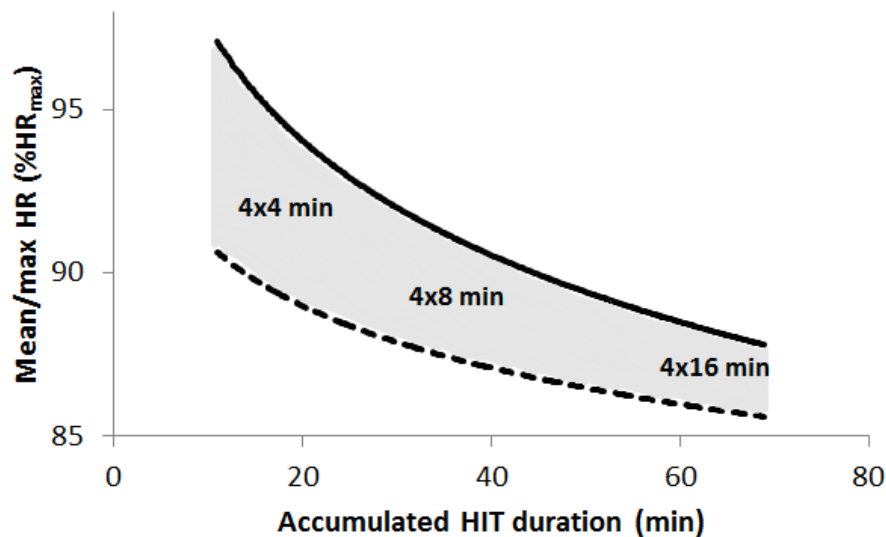
Figure 3: The typical heart rate (HR) mean (dotted line) and max (solid line) during "isoeffort" interval sessions with different total accumulated durations. Interval sessions, 4x4, 4x8 and 4x16 min, used in paper IV & V are indicated in the figure. Data are collected from ~1500 interval sessions in a large group (n=69) of well-trained cyclists, and lines represent an average of all interval bouts in each session.

example, in the early 2000's, Laursen et al (83, 84) compared different HIIT regimens on endurance adaptions in 38 highly trained endurance athletes divided into four groups. Two groups performed twice per week 8 x ~2 min (total accumulated duration of 16-20min) at the power eliciting $\dot{V}O_{2peak}$, with different recovery times between bouts. A third group performed 12 x 30 s at supra-maximal intensity, and a control group performed only easy and moderate training. All three HIIT groups improved performance and physiological variables to the same extent (~3-8%), while the control group was unchanged after 4 weeks of training. Interestingly, intervals at $\dot{V}O_{2max}$ intensity and supra-maximal HIIT sessions induced similar performance improvements. Despite limited understanding of the dose (intensity/duration) - response relationship there was a growing interest by the sport science community at that time for characterizing training protocols allowing athletes to accumulate the longest duration >90% $\dot{V}O_{2max}$, and some reviews appeared discussing that and related topics (23, 81, 82, 97).

More recently, research has shown that the physiological adaptations to HIIT sessions are sensitive to the interactive effects of both intensity and accumulated duration, and several studies have tried to compare different protocols. For example, Helgerud et al (59) found that a total accumulated HIT duration of ~10-15 min at ~95% HR_{max} had a greater impact on endurance performance than accumulating ~25 min at ~85% HR_{max} during a 3 session·week^{-1} interval training program lasting 8 weeks. However, Seiler et

14

al (137) and Sandbakk et al (128) concluded that accumulating ~30-45 min at ~90% HR_{max} twice per week was a more effective HIIT prescription than accumulating 15-20 min at ~95% HR_{max}. Stepto et al also (143) found superior adaptions to a 4x8 min interval prescription compared to shorter duration protocols conducted with higher intensity. In addition, a meta-analysis examining 37 studies and 334 untrained subjects using HIIT in combination with continuous LIT training, found a mean increase in $\dot{V}O_{2max}$ of 0.5 $L^.min^{-1}$. However, a subset of nine studies that featured longer accumulated interval duration showed even larger (~0.8-0.9 $L^.min^{-1}$) changes in $\dot{V}O_{2max}$ with evidence of a marked response in all subjects (2). Among the studies mentioned above, only the experiments by Stepto et al (143) and Sandbakk et al (128) were conducted on well-trained to elite athletes.

When evaluating studies comparing different HIT protocols, there are some pitfalls one must be aware of to ensure an appropriate comparison. A few years ago Seiler et al (137) highlighted that several relatively influential experimental studies (30, 31, 34, 49) comparing the effects of different protocols typically matched the intervention for total work (*"isoenergetic"* matching). They argued that *isoenergetic* matching was not representative of how endurance athletes actually compose and execute their own training sessions, and therefore of little practical relevance when attempting to adapt research findings to training practice. Conceptually, elite athletes typically match their HIT sessions for overall effort and accumulated fatigue, *"isoeffort"* matching (exemplified in Figure 3), and not total work. Indeed, taken to its illogical extreme, *isoenergetic* matching could pit a 30 min high intensity interval session against numerous hours of office work seated at a desk. The highlighted studies above, finding divergent endurance adaptions following different HIT protocols typical of actual training practice, by Stepto et al (143), Seiler et al (137) and Sandbakk et al (128), all used an *isoeffort* matching approach.

In summary, exploring experimental studies suggests that higher work intensity is a more powerful adaptive stimulus across the total intensity spectra from easy to maximal when evaluated in an "isolated fashion". However, a slight intensity reduction in the HIT-range (e.g. reduction from 95 to 90% HR_{max}) facilitates large increases in tolerable accumulated duration, and better overall adaptive responses in recreational to well-trained athletes. Interestingly, there may be minimal differences in parasympathetic recovery time as long as the intensity exceeds a moderate intensity (zone 2 in a 3-zone model) (136). Discrepancies in reported results might be explained

by the characteristics of the added HIT stimuli, baseline performance level, age, and small sample sizes. Hence, there is a need to further explore these questions.

Periodization

The term training "periodization" originates primarily from older eastern European texts and is widely and rather indiscriminately used to describe and quantify the planning process of training (94). Periodization plans add training load-structure, with well-defined training periods designed to stimulate specific physiological adaptations (e.g. $\dot{V}O_{2max}$) or performance qualities in a specific order presumed optimal for performance development. Such endurance training models involve manipulation of different training sessions periodized over timescales ranging from micro- (2-7 days), to meso- (3-6 weeks) and macro cycles (6-12 months; including preparation, competition and transition periods) (15). Therefore, we suggest training periodization to be defined as *"a purposeful ordering of specific training-loads during short-term (micro-cycles) and long-term (meso- to macro-cycles) periods, to attain the desired training adaptions and planned results" (definition modified after* (79, 155)).

Matveyev first introduced a "traditional model" based on the training of successful Soviet athletes during the 1950s and 60s (94). Key features were rather large variation in training volume, intensity and specificity across an annual cycle (Figure 4). Since then, other organization models and training philosophies have emerged, and recently the traditional model from Matveyev has been debated and criticized in favor of a block-periodization model (69-71). The rationale for favoring a block-model is that cycles of highly concentrated specialized workloads are superior to traditionally designed plans directed for concurrent development of many athletic abilities at low/medium workload concentration, in already highly trained athletes. It is important to point out that the Matveyev model spans over a training year, while block periodization models describe training plans during much shorter training periods.

Recent experimental studies highlight block periodization as a potential modifier of the adaptive response. For example, Rønnestad et al found superior adaptive effects of both a single 4-week (119) and a 12-week (117) HIT block periodization program in well-trained cyclists. In those studies, each 4-week cycle consisted of one week of five HIT sessions, followed by three weeks of one HIT session, when compared to a traditional program incorporating "two weekly HIT sessions". Those studies were followed up by a 5-week block periodization study in well-trained XC-skiers, with
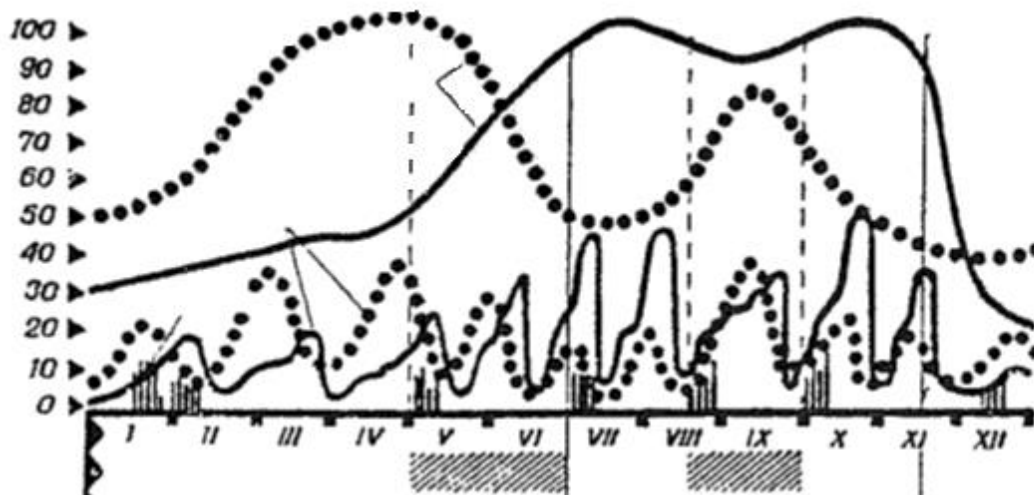
Figure 4: *Original periodization model presented by Matveyev (1965). Dotted lines indicate volume of training and solid lines indicate intensity of training. The competition periods are indicated by striated areas. Figure from Matveyev, 1964 (94).*

similar conclusions (121). However, other investigators report superior effects following a polarized TID compared to a HIT block periodized training concept (144). The latter study did not compare groups performing the same quantity of HIT sessions, which may have affected the results. Retrospective analyses of world-class kayakers (47, 48) and alpine skiers (20) have also demonstrated superior responses to block training periodization, compared to a mesocycle structure with evenly distributed HIT sessions.

The periodization term is complicated and encompasses more than HIT load density alterations compared in the recent studies outlined above. Kiely (78, 79) importantly points out that periodization studies have not distinguished the "sequencing effect" from an effect of "non-directional" variation in training that seems to be important for avoiding training monotony and overreaching/overtraining. Experimental studies that have explored the effects of HIT in well-trained athletes have, as mentioned, primarily been short –term comparisons of different interval training models. Therefore, although some evidence suggests superior responses by increased HIT frequency during a short period followed by relative HIT load reduction, there is currently little empirical data comparing different HIT stimulus ordering approaches, and how they are integrated into a current best practice model combining both LIT and HIT. For example, we could not identify any studies investigating the impact of different models of long-term HIT periodization for endurance athletes. However, we have seen some examples from retrospective training descriptions in elite athletes that give some

anecdotal support for sequencing HIT sessions toward increased HIT intensity and decreased HIT accumulated and work bout duration, from GP to CP (52, 150, 152). Also after the onset of this thesis, additional evidence emerged from a study of elite orienteering runners (155), in addition to data from the World and Olympic champions in *paper III*. We found that HIT sessions were distributed virtually equally among zones 3, 4 and 5 during the annual cycle. However, getting closer to, and in, the CP, both duration and frequency in zones 3 and 4 were moderately reduced, while the frequency of HIT sessions in zone 5 increased. That is, as the desired peak performance came closer, TID became more polarized, with higher intensity HIT, but virtually constant total dose of HIT.

These observations highlight mesocycle organization as a potential modifier of the adaptive response. However, while research has progressed our understanding of the intensity/accumulated duration relationship during HIT sessions and its relation to endurance performance development in an isolated fashion (128, 137), the cumulative effects of the order of such sessions are not well understood.

Table 1: An overview of retrospective studies describing training characteristics in endurance athletes (1985-2016).

Reference	Subjects: Nation & sport n (♂/♀) Performance level	Methods: Data collection/ time-period	TID quantification	Training characteristics: Training volume Mean (range)	Intensity distribution
		BEFORE THE ONSET OF THIS STUDY			
Bale et al 1985 (3)	British marathon runners n = 36 (♀) Elite <2.55 h (n=11), Good <3.08 h (n=12), Moderate<3.30 h (n=13)	Questionnaire including training characteristics before 16km national championship	3 zones based on session content: Z1: Long runs Z2: Fast runs Z3: Intervalls/Fartlek	Elite/good/moderate: Running distance: ~105/76/62km/wk. Sessions per wk: ~10/7/6	Elite/good/moderate: Z1: 61/66/64% Z2: 22/16/18% Z3: 17/18/18%
Hartmann et al 1990 (57)	German elite rowers n = 40 (♂)	Analysis during prep and comp phase	4 zones based on sessions within blood lactate zones: Z1: <2mM Z2: 2-4mM Z3: 4-8mM Z4: >8mM	Not reported	Prep/comp: Z1: 86-94/70-77% Z2: 5-9/15-22% Z3: 1-4/6% Z4: 0-3/2%
Robinson et al 1991 (115)	New Zealand runners (800/1500m to marathon) n = 13 (♂) Nationally ranked $\dot{V}O_{2peak}$: 66.3 ml·kg⁻¹·min⁻¹	SR analysis of HR during 6-8 weeks in build-up period. Racing, interval sessions and warm-up/cool down were excluded	2 zones based on HR: Z1: < AT Z2: > AT	Running distance: 85km/w (26-180) → 5-6h/wk + excluded data	Z1: ~96% Z2: <4%
Vermulst et al 1991 (158)	Dutch rowers n =6 (♀) Competed in OG 1988 (n=5)	SR diary concerning daily training volume during 9 months preceding the OG	Not quantified. Only total training time/km and specific training	~10 (7-19) h/wk More specific row-training closer to the OG	Not reported
Mujika et al 1995 (100)	Elite swimmers (100m or 200m) n = 18 (10♂/8♀)	Training patterns of the training program were quantified during a comp season (weeks = not reported)	5 zones based on speed and lactate: Z1: speed<B.L.A.T Z2: speed=B.L.A.T Z3: speed>B.L.A.T Z4: lactic swimming Z5: sprint swimming	1126km, frequency: 316 sessions and dryland training; 1108min (period = not reported)	Swim-specific training: Z1: ~78% Z2: ~11% Z3: ~7% Z4: ~3% Z5: ~1%
Steinacher et al 1998 (141)	General description of training characteristics in German rowers. Specific examples of 1995 German Junior Nat. team before WC.	Training schedules	2 zones based on lactate: Z1: < 4mM Z2: > 4mM	High load phase: ~22h/wk (60% (~12h/wk) rowing specific) Tapering phase: ~14h/wk	Row-specific training: Z1: ~93% Z2: ~7%

Study	Subjects	Zones	Protocol	Training volume	Intensity distribution
Lucia et al 1999 (87)	Professional cyclists $n = 8$ (♂) $\dot{V}O_{2max}$: 74.0±5.8 ml·kg⁻¹·min⁻¹	3 VT zones calc. on HR: Z1: $<VT_1$ Z2: VT_1-VT_2 Z3: $>VT_2$	Recorded during Tour de France HR analyses during 3 weeks/22 competitions	4400km total cycling distance at 40.2km/h average speed (~102h). ~190km (4h 50min) per competition	Z1: 70% Z2: 23% Z3: 7%
Lucia et al 2000 (88)	Professional road cyclists $n = 13$ (♂) $\dot{V}O_{2max}$: 74ml·kg⁻¹·min⁻¹	3 VT zones calc. on HR: Z1: $<VT_1$ Z2: VT_1-VT_2 Z3: $>VT_2$	HR analyses during 7 months, divided in 3 periods: rest, pre comp and comp	Cycling: Rest, pre comp, comp; 267, 713 and 810km/wk Total accumulated volume: 21.000km (7mo)	Rest/pre comp/comp: Z1:: 88/78/77% Z2: 11/17/15% Z3: 1/5/8%
Steinacker et al 2000 (140)	German junior national team Rowers $n = 8$ (♂)	2 zones based on lactate: Z1: < 4mM Z2: > 4mM	During prep period before WC Training schedules during 5 weeks	High load phases ~190min/day (~22h/wk) 59% (~13h/wk) rowing specific Tapering phase 108-132min/day	Row-specific training: Z1: ~93% Z2: ~7%
Billat et al 2001 (11)	Portuguese/French national level marathon runners $n = 20$ (♂&♀) Top class (PB <2.12/2.31) High class (PB: 2.12-2.16) $\dot{V}O_{2max}$:♂80/♀69 ml·kg⁻¹·min⁻¹.	5 zones based on running paces: Z1: < vMarathon Z2: vMarathon Z3: v1/2-marathon Z4: v10000m Z5: v3000m	Training logs from coach were analyzed during 12 wks before the Olympic trial	♂ Top class/High class: 206/168 km/wk ♀ Top class/High class: 166/150 km/wk → ♂ 11-14h/wk and ♀ 10-11h/wk	♂/♀ all runners: Z1: 78/77% Z2: 4/7% Z3: 9/7% Z4: 6/5% Z5: 4/4%
Schumacher & Mueller 2002 (107)	German national pursuit team cyclists $n = 7$ (♂) $\dot{V}O_{2max}$: 68ml·kg⁻¹·min⁻¹	3 zones based on HR/lactate: Z1: <IaT Z2: ~IaT Z3: >IaT	Training schedules 1 year prior the Sydney OG were analyzed	Cycling: 29-35.000km/yr → 950-1150h/yr	Z1: 94% Z2: 4% Z3: 2% Not included road races = more high intensity
Billat et al 2002 (9)	Portuguese/French elite marathon runners $n = 9$(♂&♀) National teams (PB:♂2.11h/♀ 2.35h). $\dot{V}O_{2peak}$:♂74/♀65 ml·kg⁻¹·min⁻¹	5 zones based on running paces: Z1: < vMarathon Z2: vMarathon Z3: v1/2-marathon Z4: v10000m Z5: v3000m	Training logs of the coach were analyzed during 8 wks of pre-competitive training before a marathon trial	Weekly running distance: 180km/wk (♂) 155km/wk (♀) (~90% of previously run, 200/170km/wk) → ♂12h/wk & ♀10h/wk	♂/♀ runners: Z1: 75/81% Z2: 7/6% Z3: 7/6% Z4: 6/4% Z5: 5/4%

20

	Participants	Method	Total data-collection time	Tour/Vuelta: Z1: <VT: 74/72% Z2: VT-RCP: 23/25% Z3: >RCP: 3/3%
Lucia et al 2003 (90)	Professional road cyclists n = 7 (♂) $\dot VO_{2max}$: 75 ml·kg⁻¹·min⁻¹	HR data were collected from cyclists who finished both Tour and Vuelta the same year	3 zones according to HR/calculation of training load: Z1: <VT Z2: VT-RCP Z3: >RCP	Total data-collection time: Toru: 92.5t Vuelta: 85t
Billat et al 2003 (10)	Kenyan elite runners n = 19 (♂&♀) 10km PB: ♂28/♀32min. $\dot VO_{2max}$: ♂75/78/♀69 ml·kg⁻¹·min⁻¹	Training log/diaries during 8 wks of specific training before a 10km trial were analyzed. Divided in high speed training (HST) and low speed training (LST)	5 zones based on training sessions classified according to velocity and duration: Z1:<vLT(long run >90min) Z2: vLT (tempo training) Z3: v∆50 (long interval) Z4: v$\dot VO_{2max}$ (~400m int) Z5: >v$\dot VO_{2max}$ (~200m int)	Weekly running: ♂ HST: 158km/wk ♂ LST: 174km/wk ♀ HST: 127km/wk → 8-12h/wk	♂HST/LST/♀HST: Z1: 84/84/88% Z2: 7/14/0% Z3: 4/1/4% Z4: 5/0/8% Z5:1/1/1%
Fiskerstrand & Seiler 2004 (40)	Norwegian international level rowers n = 21 (♂) During 3 decades: 70s/80s/90s: $\dot VO_{2max}$: 65/74/73 ml·kg⁻¹·min⁻¹	Training history based on survey/questionnaire information during the athlete's internationally competitive years. Intensity distribution based on data from April-September	4 zones based on pace/lactacte: Z1: Long distance training, specific/non-specific (1-2.5mM) Z2: Interval training (5-10mM) Z3: Race pace training Z4: Over-speed training	70s: 924h/yr (600-1020) 80s: 966h/yr (840-1140) 90s: 1128h/yr 1104-1200)	70s/80s/90s: Z1: 38/55/60% Z2: 17/15/21% Z3: 9/7/4% Z4: 13/6/3%
Esteve-Lanao 2005 (37)	Well-trained, sub-elite Spanish endurance runners n = 8 (♂) $\dot VO_{2max}$: 70 ml·kg⁻¹·min⁻¹	HR data/watches were collected during 6 months before NC	3 zones based on HR "time-in zones": Z1: <VT (→71%HRmax) Z2: VT – RCT Z3: >RCT (>87% HRmax)	Running distance: 70km/wk. → ~5h/wk	Z1: 71% Z2: 21% Z3: 8%
Seiler & Kjerland 2006 (133)	Norwegian male sub-elite junior XC skiers n = 12 (♂) $\dot VO_{2max}$: 73 ml·kg⁻¹·min⁻¹	SR training diaries in addition to HR data from watches during 32 consecutive days (pre-comp, October-November)	3 zones based on 3 methods: 1- HR time-in-zone, 2 - HR/lactate session goal, 3 - sRPE: Z1: <VT₁/2mM/ sRPE<4 Z2: VT₁-VT₂/2-4mM/sRPE 5-6 Z3: >VT₂/4mM/ sRPE>7	During 32 days each athlete averaged 35 training sessions ranging from 70-140min. Corresponding to 14-15h/wk	TIZ/SG/sRPE: Z1: 91/75/76% Z2: 6.4/8/6% Z3: 2.6/17/18%

21

Reference	Participants	Methodology	Intensity zones	Volume	Intensity distribution
Zapico et al 2007 (162)	Spanish elite U23 cyclists n = 14 (♂&♀) $\dot{V}O_{2max}$: 73-81 ml·kg⁻¹·min⁻¹	HR data/watches were collected during 6 months before the main comp period, and split in winter/spring periods.	3 zones based on HR "time-in zones": Z1: <VT_1 Z2: VT_1-VT_2 Z3: >VT_2	Winter: 21h/3months Spring: 260h/3months	Winter/spring Z1: 78/70% Z2: 20/22% Z3: 2/8%
Karp 2007 (77)	US elite marathon runners competing in Olympic trials n = 93 (♂&♀) (PB: ♂/♀: 2.19h/2.43h)	Questionnaire including training characteristics the whole year leading up to the Olympic trials	5 zones based on pace: Z1: <vMarathon Z2:vMarathon Z3: >vMarathon (1/2mar) Z4: >v10k Z 5: >v5k	Running distance: ♂145km/wk (peak 193) ♀:116 km/wk (peak 152)	♂/♀ Z1: 72/63% Z2: 10/13% Z3: 10/12% Z4: 5/7% Z5: 3/5%
Tønnessen 2009 (152)	Norwegian international level athletes n = 3(♀) XC-ski/Orienteering/Running: $\dot{V}O_{2max}$:77/72/78 ml·kg⁻¹·min⁻¹	SR training diaries collected for several years (career). Most successful year presented here	5 zones based on HR/lactate (SG/TIZ): Z1: 55-75%/<1.5mM Z2:75-85%/1.5-2.5mM Z3: 85-90%/2.5-4mM Z4: 90-95%/4-6mM Z5: 95-100%/6-10mM	XC-ski:783h/yr Orienteering: 519h/yr Running: 558h/yr	XC-ski/ Orienteering/Running: Z1: 84/1/80% Z2: 6/77/10% Z3: 3/8/5% Z4: 6/15/3% Z5: 2/0/2% More specific and Z5 in comp period
Guellich et al 2009 (53)	German junior national level rowers n = 36 (♂) 3 years later 14 reached the final in OG (9 medals)	SR training diaries + HR recording during 37 wks before WC divided in prep/specific prep/comp periods. Comparison between national/ international successful athletes later	3 zones based on HR/la (SG/TIZ): Z1: <VT_1/2mM Z2: VT_1-VT_2/2-4mM Z3: >VT_2/4mM	13h/wk, 11 sessions/wk. Specific rowing training was 52% of total time. More row-specific training in international successful rowers during comp period	Row specific training: Z1: 95% Z2: 2% Z3: 3% More Z3 in international successful rowers during comp period
Guellich & Seiler 2010 (51)	German junior national level track cyclists n = 51 (♂) 19 won medals at junior WC	SR training diaries + HR recording during 15 weeks in basic prep period. Comparison between responders/non-responders	5 zones based on HR-TIZ and L: Z1: no prescription Z2: 60-75%/<2mM Z3/strength: 67-73%/2-3mM Z4: 70-90%/3-6mM Z5: 90-100%/>6mM	Responders: 4073km/9h/wk Non-Responders: 3648km/8h/wk Total: 11-12h/wk included strength and general training	Responders/non-responders: Z1: 5/2% Z2: 86/84% Z3: 3/2% Z4: 6/12% Z5: 0/0%

22

Study	Subjects	Design	Zones	Training	Intensity distribution
Pallares et al 2010 (47)	Spanish elite kayak paddlers, finalists at WC n = 10 (♂) $\dot{V}O_{2max}$: 68 ml·kg⁻¹·min⁻¹	Experimental design following 2 seasons. Analyzes based on SR training during 22wks (traditional period) and 12wks (block period), both divided in 3 phases	3 zones based on HR and speed: Z1: light, <VT_2 Z2: moderate, VT_2–90% $\dot{V}O_{2peak}$ Z3: high, >90% $\dot{V}O_{2peak}$	Traditional period: 244h endurance & 58h strength,13,6h/wk. Block periode: 121h endurance & 36h strength,13h/wk	Traditional/block period Z1: 37/28% Z2: 42/42% Z3: 21/30% Same adaptation, but 10 wk difference
Tjelta & Enoksen 2010 (150)	Norwegian junior elite long-distance runners, competed in European XC championship n = 4 (♂) $\dot{V}O_{2max}$: 79 ml·kg⁻¹·min⁻¹	SR training diaries and a detailed questionnaire including training characteristics for one year, divided in macro-cycles; Build up/track/XC	5 zones based on pace, HR and lactate (SG/TIZ): Z1:Easy, 62-82%, <2mM Z2:Mar/1/2mar, 82-92%, 2-4.5mM Z3:10-3km, 92-97%, 4.5-8mM Z4:1.5km-400m, 97-100%, >8mM Z5:Sprint/strides	Endurance/running training: Build up: 133km/wk Track comp: 115km/wk XC comp: 145km/wk Corresponding to 9, 8 and 10h/wk. In addition strength and speed training (not quantified)	Build up/track/XC: Z1: 78/81/78% Z2: 20/12/18% Z3: 1/5/3% Z4: 0/1/0% Z5: 1/1/1%
Siewierski 2010 (139)	Polish elite swimmers, competing at international level n = 8 (♂)	The volume and structure of training loads were analyzed based on created sheets during preparation period (57d). Three phases: Regeneration, intensification and transformation	5 zones based on lactate and swimming speed. Z1 <2mM - aerobic Z2:2-3mM - aerobic Z3 3-5mM - mixed Z4 >5mM –anaerobic/lactic acid Z5:Sprint – anaerobic/non-lactic acid	Swimming volume. Regeneration: 308km (24d/47 sessions), 90km/wk, 6.6km/session. Intensification: 193km (19d/38 sessions), 71km/wk, 5.1km/session. Transformation: 79km (14d/21 sessions), 40km/wk, 3.8km/session.	Regeneration/intensification/transformation; Z1: 6/8/11% Z2: 69/63/73% Z3: 21/20/11% Z4: 3.5/9/2.5% Z5: 0.5/0.5/1.5%
Enoksen et al 2011 (35)	Norwegian elite runners competing in international championships as senior n =6 (♂) 3 track/3 marathon	SR training diaries during 1 year, completed with an international championship. Year divided in prep, pre-comp., and comp period	7 zones based on pace, lactate and HR (SG/TIZ): Z1: Easy, <2mM, <82% Z2: Mar, 2-3mM, 82-87% Z3: 1/2mar, 3-4.5mM, 87-92% Z4: 10km, 4.5-7mM, 92-95% Z5: 5-3km, 7-11mM, 95-100% Z6: 1500-800m, >11mM, 100% Z7: Sprint/strides	Average running. Marathon: 187km/wk Track: 161km/wk 11-13 sessions/wk (3-5 HIT). Volume increased from prep to pre-comp to comp period Corresponding to 11-13h/wk	Marathon/track: Z1: 82,7/78,7% Z2: 12,4/8,6% Z3: 1,4/7,1% Z4: 1,6/0,1% Z 5: 0,3/2,8% Z 6: 0,3/1,3% Z7: 1,2/1,5% Increased HIT volume/int in pre-comp and comp

Study	Subjects	Method	Zones	Training volume	Results
Sandbakk et al 2011 (126)	Norwegian XC skiers n =24 (♂) 8 world class/8 national class $\dot{V}O_{2max}$: 71/66 ml·kg⁻¹·min⁻¹	SR training in diaries during 6 months	3 zones based on HR/La (SG/TIZ): Z1:LIT, <2.5mM, <81% Z2:MIT, 2.5-4mM, 82-87% Z3:HIT, >4mM, >88%	Total training volume during 6 months: (World class/National class): 445h/341h, 87/84% endurance + speed/strength	World class/National class : Z1: 88/89% Z2: 7/5% Z3: 5/7%
Stellingwerf 2012 (142)	Canadian elite Marathon runners n=3 (♂) (PB: 2.11-2-16h)	Athletes followed a 16wk training plan, divided in general prep (6wk), specific prep (6wk) and comp (4wk)	3 zones (SG/TIZ) (not clear): Z1:very easy-somewhat hard Z2: hard Z3: very hard-maximal	Average training volume: 174, 213 and 160km/wk. Maximum volume was 228, 266 and 199km/wk Lowest (comp wk), 115km/wk →13h/wk or ~182km/wk	TID for all athletes: Z1: 74% Z2: 11% Z3: 15%
Ingham et al 2012 (66)	UK elite 1500m runner n=1 (♂) Initial 1500m PB 3.32 min $\dot{V}O_{2max}$: 80 ml·kg⁻¹·min⁻¹	The athlete recorded daily training distance, time and HR during 2 yrs. Further training information from coach training schedules	6 zones according to running speed: Z1: <80% $v\dot{V}O_{2max}$ Z2: 80-90% $v\dot{V}O_{2max}$ Z3: 90-100% $v\dot{V}O_{2max}$ Z4: 100-110% $v\dot{V}O_{2max}$ Z5: 110-120% $v\dot{V}O_{2max}$ Z6: 120-130% $v\dot{V}O_{2max}$	Total training volume not reported	Yr 1/2: Z1: 18/55% Z2: 45/20% Z3: 20/9% Z4: 10/6% Z5: 5/5% Z6: 2/5% More polarized yr 2 and better results
Yu et al 2012 (61)	Chinese elite speed skaters (500-1000m), Olympic level n = 9 (♂&♀) $\dot{V}O_{2max}$:♂53/♀48 ml·kg⁻¹·min⁻¹	SR training in diaries and HR/lactate monitoring during 2 yrs	3 zones based on HR/lactate (SG/TIZ): Z1: <2mM, <79/82% Z2: 2-4mM, 79/82-89/92% Z3: >4mM, >89/92%	~280-290 training sessions each yr Endurance ~35% Speed ~10% Skating ~30% Skill ~6% Strength ~19%	Yr 1/2 in endurance training: Z1: ~42/85% Z2: ~51/5% Z3: ~7/10% More polarized yr 2 and better results

Tjelta 2013 (148)	Case study on male European runner, Champion in 1500m n =1 (♂) $\dot{V}O_{2max}$: 84 ml·kg⁻¹·min⁻¹.	SR training in diaries, including HR/La measurements during 5 years (17-21 yr)	5 zones based on HR/La: Z1: 62-82%/<2.0mM Z2: 82-92%/2-4mM Z3: 92-97%/4-6mM Z4: >97%/>6mM Z5: Sprint/strides	Running volume during 10wks (January-March): 110 (17yr), 130 (18yr), 140 (19yr), 150 (20yr), 150-60km/wk (21yr) In addition; strength, drills and stability 1-2 sessions/wk	During 10wks at 21 yrs: Z1:69% Z2: 26% Z3: 4% Z4/5: 1.5% During comp season; 73% Z1, as some Z2 were replaced with Z 4/5
Tjelta et al 2014 (151)	Norwegian runner n =1 (♀) 9 times New York Marathon winner	SR training in diaries in addition to interviews during 2 successful years as a track runner and marathon runner	8 zones based on speed/HR: Z1: Easy/65-78 Z2: Marathon/78-85 Z3: 1/2mar/85-89 Z4: 10k/89-93 Z5: 5-3k/93-100 Z6: 1500-800m Z7: 400m Z8: Sprint	Total training volume: As track runner: 120-130 km/wk, + 3 strength training sessions. As marathon runner: 121km/wk, 9,4 sessions/wk + strength → ~600h/yr	Track runner: Z1: 52% Z2: 28% Z3: 16% Z4: 1% Z5: 1.5% Z6: 1.5% Z7: 0% Z8: 0.5%
Orie et al 2014 (108)	Dutch international level speed skaters (distance) from 1972-2010 n = not reported	Training logs in combination with interviews were analyzed during time-period from 1972-2010	3 zones based on lactate: Z1: < 2mM Z2: 2-4mM Z3: > 4mM	"Net" training volume (60% of total):6-12h/wk → "gross" 500-1000h/yr	Year 1972/2010: Z1: ~40/80% Z2: ~40/15% Z3: ~20/5%
Mujika 2014 (99)	Triathlete n =1 (♀) International level: 7ᵗʰ in 2012 Olympics	SR training log during 1 year (50 wks) before the 2012 OG	3 zones based on power, speed, HR and lactate: Z1: < ILT Z2: ILT-OBLA Z3: > OBLA	Training volume/yr: Swim: 1230km (~600h) Bike: 427h Running: 250h 796 sessions (16/wk). Total ~1200-1300h/yr	Total/swimming/bike/run. Z1: 82/74/88/85% Z2: 11/16/10/8% Z3: 6/10/2/7%
Munoz et al 2014 (101)	Spanish recreational Iron Man triathletes n =9 (♂) $\dot{V}O_{2max}$: 55 ml·kg⁻¹·min⁻¹.	SR in personal training logs based on HR monitors during 18 weeks before IM	3 zones based on HR/La: Z1: < AeT Z2: AeT - AnT Z3: > AnT	Not reported total training volume, but 3 different programs differed in volume	Z1: 68% Z2: 28% Z3: 4% High Z1 vol. pos. corr., high Z2 vol. neg. corr. with performance
Losnegard et al 2014 (86)	Norwegian elite XC skiers n =13 (♂) National or international level. $\dot{V}O_{2max}$: 79 ml·kg⁻¹·min⁻¹.	SR training diaries during 1 yr	3 zones based on session goal/HR. Z1: < 81%HR$_{max}$ Z2: 82-87%HR$_{max}$ Z3: > 88%HR$_{max}$	~675 h/yr Decreased from prep to comp period 50-60 % ski specific	Z1: 79% Z2: 5% Z3: 7% Other training: 9% More Z3 in comp season

Study	Athletes	Methods	Volume	Intensity zones	Intensity distribution
Plews et al 2014 (111)	Elite heavy-weight rowers n = 9 (5♂ & 4♀) 2 gold and 2 bronze medals in 2012 OG	HR data were analyzed during 26 weeks build-up to the 2012 OG	~18h/wk → ~800-900h/yr	3 zones based on HR: Z1: < LT_1 Z2: $LT_1 – LT_2$ Z3: > LT_2	Z1: 77% Z2: 17% Z3: 6%
Tønnessen et al 2015 (155)	Norwegian elite orienteers n = 8 (6♂ & 2♀) World Champions $\dot{V}O_{2max}$: ♂83/♀72 ml·kg⁻¹·min⁻¹	SR training in diaries during one year. Divided in transition, general prep, specific prep and comp phase	♂/♀:636/613 h/yr 480 sessions	3 zones based on HR (%$_{max}$) and lactate (mM). Z1: 55-82/<2.5 Z2: 83-87/2.5-4.0 Z3: 88-100/4.0-10.0	Annual distribution: Z1: 80% Z2: 8% Z3: 12% More Z3 in comp phase
Tønnessen et al 2016 (154)	Norwegian world-class Nordic combined athletes n =6 (♂) World Cup victories $\dot{V}O_{2max}$: 77 ml·kg⁻¹·min⁻¹	SR training in diaries during one year. Divided in transition, general prep, specific prep, comp and regeneration phase	846 h/yr, distributed in 527 sessions. 540 h endurance training, + strength, power & jump. Reduced volume from prep to comp phase	3 zones based on HR (%$_{max}$) and lactate (mM). Z1: 55-82/<2.5 Z2: 83-87/2.5-4.0 Z3: 88-97/4.0-10.0	Annual distribution: Z1: 89% Z2: 6% Z3: 5% Less Z2/3 and more non-endurance training in comp compared to prep phase
Sandbakk et al 2016 (127)	Norwegian world-class Nordic Combined and XC-skiers n=10 (♂) $\dot{V}O_{2max}$: 70/78 ml·kg⁻¹·min⁻¹	SR training in diaries during one year. Only one representative athlete from each group was analyzed	Nordic combined/XC: 569/794 h/yr, 378/489 sessions/yr. 88/91% endurance training. Nordic Combined trained 267 h and 260 sessions ski jump in addition	3 zones based on SG/TIZ: Z1: < 81% HR$_{max}$ Z2: 81-87% HR$_{max}$ Z3: > 87% HR$_{max}$	Annual distribution Nordic Combined/XC. Z1: 87/90% Z2: 5/4% Z3: 8/6%
Sandbakk et al 2016 (124)	Norwegian elite XC skiers n =12 (♀) 6 World Class/6 National Class $\dot{V}O_{2peak}$ (diagonal stride): 71/65 ml·kg⁻¹·min⁻¹	SR training in diaries during one year divided into 6 months prep and 6 months comp period	World class/National class: Annual: 920/709 h Prep: 532/411 h Comp: 388/298 h	3 zones based on SG/TIZ: Z1: < 81% HR$_{max}$ Z2: 81-88% HR$_{max}$ Z3: > 88% HR$_{max}$	Prep & comp (World class/National class): Z1: 91/90 & 89/89% Z2: 5/4 & 4/3% Z3: 4/6 & 7/8% More polarized during comp period

Abbreviations in table: AeT = Aerobic threshold, AnT = Anaerobic threshold, AT = anaerobic threshold, B.L.A.T. = blood lactate anaerobic threshold, comp = competition, HR = heart rate, IaT = individual aerobic threshold, ILT = individual lactate threshold, LT = lactate threshold, mar = marathon, NC = National Championship, OBLA = onset of blood lactate accumulation, OG = Olympic Games, PB = Personal best, prep = preparation, RCP = respiratory compensation point, rest = resting, SG = session goal, SR = self-report(ed), TID = training intensity distribution, TIZ = time in zone, vLT = velocity LT, VT = ventilator threshold, WC = World Championship, Z = zone. ***Symbols:*** → = converted to.

26

Performance and physiological adaptations

HIT (defined as training intensities from MLSS, LT_2 or VT_2 to "all-out" supra-maximal exercise intensities (see Figure 1)) involves repeated short-to-long bouts of relatively high-intensity exercise interspersed with recovery periods (interval training), or training at high-intensities executed as continuous work (23). HIT performed as interval training allows athletes to accumulate additional minutes at higher intensities compared to training performed in a continuous mode (13). Buchheit & Laursen (23) suggest that a prescription for HIIT consists of manipulation of up to nine variables, including work interval bout intensity and duration, number of repetitions and series, recovery intensity and duration between bouts and series as well as exercise modality. Manipulation of any of these variables may affect acute physiological or performance responses to HIIT.

The ultimate goal of endurance training for athletes is performance improvement in a competition or specific performance task. Therefore, experimental studies including relevant performance tests are of particular interest. For cyclists, tests in the entire power-profile spectra are applicable, and in the lower power range, measurements of average power output during a 40 min or 40 km all-out trial (83, 84, 122, 143, 160) are common. Those types of tests reflect basic aerobic endurance capacity. However, measurements of peak power output during short-time and progressive tests to exhaustion (often named PPO or W_{max}) reflect more anaerobic or muscular qualities in the cyclist, and have also been shown to be a strong predictor of cycling performance in professional cyclists (91), triathletes (8) and well-trained cyclists during different time-trial distances (4, 58). The importance of W_{max} is also underlined by the finding of a large correlation between changes in W_{max} and change in mean power output during a 40-min all-out trial ($r = 0.69$, $P < 0.01$) (120). In the highest range of the power-profile, a test reflecting sprint capacity is required, and a traditional Wingate test is often used, i.e. (122) for measurement of both maximal and average power during 20-60 sec all-out cycling (164).

Current physiological laboratory testing of endurance athletes conforms to a now well-accepted model incorporating three major physiological variables accounting for most of the inter-individual variance in aerobic endurance performance: $\dot{V}O_{2max}$, LT and work efficiency (109). Several studies support this model (27, 55, 75) and it provides a useful framework for comprehensive examination of the effects of aerobic training on endurance performance. $\dot{V}O_{2max}$ may be the single most important factor determining

success in aerobic endurance sports over various performance levels, and is mainly limited by oxygen delivery to working muscles (65, 165).

LT is defined as the intensity of work (or $\dot{V}O_2$) at which the [la⁻] gradually starts to increase during continuous exercise (33). The concept (39) has numerous definitions involving both ventilatory and blood based measurement approaches, and there is probably no area in exercise physiology that has been more debated (135). Any right- or downward movement of the [la-] curve results in improved power output/velocity at LT regardless of how LT has been determined. There also exists a close relationship between different LT's and MLSS, although divergences are reported (151). A fixed [la⁻] value is frequently used to evaluate endurance capacity, whereas 4 mMol·L⁻¹ (OBLA) may be the most frequently used method. However, a fixed value does not take into account considerable inter-individual differences and therefore can underestimate or overestimate real endurance capacity. In addition, [la⁻] at MLSS can vary considerably (2-10 mMol·L⁻¹) (39). The sustainable oxygen consumption rate can improve in response to training with an increased $\dot{V}O_{2max}$ and maintained relative LT, or via an increased fractional utilization of a given $\dot{V}O_{2max}$ (109).

Work efficiency is referred to as the ratio between work output and oxygen cost, and may account for as much as 2/3 of the variation in performance in highly trained groups with similar ability (26). Work efficiency is typically calculated as gross efficiency (GE) or delta efficiency (28). A change in $\dot{V}O_{2max}$ is often highlighted as the key physiological variable when evaluating the response to endurance training. However, among experienced athletes with well-developed $\dot{V}O_{2max}$ capacity, both LT and work efficiency may be more responsive variables, exemplified in two case studies by Jones (73, 74) following the female world-record holder in marathon, Paula Radcliff, for five years during her track and marathon career.

Finally, the energy contribution from anaerobic capacity plays an important role in performance for event durations below 10 minutes (135). No gold standard method of assessing the anaerobic energy contribution to HIT has been established. Therefore, short-term performance tests (164), measurement of accumulated O_2 deficit and peak [la⁻] tend to be the accepted surrogate methods (22, 96). All of the physiological variables discussed above are directly or indirectly related to training variables as intensity, duration and frequency during short- to long- timeframes.

In general, experimental studies indicate that adding 2-3 HIT sessions per week, in combination with a high LIT volume, induce 2-10% average aerobic performance improvements in groups of well-trained athletes, over timeframes from a few weeks to three months, i.e. (84, 117, 128, 137, 143). Importantly, this range in improvements reported is not clearly related to the intervention duration. Performance improvements in response to short-term HIT addition are mainly associated with improvements in physiological variables as $\dot{V}O_{2max}$ and LT (83-85, 89, 117, 129, 143, 146). Both Lucia et al (88) and Sassi et al (129) reported that GE did not respond to training load elevation among elite cyclists followed for 3 months to one year. Importantly, changes reported in the above studies are most often only reported as net changes from pre- to post- intervention period. There is still limited documentation of the time-course of adaptive development during a longer training cycle, or how this development trajectory might be influenced by the organization and execution of the HIT component during the training cycle. In addition, little is known regarding whether manipulation of different HIT-session variables (intensity, duration and organization patterns) at a sustainable HIT frequency (2-3 sessions·week^{-1}) can alter the overall response to HIT in already well-trained to elite athletes.

Although it is common to observe meaningful increases in both performance and physiological capacity when adding 2-3 HIT sessions to a high volume of LIT, additional increases in HIT frequency do not necessarily induce further improvements, and may instead induce symptoms of overreaching/overtraining (12, 56). The balance between training as adaptive signal and training as inducer of severe stress responses may be captured by changes in key hormonal responses. Resting blood concentrations of FT, TT, cortisol (C) and FTCR are considered useful biomarkers of anabolic and catabolic hormonal control (16, 24, 50, 62, 163). For example, a ≥30% decrease in FTCR has been proposed as a marker of the overtraining syndrome (5, 46), although doubt has been cast as to whether FTCR is able to differentiate between functional overreaching and overtraining (156, 157). However, the relationship between training adaptations and changes in resting FT, TT and C is not well established. Both increases and decreases in FT and TT have been observed during short-term high-intense training periods (62, 163). Therefore, the effect of multiple training-cycles with different intensities and accumulated HIT duration on hormonal responses in well-trained endurance athletes remains to be thoroughly investigated.

Aims of the thesis

The overall objective of this PhD project was therefore to investigate training organization patterns in elite endurance athletes. Three independent studies were carried out: one methodological, the second descriptive, and the third experimental. These three projects addressed five specific aims:

I.   Quantify the accuracy of SR training duration and intensity distribution among elite endurance athletes (*study I/paper I*).

II. Compare three methods of TID quantification in a large sample of training sessions performed by elite endurance athletes (*study I/paper II*).

III. Present highly accurate day-to-day annual training data from a cohort of Olympic or World Championship gold medal winning endurance athletes, and quantify and examine relationships between annual training and peaking characteristics in these athletes (*study II/paper III*).

IV. Compare the effects of three different HIT models, balanced for total training load and HIT load, but periodized in a specific mesocycle order or in a mixed distribution, on endurance adaptions during a 12-week training period in well-trained endurance athletes (*study III/paper IV*).

V.   Investigate the development of performance, physiological and hormonal responses every fourth week during a 12-week HIT period in three groups with different interval training prescriptions (*study III/paper V*).

Methods

This thesis is based on five papers emerging from three independent and original studies on well-trained or elite endurance athletes conducted from 2012 to 2016. The thesis builds on a triangulation of different quantitative methods (Figure 5): *Study I (papers I & II)* answer key methodological considerations of validity and comparability related to interpreting SR training diary and HR monitoring data in elite athletes. *Study II (paper III)* describes the training patterns of top international-level XC skiers over the course of a training year ending with an Olympic or World Championship gold medal. *Study III (papers IV & V)* emerge from a multi-center experimental training intervention designed and organized by the candidate and performed on well-trained, but sub-elite subjects.
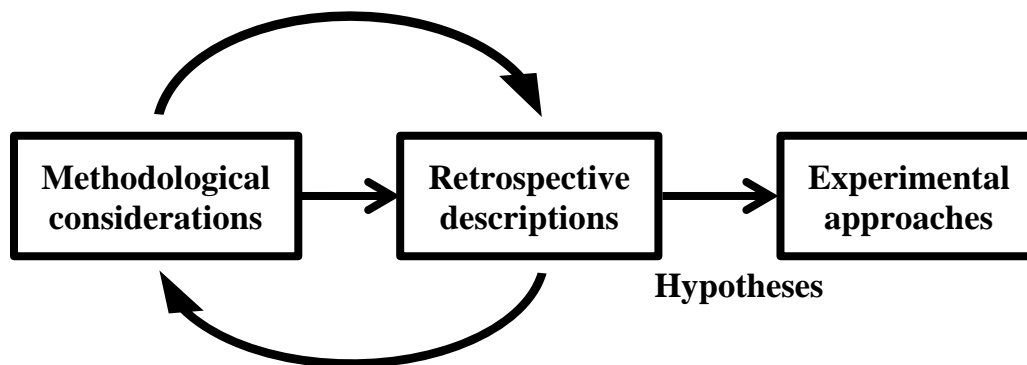
Figure 5: Illustration of how three independent quantitative methods used in the present thesis influences each other. The overall research question was answered through a method-triangulation, including methodological, descriptive and experimental approaches. Methodological considerations are needed to better interpret retrospective training descriptions in elite athletes. Retrospective descriptions are hypothesis generating, and research questions may be answered through experimental approaches.

Subjects

In total, 109 (89 male and 20 female) XC skiers and cyclists volunteered to participate in this thesis. The characteristics of the subjects are summarized in Table 2. *Study I* included 29 international level XC skiers. Of these, 28 athletes had won medals in senior or junior World or Olympic Championships. Five subjects were excluded from data analysis in *paper I* due to inconsistent SR in diaries. In *study II* eleven athletes had all won at least one Olympic or World Championship senior gold medal. In total, included males had won 41 (5-26) and females 25 (1-9) senior Championship gold medals from 1985-2011. *Study III* included 69 local cyclists who were classified as well-trained (72) or at performance level 4 according to an athlete categorization by

De Pauw et al (32). They were all competitive at recreational to national level. Six subjects were excluded from the final data analysis due to absence from post-testing.

Table 2. Subject characteristics in *studies I – III*.

Study	n	Age	Body mass	$\dot{V}O_{2max}$	Type of athlete
I	♂ 12 (16)	25 ± 3	76 ± 6	81 ± 4	Current elite XC skiers on the
	♀ 12 (13)	24 ± 4	60 ± 6	71 ± 5	Norwegian national team
I	♂ 16	26 ± 3	78 ± 7	80 ± 5	Current elite XC skiers on the
	♀ 13	24 ± 4	61 ± 7	70 ± 5	Norwegian national team
II	♂ 4	28 ± 1	77 ± 8	85 ± 5	Former and current elite XC skiers
	♀ 7	25 ± 4	61 ± 6	73 ± 3	with Olympic/WC gold medal
III	♂ 63 (69)	38 ± 8	80 ± 8	61 ± 6	Current well-trained cyclists

Note; Five and six subjects were excluded from final data-analysis in *study I* and *III*, respectively. Numbers in *study III* are presented as pre-values. Data are mean ± SD.

Study design

Study I

Data collection was performed during a ~14 day altitude-training camp in Val Senales, Italy, October 2012. The athletes were blinded to our specific research aims. Athletes were instructed to carry out their normal training, use a HR monitor (Garmin Forerunner 910XT or 610, Garmin, Olathe, KS, USA) during every session and report all of their training in diaries. In total, athletes contributing to *paper I* and *II* from *study I* reported 500-600 training sessions, which were accompanied by HR data and [la⁻] measurements (380 samples).

In *paper I* SR training duration was compared with recorded training duration from HR monitors, and SR intensity distribution was compared with consensus agreement from three investigators who independently examined available data from each training session. This analysis was termed expert analysis, and was based on the previously described modified SG analysis method (SG/TIZ), combined with HR and [la⁻] measurements.

In *paper II* the proportion of training performed as LIT, MIT and HIT was quantified using total training time or frequency of sessions and analyzed using three methods: TIZ, SG or a hybrid SG/TIZ approach (Figure 2). The 3-zone intensity scale was used to compare proportions (ratios) in each zone across TID methods. Finally, simple conversion factors were calculated to facilitate converting TID estimates based on one

method to another. For simplicity only a binary intensity distribution model was used in these calculations. The following formulas were used:

Conversion factor for TIZ to SG = ratio SG% / ratio TIZ%
Conversion factor for SG to TIZ = ratio TIZ% / ratio SG%

Study II

One year of SR day-to-day training data leading up to the most successful competition of the athlete's career were analyzed. Training data were quantified and divided in phases: GP, specific preparation (SP) and CP and distributed into training forms, activity form and intensity zones. All athletes used the 5-zone intensity scale in their diaries, and results are presented as a modified SG (SG/TIZ) or a frequency based SG approach, either in a binary model (LIT/HIT) or a 5-zone intensity model (Table 3).

Study III

Study III was a randomized controlled trial (RCT). It was executed as a multicenter study involving three cooperating test centers completing the same experimental trial. In this context, we define the study-design as a RCT because two experimental training groups differing in the sequencing of HIT meso-cycles were compared and matched against a non-sequencing group (control). Following a 6-week pre-intervention period, all training groups were instructed to follow a 12-week intervention period consisting of 2-3 supervised HIIT sessions per week in addition to *ad libitum* LIT. All training groups were matched for total training load across 12 weeks, but differed in the content of HIT cycles. **INC** (*n=23*) performed interval training as 4x16 min in cycle 1 (week 1-4), 4x8 min in cycle 2 (week 5-8) and 4x4 min in cycle 3 (week 9-12). **DEC** (*n=20*) performed interval sessions in the opposite cycle order as INC, and **MIX** (*n=20*) performed the interval prescriptions in a mixed distribution in all cycles. All interval sessions were performed indoors as supervised group training and intensity was prescribed as maximal session effort (isoeffort). The three different interval prescriptions (4x16, 8 and 4 min) induced significantly different power output, [la⁻] and HR responses (for details, see Table 1, *paper IV*). Laboratory cycling-tests related to key endurance adaptions and measures of resting blood hormones were conducted pre, and at the end of weeks 4, 8 and 12 of the intervention (Figure 6). All subjects reported their training in a training diary similar to the one used in *study I* (Figure 7), and training data were analyzed according to Figure 8 and Table 3.
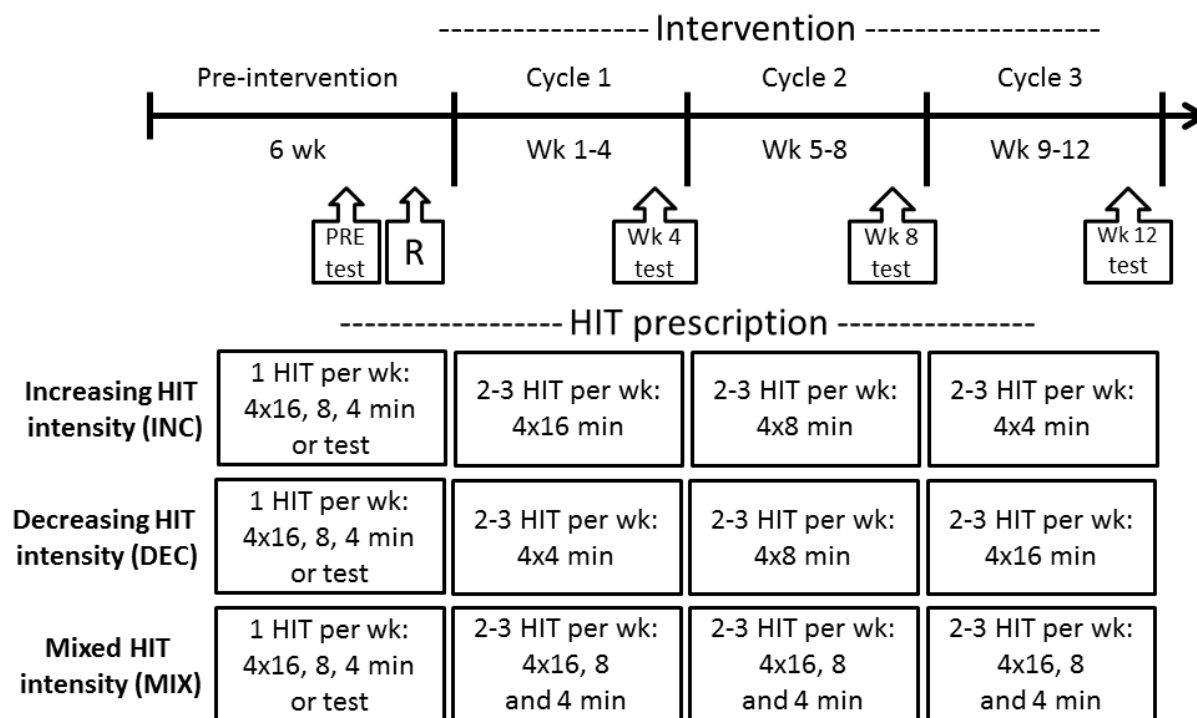
*Figure 6: Protocol used in study III. A 6-week pre-intervention period, consisting of ad libitum LIT and one prescribed interval session each week, in addition to pre-test and randomization (R), was followed by a 12-week intervention period divided in three 4-week cycles with different interval session prescription for the **increasing HIT (INC)** (n=23) **decreasing HIT (DEC)** (n=20) and **mixed HIT (MIX)** (n=20) groups. Testing was performed pre-intervention, and at the end of weeks 4, 8 and 12.*

In *paper IV,* groups were compared before (pre) and after (week 12) the entire period related to the effect of organizing different 4-week HIT cycles in a specific mesocycle order (increasing or decreasing HIT) or in a mixed HIT distribution.

In *paper V,* we explored the time-course of changes in specific performance variables and resting anabolic and catabolic hormones every 4th week during 12 weeks of intensified training. In addition, the potential interactions between different HIT prescriptions (4x16 min vs. 4x4 min) in different cycles (cycle 1 and cycle 3) were compared.

Data collection procedures and materials

Studies I & II
All athletes in *study I* currently represented the Norwegian XC ski national team and were instructed to SR day-to-day training in diaries. The information in the diary consisted of quantifiable data regarding duration in each training form, activity form and intensity zones, as well as overall perceived exertion and comments related to execution of the session. This diary template has been digitized by OLT based on

previous similar hard-copy versions developed by the Norwegian Ski Federation and is currently available online to all athletes. However, because *study I* was performed at a remote mountain training camp, athletes were provided with simple hard copies of their normal online training diary (Figure 7). *Study II* involved complete digitization of hard copy training diaries from a combination of retired and active athletes. These annual training data were analyzed based on online training diaries constructed on the same template as shown in Figure 7.

NAME: **WEEK:**

DAY DATE SESSION		ENDURANCE							Z3, Z4 OR Z5 SESSION	STRENGTH			SPRINT	PLYOMETRICS	STRETCHING	OTHER	ACTIVITY FORM							KM SKI	SESSION PERCEIVED EXERTION (1-10)	DAY FORM (1-5)	TOTAL TRAINING VOLUME (H)	COMMENTS
		Z-1 EASY	Z-2 MODERATE	Z-3 LT (LOW)	Z-4 LT (HIGH)	Z-5 VO2MAX	Z-6 ANAEROBIC T	Z-7 ANAEROBIC P		GENERAL	SPECIFIC	MAXIMAL					RUNNING	SKI CLASSIC	SKI SKATE	ROLLERSKI CLASSIC	ROLLERSKI SKATING	CYCLING	OTHER					
MON	1																											
	2																											
TUE	1																											
	2																											
WED	1																											
	2																											
THU	1																											
	2																											
FRI	1																											
	2																											
SAT	1																											
	2																											
SUN	1																											
	2																											

Figure 7: Training diary sheet used in study I. A similar, but digitized version was also used in studies II and III.

Training data was quantified and analyzed based on the information from training diaries. Total training time (or sessions) was distributed in training forms (endurance, sprint and strength training). Endurance and sprint-time were further distributed into activity forms, and endurance-time was distributed in intensity zones and analyzed according to Figure 8. The 5-zone aerobic-intensity scale developed by OLT was used to prescribe intensity distribution (Table 3). The same intensity distribution reference tools were used in all studies. Note: In *papers II* and *III* we in addition choose to collapse the 5-zone scale and present results in both a 3-zone and binary scale corresponding to physiological anchor points.
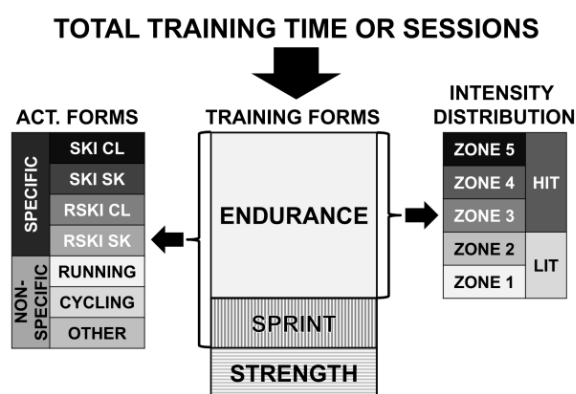
Figure 8: Based on information from training diaries, total training time or sessions were quantified in training forms, activity forms and intensity distributed.

Table 3: The 5-zone, 3-zone and binary intensity scales used in the current thesis. The 5-zone scale presented here is developed by the Norwegian Olympic Federation (OLT).

5-zone model	3-zone model	Binary model	HR (%$_{max}$)	Lactate (mM)
5	3/HIT	HIT	92-97	6-10
4			87-92	4-6
3	2/MIT		82-87	2.5-4
2	1/LIT	LIT	72-82	1.5-2.5
1			55-72	0.8-1.5

Note. The reference values in this scale are guidelines only, and individual adjustments are required.

Study III

Testing weeks consisted of standardized cycling protocols executed during 1-2 days to determinate commonly used aerobic and anaerobic physiological and performance related variables. On test day 1, (1) 4-7 submaximal steady-state 5-min steps were followed by (2) an incremental test to exhaustion and (3) a 30 s all-out Wingate test (164) (timeline shown in Figure 9).
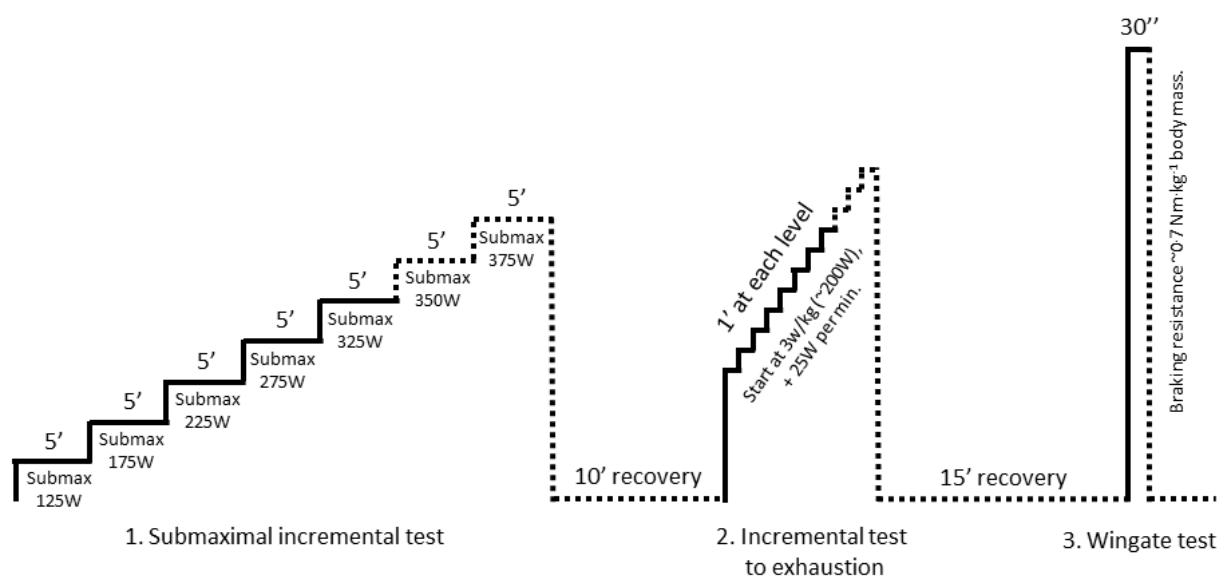
***Figure 9.** Test protocol for test day 1 (study IV & V). 1) During the submaximal steady-state 5-min steps, power output started at 125 W and increased 50 W (25 W if lactate concentration ([la⁻]) was >3 mMol·L^{-1}) after 5 min, and repeated to [la⁻] >4 mMol·L^{-1}. Oxygen uptake ($\dot{V}O_2$), heart rate (HR), rate of perceived exertion (RPE) and [la⁻] were measured during the end of the steady state phase in each step. 2) An incremental test to exhaustion started at 3 W/kg^{-1} body mass (~200 W) and increased 25 W each minute to exhaustion. $\dot{V}O_2$ and HR were measured continuously, and RPE and [la⁻] were measured at failure. 3) The Wingate test started with 20 sec at ~120 W, followed by 30 sec all out at ~0.7 Nm·kg^{-1} body mass braking resistance. Cyclists were instructed to pedal as fast as possible during the test.*

Based on the submaximal steady state steps, $Power_{4mM}$ and GE were identified (Table 4). Power output and $\dot{V}O_2$ corresponding to 4 mMol$\cdot$L^{-1} [la$^-$] were identified after plotting the true power-lactate curve for each subject, by fitting a polynomial regression model (106). GE was calculated using the method of Coyle et al. (28). Briefly, rate of energy expenditure was calculated by using gross $\dot{V}O_2$ from the first three 5 min submaximal steady state steps (125, 175 and 225 W), and GE was expressed as the ratio of work accomplished per minute to caloric expenditure per minute after conversion to the common energy equivalent joules.

The incremental test to exhaustion was performed to determine $\dot{V}O_{2peak}$ and peak power output (PPO). $\dot{V}O_{2peak}$ was calculated as the average of the two highest 30 sec consecutive $\dot{V}O_2$ measurements. Plateau of $\dot{V}O_2$ curve and/or HR $\geq$95% of known HR$_{max}$, respiratory exchange ratio (RER) $\geq$1.10 and [la$^-$] $\geq$8.0 mMol$\cdot$L^{-1} were used as criteria for the attainment of an accepted test (65). PPO was calculated as the mean power output during the last minute of the test. In addition, a theoretical maximal aerobic power (MAP) was calculated by using submaximal $\dot{V}O_2$ measurements in addition to $\dot{V}O_{2peak}$. MAP was defined as the power where the horizontal line representing $\dot{V}O_{2peak}$ meets the extrapolated linear regression representing the submaximal $\dot{V}O_2$/power relationship. To estimate fractional utilization of $\dot{V}O_{2peak}$, the previously described $\dot{V}O_2$ corresponding to 4 mMol$\cdot$L^{-1} [la$^-$], was calculated as percentage of $\dot{V}O_{2peak}$ (%$\dot{V}O_{2peak}$@4mM) (Table 4).

Finally, the 30 s all-out Wingate test (164) provided mean power during 30 s ($Power_{30s}$) (Table 4).

On test day 2 (only performed at pre and week 12 time points) subjects performed a 40 min all-out trial. The test started with 30 min warm-up at a self-selected power output followed by cycling at the highest possible mean power for 40 min. The mean power during 40 min was recorded ($Power_{40min}$) (Table 4).

Venous blood samples were collected from a sub-group of twenty-nine subjects in a rested, fasted state each testing week (pre and at the end of weeks 4, 8 and 12) to assess hormonal responses. 10 mL venous blood was collected from an antecubital vein using vacutainer tubes (Becton Dickinson, Franklin Lanes, USA). Samples were stored at room temperature (20-22°C) for 30-60 min before centrifugation for 10 min

at 3000 revolutions per minute (RPM) (Statspin Express 4, Beckman Coulter, USA). The supernatant serum was pipetted into 1 mL aliquots and immediately frozen at - 20°C until analyses. Serum was analyzed for TT, FT, C, IGF-1, IGF-BP3, human growth hormone (HGH), sexual hormone binding globulin (SHBG) and prolactin (PRL) (Table 4). The FTCR was calculated using the method of Banfi & Dolci (5).

Table 4: Physiological and performance test variables that were analyzed based on tests in *paper IV* and *V*, in addition to analyzed resting blood hormones in *paper V*.

Physiological and performance test variables	Analyzed resting blood hormones
(1) Power at 4 mMol$\cdot$L^{-1} [la$^-$] (Power$_{4mM}$)	(1) Total testosterone (TT)
(2) Gross efficiency (GE), method of Coyle et al. (28)	(2) Free testosterone (FT)
(3) Peak oxygen consumption ($\dot{V}O_{2peak}$)	(3) Cortisol (C)
(4) Peak power output (PPO)	(4) Insulin-like growth factor 1 (IGF-1)
(5) Maximal aerobic power (MAP)	(5) Insulin-like growth factor BP3 (IGF-BP3)
(6) Fractional use of $\dot{V}O_{2peak}$ at 4 mMol$\cdot$L^{-1} [la$^-$]	(6) Human growth hormone (HGH)
(%$\dot{V}O_{2peak}$@4mM)	(7) Sexual hormone binding globulin (SHBG)
(7) Mean power during 30 s (Power$_{30s}$)	(8) Prolactin (PRL)
(8) Mean power during 40 min (Power$_{40min}$)	(9) Free testosterone-cortisol ratio (FTCR)

Materials

All cycling tests (day 1) in *study III* were performed on the same Velotron (Racermate, Seattle, WA) or Lode Excalibur Sport (Lode B. V., Groningen, The Nederlands) for each individual. Both test ergometers are computer controlled and provide <2% margin of error in both accuracy and repeatability, according to the manufacturer. All HIIT sessions and 40 min all-out tests (day 2) were performed in groups on their own road racing bicycle mounted on Computrainer Lab^{TM} ergometers (Race Mate, Seattle, WA), calibrated according to the manufacturer's specifications and connected to a central PC running dedicated software (PerfPRO Studio, Hartware Technologies, Rockford, MI). $\dot{V}O_2$ was measured by an automatic system (Oxycon Pro, Jaeger GmbH, Hoechberg, Germany), evaluated against the Douglas bag system by Foss & Hallén (42). HR was measured using Polar V800 (Polar Elektro Oy, Kempele, Finland), and [la$^-$] was analyzed using a stationary lactate analyzer (EFK BIOSEN; EFK Diagnostics, Cardiff, UK).

The multi-center trial carried out in *study III* produced a large volume of data, and the results presented in this thesis represent only a part of the total data material. An index of all existing data is presented in appendix I, and our research group will publish more of this data material in future studies.

Statistics

In all *papers* (*I-V*) descriptive data are presented as mean ± SD, range (min-max) or 95% confidence intervals (95% CI).

In *paper I* a Pearson product-moment correlation was used to quantify the relationship between SR and HR recorded training duration. Correlation magnitude (*r*) was interpreted categorically as small (*r* .1-.3), moderate (*r* .3-.5). large (*r* .5-.7), very large (*r* .7-.9) or nearly perfect (*r* .9-1.0) using the scale presented by Hopkins et al. (64). The limits of agreement between SR and recorded training duration (*paper I*) were calculated using a Bland-Altman plot (14). A paired-samples *t* test was used to identify significant differences between SR and recorded training duration (*paper I*) and between TIZ and SG/TIZ methods (*paper II*), and 95% CIs bounding the difference were calculated.

In *paper III* data were not normally distributed. Therefore, a non-parametric Friedman test, followed by post-hoc test (Wilcoxon Signed Rank) was used to locate statistical differences across different phases. Male and female athlete data were merged, as a Mann-Whitney U Test revealed no significant differences across gender. A Mann-Whitney U test was used to determine whether there were differences between GP (*paper III*) and altitude training (*papers I & II*).

In *paper IV & V* differences among groups in baseline data (training history), training characteristics during intervention period and baseline blood hormones were compared using one-way between-groups ANOVA, followed by Bonferroni-corrected *post hoc* tests. A one-way repeated-measures ANOVA was used to compare differences among 4x16/8/4 min interval prescriptions.

All data related to physiological and performance testing were evaluated through GLM-analyzes, adjusted for the influence of different covariates (test location and pre-$Power_{4mM}$ ($w^.kg^{-1}$)), and presented as adjusted values. A GLM repeated-measures model (ANOVA) was used to compare differences within each intervention group, in relation to physiological and performance pre and posttests (*paper IV*), and physiological test variables and blood hormones at pre, weeks 4, 8 and 12 in *paper V*. A univariate GLM (ANCOVA) was used to access differences among intervention groups in physiological and performance related baseline characteristics and differences in delta changes across test-weeks in those variables (*papers IV & V*).

Because of expectations of small changes in these well-trained cyclists, changes among groups were further analyzed with ES calculated according to Cohens's *d* (0.2 = small, 0.5 = moderate, 0.8 = large) (25). Moderate or large ES (>0.5) are described as tendencies if comparisons are non-significant.

The frequency distribution of individual response magnitude across training groups in *paper IV* was compared using a chi-square test, and ES was calculated with Cramer's *V* with three categories (25).

A total of <2% of all data variables were missing in *paper V*, and treated as "last observation carried forward".

All statistical analyses were performed using SPSS 18.0 (*papers I-III*) or SPSS 22.00 (*papers IV & V)* (SPSS Inc, Chicago, IL, USA) and MedCalc (version 12.4.0.0) (*paper I)*, and statistical significance was accepted at the *P<0.001* level (*papers I & II*), and *P<0.05* level (*papers III, IV & V*).

Ethical considerations

As the present thesis includes data from 41 World or Olympic medal winners, some ethical considerations may be elaborated. Overall rules from the Declaration of Helsinki pinpoints the importance that studies only can be completed if the purpose of the research outweighs the inherent risks and burdens to the research subjects. As scientists, we are responsible for protecting the subject's life, health, dignity, integrity, right to self-determination, privacy and confidentiality of personal information. In addition, participation in investigations must be voluntary, and the overall research project must be submitted and approved by an ethics committee prior to project start (68). Especially with regard to *confidentiality* and *anonymity*, it is challenging to include publically well-known athletes. Confidentiality and anonymity means that information and materials are de-identified, so no third part knows who has given what data to the researcher. This gives only the researcher an opportunity to connect people and data. The researcher has to respect privacy in the form of de-identification and anonymity of experimental data (68, 105).

The data collected in *study I* and presented in *papers I* and *II* was acquired during an altitude-training camp, and the athletes were blinded to our aim as researchers and told to carry out their normal training following their coaches' recommendations. Training

methods or organization were not discussed with the athletes during the data collection period. Athletes were provided with detailed written and verbal instructions via a group meeting, and all subjects provided informed written consent before participating (appendix II). Also in *study III*, all subjects provided written informed consent after both written and verbal information about the study were given (appendix III). Data in *study II* were preexisting and collected in the period from 1985 to 2012 as part of OLT's regular monitoring of elite athletes. The athletes were not aware of being part of a research program at that time, and therefore written informed consent was provided later by OLT (appendix IV). Informed consent means that the subjects are informed in an understandable way about everything concerning his or her participation in the research project. General requirements for informed consent imply that the researcher ensures that the subjects involved in the research are competent and understand the project's purpose and consequences of participation, capable of assessing their own situation, can make an independent and voluntary decision to participate and voluntarily communicate their decision (68, 116).

All studies (*studies I-III*) were submitted to the regional ethics committee of Southern Norway for approval, but due to the nature of the investigation, the studies did not require their approval. Therefore, studies were approved by the local ethics committee of the Faculty for Health and Sport Science, University of Agder (*papers I, II, IV & V*), and/or registered with the Norwegian Social Science Data Services (*studies II and III*) *(appendix V-VII)*.

Results

Accuracy of SR duration and intensity distribution (*paper I*)

There was a nearly perfect correlation (r=.99; P<0.001) between SR and HR-watch-registered training duration in each session (n=466). A Bland-Altman plot (14) revealed that the limits of agreement were -2.7 to -1.7 min. The variation around the mean difference (-2.2 min) appeared to be random, although it was a significant difference (P<0.001). Among all sessions, 77% were within ±5 min deviation between SR and recorded values (Figure 10).
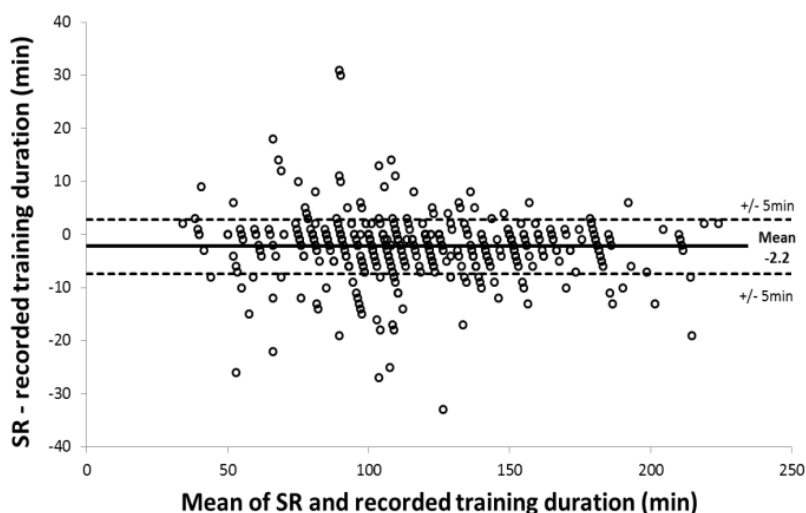
Figure 10: Bland-Altman plot of self-reported (SR) and recorded training duration, including heart rate (HR) values <55% HR_{max}. N=466 sessions.
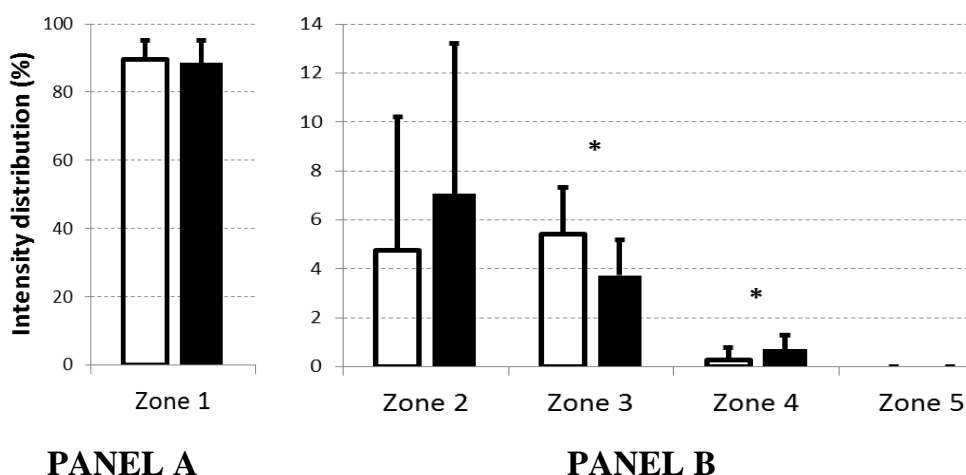
PANEL A   **PANEL B**

Figure 11: Percentage of time spent in each of the 5 intensity zones (n=24), mean ± SD. Open bars denote self-report (SR), while filled bars represent expert analysis. Panel A: Zone 1. Panel B: Zones 2-5. * P< 0.001.

There were no differences between SR and expert analyzed training duration in zones 1 and 2. However, athletes significantly overestimated time spent in zone 3 by 37±25 min (*P<0.001*) while underestimating time spent in zone 4 by 11±12 min (*P<0.001*). No training time in zone 5 was detected via SR or expert analysis (Figure 11).

Time distribution vs. session distribution (*paper II*)

Comparing TIZ and SG/TIZ methods, 96±1% and 95±2% (*P<0.001*) of total training time, respectively, was performed as LIT. HIT accounted for 4±1% and 5±2% (*P<0.001*) of total training time based on the two methods. When these same training sessions were allocated categorically using the SG method and verified by HR and [la⁻] data, 87±5% (492 of 570) of training sessions were performed primarily as LIT, and 13±5% (78 of 570) as HIT. The conversion factor from the ratio of a "time distribution" method to a "session distribution" method was ~3 in the HIT range (Figure 12).
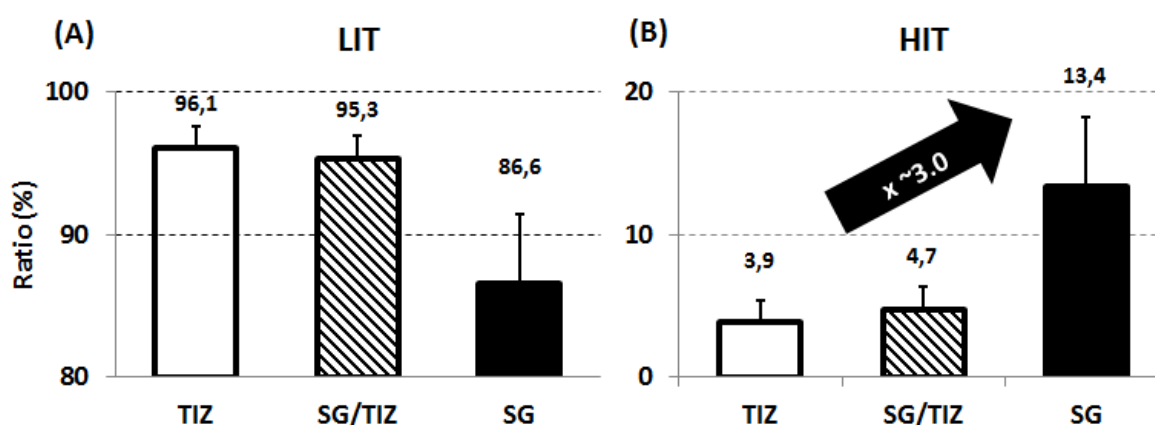
Figure 12: Training intensity distribution in 570 sessions analyzed with three different methods. The arrow illustrates how to convert training distribution from a time-based-ratio method (time in zone (TIZ) or the modified session goal method (SG/TIZ)) to a session goal (SG) method of categorical allocation of each training session. Panel A: low intensity training (LIT) range. Panel B: high intensity training (HIT) range.

Training characteristics in World-Class XC skiers (*papers I-III*)

Annual training characteristics (paper III)

Eleven Olympic and World Champion XC skiers (*paper III*) in the time period from 1985 to 2011 self-reported that annual training volume was 770±99 h (622-942) distributed across 470±68 sessions (375-584). During the GP period athletes performed 18±3 h·week⁻¹. However, monitoring athletes during three decades (1985-2011), there was a large positive correlation (*r*=0.6; *P*=0.06) between training volume and year of Champion title, mainly because of increased frequency of sessions (correlation, *r*=0.8; *P<0.05*). Endurance training accounted for 94±3% of all training

time with the remaining 5±2% composed of strength training and 1±1% sprint training. A SG/TIZ based intensity distribution showed that 91±1% of all endurance training was executed as LIT (zone 1-2) and 9±1% as HIT (zone 3-5). Total annual HIT duration was 64±14 h (46-85) distributed across 106±20 sessions (85-147) throughout the year. Endurance and sprint training was executed with sport-specific movement patterns for 64±3% (465±56 h) of total training volume.

Training characteristic variations across a season (papers II-III)
Differences in training volume, training forms, intensity distribution and activity forms across different phases and during altitude training (*papers II-III)* are presented in Table 5. Importantly (*paper III)*, monthly frequency of HIT sessions increased from GP to SP (*P<0.05)*. In addition, the monthly frequency of intensity zone 5 sessions increased from GP to SP and then remained unchanged in the CP (*P<0.05)* (Figure 13).
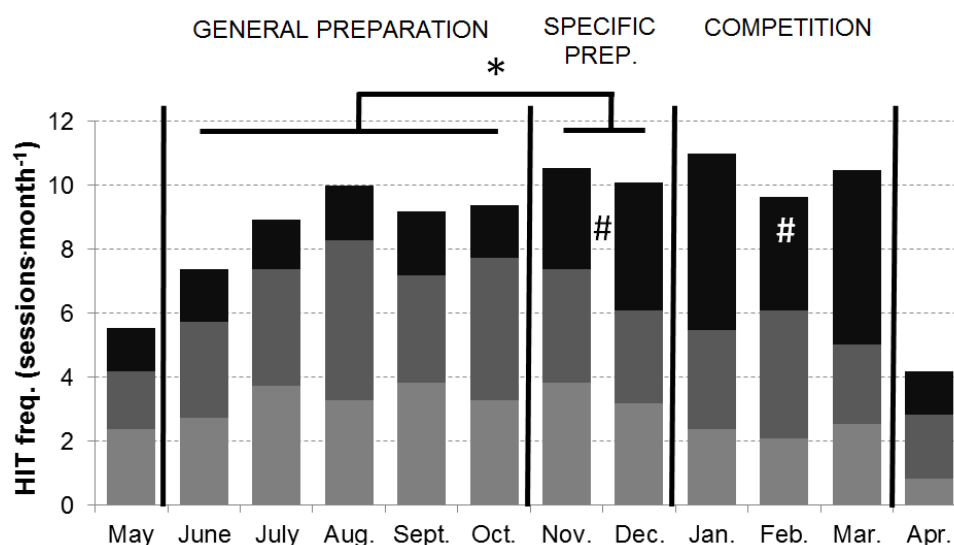
*Figure 13: High intensity training (HIT) characteristics in paper III. HIT frequency (number of sessions) distributed into zones 3, 4 and 5, respectively, across phases and months. N=11. * Difference in total HIT sessions across phases. # Difference between zone 5 sessions vs. general preparation.*

Twenty-nine elite XC skiers (*papers II)* in 2012 performing altitude training in the GP period, reported a weekly training volume of 22±4 h, distributed across 11±2 sessions. Distribution across training forms was similar to *paper III*. 94±2% was executed as LIT and the remaining as HIT. 73±14% was sport-specific training.

Table 5: Weekly training patterns during different periods throughout the season (*paper III, n=11*) and during altitude training camp in the general preparation period (*paper II, n=28*).

Weekly training patterns	Transition period	General preparation period (GP)	Altitude training (*paper II*)	Specific preparation period (SP)	Competition period (CP)	Regeneration period
Total training volume:						
Training time (h·wk^{-1})	14±5	18±3	22±4†	16±2	12±2$^{#β}$	6±4
Sessions·wk^{-1}	8±3	10±1	11±2	10±2	8±2$^{#β}$	4±2
Training forms:						
Endurance (%)	91±6	92±3	94±3	95±2*	97±2$^{#β}$	96±6
Strength (%)	8±6	7±3	5±3†	4±2*	2±2$^{#β}$	4±6
Sprint (%)	1±1	1±1	2±2	1±1	0±0$^{#}$	0±0
Intensity distribution:						
Zone 1 (%)	84±8	86±5	89±6†	88±3	83±6^{β}	84±11
Zone 2 (%)	12±8	6±4	5±5	4±3*	4±3$^{#}$	4±5
Zone 3 (%)	2±1	4±1	6±2†	3±1*	4±3	3±3
Zone 4 (%)	2±1	3±1	1±1†	3±2	5±3^{β}	3±4
Zone 5 (%)	1±1	1±1	0±0†	2±1*	5±4$^{#β}$	5±11
Activity forms:						
Specific (%)	33±20	48±6	73±14†	86±8*	92±4$^{#β}$	63±30
Non-specific (%)	67±20	52±6	27±14†	14±8*	8±4$^{#β}$	37±30

Values are mean ± SD and represent training patterns peer week in different periods. *$P<0.05$, GP vs. SP; $^{#}P<0.05$, GP vs. CP; $^{β}P<0.05$, SP vs. CP; $^{†}P<0.05$, GP vs. altitude.

Adaptions during 12 weeks of intensified training (*papers IV-V*)

Training characteristics

During 12 weeks of training, 63 subjects reported an average training volume of 10±3 h. Endurance training accounted for 97±4% of all training time with the remaining 3±4% composed of mainly strength training. A SG/TIZ based intensity distribution showed that 83±7% of all endurance training was executed as LIT (zone 1-2) and 17±7% as HIT (zone 3-5). Average HIT duration each week was 1.5±0.3 h. Endurance training was executed with sport-specific movement patterns for 81±15% of total training time. There were no significant differences among groups (INC, DEC or MIX) in any training variable measured as mean during 12 weeks.

HIT sessions prescribed as 4x16, 4x8 or 4x4 min induced significantly different power output, [la^{-}], HR and RPE responses (see Table 1, *paper IV*). During each interval session, independent of prescription, there was a significant positive evolution in both HR and RPE from interval bout 1 to 4. Power output was, in keeping with the instructions given to subjects, maintained relatively constant over the 4 interval bouts.

However, sub-analyses revealed that ~1/3 of subjects typically had to reduce their power output by the end of 4x4 min sessions.

Different HIT sessions (4 x 16, 8 or 4 min) were periodized in a specific mesocycle order for INC and DEC groups, or in a mixed distribution for MIX group (see figure 6), which resulted in different executed HIT patterns each 4-week cycle (Figure 14). This represents the only difference among the intervention groups.
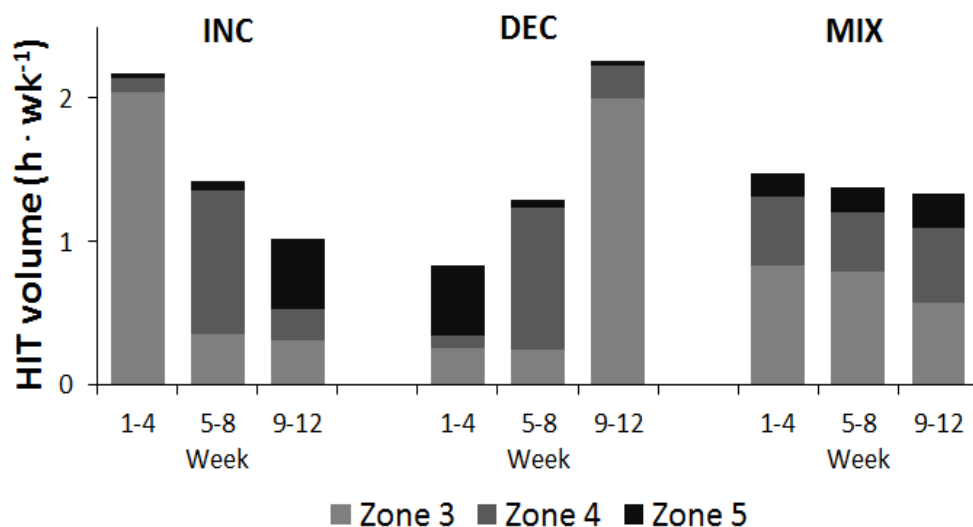
Figure 14: High intensity training (HIT) time in each 4-week cycle for the increasing (INC, n=23), decreasing (DEC, n=20) and mixed (MIX, n=20) HIT group distributed into zones 3, 4 and 5, respectively (papers IV-V).

Performance and physiological responses (papers IV & V)

After 12 weeks of intensified training the most important findings were (*paper IV*):

- All groups improved significantly ($P<0.05$) in all performance measures (Power$_{40min}$, PPO and Power$_{30s}$) from pre to week 12 (except INC group in Power$_{30s}$). The average relative improvements were 5-8% in Power$_{40min}$, 6-7% in PPO and 1-3% in Power$_{30s}$. Delta change did not differ among groups ($P>0.05$).
- All groups improved significantly ($P<0.05$) in $\dot{V}O_{2peak}$ by 4-6%. All groups improved in Power$_{4mM}$ by 3-6% (MIX group not significant). All groups decreased in GE, and delta changes were 1-3% (MIX group not significant). However, the delta changes reported did not differ among groups ($P>0.05$).
- Independent of group, 56-87% of all individual subjects achieved moderate to large (>3%) gains in performance capacity (Power$_{40min}$), but there was no significant association among training groups and individual response ($P>0.05$).

Comparing responses each 4-week cycle and across groups, the most important findings were (*paper V*):

- Of the total change in $Power_{4mM}$ and $\dot{V}O_{2peak}$ during 12 weeks, INC achieved 98±80 and 70±80%, and MIX 147±74 and 92±74%, respectively, whilst DEC achieved only 34±83 and 38±91%, during the first 4 weeks of intensified training. However, changes in PPO during week 1-4 accounted for 77±52, 64±86 and 89±88% in INC, MIX and DEC groups, respectively, of total change. There was a significant change in $Power_{30s}$ in DEC during week 1-4.
- Performance and physiological changes were accompanied by changes in resting blood hormones. Data from all groups pooled together (N=29) indicated that TT, FT and FTCR decreased significantly by 22±15% ($P<0.05$), 13±23% ($P<0.05$) and 14±31% ($P<0.05$), respectively, by the end of the first 4-week training cycle. IGF-1 increased significantly by 10±14% ($P<0.05$). Comparing pre to week 12, TT, IGF-1 and IGF-BP3 increased significantly by 24±31, 11±18 and 8±13% (all $P<0.05$), respectively.
- During the first 4 weeks of training, INC (4x16 min) revealed a moderate ES compared to DEC (4x4 min) when comparing changes in $\dot{V}O_{2peak}$ ($P=0.08$, ES: 0.7) and $Power_{4mM}$ ($P=0.14$, ES: 0.7) (Figure 15). Analysis of PPO and $Power_{30s}$ revealed no differences between INC and DEC.
- During the first 4 weeks of training, the decline in FT was significantly higher in INC compared to DEC (24±15% vs. 1±29%) ($P=0.05$, ES: 1.0). A comparison of the FTCR decline in INC (22±27%) and DEC (12±25%) groups, revealed an ES of 0.4 (moderate) ($P=0.42$) (Figure 15).

Body mass, absolute values in performance and physiological endurance variables at pre, weeks 4, 8 and 12 are presented in Table 6.

Table 6: Absolute values of body mass, performance and physiological variables at pre, weeks 4, 8 and 12 in increasing (INC, n=23), decreasing (DEC, n=20) and mixed (MIX, n=20) HIT groups.

	Pre	Week 4	Week 8	Week 12
Body mass (kg)				
INC	80.3 (77.0, 83.5)	79.9 (76.6, 83.3)	79.5 (76.2, 82.9)*	79.0 (75.6, 82.4)*#
DEC	79.7 (76.8, 82.6)	79.6 (76.7, 82.5)	79.3 (76.5, 82.2)	78.5 (75.6, 81.4)*#β
MIX	79.7 (75.8, 83.6)	79.1 (75.2, 83.1)	79.0 (75.0, 83.0)	78.2 (74.2, 82.2)*#
Power$_{40min}$ (W)				
INC	281 (267, 295)			304 (289, 320)*
DEC	279 (269, 289)	*Not tested*	*Not tested*	298 (286, 309)*
MIX	287 (275, 299)			297 (285, 309)*
PPO (W)				
INC	418 (403, 433)	440 (424, 455)*	442 (426, 459)*	446 (429, 463)*
DEC	414 (401, 427)	435 (422, 448)*	437 (425, 450)*	437 (424, 449)*
MIX	417 (402, 433)	431 (412, 451)*	432 (410, 455)	438 (418, 457)*
Power$_{30s}$ (W)				
INC	852 (827, 878)	861 (833, 890)	861 (831, 891)	862 (834, 890)
DEC	824 (787, 862)	845 (805, 886)*	845 (802, 889)	845 (802, 888)
MIX	820 (773, 867)	839 (784, 894)	839 (781, 896)	834 (780, 889)
$\dot{V}O_{2peak}$ (L·min^{-1})				
INC	5.0 (4.8, 5.2)	5.1 (5.0, 5.3)*	5.2 (5.0, 5.5)*	5.2 (5.0, 5.4)*
DEC	4.8 (4.6, 5.0)	4.9 (4.7, 5.1)	4.9 (4.7, 5.2)	5.0 (4.8, 5.2)*
MIX	4.9 (4.6, 5.1)	5.0 (4.8, 5.2)*	5.0 (4.7, 5.3)	5.0 (4.7, 5.3)
Power$_{4mM}$ (W)				
INC	277 (266, 287)	292 (281, 304)*	295 (281, 308)*	293 (278, 307)*
DEC	283 (274, 293)	288 (276, 300)	294 (282, 305)*	298 (287, 309)*
MIX	287 (273, 302)	296 (279, 313)	294 (276, 311)	293 (275, 310)
GE (%)				
INC	18.8 (18.4, 19.3)	18.6 (18.2, 19.0)	18.3 (18.0, 18.7)*	18.3 (17.9, 18.7)*
DEC	19.3 (18.9, 19.7)	19.1 (18.6, 19.6)	18.9 (18.4, 19.4)	18.9 (18.5, 19.4)
MIX	19.1 (18.7, 19.5)	19.2 (18.7, 19.7)	18.8 (18.4, 19.2)	18.8 (18.5, 19.1)

Power$_{40min}$; mean power output during 40-min all-out trial, PPO; peak power output, Power$_{30s}$; mean power output during 30 s all-out test, $\dot{V}O_{2peak}$; peak oxygen uptake, Power$_{4mM}$; power output corresponding to 4 mMol·L^{-1} lactate, GE; gross efficiency. * Sig. vs. pre, # sig. vs. week 4, $^\beta$ sig. vs. week 8.
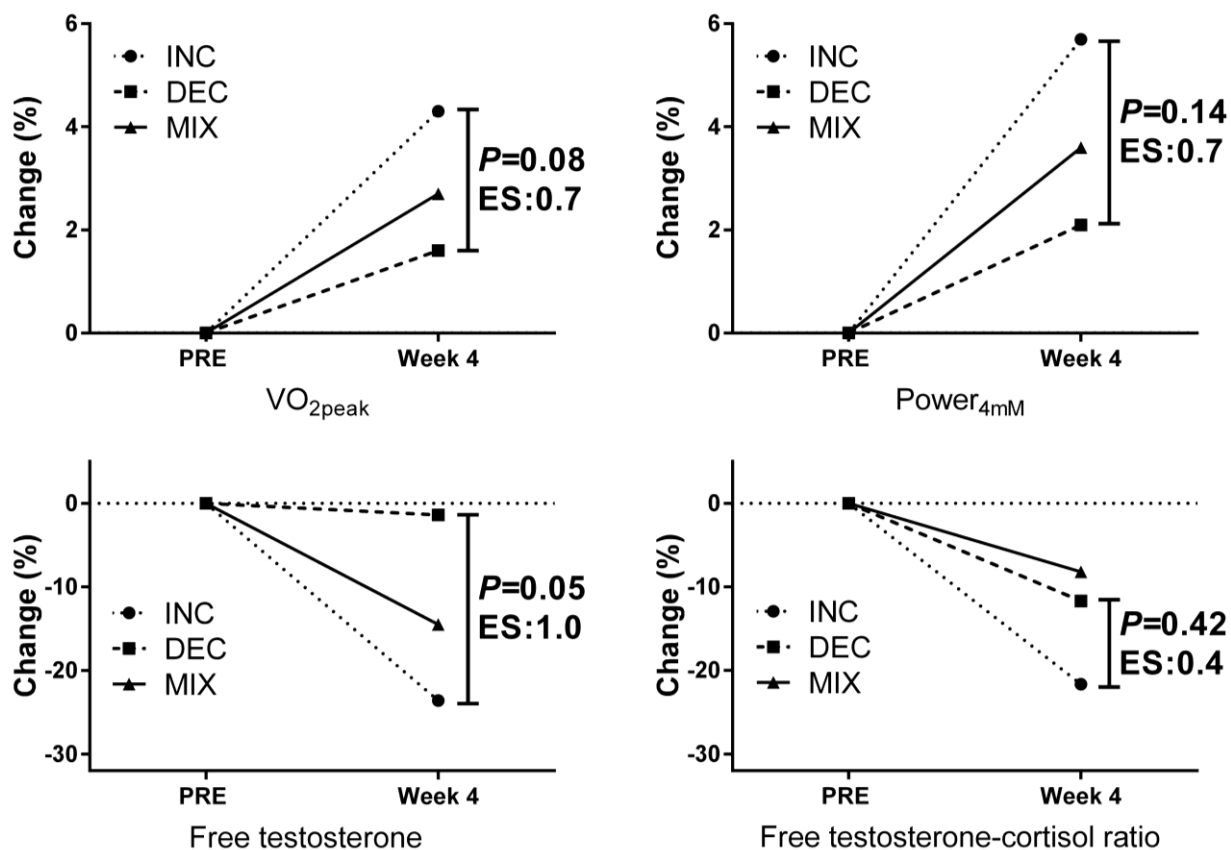
Figure 15: Mean relative changes in peak oxygen uptake ($\dot{V}O_{2peak}$) and power output corresponding to 4 mMol·L^{-1} lactate concentration (Power$_{4mM}$) (upper panel), free testosterone (FT) and free testosterone-cortisol ratio (FTCR) (lower panel) from pre to week 4 in increasing (INC, n=9), decreasing (DEC, n=10) and mixed (MIX, n=10) HIT groups.

Discussion

This thesis demonstrates that SR diaries are accurate and valid tools to evaluate the training characteristics of elite endurance athletes. However, there are several methods for distributing training volume into intensity zones, which complicates the evaluation of SR. Our data provides a quantitative comparison and defensible conversion factors across the most common HR-intensity distribution methods based on *time* or *frequency*. The retrospective analysis of training characteristics in World-Class XC skiers exemplifies required annual training patterns related to training volume and TID amongst elite endurance athletes. In addition, our data demonstrates that progression in training volume and intensity are key factors during the GP period, and further a large reduction in non-specific training volume in the CP. One specific finding, recognizing an intensity-zone organization pattern from GP to CP, was hypothesis generating for an experimental trial. There, we found that a specific HIT periodized mesocycle order or mixed distribution, focusing on manipulating the intensity prescription for interval sessions, had little or no generalizable outcome on the adaptive effect of the same overall endurance training load. However, an interval training prescription allowing athletes to accumulate more duration in the HIT range, tended to induce greater overall endurance adaptions compared to a prescription accumulating less duration in the HIT range. Consequently, different interval prescriptions every 4th week induced different adaption time-course changes in specific performance variables during 12 weeks. The first four training weeks associated with the largest aerobic adaptions, were accompanied by decreases in anabolic hormones in all groups. The following weeks, resting blood hormones rebounded to baseline levels or even increased, a response accompanied by smaller performance and physiological responses.

Methodological considerations

Most often, a mixed method refers to a research approach where both quantitative and qualitative designs are combined (98). The present thesis is built on a triangulation of three different quantitative methods (Figure 5), and therefore, by definition, also utilizes multiple methods, referred to as a mixed method (29). The advantages of using a traditional mixed method are contemporary in the present thesis. The triangulation approach represents a major strength of the overall thesis (98). By conducting a methodological study, retrospective analysis of training patterns, and finally an experimental approach based on hypotheses derived from retrospective findings, we obtained different levels of data all related to the same overall research question (29, 98). Furthermore, though these studies were conducted sequentially and

50

independently, together they provide a more comprehensive picture of appropriate endurance training patterns in elite athletes than a single method could provide alone. Our experimental papers provide interpretive insights that inform the large number of retrospective training descriptions from elite athletes, despite the experimental trial being conducted with sub-elite athletes.

To exemplify the advantages of a methodological triangulation, we highlighted in the introduction the ongoing discussion back in the early 2000's as to whether performance improvements in highly trained endurance athletes could be achieved through increases in submaximal training *or* HIT. A review by Laursen & Jenkins (82) concluded that further incremental improvements in endurance performance could only be achieved through HIT. That conclusion was likely primarily based on experimental approaches with sub-elite subjects. The conclusion was well received, reached a broad audience, and has been cited in more than 600 studies. However, subsequent retrospective analyses of successful endurance athletes have consistently documented the importance of high training volume *in addition to* a substantial portion of HIT. A decade later, the same author (81) and others (134, 138, 152), have moved the discussion to focus on optimization of the overall intensity distribution and interaction between both volume *and* intensity. This exemplifies the importance of using multiple methods to describe an overall research question.

Although we have seen an accelerating trend in describing the training of elite endurance athletes retrospectively, this source of information has its weaknesses. There are, for example, major individual differences regarding adaptive response, hence the external validity does not necessarily exist. As a coach, the most important day-to-day adjustments are impossible to read through overall "pictures". In addition, the method is now approaching a "saturation-state", particularly with respect to XC skiing (86, 124, 127, 154). However, we argue that the general "big picture" is indispensable to become a top-athlete and, therefore, the method serves as a relevant starting point for coaches and athletes seeking to optimize the training process of individuals.

The experimental training intervention was conducted as a multicenter trial involving three test locations, which administrated 29, 20 and 20 subjects, respectively. A multi-center approach is very common in classic medicine, but almost unheard of in sport science and training interventions involving well trained subjects. The main strengths

of organizing the intervention as a multicenter trial were the ability to maintain a well-structured randomized design and rigorous monitoring of all training variables, in a very large group of well-trained endurance athletes. Administrating a group of 69 well-trained athletes from one single test-center would be almost impossible due to limitations in test facilities and working researchers. However, we are conscious that, despite our best efforts to standardize all protocols, there could be small methodological differences across centers that may affect the intervention results.

Discussion of main findings

Accuracy of SR training in diaries (*paper I*)

One of the first questions that appeared in the planning process of this thesis was whether elite athletes are reporting variables such as training duration and intensity distribution accurately in diaries. SR in diaries is a commonly used method in both scientific retrospective studies (47, 52, 61, 124, 155), but also as a tool for athletes and coaches to monitor the training process. However, the method had not been validated extensively in elite athletes, and previous findings indicate that training volume is reported inaccurately in recreational subjects (17). In addition, a comparison of training duration derived from SR diaries and questionnaires conducted in elite junior rowers, indicate a deviation of up to 10% (52).

The main finding in *paper I* is that elite endurance athletes accurately SR their training data. Both SR training duration and intensity distribution closely matches verified duration derived from HR recordings and intensity distribution in zones compared with an expert analysis, although there are some small discrepancies.

The current data collection process was performed under very rigorous conditions during a high-altitude training camp. Athletes were instructed to use a HR watch during all training sessions and SR their training daily. Therefore, a high accuracy in SR training duration data was expected. We found a discrepancy of only 1.7% (77% of all 466 sessions within ±5 min of the mean difference), which was due to athletes deducting a small percentage of time spent during each session to compensate for time that in reality cannot be counted as effective training time (drinking, urinating etc.). However, by examining the HR data closely, we found that about 11% of all reported training duration was below OLT's recommended lowest limit (55% HR_{max}) for "effective" endurance training. The individual variation was from 0-20%. This means that for a typical annual training volume of 800+ hours, this difference would

52

extrapolate to 0-~200 h of total training. However, this deviation may represent an error derived due to no "gold standard" or clearly communicated common rules, and the altitude-training-camp environment probably exaggerates the source of error. In *paper I* all athletes used the modified SG/TIZ approach to distribute training time in the 5-zone intensity scale. Comparing SR intensity distribution with an expert analysis (based on HR curves, lactate values etc.) there were almost no differences in zones 1 and 2, and small, but significant, differences for zones 3 and 4. During interval sessions most athletes registered recovery phases as time in zone 3 or 4, while we as investigators did not. This primarily explains why there is a difference in zone 3, in which the majority of interval sessions were conducted. Clear common guidelines would likely prevent this discrepancy. Small inconsistencies in zone 4 were due to athletes not registering time in zone 4 despite HR and [la⁻] being in this zone for some intervals, particularly toward the latter part of session. Zone 5 was not used during this altitude training camp.

Overall, we interpret all discrepancies reported in *paper I* to be of little significance in a practical sense, making us confident that scientists and coaches can rely on the validity of SR training data from elite endurance athletes. However, to our knowledge, this is the first validation study investigating this topic in elite athletes. In addition, our subjects were all well familiarized with reporting in diaries and using the 5-zone reference scale, having used this since junior age. Therefore, the external validity to other groups and sports is not 100% clear based on our data. Additional work is needed in this area under routine training conditions and in different sports.

Comparison of different TID methods (*paper II*)

The main finding in *paper II* demonstrates differences in quantification of TID using TIZ, SG/TIZ or SG methods. In addition, practical conversion factors across methods are suggested.

Our results in *paper II* demonstrate that the volume in the HIT range is higher using the SG approach compared to any time-based methods. We suggest that a time-based estimate for HIT volume can be multiplied by ~3 to give an equivalent distribution based on categorical allocation of HIT sessions (Figure 12). When the SG method was introduced (132), one of the arguments was that a categorical approach likely gives a more realistic picture of training load over the long term compared to different "time-in-zone" methods. This was proposed because SG matches well with intensity

categorization based on sRPE, which was well established as an appropriate TID method. Foster et al introduced the method (43, 45), and it has been frequently employed in studies (44, 132, 136, 142). However, a disadvantage of a categorical approach is that elite athletes and coaches may not be familiar with those methods of analyzing training data. Therefore, TIZ or SG/TIZ may be more appropriate.

Analyzing TID data in *study I,* we saw that most athletes used the modified SG/TIZ approach, while some used a direct HR based TIZ-method. In *paper I* we chose to exclude those athletes reporting by the TIZ-method, because no studies ever had compared those methods. Especially in the HIT-range, doubts have been raised as to whether the TIZ method gives a realistic picture of the total training load over longer timeframes due to HR lag time during intervals. Our results in *paper II*, based on a quantification of 78 HIT sessions, demonstrated a difference of ~5 min HIT-time in each HIT session comparing TIZ and SG/TIZ methods. Over a season, this can account for 10-12 hours of additional HIT volume using the SG/TIZ method, which is a meaningful difference for athletes training <100 HIT hours annually. In addition we observed differences in how recovery time in between interval bouts was reported in athletes using the SG/TIZ method. Some chose to include the recovery period as HIT time while others assigned it to the specific zone in which it was performed (typically zone 1). This difference is an even greater source of error than the previously reported 10-12 hours. Both of these methodological variants are important for coaches and scientists to be aware of when analyzing TID across athletes.

Comparing TID across different methods is very complex. Table 1 illustrates the complexity by showing numerous different methods used in several studies. The results from *paper II* provide some answers related to HR-based methods. However, several additional methods exist, and more work needs to be done to better establish a common language. We recommend athletes to report their TID using the SG/TIZ method, accompanied by data from HR watches and/or lactate meters. In addition, we highly recommend that athletes report sRPE and SG to give a better picture of total training load (Figure 7). Finally, it is recommended that recovery time not be included in the HIT range, to ensure consistent and comparable TID.

Training characteristics (*papers II-V*)

Comparing training characteristics in *papers II-III* revealed many similarities, although there are some differences in altitude compared to sea level training. We argue that the

overall training model arising from *papers II-III* is an appropriate training model, also adaptable to other sports. Therefore, one of our aims in the experimental trial (*papers IV-V*) was to utilize an existing "best practice model" when we gave overall training advice, in addition to manipulating the HIT periodization structure (Figure 6). In the following sections, a comparison of training characteristics in all *papers I-V* will be discussed.

Training volume, training and activity forms and intensity distribution

Athletes in *paper III* trained, on average, ~770 h·yr⁻¹ (622-942 hours) across ~470 annual training sessions. This finding is in line with previously reported training volume in XC skiers (126, 132, 152). We saw a tendency for a positive relationship between training volume and year of championship gold medal (r=0.59, P=0.055), as our data were collected from athletes who became Olympic or World Champion during the period 1985 to 2011. This positive trend in training volume was confirmed by a newly published study describing 12 World Class female XC skiers (124). On average, these athletes trained 920 hours annually (the number 1 ranked skier trained ~980 h), a volume of training that is larger than previously reported for XC skiers (86, 126), reflecting their high performance level. Six of the athletes in this group were ranked 1 to 6 overall in the World Cup in 2015, including four Olympic Champions and five World Champions. Based on this, and other original studies (11, 40, 141) or reviews (81, 134, 138, 145) discussing the importance of high training volume, we argue that high training volume represents a foundation in the overall training pattern to achieve a top international level in endurance sports. However, we do not deny the importance of HIT (82).

Monitoring training load across different phases (*paper III*), we observed that training volume was progressively increased during GP, before being dramatically reduced during CP (Table 5). The volume reduction in CP was mainly due to reduced non-specific training. As the gold medals were achieved in CP, after a period with reduced total volume, it is possible to question whether their "actual" peak performance was at this time point. Unfortunately we do not have any objective measures of endurance performance during all phases. However, a similar training pattern was observed in another group of elite XC skiers, accompanied by physiological and performance testing during all phases of a training year (86). In general, all positive changes occurred during GP when the total training volume was highest (June to October). No further improvements occurred from October to February. Therefore, we still speculate

if athletes in *paper III* utilize a "physiologically optimal" annual training plan. However, due to a tight competition schedule from November to March, a reduced total training volume is a practically necessity due to traveling, rest before competitions etc.

Training forms and activity forms
XC skiing is a demanding aerobic endurance sport, and athletes at elite level reportedly have some of the highest $\dot{V}O_{2max}$ values across all endurance sports (60, 67, 123, 125, 153). The training characteristics reflect that aerobic demand, with 94% of all training *time* being executed as endurance training during the year, with the remaining being 5% strength and 1% sprint training (*paper III*). However, both strength and sprint training appear to play an indispensable role in the training of XC skiers (125). In practice, two to three strength and sprint sessions each week were performed to build up a prescribed strength level during GP, and one weekly session was performed to maintain that level during CP. Previous research in cyclists suggests that one bout of strength training per week is sufficient to maintain strength levels over shorter timeframes (118). Unfortunately, we do not have systematic strength testing documentation available for athletes included in *paper III*.

Sport-specific training is key to improving performance, and the principles of specificity of training tend to have greater significance for highly trained compared to recreational athletes (147). In *paper III*, during the entire year, only 64% (~500 h) of all training was executed with sport-specific movement patterns. Compared to other sports, particularly running (149), the proportion of specific training is low in these XC skiers. However, the majority of non-specific training was running, which have been reported to be a more adaptive cross-training mode compared to other modes (147). In *paper III* the specific training volume was nearly constant from GP to CP, but the portion of specific training increased from ~50 to 90% across the season, in accordance with early periodization models (Figure 4) (15). That is, when training load was lowest in CP, >90% was performed as sport-specific training. We speculate that a high portion of specific training functions as a substitute for reduced volume to achieve the highest performance level during CP.

Intensity distribution
Interpreting how total training volume is distributed into intensity zones is challenging. In the present thesis (*papers II-V*) we primarily used the SG/TIZ-method supported by

56

HR values, and distributed total time in 5- or 3-intensity zones, or in a binary scale (Table 3). In *paper III*, 87, 5, 4, 3 and 1% of endurance training during GP was distributed into zones 1-5, respectively. According to a 3-zone scale, this translates as >90% LIT. Compared to most other sports, the amount of LIT is very high in these XC skiers (Table 1).

As discussed in the introduction, some common training-models have appeared based on descriptions of elite athletes. The *polarized training model* has obtained high international acceptance during the last decade, due to both experimental trials (36, 102, 103, 144) and descriptive observations (61, 66, 108). However, exploring the data from the current *paper III* we do not observe a clear polarized pattern in the GP. This observation is also in line with many retrospective descriptions of other elite endurance athletes (100, 111, 131, 162). Recently, the topic has been discussed in a review, and a *pyramidal training model* term has appeared in the literature (145). Hence, although controlled studies have demonstrated superior responses when applying a polarized TID model, the pyramidal model is frequently observed in elite athletes. In *paper III* the total volume of HIT was evenly distributed throughout the year with an average of 5±2 h or 9 sessions per month. However, during CP the TID shifted towards a polarized model as 84, 4, 4, 5 and 5% of all endurance training was distributed in zones 1-5, respectively. Both duration and frequency in zones 3 and 4 were maintained from GP to CP, while the frequency of zone 5 sessions increased. In other words, as the main peak performance came closer, LIT volume decreased dramatically while the amount of specificity increased and HIT patterns shifted towards a more polarized model, despite virtually constant HIT training time (Figure 13). These observations helped to generate hypotheses for the present *paper IV*.

Altitude training (paper II-III)
Altitude training is a consistent feature of Norwegian endurance training. Athletes in *paper III* probably spent 60 to 100 days per year at altitude, divided into 4-6 camps of 14-21 days duration living at ~2000 m above sea level and training at 1200 to 2800 m above sea level. Unfortunately, precise records are not available regarding all days spent at altitude in *paper III*. The importance of altitude training received more focus in Norway at the beginning of the 1990's after poor results in the 1988 winter Olympic Games, and therefore the number of days was probably somewhat lower for those winning gold medals in the 1980's compared to later. However, our results from *paper II* provide precise altitude training data, representative of those athletes in *paper III*.

Therefore, comparing training volume observed in a specific altitude camp (*paper II*) to training characteristics during GP (*paper III*) demonstrates that total training volume is significant higher at altitude (Table 5). An average weekly training volume of 22 vs. 18 hours shows the importance of prioritizing volume, mainly performed as low and moderate-intensity training sessions at altitude, consistent with changed physiological responses and the greater stress of altitude training (130). In fact, almost all interval sessions were performed close to or just below MLSS-intensity (zone 3 in the 5-zone model). In addition, most of the endurance training was performed with ski specific movement patterns at altitude, primarily due to access to a glacier with snow.

Experimental trial (*papers IV-V*)

Training characteristics

The intention of the overall training model during the experimental trial was to utilize existing "best practice" knowledge derived from retrospective observations. Therefore, independent of intervention group, we gave all participants detailed advice with respect to training volume (as high as possible without overreaching), training-forms (mainly endurance training), activity forms (mainly cycling specific) and intensity distribution (utilize a polarized model, with all interval sessions performed "as hard as possible" and other training very easy). In addition, total training load was reduced for one week every fourth week, in order to be able to maintain high total stress during 12 consecutive weeks.

Our training data demonstrate that the general training patterns during a 12-week intervention period (*papers IV-V*) were relatively similar to patterns reported in *papers II-III*. However, the main differences were: 1) total training volume (10 vs. 18-22 h in *papers IV-V* vs. *papers II-III*, respectively) and 2) intensity distribution (17% vs. 9% in the HIT range). Subjects in *papers IV-V* were all non-professional athletes, and were either students or in full-time employment. As such, they had limited time available for training, and were certainly not able to do 20 h weeks. Nevertheless, we managed to recruit a group of 69 subjects averaging ~10 h during 12 weeks. Regarding differences in TID, we constructed a period of "intensified" training including 2-3 HIT sessions each week, in addition to an "easy" period every 4th week (Figure 16). The intervention was designed to resemble a normal training pattern of elite athletes during a GP leading up to CP. Bearing in mind that our reported intensity distribution in *papers II-III* also includes weeks with only easy training, traveling etc., in addition to including athletes with higher total volume, we argue that the intensity distribution

reported in *papers IV-V* is of high relevance to elite endurance athletes. In the planning process of this study, we were unsure if the amount of HIT would pose a risk of overreaching. However, subjective reported recovery status, confirmed that subjects remained at the same level after 12 weeks compared with the first week (Figure 16).
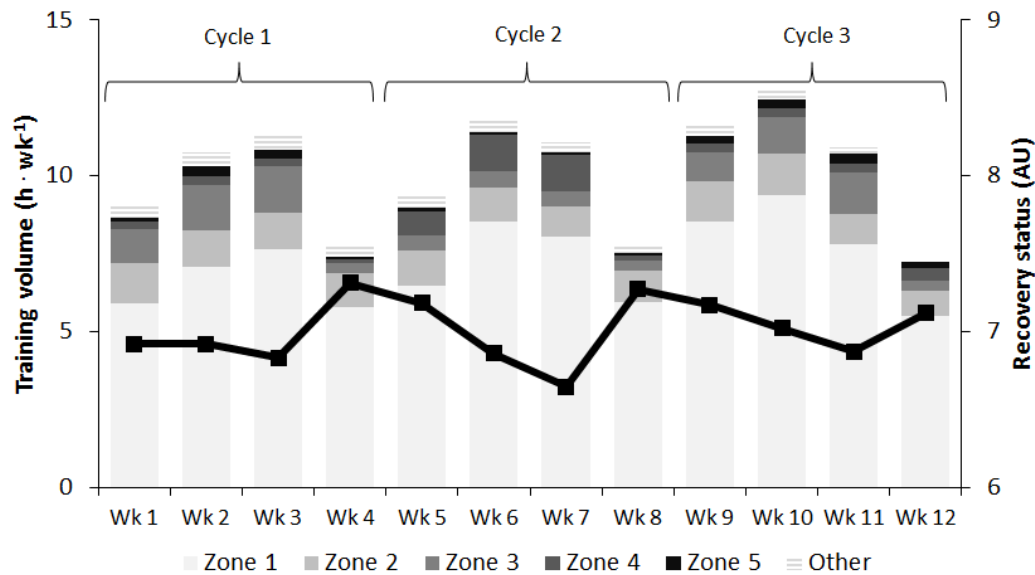
Figure 16: Training volume, intensity distribution and recovery status during 12 weeks of training in *papers IV-V*. Data are presented as mean values of all 63 included subjects.

Consequently, the overall training characteristics during the intervention period in *papers IV-V* was performed close to a "best practice" model, strengthening the external validity of the study. Importantly, we found no differences in training characteristics between groups, other than the planned intervention differences (Figure 14).

Different interval prescriptions (4x16/8/4 min) were performed with different accumulated duration and intensities (Table 1, *paper IV*). The 4x16 min was executed at an average power output just below Power$_{40min}$ and almost all subjects managed to have a consistent or slightly increasing power output evolution from the 1st to 4th interval bout. We argue that the 4x16 min intensity was near power output at MLSS, and therefore primarily generated energy via aerobic metabolism. According to the 5-zone model these sessions were typically zone 3 (or 4). The 4x4 min prescription, on the other hand, was executed in the upper range or near maximal intensities (15-20% above Power$_{40min}$) and therefore defined as zone 5 sessions. These intervals frequently failed (~1/3) according to our "consistent or increasing power" prescription, indicative of more anaerobic intracellular metabolic conditions that may not be conductive to

optimal adaptive signaling of aerobic metabolic adaptions. The 4x8 min prescription was executed at an average power output slightly above Power$_{40min,}$ and therefore defined as zone 4 sessions. In line with observations in *paper III*, we therefore utilized all intensity zones in the HIT range during this intervention period.

Performance and physiological adaptions during 12 weeks

The main finding in *paper IV* is that organizing different interval sessions in a specific periodized "increasing HIT intensity" or "decreasing HIT intensity" mesocycle order, or in a mixed intensity distribution results in minor differences in adaptive response when the overall total load is the same. Although there were no significant differences between groups, MIX group tended to induce less overall adaptive responses compared with INC and DEC groups (Table 6). It is possible to speculate that this tendency may be due to greater interval session "quality" in the INC and DEC groups who, unlike the MIX group, performed the same eight interval sessions consecutively during each mesocycle, and were thus able to more accurately pace their efforts. However, overall, rigid periodization structures are not supported by the results of this intervention study. Unfortunately, we have failed to find any other experimental studies for direct comparisons of our results.

All three groups improved in both performance (Power$_{40min}$, PPO and Power$_{30s}$) and physiological variables ($\dot{V}O_{2peak}$ and Power$_{4mM}$) (see results section for details). All response magnitudes reported here are consistent with previous studies investigating the effect of HIT during similar (89, 117, 129) or shorter (83, 146) intervention periods inn well-trained subjects. A small decrease in GE also occurred in all groups, probably due to increased $\dot{V}O_{2peak}$, which has also been reported previously (63). Previous studies report that a short-term period of HIT is associated with improvements in both $\dot{V}O_{2max}$ and LT, and that improved LT is a result of increased $\dot{V}O_{2max}$ and fractional utilization of $\dot{V}O_{2max}$ (83-85, 89, 117, 129, 143, 146). However, in the present study we found only small increases in fractional utilization of $\dot{V}O_{2peak}$ corresponding to 4 mMol$^.$L^{-1} (79 to 80%). As such, the observed increases in Power$_{4mM}$ (corresponding to LT) are likely primarily explained by increased $\dot{V}O_{2peak}$, which in turn accounts for most of the observed performance development in *paper IV*.

Despite a well-composed intervention study with excellent control of all training variables, we observed large individual differences in adaptive response independent

of intervention group. The probability of achieving "no response" or "large response" during the 12-week period was similar in all three groups. Large differences in individual responses are consistent with other recent studies (93, 159), and supplementary analyses describing characteristics of responders and non-responders are needed in future studies.

Performance and physiological evolution during 12 weeks

The first key finding in *paper V* is that both INC (4x16 min) and MIX reached $\geq 70\%$ of total progression in Power$_{4mM}$ and $\dot{V}O_{2peak}$ already during the initial 4 weeks of training, while DEC (4x4 min) reached $\geq 89\%$ of total development in PPO and Power$_{30s}$ (Table 6). However, the magnitude of specific adaptions (typically aerobic or anaerobic test-variables) was dependent on the specific interval prescription performed. Therefore, the second key finding in *paper V* is that accumulating 2-3 h per week at the "lower" end of the HIT range performing intervals as 4x16 min, tended to elicit superior adaptions in Power$_{4mM}$ and $\dot{V}O_{2peak}$ compared to accumulating ~1 h per week at the "higher" end of the HIT range performing a 4x4 min interval prescription. A large progression in Power$_{4mM}$, $\dot{V}O_{2peak}$, PPO and Power$_{30s}$ in specific groups during the first 4 weeks was accompanied with a decrease in anabolic hormones in all groups, which thereafter rebounded to baseline levels in cycles 2 and 3, when adaption magnitude was reduced.

In *paper V* we present the evolution of specific performance adaptions every 4th week during 12 weeks of training (Table 6). Most comparable training intervention studies typically only present pre to post results during similar timeframes (59, 117, 128, 137, 144), which may lead to false extrapolations to longer time-frames. Bearing in mind that most of the positive effect in specific variables was achieved already during the initial 4 weeks of training, our results indicate that extrapolating short-term adaptation rates from a training intervention involving HIT to even modestly longer time frames is ill-advised. In this context, it is interesting that observations from *papers II-III* shows that also elite XC skiers vary their training load in short-term cycles, with typically 2-3 weeks high load and 1 week load reduction. For example, altitude training camps with high-volume/low to moderate-intensity focus, are typically concluded after 2-3 weeks, due to fatigue and need to rest (*paper II*). We suggest that successful endurance athletes need frequent and considerable variation in training load to elicit further adaptions, and therefore results from short-term intervention studies should not uncritically be extrapolated to these populations. Frequent variations in

training load results in consistent but relatively sparing use of HIT over an entire training year, consistent with training descriptions of elite endurance athletes (*papers II-III,* Table 1) i.e. (11, 124).

The magnitude of specific performance adaptions reported in *paper V* differed among intervention groups, suggesting that different interval prescriptions influenced adaptions in different performance variables to varying degrees. Comparing groups, the greatest variances appeared between groups with the most "extreme" HIT prescriptions, 4x16 min vs. 4x4 min. As previously discussed, the 4x16 min prescription accumulated 2-3 h peer week at intensities near MLSS (zones 3-4), compared to ~1 h peer week at near maximal intensity (zone 5) for 4x4 min. During week 1-4, the 4x16 min interval training prescription (INC group) tended to induce greater adaptations in $Power_{4mM}$ and $\dot{V}O_{2peak}$ compared to 4x4 min (DEC group) (Figure 15). This tendency was reproduced in the final cycle when much of the short-term adaptation had been realized. Similar results have previously been presented by our research group (128, 137). Both of these studies concluded that accumulating more minutes in the HIT range at a slightly lower intensity level, induced a greater overall adaptive response compared to fewer minutes at higher intensities. This information about how best to execute training within the HIT range, enriched our previous understanding based on studies evaluating differences after exclusively LIT, MIT or HIT, i.e. (59).

Nevertheless, the results from *paper V* are interesting in a number of ways. First, in contrast to the superior effects of 4x16 min intervals on $Power_{4mM}$ and $\dot{V}O_{2peak}$ compared to 4x4 min, the latter was the only prescription which significantly improved both PPO and $Power_{30s}$ during week 1-4 (Table 6). This may be a function of specificity, as 4x4 min intervals cause higher power output and therefore stimulated a muscular external force closer to power output at PPO and $Power_{30s}$ compared to 4x16 min. In addition, PPO performed as an incremental test is a function of both aerobic and anaerobic energy supply. Therefore, an individual can increase in PPO with modest changes in aerobic energy supply adaptations, or vice versa. Due to no or only small aerobic performance adaptions following 4x4 min in cycle 1, we speculate as to whether the observed increase in PPO is a result of primarily anaerobic energy supply adaptions. Interestingly, no significant differences or tendencies (ES<0.5) occurred between 4x4 min and 4x16 min groups comparing delta changes in PPO during cycle 1, as both interval prescriptions induced significant changes (Table 6).

Therefore, the 4x16 min prescription induced, as expected, superior adaptions in typically aerobic variables, but also "matched" the 4x4 min prescription in a typically anaerobic performance outcome.

Secondly, in the study by Seiler et al (137), the combination of 4x8 min at ~90% HR_{max} intensity twice weekly, induced larger improvements than twice weekly interval training of both 4x16 min at MLSS intensity or 4x4 min at ~94% HR_{max}. There were no differences between 4x4 min and 4x16 min. These findings are comparable with conclusions from recent experimental trials examining the effect of polarized vs. threshold training (36, 102, 103), indicating that training at threshold intensity induces inferior outcomes compared to training at higher intensities. However, the finding from Seiler et al (137) is in contrast to our results in *paper V,* as we found different adaption magnitudes comparing 4x4 min to 4x16 min. This discrepancy might be explained by different performance levels between the two studies. Subjects in the study by Seiler and colleagues were recreationally trained ($\dot{V}O_{2peak}$: 4.3 $L\cdot min^{-1}$) while subjects in *paper V* were classified as well-trained ($\dot{V}O_{2peak}$: 4.9 $L\cdot min^{-1}$). It is possible that well-trained subjects are able to utilize a higher relative power output during 64 min interval training, compared to recreational trained subjects, and therefore to a greater extent stimulate central components in the oxygen transport cascade. Our results suggest that it is advantageous for well-trained endurance athletes to accumulate a large training volume at or near MLSS intensity, a finding confirmed by retrospective observations in elite runners competing over distances from 1500m (148, 149).

Finally, delta adaptations and differences between groups reported in *paper V* were accompanied by measures of resting blood hormones. Critically, we found a decreased level of testosterone in all groups in parallel with large performance adaptations during week 1-4, which thereafter returned to baseline levels accompanied by smaller adaptations the following weeks. Although an anabolic response was expected together with physiological adaptations, similar findings have been found previously (54, 62), and we speculate that this may be connected to increased androgen receptor expression (80, 113) (see discussion in *paper V*). However, comparing 4x16 min vs. 4x4 min during week 1-4, we found a different adaption in specific performance variables and different changes in resting blood hormones (Figure 15). The decline in FT ($P=0.05$, ES=1.0) and FTCR ($P=0.42$, ES=0.4) was larger following a 4x16 min prescription compared to 4x4 min. A small decrease in FTCR may indicate a

functional, controlled overreaching, while ≥30% has been set as a boundary to diagnose overtraining (5, 157). In the present *paper V* the 4x16 min prescription induced the greatest decline in FTCR in both week 1-4 and week 9-12, although this was still <30%. This suggests that 2-3 weekly sessions of 4x16 min was demanding, but tolerable. Such a training load may be necessary to stimulate aerobic enhancements in already well-trained cyclists. The results from *paper V* indicate that differences in hormonal changes may contribute towards explaining the observed differences in aerobic adaptation between the training groups.

Future research

After four years delving deep into a specific research question, I ask myself: What direction is appropriate for future research related to training organization patterns in elite endurance athletes?

Retrospective descriptions are still potentially useful. However, future descriptive studies have to be detailed, long-lasting descriptions, preferably connected to performance and physiological test variables in high-level athletes in selective sports. Connecting environmental factors as a child, physiological adaptations as an athlete and training characteristics during several years could expand our understanding of champion performance development. In addition, accurate descriptions of training patterns related to before, during and after altitude-training are lacking in the scientific literature.

Experimental approaches are also needed. Training intervention studies in well-trained to elite athletes are still limited in number. However, due to expectations of small changes and large individual variation in a cohort of well-trained individuals, high numbers of subjects are required to find meaningful differences between groups in training intervention studies. Therefore, one method to achieve high n, is a multicenter approach as in the present *study III*. In total, we administered 69 subjects through a 5-month period, which was a three-fold of what would be practical by one laboratory alone. Another method to collect *big data* is utilizing web-tools as online diaries (e.g. Training Peaks).

However, in the final stage of this thesis, my main-thoughts for future research are related to better understanding of individual variations related to training. Analyzing data in *study III* revealed large inter-individual variation in adaptive response. *Paper*

IV revealed a similar likelihood of either large- or non-response independent of intervention group (Figure 3, *paper IV)*. At the individual level independent of intervention group, we found for example a range from -9 to +36% in $Power_{40min}$ after 12 weeks with similar loads of HIT, a range which was representative for all test variables presented. Large individual variation is also commonly observed in other experimental training intervention studies (18, 19, 93). A future paper from our research group will focus on the observed large inter-individual variation and search for characteristics of responders vs. non-responders. However, future research should also focus on links between responders/non-responders and genetics, environmental factors, lifestyle, as well as factors related to training characteristics and restitution, although related topics have been tried answered previously (93, 159).

Conclusions and practical applications

The present thesis provides evidence that elite endurance athletes overall, accurately SR their training duration and intensity distribution in training-diaries. Hence, SR training data is valuable for athletes, coaches and scientists to evaluate or describe training patterns in high-level training groups. However, training intensity distribution is a confusing area due to several different methods and interpretations. Our data provides a quantitative comparison of differences within the most common HR analysis methods. Most important, a "time-based" intensity distribution method results in significantly less time being registered in the HIT range compared to a categorical method. These differences are important to consider when evaluating long-term training data. Defensible conversion factors for comparisons of training-data employing different intensity distribution methods are suggested. However, as no gold standard exists, common guidelines and educational purposes within training groups may further increase validity. For elite athletes, we recommend the SG/TIZ approach to allocate periods clearly in a 5-zone intensity scale. Intensity distribution should be supported by external load, HR and lactate, as well as self-perceived exertion, to create a consistent picture of specific and overall training load. Recovery phases during interval sessions are recommended to be registered in zones corresponding to the actual external load.

The present annual training descriptions of Olympic and World Champion XC skiers provide benchmark values related to training characteristics for athletes striving for international medals. Moreover, the paper was innovative in 2014 in terms of detailed, long-term training characteristics divided in phases in a large cohort of World Class athletes. Our data show that in order to reach a world-class level, a training volume of ~800 h/500 sessions per year is required, of which ~500 h is executed as sport-specific training. Approximately 90% of all endurance training was executed as LIT and ~10% as HIT using the SG/TIZ-method, indicating HIT to be an important, but relatively sparingly used component. However, HIT patterns tended to become progressively more "polarized" from the early GP to CP, an observation that helped to generate hypotheses for our experimental study.

Based on the observed HIT patterns in elite endurance athletes, our experimental data suggests that organizing different interval session prescriptions in a specific periodized mesocycle order, or in a mixed distribution, during a 12-week training period, had little or no effect on training adaption when the overall training load was the same.

However, due to different adaption magnitudes following different interval prescriptions, we found a clear pattern that most of aerobic performance adaption was achieved already within the first 4 weeks following a 2-3 weekly 4x16 min interval prescription. Accumulating more minutes at slightly lower intensity in the HIT range, was superior to fewer minutes and higher intensity in variables as $Power_{4mM}$ and $\dot{V}O_{2peak}$. Consequently, a "traditional" periodized HIT pattern as observed in our retrospective data may be appropriate. However, we recommend athletes to be aware of the consequences of reducing total training load, including accumulated duration in the HIT range. Hence, highly structured training plans based on the nature of the specific sport and experiences of individual adaption responses are needed.

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Do elite endurance athletes report their training accurately?

Do Elite Endurance Athletes Report Their Training Accurately?

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Purpose: The purpose of this study was to validate the accuracy of self-reported (SR) training duration and intensity distribution in elite endurance athletes. *Methods:* Twenty-four elite cross-country skiers (25 ± 4 y, 67.9 ± 9.88 kg, 75.9 ± 6.50 mL · min^{-1} · kg^{-1}) SR all training sessions during an ~14-d altitude-training camp. Heart rate (HR) and some blood lactate measurements were collected during 466 training sessions. SR training was compared with recorded training duration from HR monitors, and SR intensity distribution was compared with expert analysis (EA) of all session data. *Results:* SR training was nearly perfectly correlated with recorded training duration ($r = .99$), but SR training was 1.7% lower than recorded training duration ($P < .001$). SR training duration was also nearly perfectly correlated ($r = .95$) with recorded training duration >55% HR$_{max}$, but SR training was 11.4% higher than recorded training duration >55% HR$_{max}$ ($P < .001$) due to SR inclusion of time <55% HR$_{max}$. No significant differences were observed in intensity distribution in zones 1–2 between SR and EA comparisons, but small discrepancies were found in zones 3–4 ($P < .001$). *Conclusions:* This study provides evidence that elite endurance athletes report their training data accurately, although some small differences were observed due to lack of a SR "gold standard." Daily SR training is a valid method of quantifying training duration and intensity distribution in elite endurance athletes. However, additional common reporting guidelines would further enhance accuracy.

Keywords: validity, self-report, expert analysis, XC skiers, heart rate

Recently, the training characteristics of elite runners, rowers, cyclists, and cross-country skiers have been described with a focus on basic aspects of training volume and intensity distribution over time frames from weeks to an entire season.[1–12] The key method for quantifying training characteristics is self-reported (SR) training in diaries.[5,8–13] Such data may be used to examine the relationship between training dose and training adaptation alongside performance and serve as a basis for mechanistic hypothesis generation. This, however, requires that self-report diaries be valid with regard to activity form, volume, intensity distribution, and frequency of training. In a validation study of SR training duration in recreational athletes, Borresen and Lambert[14] concluded that quantification of an athlete's actual training volume may be inaccurate when relying exclusively on SR data. However, that study was not conducted with elite athletes under rigorous conditions. Validation of individual session duration and total training volume is seemingly straightforward, but validation of intensity distribution is more challenging, both conceptually and operationally.

One approach is to continually register heart rate (HR) during each session and use standardized or test

profile-based HR-zone cutoffs to allocate HR time in zone to each intensity zone independent of power or pace.[6,7,13,15] An alternative and commonly used method for SR intensity distribution among elite athletes is described as a "modified" session-goal HR analysis in the literature[13] and employed in several recent studies.[8–11] The session-goal HR method refines the time-in-zone method by using the primary goal of the session as a starting point for analyzing the intensity of the intended or core portion of each training session (steady-state, threshold training, or interval training). This method can be used as an alternative approach to time-in-zone HR analysis or as in the original session-goal method,[13] a basis for a categorical allocation of each whole training session to an intensity zone, with or without corroborating perceived effort quantification.[13,16] Validating intensity distribution gives rise to several challenges due to inconsistent methods and the absence of a commonly accepted "gold standard."

Despite the importance of SR training data in describing endurance training best practice and developing testable training hypotheses, we have failed to identify previous studies validating the accuracy of SR training data provided by elite-level athletes regarding session duration or intensity distribution. Therefore, the primary aim of the current study was to quantify the accuracy of SR training duration and intensity distribution among elite endurance athletes under rigorous altitude-training-camp conditions.

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Methods

Subjects

Twenty-nine elite cross-country skiers, age 20 to 32 years, volunteered to participate in the study, which was approved by the Regional Ethics Committee of Southern Norway. All subjects provided informed written consent before participation. The 29 subjects were all athletes selected for the Norwegian National Team. Of the study participants, 10 athletes had won medals from senior world or Olympic championships. Of the remaining 19 athletes, 18 had won medals from junior world championships or placed among the top 3 in World Cup events. In the cross-country-skiing world championship (Val di Fiemme, 2013) 4 months after this data-collection period, the athletes included in this study won 7 gold, 4 silver, and 5 bronze medals. Five of the subjects reported their intensity characteristics in a manner inconsistent with other 24 and were excluded from the final analysis. The physical characteristics of the 24 subjects included in the current analyses are presented in Table 1.

Intensity-Zone Determination

The Norwegian Olympic Federation employs a 5-zone aerobic-intensity scale to prescribe and monitor training for endurance athletes. This scale is a general guideline, and the different zones are primarily based on lactate (La$^-$) and HR ranges[17] (Table 2).

Intensity-zone validation requires a reference standard for each athlete. In the current study, 5 aerobic-intensity zones in line with the Norwegian Olympic Federation's recommendations were determined before data collection for each athlete based on SR HR and La$^-$ values defining individual intensity-zone cutoffs. All athletes were well familiarized with the 5-zone reference scale, having used this scale since junior age. Individual adjustments to HR and La$^-$ values were performed based on experience and knowledge of each athlete's own physiological characteristics. In addition, the SR intensity zones were verified against HR and La$^-$ values acquired using standardized, onsite treadmill testing

Table 1 Physical Characteristics of the Subjects, Mean ± SD

	Male, n = 12	Female, n = 12
Age (y)	24.8 ± 3.23	24.2 ± 4.19
Height (cm)	179.8 ± 5.77	167.8 ± 5.36
Body mass (kg)	75.6 ± 6.33	60.2 ± 5.97
HR$_{max}$ (beats/min)	193.8 ± 8.33	194.8 ± 7.51
VO$_{2max}$ (mL · kg^{-1} · min^{-1})	80.9 ± 3.70	70.9 ± 4.58
VO$_{2max}$ (L/min)	6.1 ± 0.46	4.3 ± 0.32

Table 2 The Norwegian Olympic Federation's 5-Zone Intensity Scale

Intensity zone	Lactate[a] (mmol/L)	Heart rate (% of maximum)
5	6.0–10.0	92–97
4	4.0–6.0	87–92
3	2.5–4.0	82–87
2	1.5–2.5	72–82
1	0.8–1.5	55–72

Note: The reference values in this scale are guidelines only, and individual adjustments are required.

[a] Measured with lactate pro LT-1710.

during the data-collection period. Although HR monitors and La$^-$ measurements have been found to provide accurate measures during physical activity, factors such as day-to-day variation, training status, training form, activity form, environmental conditions, diurnal variation, hydration status, altitude, and medication may influence the relationship between work load and HR/La$^-$ values.[18] The athletes' SR intensity zones were therefore used as a reference standard, as opposed to laboratory testing results, which are obtained under conditions not identical with training and only have relevance for the zone 2 to 3 and zone 3 to 4 boundaries.

Registration of Training

Validation was performed during an altitude-training camp in Val Senales, Italy, October 2012, and average length of the data-collection period was 14 days (range 8–18; Table 3). During the period, 6 of the athletes contracted an illness or injury lasting 2 or more days. Athletes carried out their normal training and were instructed to follow their coaches' recommendations. Training methods or organization was not discussed with the athletes during the data-collection period. The athletes were blinded to our aim to quantify SR training validity and were told that this was part of data collection to monitor team training characteristics. Athletes were provided with detailed written and verbal instructions via a group meeting explaining the importance of keeping their training diaries and using an HR monitor during every training session.

Self-Report

Due to concerns about Internet access stability, athletes were provided with simple hard copies of their normal online training diary and asked to record their daily training information after each session as per their normal routine. The information in the diary consisted of quantifiable data regarding activity form, duration, intensity distribution, and comments. The majority of athletes (24 of 29) divided the total duration of each session

into intensity zones, based on a modified session-goal approach[13] where objective information from their HR watches, La[-] measurements, and stress responses was used to determine relevant zones. Five athletes transferred their HR-watch data directly into software and recorded time-in-zone analysis from software analysis as SR training. These 5 athletes were excluded from all analyses for consistency. There were also some differences in registration protocols for interval sessions. Some athletes included the recovery time between interval work bouts as moderate or high intensity (zones 3–5), whereas others logged it as training time in zone 1.

Recorded Training Duration

All athletes used Garmin HR watch Forerunner 910XT or 610 (Garmin, Olathe, KS, USA) for every session. HR-sampling frequency was 1 Hz. HR data were uploaded to Garmin training center (version 3.6.5) and further analyzed in Microsoft Excel (2010). In total, 466 of 530 sessions (88%) were analyzed with recorded HR data. Data from the remaining 12% of sessions were excluded due to incomplete HR data.

SR training duration was compared with "actual" training duration from complete HR records via 2 methods. First, we compared SR session duration with the total recorded session duration retrieved from HR files. Second, we restricted "actual" training duration to include only HR values >55% of HR_{max} (typically HR >~100). The rationale for this second analysis was that training with lower HR than 55% HR_{max} is below the Norwegian Olympic Federation recommendation for zone 1 (Table 2).

Expert-Analysis Intensity Distribution

Validation of SR intensity distribution was achieved by comparison of SR data from athletes with individual analysis by investigators of all available data for each training session. This analysis was termed expert analysis (EA). The EA method is based on the previously described modified session-goal analysis, combined with HR and La[-] measurements. Sessions performed in zones 1 and 2 were defined using HR curves as a starting point and then categorized into time in different zones in an appropriate manner. Sessions in zones 3, 4, and 5 used the primary goal of the session's core section, alongside HR and La[-] values to distribute the training time into the appropriate intensity zones. Recovery phases in interval sessions (zones 3–5) were categorized as zone 1 or 2, depending on the external load during that phase. EA included allocation of HR values <55% HR_{max} to match total SR time, categorized as zone 1.

Statistical Analyses

Total training volume was calculated as the total duration of endurance, strength, sprint, and plyometric training. Endurance training was further categorized into 5 intensity zones. In analyses of SR training validity, only the endurance portion of total training time was included.

Training-characteristics data are reported as mean ± SD and range. Pearson product–moment correlation was used to quantify the relationship between SR and HR-based recorded training duration. Correlation magnitude (r) was interpreted categorically as small (r .1–.3), moderate (r .3–.5), large (r .5–.7), very large (r .7–.9), and nearly perfect (r .9–1.0) using the scale presented by Hopkins et al.[19] A paired-samples t test was used to identify systematic differences between the methods, and the 95% confidence intervals (CI) bounding the difference were calculated. The limits of agreement between SR and recorded training duration were calculated using a Bland-Altman plot.[20]

All statistical analyses were performed using SPSS 18.0 (SPSS Inc, Chicago, IL, USA) and MedCalc (version 12.4.0.0), and statistical significance was accepted at the $P < .001$ level.

Results

General Training Characteristics

General training characteristics based on 466 SR training sessions during the altitude camp are shown in Table 3. All sessions were either endurance sessions or endurance sessions including strength, sprints, or plyometric training. Each training day typically consisted of 2 sessions. AM sessions were primarily on-snow skiing on a glacier ~3000 m above sea level, and PM sessions were primarily roller-skiing or running in the valley near Val Senales (1200–2200 m above sea level).

Accuracy in SR Training Duration

There was a nearly perfect correlation ($r = .99$; $P < .001$) between SR and HR-watch-registered training duration in each session (N = 466; Figure 1[a]). SR training duration (117 ± 36 min) was slightly but significantly lower than training duration derived from HR recordings (119 ± 37 min; 98.3% ± 6.4%; 95% CI 97.7–98.9; $P < .001$).

Figure 2(a) shows the Bland-Altman plot of SR and recorded training duration in each session (N = 466).[20] The limits of agreement were –2.7 to –1.7 minutes. The variation around the mean difference (–2.2 min) appeared to be random. Among all sessions, 77% were within ±5 minutes deviation between SR and recorded values.

There was a nearly perfect correlation ($r = .95$; $P < .001$) between SR and HR-watch-registered training duration >55% HR_{max} in each session (N = 466; Figure 1[b]). However, under training-camp conditions, athletes systematically "overreported" the duration of training time that their HR exceeded 55% HR_{max}. Averaged SR training duration (117 ± 36 min) was significantly higher than training duration derived from HR recordings >55% HR_{max} in each session (106 ± 34 min), a difference of 11.4% ± 13.5% (95% CI 10.3–12.5%; $P < .001$). The mean difference in SR versus recorded training duration >55% HR_{max} was 10.7 minutes; CI 9.7–11.8; $P < .001$ (Figure 2[b]).

Table 3   General Training Characteristics Based on Self-Reported Training, N = 24

	Mean ± SD	Range (minimum–maximum)
Recorded training days per athlete	13.3 ± 1.83	8–18
Self-reported training volume (h)	39.5 ± 9.40	25–60
Self-reported endurance training volume (h)	37.7 ± 8.86	24–57
Endurance training (%)	95.7 ± 1.83	92–100
Strength training (%)	3.4 ± 1.67	0–7
Sprint training (%)	0.8 ± 0.74	0–3
Plyometric (%)	0.1 ± 0.20	0–1
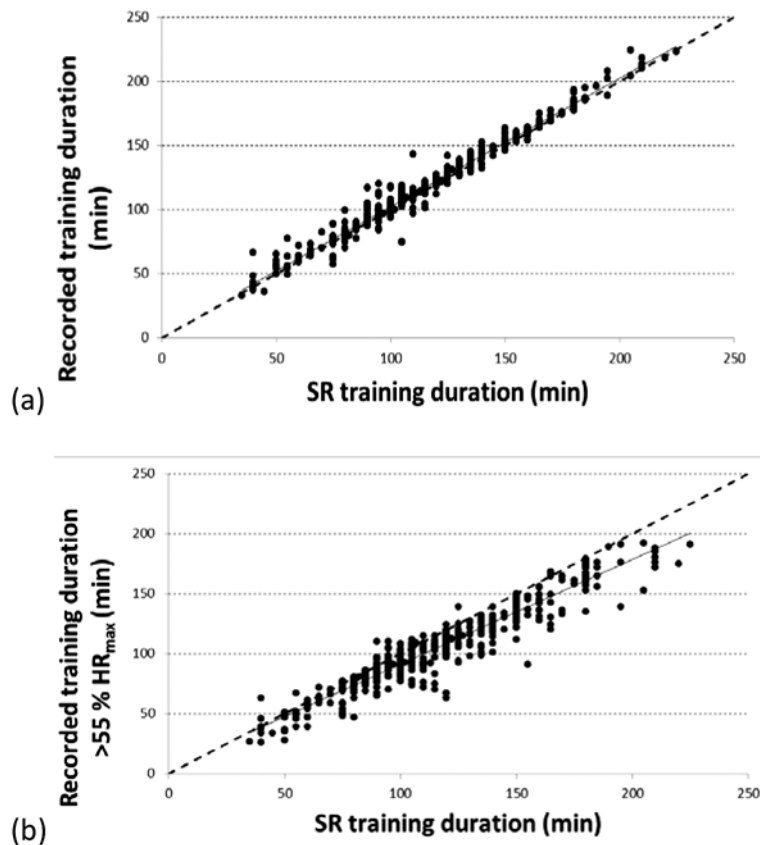
Figure 1 — Relationship between self-report (SR) and recorded training duration in each session (N = 466). Dotted line indicates line of identity. (a) Recorded training duration including heart-rate (HR) values <55% HR_{max}. (b) Recorded training duration excluding HR values <55% HR_{max}.

Intensity Distribution

SR training volume was not significantly different from EA allocations for intensity zones 1 and 2 (Table 4 and Figure 3). Compared with EA-based distributions, the athletes' SR method significantly overestimated total time spent in zone 3 during the training camp by 37 ± 25 minutes (1.7% ± 0.9%; $P < .001$) while underestimating total time spent in zone 4 by 11 ± 12 minutes (0.4% ± 0.4%; $P < .001$). During the entire camp, no training time in zone 5 was detected via EA and none was identified by SR training.
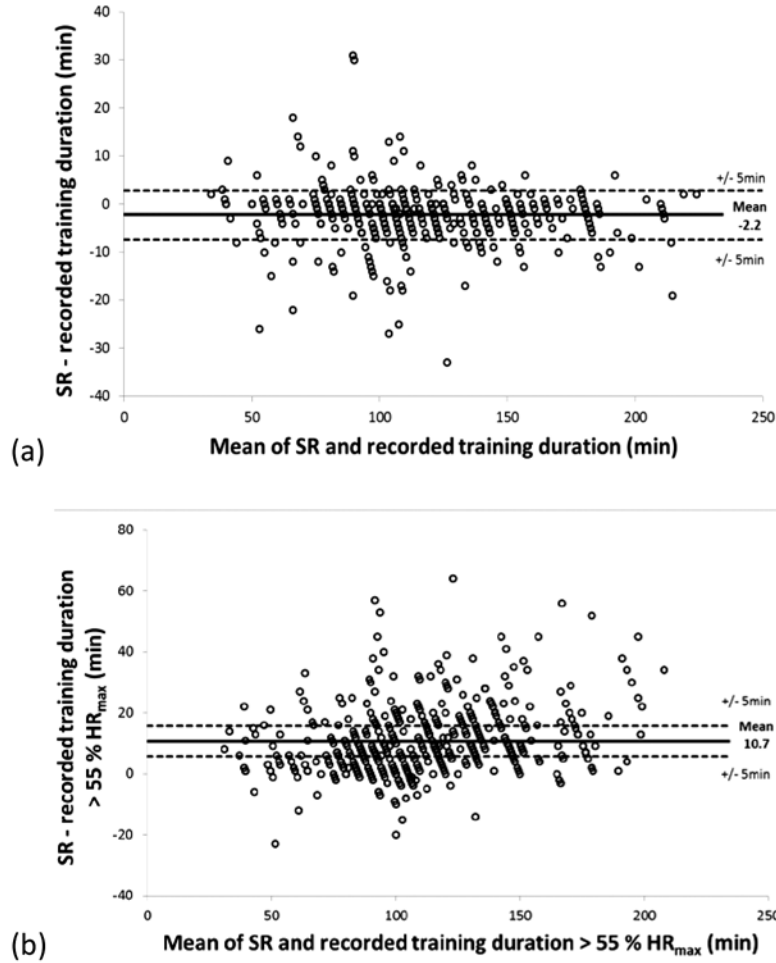
Figure 2 — Bland-Altman plot of self-report (SR) and recorded training duration (N = 466). (a) Recorded training duration including heart-rate (HR) values <55% HR_{max}. (b) Recorded training duration excluding HR values <55% HR_{max}.

Table 4   Mean Training Time (min) Distribution in Different Zones Based on Self-Report (SR) and Expert Analysis (EA), N = 24

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5 min
Self-report	2026 ± 497	109 ± 133	123 ± 51	7 ± 12	0 ± 0
Expert analysis	1990 ± 46[a]	171 ± 158	86 ± 35*	17 ± 15*	0 ± 0

[a] Includes heart-rate (HR) values <55% HR_{max} matching self-report.

*Paired-samples *t* test, $P \leq .001$.

Discussion

The main finding of this study is that elite endurance athletes accurately self-report their training data. SR training duration closely matches verified duration derived from HR recordings. Furthermore, the SR intensity distribution is also accurate, although there are slight differences between zones compared with EA.

We chose to perform data collection under very rigorous conditions during a high-altitude-training camp. For Norwegian cross-country skiers, altitude training forms an important and routine component of the annual training regimen, with 60 to 100 days typically spent at altitude in the period September to February. We were also interested in examining the athletes' intensity control during high-intensity training sessions because training "incorrectly" at
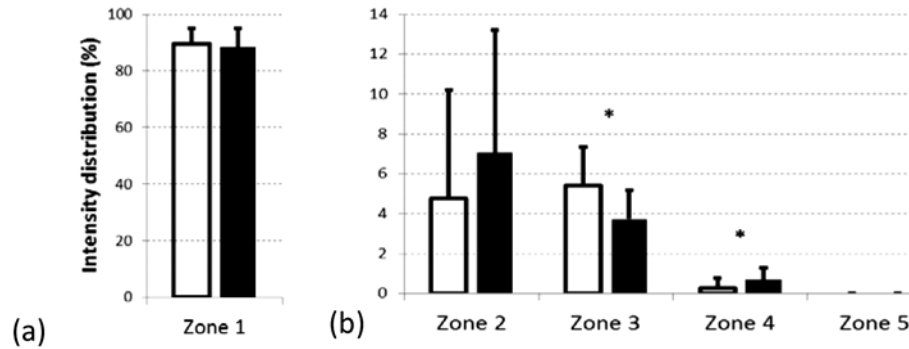
Figure 3 — Percentage of time spent in each of the 5 intensity zones (N = 24), mean ± SD. Open bars denote self-report (SR), while filled bars represent expert analysis (EA). EA zone 1 includes heart-rate (HR) values <55% HR$_{max}$ matching SR. (a) Zone 1. (b) Zones 2–5. *Paired-samples *t* test, *P* £ .001.

altitude can increase the risk of overreaching.[21] However, it is worth noting that SR training would likely have been even more accurate under normal sea-level conditions, particularly with regard to intensity distribution. Physiological parameters such as HR and La$^-$ can respond somewhat differently at altitude,[18] which in turn may influence the athlete's perceived exertion and intensity control.

SR Training Duration

During an approximately 14-day period, agreement between SR and HR-recorded training duration was very high, with SR training duration in each session being 98.3% of the training duration derived from HR recordings including HR values <55% HR$_{max}$. Overall, a nearly perfect correlation (*r* = .99) was found between SR and recorded duration in each session. No previously published studies have reported similar comparisons for elite athletes. Contradictory to our findings, Borresen and Lambert[14] showed that recreational athletes' quantification of training volume can be inaccurate when based on SR data alone. However, comparing the current study results directly with the results of Borresen and Lambert[14] is unsuitable due to different methods used.

In the current study athletes were instructed to use an HR watch during all training sessions and report their training daily. As such, it is reasonable to expect high accuracy in SR training duration data. Even a discrepancy of only 1.7% may be viewed as noteworthy, and this difference was in fact statistically significant (*P* < .001). In practice, the discrepancy was due to athletes deducting a small percentage of time spent during each session to compensate for time that in reality cannot be counted as effective training time (drinking, urinating, very low intensity, etc). This would also explain the variation around the mean shown in Figure 2(a). However, this variation is small, with 77% of all 466 sessions within ±5 minutes of the mean difference.

There was also a nearly perfect correlation (*r* = .95) between SR and recorded training duration >55% HR$_{max}$.

However, under training-camp conditions, athletes systematically overreported training duration >55% HR$_{max}$ by about 11%. This indicates that a meaningful portion of reported training was performed at intensity below the Norwegian Olympic Federation's recommended lowest limit for "effective" endurance training. If this practice were followed over the 800+ hours of these athletes' typical annual training volume, the difference would extrapolate to ~100 hours of total training. However, the altitude-training-camp environment on the glacier probably exaggerates this overestimation of "effective" training time.

The overreporting of training duration during a training camp can be partly explained by the norms and culture for recording training time in this specific cross-country-skiing environment, where athletes keep their watches running during the entire session, even when stopping briefly for various reasons (eg, hydration, urination, and conferring with coach). Other possible explanations are that HR may drop below 55% HR$_{max}$ when skiing downhill or simply that the athletes (as instructed by their coach) deliberately train extremely slowly during initial training sessions at this altitude. In addition, the environment that athletes are exposed to during an altitude-training camp may be viewed as atypical: coaches continuously providing feedback, physiologists measuring lactate and giving feedback on intensity, technique training sequences that include recovery phases, testing of a large number of skis, highly disciplined routines with regard to drinking every 20 minutes, and so on. To our knowledge, no studies to date have shown similar results. However, more studies, and during normal conditions, are necessary to corroborate these findings.

SR Intensity Distribution

There were almost no differences with regard to SR intensity distribution for zones 1 and 2 and only small differences for zones 3 and 4 compared with the EA. Zone 5 training was either reported in SR training or detected by EA during any of the 466 sessions analyzed.

In the low-intensity range (zones 1 and 2) no significant allocation differences were found, although athletes tended to self-report some zone 2 training time to zone 1. Other than individual HR cutoffs for zones (Table 2), there are no clear physiological distinctions between zone 1 and 2, and in practical terms it may therefore be difficult for athletes to allocate total time in easy sessions between these 2 zones. Some athletes failed to record any time in zone 2, while others used HR data from watches to distribute total time. During EA, investigators used HR curves to allocate phases during a training bout where HR was clearly in zone 2. For these reasons we found some small but not significant differences between SR and EA methods for zones 1 and 2.

In the high-intensity range (zones 3–5), small but significant differences were found between self-report and EA in zones 3 and 4. SR intensity distribution overestimated time in zone 3 and underestimated time in zone 4. During interval sessions most athletes registered recovery phases as time in the same high-intensity zone as the effort (zone 3–4), while we as investigators did not, due to lower external load during that phase. This primarily explains why there is a difference in zone 3, in which the majority of interval sessions were conducted. In addition, we found a small discrepancy in zone 4. This was due to athletes not registering time in zone 4 despite HR and La$^-$ values being in this zone for some intervals, particularly toward the latter part of sessions.

A limitation of this validation study was that no zone 5 training was prescribed during the altitude camp, so the full range of intensity distribution was not used during the training period. However, self-report of no zone 5 training was confirmed by EA throughout all 466 evaluated sessions, giving support to the validity of SR.

Practical Applications

There is no self-report gold standard, and although we found some minor discrepancies between SR and recorded duration or EA intensity distribution, we suggest that these small differences are due to the absence of clearly defined guidelines. Our findings indicate that scientists and coaches can rely on the validity of SR training data from elite endurance athletes, but common guidelines would further ensure the accuracy and comparability of SR data across individuals and sport disciplines.

For continuous training in zone 1 and 2, we recommend the use of HR values and external load to allocate periods clearly in different zones for SR diaries. Furthermore, we suggest stopping watches in the case of obvious pauses during training (eg, drinking, urinating, etc). For higher-intensity continuous or interval sessions at or above the lactate threshold (zones 3–5 in the current study) we recommend distributing training time using a modified session-goal approach, where the intended core portion of each session is used as the starting point for allocating zones, in combination with HR and La$^-$ values. While there are defensible arguments in both directions,

we recommend that recovery phases during interval sessions be registered in zones corresponding to the actual external load. That is, an interval session of 5×8 minutes in zone 4 with 2-minute recoveries would be recorded as 40 minutes of zone 4 training time, not 48 minutes. This will promote both internal consistency across zones and consistency throughout the season. Including recovery time between intervals as time in the high-intensity zone can create a "false increase" in high-intensity training if the work-to-recovery ratio is changed as part of the periodization process.

To our knowledge, this is the first validation study investigating SR training information by elite-level athletes. Additional work is needed in this area under routine training conditions and with different sports as a quality-assurance platform for further research on optimization of the training process.

Conclusions

This study provides evidence that, overall, elite endurance athletes accurately self-report their training duration and intensity distribution. Common guidelines and a specific gold standard for SR training may further increase validity.

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Paper II

From heart-rate data to training quantification: A comparison of 3 methods of training-intensity analysis.

From Heart-Rate Data to Training Quantification: A Comparison of 3 Methods of Training-Intensity Analysis

Øystein Sylta, Espen Tønnessen, and Stephen Seiler

Purpose: The authors directly compared 3 frequently used methods of heart-rate-based training-intensity-distribution (TID) quantification in a large sample of training sessions performed by elite endurance athletes. *Methods*: Twenty-nine elite cross-country skiers (16 male, 13 female; 25 ± 4 y; 70 ± 11 kg; 76 ± 7 mL · min^{-1} · kg^{-1} VO$_{2max}$) conducted 570 training sessions during a ~14-d altitude-training camp. Three analysis methods were used: time in zone (TIZ), session goal (SG), and a hybrid session-goal/time-in-zone (SG/TIZ) approach. The proportion of training in zone 1, zone 2, and zone 3 was quantified using total training time or frequency of sessions, and simple conversion factors across different methods were calculated. *Results*: Comparing the TIZ and SG/TIZ methods, 96.1% and 95.5%, respectively, of total training time was spent in zone 1 ($P <$ .001), with 2.9%/3.6% and 1.1%/0.8% in zones 2/3 ($P <$ .001). Using SG, this corresponded to 86.6% zone 1 and 11.1%/2.4% zone 2/3 sessions. Estimated conversion factors from TIZ or SG/TIZ to SG and vice versa were 0.9/1.1, respectively, in the low-intensity training range (zone 1) and 3.0/0.33 in the high-intensity training range (zones 2 and 3). *Conclusions*: This study provides a direct comparison and practical conversion factors across studies employing different methods of TID quantification associated with the most common heart-rate-based analysis methods.

Keywords: XC skiers, endurance training, intensity distribution, time in zone, session goal

The training dose-adaptive response relationship is at the core of sports physiology and performance. However, quantifying training dose remains an area of some confusion. Focusing on endurance athletes, training dose can be measured in terms of external work executed (distance, power, velocity)[1,2] or internal physiological responses elicited by that work (heart rate [HR], blood lactate, VO$_2$).[3-13] Training dose can also be measured by how the stimulus was perceived (session rating of perceived exertion [RPE]).[12,14-18] Most high-level endurance athletes maintain a training diary where they report their training. In reality, some combination of all 3 of these basic descriptions of the training dose is usually reflected in athlete self-report.[1-3,6-8,10-12,19,20]

Three basic approaches are described in the literature for quantifying endurance-training sessions based on the HR response. One approach is time in zone (TIZ).[4,5,9-12] Dedicated software allocates HR registration data to intensity zones defined from cutoffs registered in the software by the athlete or coach. A second method is session goal (SG).[12] This categorical approach assigns the entire session into a single intensity zone with the assumption that the "goal portion"

of the session primarily determines its impact as an adaptive signal and source of physiological stress. A categorical approach likely gives a realistic picture of the total training-intensity distribution (TID) over the long term and is frequently cited in the literature.[12,14-18] The SG method has also been found to agree well with intensity categorization based on session RPE (sRPE).[12] A third approach is a hybrid combination of SG and TIZ, called the modified SG approach (SG/TIZ) in the literature.[6-8,13,19] The goal of the session is used to aid in allocating training time to intensity zones, based on a combination of actual HR registration and workloads applied.

Figure 1 illustrates the 3 methods by depicting beat-for-beat HR responses to a typical endurance session lasting ~90 minutes. The elite athlete performed interval training organized as 5 × 8-minute work periods with 2-minute recoveries, in addition to a warm-up and cooldown period. Blood lactate concentrations during the first, third, and fourth rest periods were 3.5, 4.2, and 5.6 mmol/L, respectively. The session was prescribed as a zone 3 interval session based on the 3-zone model (Table 1). The athlete's maximal HR is 200. The TIZ method uses the HR curve (solid line) to allocate time in different zones. Thirty-five minutes are distributed in zone 3, plus 48 minutes in zone 1 and 5 minutes in zone 2. The SG approach categorizes this whole workout as a zone 3 session based on the highest intensity achieved

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and the accumulated duration at that intensity. The dotted line indicates the SG/TIZ method, giving 40 minutes in zone 3 and 48 minutes in zone 1, and is based on the workload actually performed rather than HR alone. Both the SG and SG/TIZ methods use lactate values as additional information to determine correct intensity zones (Table 1). Critically, the validity of all 3 methods for investigating training dose, adaptive response, and performance development depends on consistent and comparable interpretation of training data by coaches and scientists.

Seiler and Kjerland[12] provided data comparing SG with TIZ. However, that was not the primary focus of that study, which described the concept of a polarized TID. No study since has systematically quantified TID derived from 3 different methods in highly trained athletes. The TID of endurance athletes has received increased attention in both descriptive[1–3,6–13,18,20] and experimental studies,[21–23] as well as recent reviews.[24,25] Because these 3 methods are used interchangeably there can be confusion regarding interpretation of training data, although the problem has been discussed.[12]

The purpose of this study was therefore to directly compare 3 methods of TID quantification in a large sample of training sessions performed by elite endurance athletes.
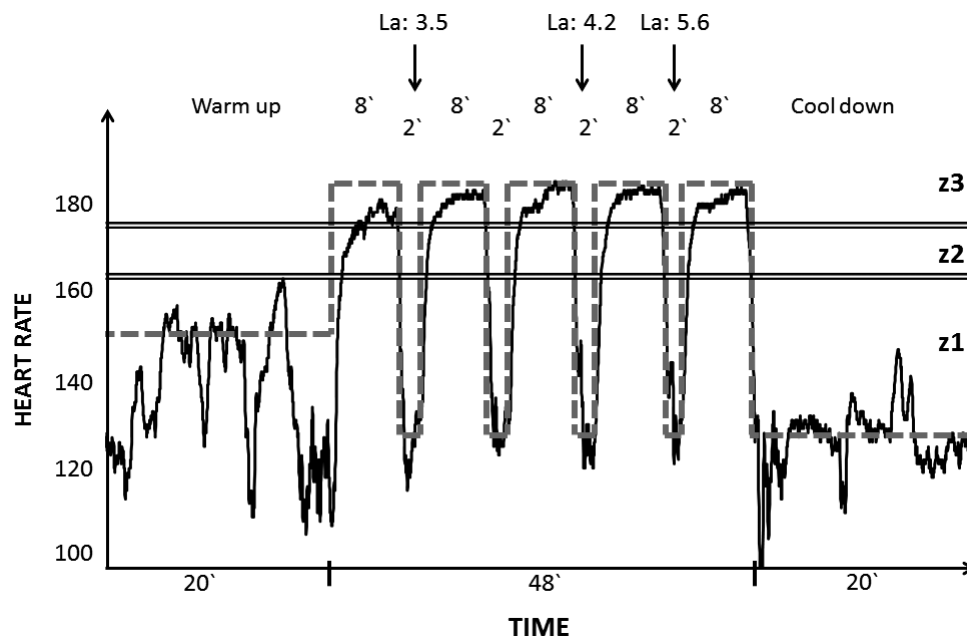
Figure 1 — Illustration of intensity distribution using 3 different methods. Three basic intensity zones are exemplified here. The time-in-zone method uses the heart-rate curve (solid line) as the basis for allocating time in different zones. The session-goal/time-in-zone method uses the dotted line in combination with lactate values. The session-goal approach defines this example as a zone 3 session based on the intensity during the core section of the session in combination with lactate values.

Table 1   The 5-Zone Intensity Scale Used by the Norwegian Olympic Federation and the 3-Zone and Binary Models Used in the Current Study

Intensity zone	Lactate[a] (mmol/L)	Heart rate (% max)	3-zone model	Binary model
5	6.0–10.0	92–97	Zone 3	high-intensity training
4	4.0–6.0	87–92	Zone 3	high-intensity training
3	2.5–4.0	82–87	Zone 2	high-intensity training
2	1.5–2.5	72–82	Zone 1	low-intensity training
1	0.8–1.5	55–72	Zone 1	low-intensity training

Note: The reference values in this scale are guidelines only, and individual adjustments are required.

[a] Measured with lactate pro LT-1710.

Methods

Subjects

Twenty-nine elite cross-country skiers volunteered their informed written consent to participate in the study, which was approved by the Regional Ethics Committee of Southern Norway. Their physical characteristics are shown in Table 2. All subjects were on the Norwegian Cross-Country National Team. Of these, 28 athletes had won medals in senior or junior World or Olympic championships and were experienced in the use of HR watches and training-intensity control.

Training-Data Collection

Data collection was performed during an altitude-training camp in Val Senales (Italy) in October 2012. The average length of the data-collection period for each athlete was 14 days (range 8–18 d). Athletes were instructed to carry out their normal training and use an HR monitor during every session. In total, complete HR data were collected from 570 sessions with accompanying lactate measurements (380 samples).

Intensity-Zone Classification

Norwegian athletes normally use a 5-zone aerobic intensity scale for prescription and reporting of endurance training. This scale is a standardized guideline, with individual test profiles used to identify specific HR and blood lactate cutoffs (Table 1). In the current study, athletes were asked to report their individualized 5-zone scale previously established based on physiological testing and field experience. Laboratory testing includes a standardized incremental submaximal exercise test running at 10.5% inclination on a treadmill. The test consists of four 5-minute stages at increasing velocity (55–90% of VO_{2max}), with VO_2 and HR sampled during the last minute of each stage and blood lactate measured in the 30-second recoveries between stages. This lactate-profile test is followed by a VO_{2max} test (described previously[26]). All athletes were tested regularly (during the last year). The design of intensity zones based on these tests has been previously described.[27] Although HR and lactate values differ slightly at different time points, with different sport-specific movements and so on, zones can be expected to remain relatively constant over the course of a training year,[28] and athletes therefore only use 1 scale to simplify their daily intensity-control regimen.

To compare the 3 TID methods described, we chose to collapse the 5-zone scale into 3 zones corresponding to physiological anchor points such as first and second ventilatory and lactate thresholds ($VT_{1/2}$ and $LT_{1/2}$).[24] To calculate conversion factors across different methods, only a binary model was used, low-intensity/high-intensity training (LIT/HIT), to simplify the method and core study outcome (Table 1).

Data Analyses

All training sessions were analyzed using 3 methods; TIZ, SG, and SG/TIZ (Figure 2).

- *TIZ:* HR was recorded continuously during sessions and divided into HR-zone cutoffs to allocate exact time in zone 1, 2, or 3 (Figure 1 and Table 1). Individual HR cutoffs between zones were provided by each athlete as described. All athletes used a Garmin HR watch Forerunner 910XT or 610 (Garmin, Olathe, KS, US) with a sampling frequency of 1 Hz. HR data were subsequently uploaded to the Garmin Training Center (version 3.6.5) and further analyzed in Microsoft Excel (2010).

- *SG:* In the SG approach, the primary goal of the session was used as a basis for categorical allocation of each whole training session to zone 1, 2, or 3 (Figure 1 and Table 1). Interval sessions where the intended intensity during the core portion was in zone 2/3 were categorized as zone 2/3 sessions if

Table 2   Physical Characteristics of the Subjects (Mean ± SD)

	Men, n = 16	Women, n = 13
Age (y)	26 ± 3.0	24 ± 4.0
Height (cm)	181 ± 5.0	168 ± 5.0
Body mass (kg)	77.6 ± 6.5	61.2 ± 6.6
Heart rate max (beats/min)	194 ± 8.0	195 ± 8.0
VO_{2max} (mL · kg^{-1} · min^{-1})	79.8 ± 5.0	70.3 ± 5.0
VO_{2max} (L/min)	6.2 ± 0.5	4.3 ± 0.3
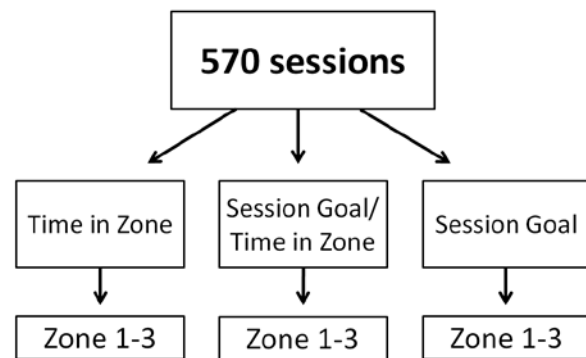
Figure 2 — Training sessions executed by 29 elite athletes during 8- to 18-day training camp, along with accompanying heart-rate (HR data), lactate measurements, and lactate profile test data, were distributed into 3 intensity zones via 3 different methods: HR-derived time in zone, a categorical session-goal allocation, and a hybrid session-goal/time-in-zone distribution.

HR and lactate measurements confirmed that they were executed as planned (Table 2). All of these sessions were planned and executed such that the accumulated high-intensity work time exceeded 25 minutes. For continuous sessions, an accumulation of >15 minutes was set as a threshold for categorizing the entire session as zone 2/3.

- *SG/TIZ:* The SG/TIZ approach combines the SG and TIZ approaches. For continuous sessions, TIZ was defined using HR curves as a visual starting point (Figure 1 and Table 1). Periods that were clearly in zone 2/3 for several minutes were distributed there appropriately. Interval sessions used the primary goal of the session's core section, alongside HR and lactate values, to distribute training time into zone 2/3. Recovery phases in interval sessions were categorized as zone 1 only if active rest was used.

Data from each method were further analyzed and compared. Proportions (ratios) of zones 1, 2, and 3 were calculated using total training time in the TIZ and SG/TIZ methods and frequency of sessions in the SG method.

Conversion-Factor Calculation

Assuming that the overall session structure used by elite or recreational athletes is reasonably comparable, we calculated simple conversion factors to facilitate converting TID estimates based on one method to another. For simplicity only a binary model was used in these calculations, 1 conversion factor for TID ratio in the LIT (zone 1) range and 1 conversion factor in the HIT (zones 2 and 3 combined) range. The following formulas were used:

$$\text{Conversion factor for TIZ to SG} = \text{ratio SG\%/ratio TIZ\%}$$

$$\text{Conversion factor for SG to TIZ} = \text{atio TIZ\%/ratio SG\%}$$

Statistical Analyses

Total training time is reported as mean ± SD, both as group values from 29 athletes and total values from 570 training sessions. A paired-samples *t* test was used to identify differences between training time in the TIZ and SG/TIZ methods, and 95% confidence intervals bounding the difference were calculated. Conversion factors between different methods were calculated based on total training ratios.

All statistical analyses were performed using SPSS 18.0 (SPSS Inc, Chicago, IL, USA), with statistical significance accepted as *P* < .05.

Results

Time Distribution Versus Session Distribution

Comparing TIZ and SG/TIZ methods, 96.1% ± 1.4% and 95.5% ± 1.5% of total training time, respectively, was in zone 1 (*P* < .001). Training in zone 2 accounted for 2.9% ± 1.3% and 3.6% ± 1.5% (*P* < .001), and zone 3 1.1% ± 0.9% and 0.8% ± 0.7% (*P* < .001), of total training time based on the 2 methods. The relative underestimation of HIT time (zones 2 and 3 combined) was 16.6% ± 19.0% (confidence interval: 9.2–24.0, *P* < .001) when using TIZ versus SG/TIZ (Table 3 and Figure 3).

When these same training sessions were allocated categorically using the SG method and verified by HR and lactate data, 86.6% ± 4.8% (492 of 570) of training sessions were performed primarily as zone 1, 11.1% ± 5.0% (64 of 570) as zone 2, and 2.4% ± 2.8% (14 of 570) as zone 3 (Table 3 and Figure 3).

The conversion factor from the ratio of TIZ or SG/TIZ to SG was ~0.9 in the LIT range and 3.0 in the HIT range. The conversion factor from SG to TIZ or SG/TIZ was estimated to be 1.1 in the LIT range and 0.33 (1/3) in the HIT range (Figure 4).

Table 3   Training Time in TIZ and SG/TIZ Methods and Frequency of Sessions in SG Method Based on Mean and Total Training Data From 29 athletes During 8–18 Training Days (1107.6 h, 570 Sessions)

|		TIZ (h)	TIZ (%)	SG/TIZ (h)	SG/TIZ (%)	SG (no. of sessions)	SG (%)
Mean ± SD (N = 29)	Zone 1	36.7 ± 8.4	96.1 ± 1.4	36.5 ± 8.3	95.5 ± 1.5	17.0 ± 2.8	86.6 ± 4.8
	Zone 2	1.1 ± 0.5	2.9 ± 1.3	1.4 ± 0.6	3.6 ± 1.5	2.2 ± 1.0	11.1 ± 5.0
	Zone 3	0.4 ± 0.4	1.1 ± 0.9	0.3 ± 0.3	0.8 ± 0.7	0.5 ± 0.6	2.4 ± 2.8
Total (570 sessions)	Zone 1	1063.8		1057.7		492	
	Zone 2	31.6		40.6		64	
	Zone 3	12.2		9.3		14	
	Total	1107.6		1107.6		570	

Abbreviations: TIZ, time in zone; SG, session goal.

Time in HIT Sessions

Mean duration of HIT periods was significantly lower in TIZ than in SG/TIZ, 32.5 ± 8.6 versus 38.2 ± 6.5 minutes, $P < .001$. TIZ underestimated time spent working in the HIT range by $27.5\% \pm 43.7\%$.

Discussion

This study provides directly comparable data demonstrating differences in quantification of TID using 3 analysis methods frequently reported in the literature.[4–13,19]
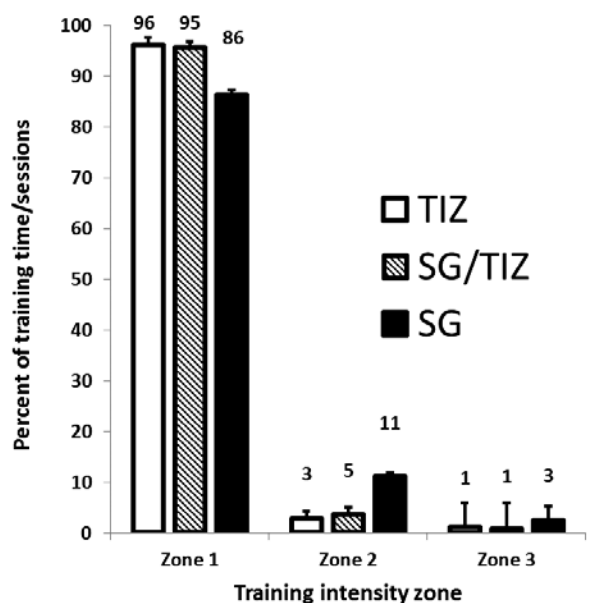
Figure 3 — Training-intensity distribution in 570 sessions analyzed with 3 different methods: time in zone (TIZ), session goal/time in zone (SG/TIZ), and session goal (SG).

Data from numerous studies[1–13,18] report athletes' TID using a 3-zone model. Critically, the distribution ratio is often based on different methods (time-based allocation vs categorical allocation) and on athletes at different levels, making comparisons across studies difficult. While our sample athletes employed a nationally standardized 5-zone aerobic intensity scale, we chose to convert their training data to the same 3-zone intensity scale, anchored around VT_1/LT_1 and VT_2/LT_2, that has been most frequently used in research on TID,[10–12,21–24] as well as intensity distribution during long single-day[13] and multiday events.[4,5]

A useful conversion factor between a time-based and a categorical TID approach emerges from these data using a binary model (zone 1 = LIT, zones 2 and 3 = HIT). Assuming that the basic content and structure of HIT sessions is reasonably consistent across athlete groups and sport disciplines, we suggest that HR-based TIZ estimates for HIT sessions can be multiplied by ~3 (Figure 4) to give an equivalent distribution based on categorical allocation of HIT sessions. In elite athletes training ≥800 h/y, or 500 training sessions/y, where HR analysis using TIZ shows 93%/7% in LIT/HIT, the categorical SG distribution of endurance sessions will approximate 81%/21% LIT/HIT. This difference is largely explained by the fact that LIT sessions are often longer than HIT sessions and HIT sessions generally include considerable warm-up and cooldown time and recovery time between high-intensity bouts. For example, a 6×4-minute HIT session at 95% HR_{max}, lactate values >6 mmol/L, with 2 minutes recovery, a 20-minute warm-up, and a 15-minute cooldown would result in a TIZ distribution of ~20 minutes HIT and 45 minutes LIT. As such, even this high-intensity session would be quantified as ~70% LIT, despite blood lactate values clearly indicating that the session was very demanding. By extension, SG-based TID can be converted to estimates of TIZ using a conversion factor of ~0.33 in the HIT range (Figure 4). Because these 2 TID-calculation
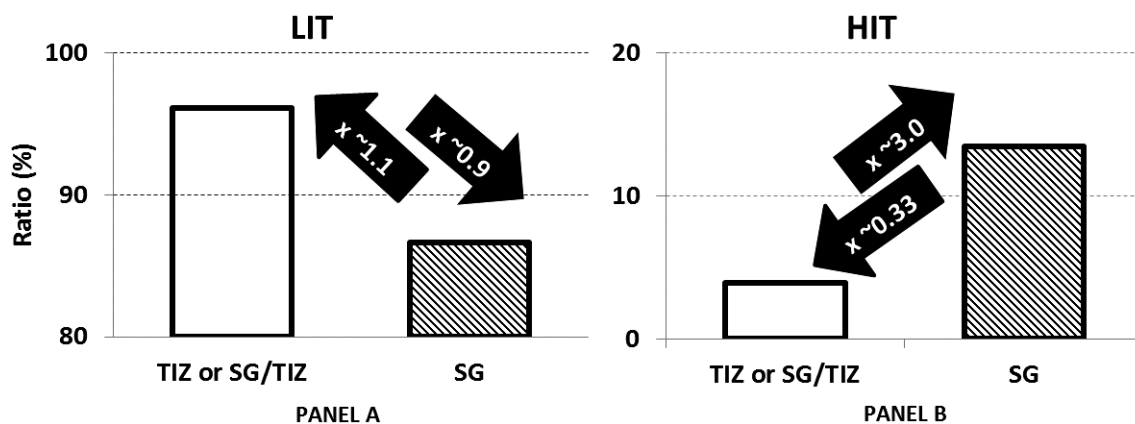
Figure 4 — The figure illustrates how to convert reported training distribution from a time-based-ratio method (time in zone [TIZ] or session goal/time in zone [SG/TIZ]) to a method of categorical allocation of each training session (SG), or vice versa. Panel A: low-intensity-training range; Panel B: high-intensity-training range.

methods are frequently reported in the literature,[4,5,10–12] this conversion factor can facilitate more informed comparisons of studies concerning elite athletes, as well as less confusion regarding interpretation of TID data. In addition, the conversion factors appear reasonable when used in subelite/recreational athletes. Converting TID data from TIZ to SG in junior athletes training ~500 h/y with 91%/9% LIT/HIT (TIZ method) provides ~27% HIT when converted to the SG method, which is comparable to the reported 25%.[12] Recreational athletes training 5 sessions/wk or 5 h/wk, including 2 HIT sessions, give ~15% of training time, or 40% HIT sessions, in TIZ or SG, respectively. These examples suggest that the conversion factor identified from elite athletes' training is transferable across different training levels.

In 78 HIT sessions quantified in this study, the average time difference between SG/TIZ and TIZ calculation of HIT time was 27.5% (38.8 min vs 32.5 min), due to HR "lag time" in the TIZ method (Figure 1). Over a season, this can account for 10 to 12 hours of additional zone 2/3 training in an athlete training 800 h/y. In addition, interval sessions include rest and recovery time. How these rest intervals are treated in TID can be a significant source of inconsistency across studies when employing the SG/TIZ approach.[19] We argue that recovery time should not be included as zone 2/3 time. Rest duration varies across different interval session types and can be modified during a mesocycle as part of a periodization plan. Therefore, this portion of the interval session should be assigned as zone 1 or to the specific zone in which it is performed if conducted as active recovery.

Several studies have reported using the TIZ[4,5,9–12] or SG/TIZ method[3,6–8,13] in studies of athletes. More important, these methods are frequently used among athletes as self-report in diaries. We have previously shown that when self-reporting training, elite athletes used a "conceptual" routine close to the SG/TIZ method.[19] In the Norwegian national cross-country team, 24 of 29 athletes used the SG/TIZ method, while the remainder analyzed their HR data directly using TIZ. Use of the TIZ method is straightforward due to easy accessibility to HR watches and accompanying analysis programs. In the Norwegian cross-country junior national team, TIZ is even more common than the SG/TIZ method (personal communication). This pinpoints the importance of being able to analyze and compare these methods. TIZ and SG/TIZ methods are attractive since they are easy to analyze, individualized, and noninvasive. However, TIZ methods have in some cases been shown to poorly match perceived effort for a given workout[12] and may underestimate the actual stress load,[29] so we highly recommend that athletes using a time-based method also self-report sRPE and SG in diaries to give a realistic picture of the long-term TID.

We previously argued in a review[24] that a "typical" TID between LIT and HIT in elite endurance athletes approximates 80% LIT and 20% HIT based on a categorical approach allocating entire training sessions into intensity categories. In the current study, subjects only performed 13% to 14% of training sessions as HIT (zone 2–3) using the SG method. However, this was a training camp where athletes resided and performed LIT at ~3000 m and HIT at ~1800 m. Consequently, the TID consisted of a lower proportion of HIT, consistent with the greater stress of altitude training. HR responses at altitude differ from those at sea level,[30] but due to individualized downward adjustment of external load, athletes trained using their normal intensity scale after initial acclimatization. Of 29 athletes, 24 used the same intensity reference values at sea level and altitude. The remaining athletes reported <5-beats/min lower values in each zone at altitude. Collecting data at high altitude could influence the results, and their reproducibility at sea level remains unclear.

It is also worth noting that these elite athletes use a polarized[24] training model. LIT sessions are typically very easy, and HIT sessions considerably harder. Although the reference scale (Table 1) suggests 82% or 2.5 mmol/L as the lower limit, sessions in zone 2 are, due to very high aerobic capacity and lactate threshold, normally conducted with HR ~90% and lactate 1.5 to 4.0. The high-intensity zone is therefore narrower in elite than recreational athletes, and comparison of data across different performance levels must be conducted with caution.

A limitation of this study is that standardized perceptual measures of training intensity were not included in the athletes' self-report. sRPE has been frequently employed in recent studies. This categorical method is appropriate for estimating long-term TID patterns[12,14–18] and likely provides an accurate representation of the training load over time.[12,14,29] Foster et al[15,16] introduced the sRPE method to provide a measure of the global perception of intensity during an entire training session. Using sRPE as a basis for session intensity classification, Stellingwerff[18] found that TID in 3 male elite marathon runners during 1 year was 74%/11%/15% in zones 1/2/3. Norwegian endurance athletes are unfortunately not accustomed to the sRPE method, and as a compromise we agreed with their coaches not to influence their normal patterns more than necessary. However, we suggest that sRPE and SG data correspond well and are reasonably interchangeable. Seiler and Kjerland[12] found 92% agreement between a 3-zone categorization of sRPE and the 3-zone SG method in junior cross-country skiers. Nevertheless, the disadvantage of the SG method is that elite athletes and coaches may not be familiar with this categorical method of analyzing training data. However, it seems that athletes do informally think of sessions in terms of some form of binary intensity classification. For example, the Norwegian national cross-country ski team has formulated as a "success rule" that ~100 to 140 sessions in zones 2 to 3 should be integrated into the annual training load of >800 hours (personal communication).

Practical Applications

In this study we objectively compared 3 conceptually different methods of quantifying TID. In recent years, TID has been extensively explored and several studies have described training characteristics in elite athletes via these 3

methods.[1–3,6–13,18] In addition, self-report among athletes in training diaries normally uses methods close to the SG/TIZ or TIZ method.[1,2,6–8,10–12,19] The current study shows that due to dissimilarities in the methods used, it is inappropriate to compare TID both across different self-report methods from athletes and between studies without taking into account the discrepancies between methods. Therefore, the results from the current study may help athletes, coaches, and scientists when interpreting studies of TID and endurance performance. We suggest the following guidelines:

- Normal methods of self-report in diaries, such as TIZ or SG/TIZ, underestimate the ratio of total training in the HIT range compared with the SG method. We suggest a conversion factor of 3 when converting total training ratio from TIZ or SG/TIZ to SG and 0.33 from SG to TIZ or SG/TIZ in the HIT range.

- TIZ underestimates time in the HIT work-intensity range compared with the SG/TIZ method due to HR "lag time." The magnitude of this distortion may depend on how sessions are composed (HR "fast component," recovery duration, etc). In elite athletes this difference can account for 10 to 12 h/y and must be taken into account when evaluating self-report training diaries using different methods.

- The SG/TIZ approach should be generally recommended for athletes, coaches, and scientists to standardize TID. In addition, we highly recommend that athletes self-report sRPE and SG to give a better picture of total training load.

- In interval sessions, recovery time should be subtracted from zone 2 to 3 training time to ensure consistent and comparable TID.[19]

Conclusions

This study provides a quantitative comparison of TID differences associated with the most common HR-based analysis methods. These data provide defensible conversion factors for comparisons of studies employing different methods of TID quantification that will hopefully contribute to greater clarity on this topic.

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The road to gold: Training and peaking characteristics in the year prior to a gold medal endurance performance.

PLOS ONE

The Road to Gold: Training and Peaking Characteristics in the Year Prior to a Gold Medal Endurance Performance

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Abstract

Purpose: To describe training variations across the annual cycle in Olympic and World Champion endurance athletes, and determine whether these athletes used tapering strategies in line with recommendations in the literature.

Methods: Eleven elite XC skiers and biathletes (4 male; 28±1 yr, 85±5 mL. min^{-1}. kg^{-1} $\dot{V}O_{2max}$, 7 female, 25±4 yr, 73±3 mL. min^{-1}. kg^{-1} $\dot{V}O_{2max}$) reported one year of day-to-day training leading up to the most successful competition of their career. Training data were divided into periodization and peaking phases and distributed into training forms, intensity zones and endurance activity forms.

Results: Athletes trained ~800 h/500 sessions.year^{-1}, including ~500 h. year^{-1} of sport-specific training. Ninety-four percent of all training was executed as aerobic endurance training. Of this, ~90% was low intensity training (LIT, below the first lactate threshold) and 10% high intensity training (HIT, above the first lactate threshold) by time. Categorically, 23% of training sessions were characterized as HIT with primary portions executed at or above the first lactate turn point. Training volume and specificity distribution conformed to a traditional periodization model, but absolute volume of HIT remained stable across phases. However, HIT training patterns tended to become more polarized in the competition phase. Training volume, frequency and intensity remained unchanged from pre-peaking to peaking period, but there was a 32±15% (P< .01) volume reduction from the preparation period to peaking phase.

Conclusions: The annual training data for these Olympic and World champion XC skiers and biathletes conforms to previously reported training patterns of elite endurance athletes. During the competition phase, training became more sport-specific, with 92% performed as XC skiing. However, they did not follow suggested tapering practice derived from short-term experimental studies. Only three out of 11 athletes took a rest day during the final 5 days prior to their most successful competition.

Introduction

Winning a gold medal in a major international championship requires not only outstanding athletic ability and long-term training progression, but also that the athlete achieves peak performance at the right time. In recent years, increased attention has been given to quantifying the training characteristics of elite endurance athletes [1–3] and this information has provided a fruitful foundation for hypothesis testing regarding training load and physiological adaptation. At the same time, a strong knowledge base has developed regarding best practice for the tapering and peaking process, based largely on experimental interventions [4–6]. However, studies linking the characteristics of the long-term training process to those of the short term pre-peaking and peaking process are lacking.

Recently, a number of descriptive studies, both retrospective and prospective, have been published on the training character-istics of athletes from endurance sports such as running [7–12], cycling [13–14], XC skiing [15–17], swimming [18–19], rowing [20–21], triathlon [22–23], speed skating [24–25] and kayaking [26]. Training load variables such as volume, frequency and intensity distribution appear to play an interactive role in maximizing physical capacity and performance [27]. Depending on the specific muscular loading characteristics of the sport, athletes typically train 500 h (distance running) [7,8,11,12,28,29] to well in excess of 1000 h per year (rowing, swimming, cycling, triathlon) [13–14,18–23] performed during 400–800 annual training sessions [11–12,15–17,23], in order to reach an internationally elite level. When examining the intensity distribution of this large training volume, a number of studies across a broad range of sports converge on the finding that 75–90% of all endurance training time is performed as low intensity training (LIT, below the first lactate turn point) for athletes training >

500 h per year. The remaining 10–25% is comprised of high intensity training (HIT) performed above the first lactate turn point [7–8,14–15,22–23]. This approximate "80–20" distribution between low and high intensity training among high-level performers is a robust finding [3], even if mechanistic explanations for its ubiquity remain speculative. Furthermore, the "best practice" magnitude and distribution of HIT remains unclear. In addition, the training-dose response relationship has a significant individual variation component, which further complicates the generalizability of the picture. While the influx of descriptive data on the training of elite endurance athletes has informed training practice, and stimulated new experimental studies, methodological compromises are inherent to the challenge of measuring behavior reliably and precisely in highly selected groups. Available descriptive studies typically only present data over a shorter time frame [7–8,12], at a sub-elite level [9,14–15,17,21–22] or as single case studies [11,23,28–29]. Accuracy in training monitoring is also unclear, due to weaknesses in methods such as questionnaires [10] or compilation and analysis of data that are in part or completely based on training plans instead of strict quantification of actual training performed [7–8,20]. Limited data currently exist on the long-term training of highly trained and elite athletes, based on accurate training monitoring [30].

Short-term training manipulations to achieve peaking for optimal sports performance have been investigated for more than 20 years. A synthesis of studies on well-trained athletes from a variety of different sports has shown a performance improvement of up to 3%, providing the final 4–28 days of training are executed correctly [5–6,31–33]. All other things being equal, a well-executed peaking phase can therefore dramatically increase the odds of winning a gold medal at a championship event for an individual athlete with finalist potential. In the research literature, the peaking process is typically divided into two phases: a pre-tapering phase, and the final taper period culminating with the intended competition. The aim of the pre-tapering phase is to stimulate a controlled "over-reaching" state and elicit a super-compensatory adaptive response in the following taper. Experimentally, the optimal duration of the actual taper depends on the training executed in the pre-taper [6,33–34]. The taper is initiated approximately 14 days prior to the desired peak performance, and the aim of this phase is to facilitate regeneration and reduce fatigue, while maintaining or increasing fitness and technical/psychological readiness in order to mobilize maximal performance in competition [4–6,35]. The optimal training volume, frequency and intensity in each phase is debated [4–6,31,35], but a reduction in training load of between 41–60% from pre-taper to taper has been recommended. This reduction appears to be best achieved via reduced training duration per session, while maintaining session frequency [5]. Maintaining training intensity is considered to be a key factor in a successful peaking regime, and it is therefore recommended that the frequency of HIT sessions be maintained during the taper [36–39]. Despite 20 years of research on tapering and peaking for athletic performance, we are unaware of any study that has successfully quantified the "real life" peaking strategies of athletes achieving ultimate success in Olympic Games or World Championship events. It is therefore unclear how the models developed from controlled experimental studies are translated to the actual peaking practices of elite endurance athletes. Furthermore, few studies havelinked peaking strategies to annual training characteristics and the competitive season of elite athletes [30].

The current study therefore aimed to: 1) present highly accurate day-to-day annual training data from a cohort of endurance athletes that all won Olympic or World Championship gold medals and, 2) quantify and examine relationships between annual training and peaking characteristics in these athletes.

Methods

Subjects

Four male and seven female former and current Norwegian elite XC skiers and biathletes were included in the study (Table 1). All athletes had won a least one individual Olympic or World Championship senior gold medal during their career. In total, included males had won 41 (5–26) and females 25 (1–9) gold medals (includes both individual and relays from 1985 through 2011). In addition, included athletes had systematically and accurately recorded their day-to-day training in detail from junior through to senior level. In the current study, we have analyzed and reported the year specifically leading up to their most successful competition at senior level. The regional ethics committee of Southern Norway reviewed the study and concluded that, due to the nature of the investigation, it did not require their approval. The study was therefore submitted to and approved by the Norwegian Social Science Data Services (NSD), and all athletes gave their oral and written informed consent prior to study participation.

Physiological testing

All athletes underwent regular physiological testing during their career. The test values presented in Table 1 represent the highest result achieved during the analyzed year. There were no physiological tests performed during the competition period, and the presented results therefore represent tests from October or November, while Olympic or World Championship events were typically held in February-March. All physiological testing was conducted at the Norwegian Olympic training center. $\dot{V}O_{2max}$ testing was performed as running at 10.5% inclination on a motorized treadmill (Woodway Gmbh, Weil am Rhein, Germany) calibrated for speed and incline. The procedure started with an extensive warm-up sequence, followed by a stepwise increase in running velocity every minute thereafter until volitional exhaustion, normally occurring after 4–6 minutes. Starting velocity for all athletes corresponded to 85–90% of $\dot{V}O_{2max}$. The increase was 1 km.h^{-1}.min^{-1}, and the last velocity step was held for at least 1 min. The test was terminated before voluntary exhaustion if the $\dot{V}O_2$values leveled off or decreased despite increasing workload and ventilation, in addition to respiratory exchange ratio (RER) > 1.10. $\dot{V}O_{2max}$ was defined as the highest average of two consecutive 30 s measurements. Oxygen uptake was measured using EOS Sprint (Jaeger-Toennis, Wurtzburg, Germany) until 2002, after which an Oxycon Pro (Jaeger-Toennis, Wurtzburg, Germany) metabolic test system was used. An internal comparison between the two analyzers was conducted during the transition in 2002 and showed identical regression lines for the treadmill running velocity $-\dot{V}O_2$ relationship with both systems. Primarily two exercise physiologists supervised all testing during the entire period.

Training monitoring

Athletes included in the study recorded their day-to-day training during their most successful year in paper diaries designed by the Norwegian Ski Association [40–41], the Norwegian Biathlon Association [42] or, since ~2005, in the digital version developed by the Norwegian Olympic Federation (OLT). The training recorded for each session included total training time distributed across training form (strength, endurance, sprint), activity form

Table 1. General characteristics of athletes included in the study.

Subject	Gender	Age	Height	Weight	$\dot{V}O_{2max}$ (ml·kg^{-1}.min^{-1})	$\dot{V}O_{2max}$ (l.min^{-1})
1	M	28	180	77	92.5	7.13
2	M	26	190	82	81.9	6.73
3	M	29	189	83	84.8	7.07
4	M	28	179	66	81.2	5.25
5	F	23	172	55	72.9	3.90
6	F	23	176	63	73.6	4.64
7	F	29	173	63	76.6	4.81
8	F	20	175	69	70.4	4.83
9	F	28	166	61	69.1	4.24
10	F	22	162	51	76.0	3.93
11	F	30	169	64	71.4	4.60
Mean ± SD, Male		28±1	185±6	77±8	85.1±5.2	6.5±0.9
Mean ± SD, Female		25±4	170±5	61±6	72.9±2.8	4.4±0.4

Values are reported from the analyzed year in the current study.
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(skiing, roller-skiing, running, cycling etc.), and intensity zone, as well as specific comments regarding session details. All paper training diaries were transferred session by session to digital format by persons from the current research group. Total training time and frequency of sessions was distributed in line with the structure in Figure 1. Digitized diary data was rigorously cross-checked for internal consistency among different training distribution breakdowns at the individual level. Internal consistency of digitized training records from all included athletes was ≥99%.

All the athletes included in the study used a 5 intensity zone model, where zones 1–2 are classified as LIT and zones 3–5 as HIT. The intensity scale presented in Table 2 represents average self-reported zone-cut offs from 29 elite XC-skiers from a previous study [43]. In the results section we have presented the data either in a binary model (LIT/HIT) or a 5-zone model were zones 1–2 are below the first lactate threshold (LT^1), zone 3 between LT^1 and LT^2, and zones 4–5 above LT^2 [3,44]. The intensity distribution is classified both according to a time in training zone approach and a frequency based session goal approach (SG). These methods and the intensity zones cut-offs have been described in detail recently [43].

Annual periodization phases and peaking model

General training data from the entire year are either presented as annual training characteristics or divided into different periodization phases as presented in Table 3. Peaking characteristics were quantified based on the final 6 weeks of training prior to the gold medal winning performance, as delineated in Table 3.

Statistical analyses

All data in text, tables or figures are presented as mean ± standard deviation (SD) and/or range. Statistical comparisons between different periodization phases are focused on the general preparation period (GP), specific preparation period (SP) and competition period (CP) in addition to comparing the actual peaking phase with pre-peaking phase, GP and SP. Data were not normally distributed. Therefore each variable from the GP, SP and CP (overall, pre-peaking and peaking phase) was tested with a non-parametric Friedman test, followed by a post-hoc test (Wilcoxon Signed Rank) to locate statistical differences. Male

and female athlete data are merged, as a Mann-Whitney U Test revealed no significant differences in any relevant variables across gender (data not shown). All figures and statistical analyses were performed using Microsoft Excel or SPSS 18.0 (SPSS Inc, Chicago, IL, USA) and statistical significance was accepted at the $P<.05$ level or Bonferroni adjusted alpha level.

Results

Annual training characteristics

Total training volume was 770±99 h (622–942) distributed across 470±68 sessions (375–585) throughout the gold medal year. Endurance training accounted for 94±3% of all training time with the remaining 5±2% composed of strength training and 1±1% ski sprint training. Time in training zone based intensity distribution showed that 91±1% of all endurance training time was executed as LIT (zone 1–2) and 9±1% as HIT (zone 3–5).

Monthly training distribution of specific and non-specific activity forms during each training phase are presented in Figure 2. Endurance and sprint training was executed with sport-specific movement patterns (ski or roller ski) for 64±3% (465±56 h/min-max: 376–569 h) of total training time, with the remaining 36±3% (265±47 h/min-max: 196–337 h), composed of non-specific activity forms (running, cycling etc.) throughout the year. The proportion of sport-specific training increased significantly from GP (48±6%) to SP (87±8%) and CP (92±4%) ($P<.01$).

The distribution across all five intensity zones was: zone 1: 86.0±3.4%, zone 2: 5.3±3.0%, zone 3: 3.3±0.9%, zone 4: 3.3±1% and zone 5: 2.1±1.0%. When all endurance sessions were nominally categorized using the SG approach, the distribution was 77±2% LIT and 23±2% HIT (Figure 3, A). Weekly training patterns during each training phase are presented in Table 4.

Total annual HIT duration (including competitions) was 63±14 h (46–85 h) distributed across 106±20 sessions (85–147) throughout the year. The relative distribution of HIT duration in intensity zones 3, 4 and 5 was 39±10%, 37±13% and 24±13% respectively, and 32±6%, 38±14% and 30±13% according to a SG distribution. Monthly frequency of HIT sessions increased

TOTAL TRAINING TIME OR SESSIONS
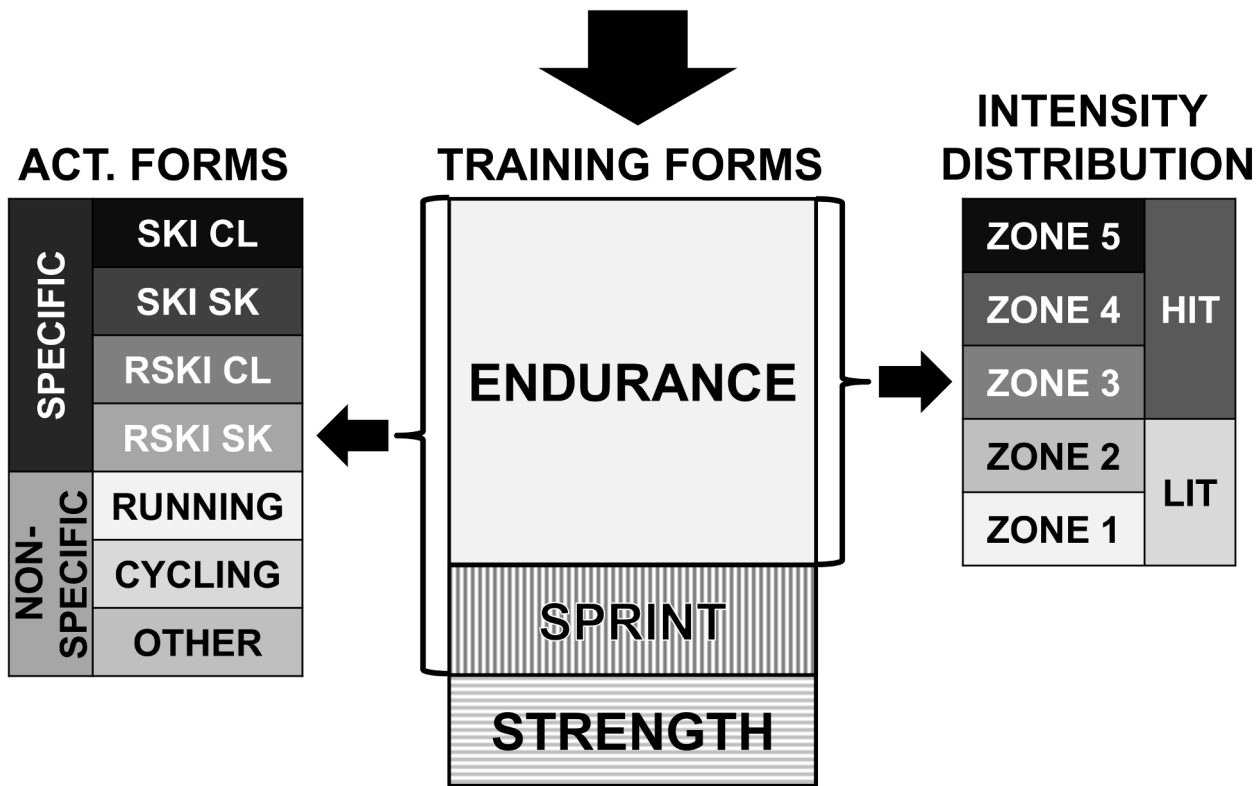
Figure 1. Training distribution methods. Total training time was divided into training forms (endurance, sprint and strength). Endurance time and frequency were further distributed into 5 intensity zones in line with table 2. Zones 1–2 are LIT and zones 3–5 are HIT. Endurance and sprint time together were divided into activity forms. Ski and roller ski were classified as specific, and running, cycling or other as non-specific activity forms. doi:10.1371/journal.pone.0101796.g001

from GP to SP ($P<.01$). In addition, the monthly frequency of intensity zone 5 sessions increased from GP to SP and then remained unchanged in the CP ($P<.01$) (Figure 3, B). Weekly HIT patterns during each training phase are presented in Table 4.

Peaking characteristics

Total training time ($h.wk^{-1}$) decreased by $9\pm14\%$ from the pre-peaking to peaking phase, but this did not reach statistical significance. However, the reduction from GP, when training volume was highest, to the peaking phase, was $32\pm15\%$ ($P<.01$). This decrease in total training volume was entirely due to a reduction in non-sport-specific training. Individual data for each of

the 11 athletes are presented in Figure 4. The decrease in training volume from GP and pre-peaking phase to the peaking phase was achieved via a reduction in both endurance and strength training, while sprint training time remained stable, although there was a tendency for sprint training time to increase slightly from the pre-peaking phase to the peaking phase. There were no significant changes in total session frequency per week between the peaking phase and any of the other phases (Figure 5 A and Table 4).

There was non-significant decrease of $9\pm15\%$ in LIT endurance training ($h.wk^{-1}$) from the pre-peaking phase to the peaking phase. However, LIT training volume decreased by $31\pm17\%$ ($P<.01$) from GP to the peaking phase. In contrast, HIT time ($h.wk^{-1}$) remained stable from both pre-peaking phase to the

Table 2. The 5-zone, 3-zone, and binary intensity scales used in the current study.

Intensity Zone	Typical Blood lactate[A] (mmol. L^{-1})	Typical Heart Rate (% max)	Three zone model	Binary model
5	>5.8	>94	>LT^2	
4	3.7–5.7	89–93		HIT
3	2.1–3.6	84–88	LT^1–LT^2	
2	1.3–2.0	74–83		LIT
1	<1.2	54–73	<LT^1	

[A]Measured with Lactate Pro LT-1710. Reference values presented are derived from the average self-reported zone-cut offs of 29 elite XC-skiers [43], and individual adjustments are required.
doi:10.1371/journal.pone.0101796.t002

Table 3. Training phases in annual cycle, including peaking phases.

Period in annual training cycle	Duration
Preparation period (PP)	May-December
Transition period	_May_
General preparation period (GP)	_June-October_
Specific preparation period (SP)	_November-December_
Competition Period (CP)	January-March
Pre-peaking phase	_6–3 weeks before championship event_
Peaking phase	_Last 14 days before championship event_
Regeneration period	April

peaking phase and from GP to the peaking phase (Figure 5 A and Table 4).

LIT endurance session frequency decreased from GP to the peaking phase by $21\pm24\%$ ($P = .016$) but remained stable from pre-peaking phase to the peaking phase. Weekly HIT session frequency increased by $40\pm27\%$ ($P<.01$) from GP to the peaking phase, but remained stable from pre-peaking phase to the peaking phase (Figure 5 B). Training volume and frequency distribution among zones 3, 4 and 5 through the different phases are presented in Figure 5 B and Table 4.

Discussion

To the authors' knowledge, this is the first study to connect accurate annual day-to-day training data to a specific peaking period in a group of athletes achieving ultimate international success in an endurance sport. The main findings of the present study are: 1) The annual training data for these Olympic and World champion XC skiers and biathletes conforms to previously reported training patterns amongst elite endurance athletes. 2) In contrast, peaking characteristics for these gold medalists did not conform to suggested best practice for tapering strategies in elite endurance athletes, as derived from partly experimental studies.

Annual training characteristics

Training volume. High training volume has emerged as a key commonality in successful endurance training [20,1–3,25]. Athletes in the current study trained $\sim$800 h.year^{-1} across $\sim$500 annual training sessions although there were individual differences. This finding is in line with previous studies reporting training volume in elite XC skiers [1,16–17]. Muscular loading differences and stress associated with different activities probably explain why there is large variation in reported annual training volume across sports. For example, top international runners are reported to train "only" 500–600 h.year^{-1} [7–8] while a case study of an international level triathlete reports >1000 h.year^{-1} [23]. The current data show a tendency for developments in training
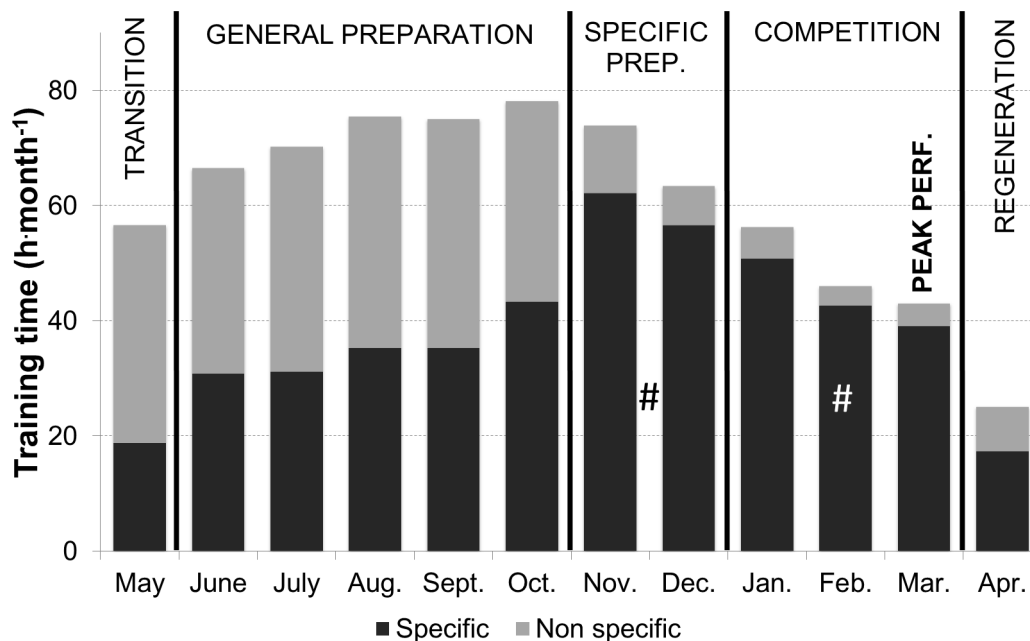
Figure 2. Annual organization of specific and non-specific activity forms. Endurance and sprint training time (h) distributed into specific (ski and roller ski) and non-specific (running, cycling and other) activity forms during each month and divided in phases. # Difference in specific training time vs. GP ($P<.01$).

Figure 3. Annual training characteristics. A: Total training time (h) distributed into endurance training (zones 1–5), strength and sprint (bars, y-axis), and total training frequency (sessions) (line, z-axis) during each month and divided into phases. B: HIT frequency (sessions) distributed into zones 3, 4 and 5 (bars, y-axis) during each month and divided in phases. There was a statistically significant difference (P<.05) in total HIT sessions and zones 3, 4 and 5 respectively across the GP, SP and CP. Pairwise post-hoc tests showed: * Difference in total HIT sessions across phases (P<.01). # Difference between zone 5 sessions vs. GP (P<.01).
doi:10.1371/journal.pone.0101796.g003

patterns during the time period from 1985 to 2011, with a positive relationship between total training volume and year of championship title (r = .59, P = .055). Increased training volume appears to be mainly due to increased frequency of training sessions from 1985 to 2011, while average duration per training session has remained relatively stable at 1.7±0.2 h.

During the entire training year, 94% of all training *time* was executed as endurance training. However, strength and sprint training appear to play an important role in the training of XC skiers [45]. Strength training was carried out as general, specific or maximal, while sprints included both specific ski sprint-related exercises and jumps. Interestingly, ~90% of all strength and sprint

training was executed during the preparation period (PP). In practice, this means two to three strength and sprints sessions.-week^{-1} in PP compared to one weekly session during CP, typically conducted at the end of endurance training sessions. The main underlying philosophy for these athletes was to build up a prescribed strength level during PP and then maintain this level during CP. Unfortunately, systematic strength testing documentation was not available for these athletes. We are therefore not able to verify whether strength characteristics of these athletes were stable during CP. However, previous research suggests that one bout of strength training per week is sufficient to maintain strength levels over shorter time frames [46].

Table 4. Weekly training patterns during different phases throughout the season.

Weekly training patterns	Transition phase	General preparation phase	Specific preparation phase	Competition phase			Regeneration phase
				Overall	Pre-peaking	Peaking	
Total training:							
Training time (h·wk⁻¹)	13.9±5.3	17.9±2.5	16.5±2.4	11.6±2.2 #β	13.5±3.1 #β	12.1±2.4 #β	6.1±3.7
Tr. sessions·wk⁻¹	8.1±2.8	10.1±1.0	10.3±1.7	8.3±2.1 #β	8.9±1.9 #β	9.2±2.3	4.3±2.3
Training forms:							
Endurance (h·wk⁻¹)	12.7±4.9	16.5±2.6	15.7±2.2	11.2±2.0 #β	12.9±2.8 β	11.7±2.3 #β	5.9±3.6
Strength (h·wk⁻¹)	1.1±1.0	1.2±0.5	0.7±0.4 *	0.3±0.2 #β	0.5±0.4 #	0.2±0.2 #β	0.2±0.3
Sprint (h·wk⁻¹)	0.1±0.1	0.2±0.2	0.1±0.1	0.1±0.1	0.1±0.1	0.2±0.2	0.0±0.0
Intensity distribution:							
Zone 1 (h·wk⁻¹)	10.8±4.7	14.3±2.6	13.8±2.1	9.4±2.3 #β	11.2±2.8 β	9.7±2.0 #β	4.9±2.9
Zone 2 (h·wk⁻¹)	1.3±0.9	0.9±0.6	0.6±0.5 *	0.4±0.3 #	0.4±0.5 #	0.6±0.8	0.3±0.5
Zone 3 (h·wk⁻¹)	0.3±0.2	0.6±0.2	0.5±0.2	0.4±0.3	0.4±0.2 #	0.4±0.4	0.2±0.3
Zone 4 (h·wk⁻¹)	0.2±0.2	0.5±0.2	0.4±0.3	0.5±0.3	0.5±0.4	0.7±0.4 β	0.3±0.3
Zone 5 (h·wk⁻¹)	0.1±0.1	0.2±0.1	0.4±0.2 *	0.5±0.3	0.4±0.3	0.2±0.3	0.2±0.2
Activity forms:							
Specific (h·wk⁻¹)	4.3±3.3	8.1±1.7	13.7±2.3 *	10.3±1.5 #β	12.2±2.6 #	10.8±1.8 #	4.1±3.2
Non-Specific (h·wk⁻¹)	8.5±4.6	8.6±1.5	2.1±1.2 *	1.0±0.6 #β	0.8±0.6 #β	1.0±1.0 #β	1.8±1.5

Values are mean ± SD and represent training hours per week in different phases. A non-parametric Friedman test indicated that there was a statistically significant difference in all variables across the GP, SP and CP (P<.05 level). A pairwise post-hoc test (Wilcoxon Signed Rank) was used to determine whether there was a statistically significant difference between the GP, SP or CP, as well as pre-peaking and peaking phases (P<.01 level).
*P<.01, GP vs. SP;
#P<.01, GP vs. CP, pre-peaking or peaking;
βP<.01, SP vs. CP, pre-peaking or peaking;
†P<.01, pre-peaking vs. peaking.
doi:10.1371/journal.pone.0101796.t004
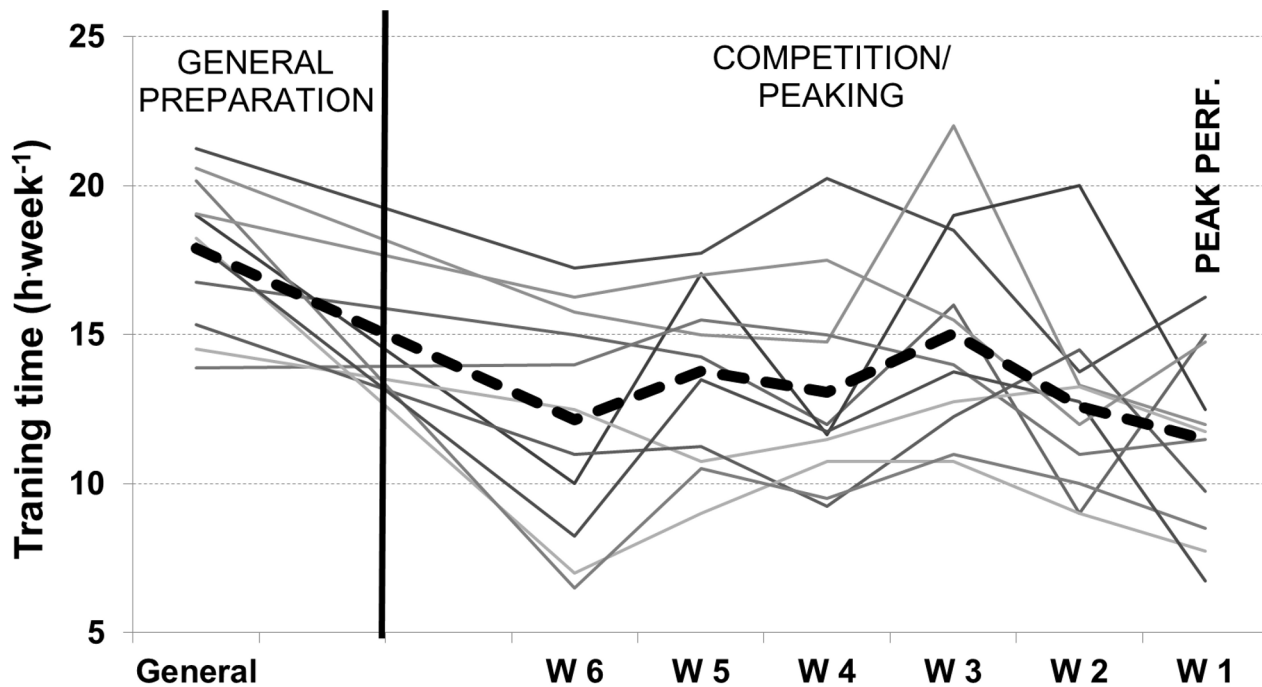
Figure 4. Individual peaking characteristics. Individual (lines) and average (dotted bold line) total weekly training volume during GP, and the last 6 weeks prior to championship title.
doi:10.1371/journal.pone.0101796.g004

Activity forms. During the entire training year, 64% (~500 h) of all training was executed with sport-specific movement patterns (skiing/roller-skiing). However, over the course of the training year the amount of specific training increased from ~50 to 90%. That is, in line with the early periodization models [48], when training load was highest in PP only ~50% of all training was executed as ski or roller-ski. Otherwise, when training load was lowest in CP, >90% was performed as sport-specific training.

Sport-specific training is outlined as a key to improving $\dot{V}O_{2max}$ [51–52]. Hence, a high portion of sport-specific training during the CP for these athletes appears to be essential in order to reach an international performance level. However, we maintain that a large volume of non-specific activity forms during PP serve an important purpose in increasing trainability and improving general aerobic capacity [53–54].

Intensity distribution. Recently there has been some debate regarding findings suggesting that HIT induces superior physiological and performance adaptations compared with LIT [47]. The trend among endurance athletes is to adopt a polarized intensity distribution model integrating both intensity domains [7,9,16,20,25]. The present data consistently demonstrate that these 11 gold medalists executed a large proportion of their total training as LIT throughout the annual cycle. Total LIT time was progressively increased during PP, in line with some key features from the early periodization models of Matwejew [48], before being reduced dramatically during CP. However, it is important to emphasize that the marked intensity shift to more HIT described in Matwejew's models was not observed in this group of elite athletes.

The current study contributes unique knowledge to our understanding of the self-selected duration and distribution of HIT in elite endurance sports. Depending on the quantification methods used [43], results from several other studies suggest that

an approximate 80/20% LIT/HIT distribution is optimal, although the percentage of HIT varies from ~10–30% [7–9,14–16,44,49–50] using a time in training zone method [43]. However, in the current study only 9% of annual endurance training time, or ~60 h/~100 sessions were reported to be above LT[1]. This is in contrast to other top Olympic athletes reported to perform a greater amount of HIT in addition to high total training volume [23,28–29]. The total volume of HIT training was evenly distributed throughout the year with an average of 5±2 h or 9±3 sessions·month^{-1}. Interestingly, it was also found that HIT training sessions were distributed virtually equally among zones 3, 4 & 5, with average durations of 0.8/0.6/0.5 h in zones 3/4/5 respectively. However, from the PP to CP, both duration and frequency in zones 3 and 4 were maintained, while the frequency of zone 5 training sessions increased. That is, as the main performance peak came closer, LIT time decreased dramatically while HIT patterns shifted towards a more polarized model, despite virtually constant HIT training time.

Peaking practice

Training volume and specificity. Optimizing the reduction in training load during the peaking phase is believed to be a key to optimal championship performance [6,30]. Training load is described as a combination of training volume, intensity and frequency [27]. A meta-analysis conducted by Bosquet et al [5] concluded that athletes could maximize taper-associated benefits by reducing training volume by ~50%, without reducing training frequency or training intensity.

In line with current best practice [4–6], we defined the peaking phase as the last 14 days prior to the athletes' most successful competition (Olympic/World Championship gold medal), and compared training patterns in this final training phase to the penultimate phase beginning 4 weeks prior to the peaking phase (pre-peaking phase). With regards to training volume, we found
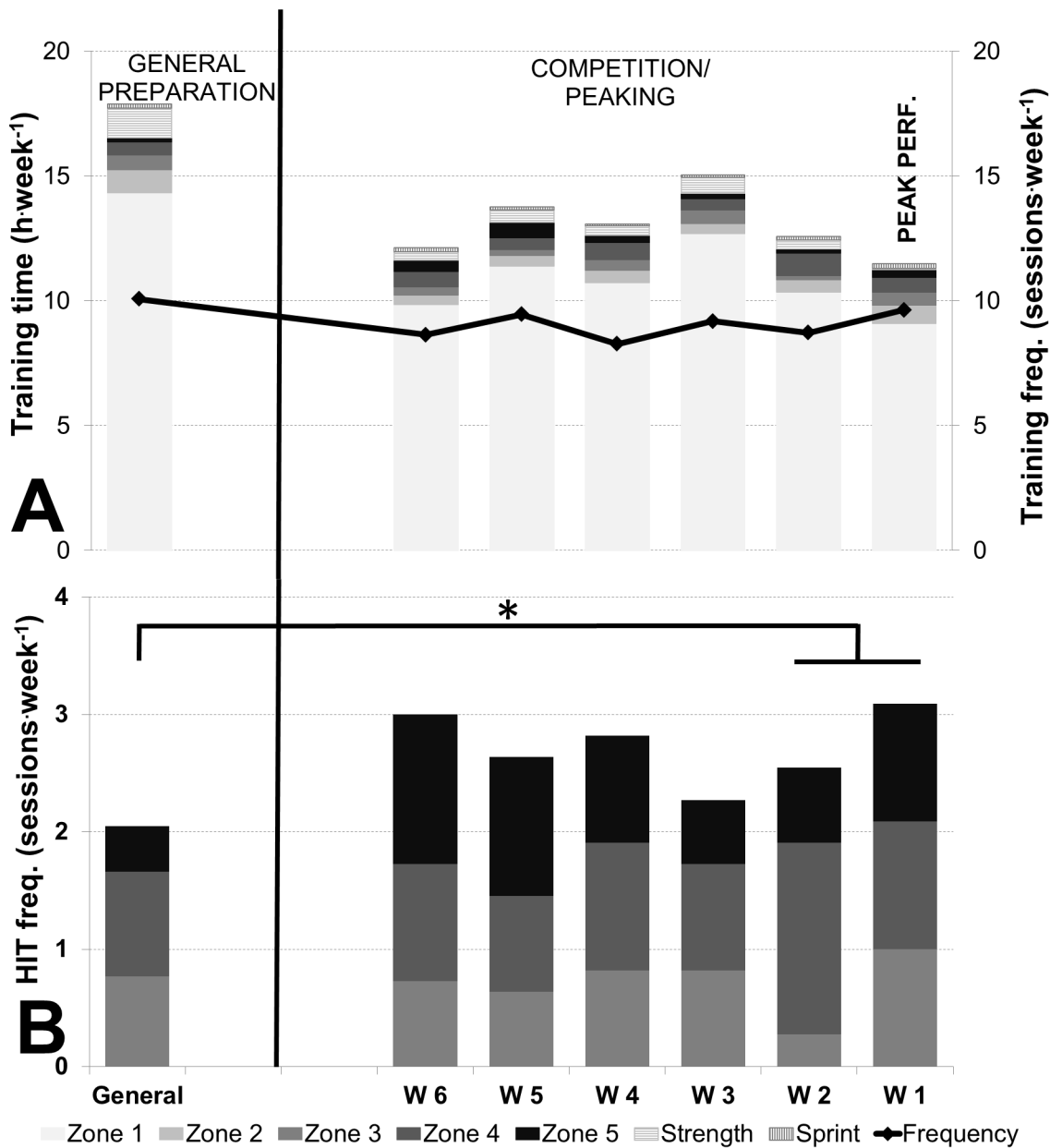
Figure 5. Peaking characteristics. A: Weekly training time (h) distributed into endurance training (zones 1–5), strength and sprints (bars, y-axis), and total training frequency (sessions) (line, z-axis) during GP, and during the last 6 weeks prior championship title. B: HIT frequency (sessions) distributed into zones 3, 4 and 5 (bars, y-axis) during GP, and during the last 6 weeks prior to championship title. There was a statistically significant difference ($P<.05$) in total HIT sessions and zones 3 and 5 respectively across GP, pre-peaking phase and peaking phase. Pairwise post-hoc tests showed: * Difference in total HIT sessions across phases ($P<.01$). There were no statistically significant differences in zones 3, 4 or 5 across phases.
doi:10.1371/journal.pone.0101796.g005

only a 4 and 15% (NS) decrease in training volume during days -14 to -8 and days -7 to-1 respectively, compared to the pre-peaking phase. This is substantially less than the current taper recommendations of a ~50% reduction (Figure 6). It is possible to speculate as to why these champion athletes chose a strategy very different from experimentally derived optimum. Bosquet et al [5] reported no effect on performance if the reduction in training volume was 20% or less. However, there was large individual variation in peaking behavior in the current study, and no clear patterns emerged. In fact, 4 of the 11 athletes increased their training volume during the last seven days. However, existing research has limitations in terms of narrow focus on one single competition

[32]. In contrast, our results demonstrate that competitions are frequently integrated into the peaking process in elite sports. The competition schedule, designed by the International Ski Federation, is crucial in planning a taper and must be integrated into the peaking regime. The WC season in these sports typically consists of two competition days per week over up to 14 weeks with a maximum of two to four competition free weeks. Such a schedule may interfere with an optimal tapering process. Rather than incorporating a single tapering phase, such a schedule may rather require the athlete to perform repeated "mini-tapers" prior to each competition.

Since there was minimal decrease (NS) in overall training volume during the four-week pre-peaking period, we chose to compare training performed during the peaking phase to GP, where weekly training volume was highest. Once the athletes started their WC season, in either XC or biathlon, their total training volume was consistently lower than that reported during GP. Relative to GP, training volume was, respectively, 29 and 35% lower during the penultimate and final weeks before each athlete's gold medal race. High competition stress load and frequent travel may dictate the reduced training volume during this phase, rather than a predetermined periodization model. These data indicate that peak training volume for these athletes was markedly dissociated in time from peak performance by up to 4 months, even accepting individual variations. It is unclear whether high training volume executed during PP 4–9 months prior still influences physical capacity during the peaking phase, following an extended period of reduced training volume where competitions themselves become a key source of HIT.

Several decades ago, Hickson et al [55] reported that trained athletes retain most of their physiological and endurance performance adaptations during 15 subsequent weeks of reduced training. However, for an Olympic athlete, even a small performance decrement associated with reduced training could be the difference between a medal and fourth place. Unfortunately, similar to strength performance, we do not have data for endurance tests throughout the year. Our objective testing data for these athletes terminates 3–4 months prior to their gold medal

performances. In elite practice, laboratory testing typically ends when the competitive season begins. However, in a similar group of athletes with virtually identical training patterns as in the current study, Losnegaard et al [17] found that aerobic physiological adaptations were maintained, and performance and anaerobic adaptations were even enhanced, several months after peak training volume.

To our knowledge, no data are available providing mechanistic links that span such an extended time period. It is possible to speculate that a prolonged period of high training volume during PP could favorably alter genomic sensitivity to training during the season through epigenetic mechanisms [51]. Such cellular level adaptations to high training volume could be a mechanistic bridge linking PP training characteristics to training effects several months later, when high training volumes are precluded by the competition and travel stress load.

During both the pre-peaking phase and the peaking phase, virtually all (92%) training was conducted as XC skiing. This shift towards more specific movement patterns when competition approaches may explain why peak performance is possible even after several months with reduced training volume [51–52].

Training frequency. The athletes in the current study trained, on average, 8–10 sessions·week^{-1}, with no significant differences in training frequency between the peaking phase and other phases (Table 2). This finding is in line with current taper recommendations [4–6]. Nor were there any significant differences in the number of LIT or HIT sessions from the pre-peaking
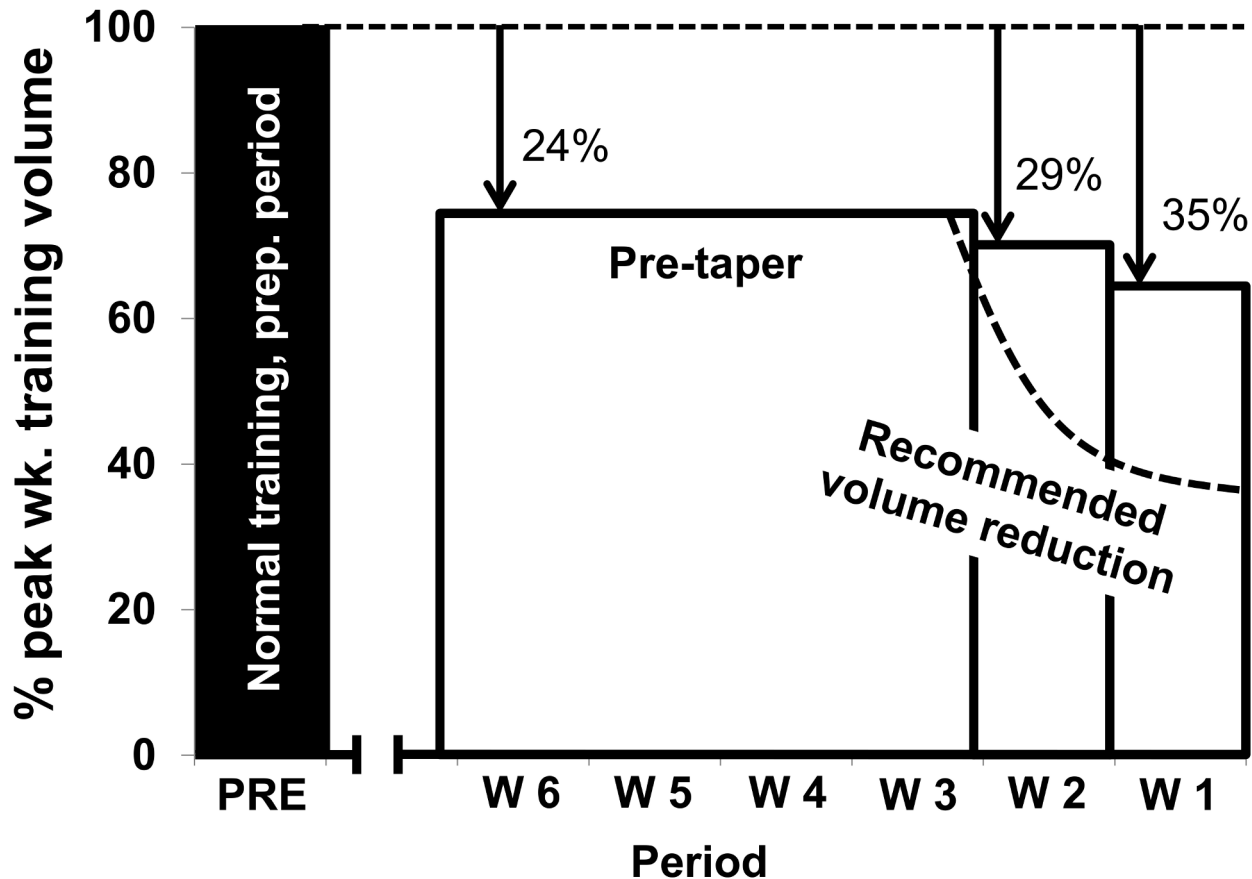
Figure 6. Taper comparison. Schematic representation of the actual taper observed in current study compared to recommended volume reduction. Adapted from Mujika & Padilla [4].
doi:10.1371/journal.pone.0101796.g006

phase to the peaking phase. However, LIT frequency decreased from GP (8 sessions·week^{-1}) to the peaking phase (6 sessions·week^{-1}), indicating that the observed reduction in total LIT time was a result of both reduced session frequency and session duration.

Intensity distribution and rest days. Adaptive stimuli from HIT sessions appear to be a key component in maintaining and enhancing physiological and performance adaptations q during a taper period [36–37,39]. McNeely & Sandler [31] reported that frequent short HIT bouts >90% $\dot{V}O_{2\max}$ are more effective than LIT to enhance endurance performance, and that, during a taper, steady-state workouts should be replaced by HIT intervals and short sprints in order to improve performance. Interestingly, we found that HIT duration did not change (1.3 h·week^{-1}) during any of the phases. However, HIT frequency increased from 2 sessions·week^{-1} in GP to 3 sessions·week^{-1} in the peaking phase ($P<.01$). In addition, there was a tendency towards increased sprint training duration from the pre-peaking phase to the peaking phase. Hence, HIT sessions during the peaking phase were typically executed more frequently but with shorter duration than during GP, alongside more frequent bouts of sport-specific "anaerobic sprint training". Examining distribution of training among intensity zones 3, 4 and 5, we observed a tendency toward a decrease in zones 3 and 4 and an increase in zone 5 in both duration and frequency from GP to CP. This suggests that total HIT duration did not change throughout the year, but that the actual executed intensity shifted towards a more polarized model as the major competition approached.

To our knowledge, details regarding best practice models of HIT patterns and recovery strategies during the final days prior to peak performance are lacking in the literature. However, the current data show that short bouts of HIT were performed evenly throughout the final 14 days (~5 sessions in total per athlete) (Figure 7). Interestingly, 10 out of 11 athletes performed a HIT session within 48 h of competition. The exact intensity during these HIT sessions is somewhat inconsistent, but was typically above LT^2. Competitions performed during the final days but not seen as "primary events" were also integrated into the peaking strategy. Whether these contribute to a beneficial peaking regime, or interfere with the optimal strategy is not clear. Eight of 11 athletes in the present study competed in at least one championship final prior to the event in which they won a gold medal. With regard to recovery strategies, rest days were typically concentrated in days 12 to 6. Among all 11 athletes, only 3 athletes took a rest day during the last 5 days, compared with 14 athlete rest days taken in the middle period of the peaking phase. That is, rest days were 3 times more likely to be taken during the middle portion of the peaking phase (days 12–6) compared with the final 5 days. However, it is not clear whether this organization of HIT and rest days during the final 14 days was the result of strategic planning to optimize performance, or merely coincidental. It has been previously reported that runners taking a rest every third day during a six day taper performed worse than those athletes who trained every day [56], and this topic may be a fruitful area for future research.

Altitude training. Altitude training is incorporated into the training of most world-class XC skiers, and is a consistent feature of Norwegian endurance training. For athletes in the current study, precise records are not available regarding all days spent at altitude or the specific altitude at which each training session was performed. For the last 2–3 decades, 4–6 annual training camps of 14–21 d duration living at 1800–2000 m above sea level and training at 1200 to 2800 m above sea level, have been integrated throughout the annual cycle. The aim of these altitude training
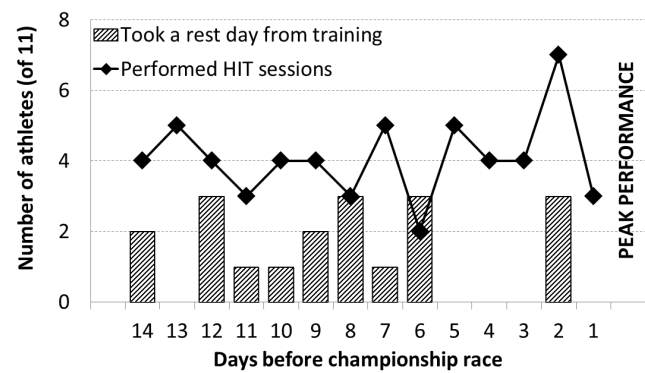
Figure 7. Peaking phase. Number of athletes (of 11) who performed HIT sessions (line) and number of athletes who took a rest day from training (bars) during the final 14 days prior to peak performance.
doi:10.1371/journal.pone.0101796.g007

camps is to stimulate increased hemoglobin mass, and specifically acclimate to competition venues located above 1400 m. The athletes in the current study typically spent 60 to 100 days training at altitude during the season quantified, although this was likely somewhat lower for those athletes winning gold prior to 1992. In addition, where championship events were held at moderate altitude (e.g. in Salt Lake City, 2002) altitude camps were also an important feature of the final weeks of training. Based on a previous study of 29 XC skiers training at altitude [43], objective data suggest that intensity distribution during altitude camps shifts towards lower intensity. Training at the highest aerobic intensities during such camps is essentially absent, unless it is performed at reduced altitudes. The likely impact of this emphasis on altitude training was to somewhat reduce the amount of HIT performed during PP.

Winning an international title in endurance sports clearly requires outstanding physiological capacity and performance level. Controlled laboratory trials of world-class elite athletes are challenging, and training literature based on less well-trained individuals may be misleading when linking findings to elite athletes. Our current data outlines unique and accurate day-to-day training data throughout a season that concluded with each athlete winning an Olympic or World championship title. Experimental approaches may in many ways be artificial, while descriptive training studies allow investigation of elite endurance athletes in a real-life situation. This may therefore provide a fruitful foundation from which to generate novel experimental research questions.

We did not find evidence of athletes following the current tapering recommendations regarding training volume reduction. However, when comparing training patterns during the peaking phase to training executed during PP several months earlier, we found a picture more analogous to that derived from experimental studies, although the magnitude of training time reduction was still lower. It is possible to speculate as to whether the medal-winning performances of these athletes was truly representative of their best possible performance, or if they could have skied even faster had they followed recommended tapering strategies specifically for that one event. On the other hand, the more progressive reduction in training time from GP to CP observed in the current study, continued to a lesser degree throughout the CP up until the major competition, may be the ideal strategy in sports where the competition schedule is organized as it is in XC skiing and biathlon. A three month competition phase during which athletes are typically required to compete once or twice every week, precludes the application of the recommended tapering strategy

presented in the research literature. Regardless, the performance of these athletes was sufficient to beat the rest of the field on the day, and take home the gold medal.

A central concern in a descriptive study such as this, where training self-report is the key data source, is whether the data are accurate and valid. We have recently demonstrated that elite endurance athletes report their training accurately, although we found some small discrepancies related to intensity distribution [57]. We believe the current data represent the same validity as shown in Sylta et al [57], since both athlete groups used similar monitoring routines, and some of the athletes are, in fact, represented in both papers. In addition, athletes recorded their training on a daily basis, which likely reduced reporting error.

Conclusions

These data show that winning an international title in XC skiing or biathlon requires a training load of ~800 h/500 sessions·year^{-1}, of which ~500 h is executed as sport-specific movement patterns. Endurance training time for these athletes was distributed as approximately 90% LIT and 10% HIT, equal to a ~80/20% SG distribution. Training volume was highest during GP and decreased progressively during SP and CP. Concurrently, the proportion of sport-specific training increased markedly. Total amount of HIT remained stable across all phases, although HIT training patterns tended to become more polarized in CP.

These athletes did not appear to incorporate a taper in the final weeks leading up to competition, with training volume, frequency and intensity remaining unchanged from the pre-peaking phase to the peaking phase. Hence, we did not observe the recommended ~50% training volume reduction that has been proposed as the optimal tapering strategy based on previous experimental studies. However, there was a clear reduction in training volume from GP to the peaking phase. This reduction was almost entirely due to a reduction in non-sport-specific LIT with virtually all training during the pre-peaking phase and the peaking phase composed of ski training. Only three out of 11 athletes incorporated a rest day in the final five days leading up to the best athletic performance of their career, A very large training load during the GP appears to be an important precondition for exceptional athletic performance several months later, although exactly how training loads in June-October are mechanistically connected to performance several months later remains unclear.

Author Contributions

Conceived and designed the experiments: ET SS. Performed the experiments: EH IS ET ØS. Analyzed the data: ET ØS SS IS TH. Contributed reagents/materials/analysis tools: ET EH. Contributed to the writing of the manuscript: ET EH ØS SS IS TH.

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Paper IV

The effect of different high intensity periodization models on endurance adaptions.

The Effect of Different High-Intensity Periodization Models on Endurance Adaptations

ØYSTEIN SYLTA[1], ESPEN TØNNESSEN[2], DANIEL HAMMARSTRÖM[3], JØRGEN DANIELSEN[4], KNUT SKOVERENG[4], TROELS RAVN[1], BENT R. RØNNESTAD[3], ØYVIND SANDBAKK[4], and STEPHEN SEILER[1]

[1]Faculty of Health and Sport Sciences, University of Agder, Kristiansand, NORWAY; [2]The Norwegian Olympic Federation, Oslo, NORWAY; [3]Section for Sport Science, Lillehammer University College, Lillehammer, NORWAY; and [4]Centre for Elite Sports Research, Department of Neuroscience, Norwegian University of Science and Technology, Trondheim, NORWAY

ABSTRACT

SYLTA, Ø., E. TØNNESSEN, D. HAMMARSTRÖM, J. DANIELSEN, K. SKOVERENG, T. RAVN, B. R. RØNNESTAD, Ø, SANDBAKK and S. SEILER. The Effect of Different High-Intensity Periodization Models on Endurance Adaptations. *Med. Sci. Sports Exerc.*, Vol. 48, No. 11, pp. 2165–2174, 2016. **Purpose**: This study aimed to compare the effects of three different high-intensity training (HIT) models, balanced for total load but differing in training plan progression, on endurance adaptations. **Methods**: Sixty-three cyclists (peak oxygen uptake ($\dot{V}O_{2peak}$) 61.3 ± 5.8 mL·kg^{-1}·min^{-1}) were randomized to three training groups and instructed to follow a 12-wk training program consisting of 24 interval sessions, a high volume of low-intensity training, and laboratory testing. The increasing HIT group ($n = 23$) performed interval training as 4×16 min in weeks 1–4, 4×8 min in weeks 5–8, and 4×4 min in weeks 9–12. The decreasing HIT group ($n = 20$) performed interval sessions in the opposite mesocycle order as the increasing HIT group, and the mixed HIT group ($n = 20$) performed the interval prescriptions in a mixed distribution in all mesocycles. Interval sessions were prescribed as maximal session efforts and executed at mean values 4.7, 9.2, and 12.7 mmol·L^{-1} blood lactate in 4×16-, 4×8-, and 4×4-min sessions, respectively ($P < 0.001$). Pre- and postintervention, cyclists were tested for mean power during a 40-min all-out trial, peak power output during incremental testing to exhaustion, $\dot{V}O_{2peak}$, and power at 4 mmol·L^{-1} lactate. **Results**: All groups improved 5%–10% in mean power during a 40-min all-out trial, peak power output, and $\dot{V}O_{2peak}$ postintervention ($P < 0.05$), but no adaptation differences emerged among the three training groups ($P > 0.05$). Further, an individual response analysis indicated similar likelihood of large, moderate, or nonresponses, respectively, in response to each training group ($P > 0.05$). **Conclusions**: This study suggests that organizing different interval sessions in a specific periodized mesocycle order or in a mixed distribution during a 12-wk training period has little or no effect on training adaptation when the overall training load is the same. **Key Words**: CYCLING, ENDURANCE PERFORMANCE, LACTATE THRESHOLD, MAXIMAL OXYGEN CONSUMPTION, PEAK POWER OUTPUT, TRAINING ORGANIZATION

To maximize physiological adaptations and performance capability in elite athletes, all factors involved in the training organization need to be optimized. In endurance sports, these include the duration and intensity of individual training sessions, the frequency of training sessions, and the organizational pattern of these stimulus variables over time. Recent descriptive studies of some of the world's best endurance athletes have shown that successful athletes in cycling (14,25,35), running (1,2), and cross-country skiing (21,22,33) perform a high volume of low-intensity training (LIT) (defined as work eliciting a stable blood lactate concentration [la$^-$] of less than approximately 2 mmol·L^{-1}) in addition to much smaller but substantial proportions of both moderate-intensity training (MIT) (2–4 mmol·L^{-1} blood lactate) and high-intensity training (HIT) (training above maximum lactate steady-state intensity [>4 mmol·L^{-1} blood lactate]) throughout the preparation period. The majority of descriptive studies present a "pyramidal" training intensity distribution (TID), with high volume of LIT, substantial MIT, and less HIT, whereas a few studies suggest athletes to adopt a "polarized" TID (reduced volume

APPLIED SCIENCES

of MIT, somewhat higher HIT), which have been proposed to give superior endurance adaptations (27,29). However, although some evidence suggests superior responses by increased HIT in a clearly polarized TID, there is currently limited empirical data comparing different stimulus ordering approaches for the HIT component of training that is often seen as critical to maximizing adaptations.

The term training "periodization" originates primarily from older eastern European texts and is widely and rather indiscriminately used to describe and quantify the planning process of training (11). Periodization plans add training load structure, with well-defined training periods designed to stimulate specific physiological adaptations (e.g., $\dot{V}O_{2max}$) or performance qualities in a specific order presumed optimal for performance development. Such endurance training models involve the manipulation of different training sessions periodized over timescales ranging from microcycle (2–7 d), to mesocycle (3–6 wk), to macrocycle (6–12 months; including preparation, competition, and transition periods). Recent experimental findings indicate improved training adaptations after shorter, highly focused training periods of HIT compared with mixed programs with the same total quantity of intensive sessions (18–20). For example, Rønnestad et al. (18) found superior effects of a 12-wk block periodization program, where each 4-wk cycle consisted of 1 wk of five HIT sessions, followed by 3 wk of one HIT session per week, when compared with a traditional program incorporating "two weekly HIT sessions." However, others report superior effects after a polarized TID compared with an HIT block periodized training concept (28). The latter study was, however, not conducted with groups performing the same quantity of HIT sessions, which may have affected the results.

These recent findings not only confirm HIT to be an important stimulus for endurance adaptations but also highlight mesocycle organization as a potential modifier of the adaptive response. Previous research has shown that the physiological adaptations to HIT sessions are also sensitive to the interactive effects of intensity and accumulated duration. For example, both Seiler et al. (26) and Sandbakk et al. (23) have recently demonstrated that slight reductions in HIT work intensity facilitated large increases in tolerable accumulated duration and better overall adaptive responses in well-trained cyclists and cross-country skiers. Although research has progressed our understanding of the intensity/accumulated duration relationship during HIT sessions and its relationship with endurance performance development in an isolated fashion (23,26), the accumulative effects of the order of such sessions are not well understood. Different patterns of HIT ordering are used by elite athletes. Some endurance athletes increase HIT intensity and decreasing HIT duration from the preparation to the competition period (32,33). However, anecdotal evidence also shows that some successful athletes use a "reversed" model, where HIT intensity is decreased and HIT duration increased, or a "mixed" model with larger microvariation of various HIT sessions (e.g., interval sessions) throughout the training period.

Therefore, the main purpose of this study was to compare the effects of three different HIT models, balanced for total load but periodized in a specific mesocycle order or in a mixed distribution, on endurance adaptations during a 12-wk training period in well-trained endurance athletes. We simulated a preparation period in which cyclists in increasing (INC), decreasing (DEC), and mixed (MIX) HIT groups performed training periods that were matched for all features (frequency, total volume, and overall HIT load) except the mesocycle order or distribution of HIT sessions. We hypothesized that the INC HIT organization would be best tolerated and give best overall adaptive effects.

METHODS

This was a multicenter study involving three test centers completing the same controlled experimental trial. At each test center, three matched periodization groups were instructed to follow a 12-wk high-volume LIT model, in addition to a significant portion HIT performed as prescribed as supervised interval sessions. Performance and physiological tests were compared before and after the intervention period.

Subjects

Sixty-nine male cyclists (38 ± 8 yr, $\dot{V}O_{2peak}$ 62 ± 6 mL·kg^{-1}·min^{-1}) were recruited to the study using announcements in social media and through local cycling clubs. Inclusion criteria were as follows: 1) male, 2) $\dot{V}O_{2peak}$ >55 mL·kg^{-1}·min^{-1}, 3) training frequency more than four sessions per week, 4) cycling experience >3 yr, 5) regularly competing, and 6) absence of known disease or exercise limitations. Study participation was administered from three different test locations, including 29, 20, and 20 subjects, respectively. All subjects were categorized as well trained (12) or at performance level 4 according to an athlete categorization by De Pauw et al. (6). All subjects completed the intervention. However, we excluded six subjects from the final analyses because of absence from posttesting and/or <70% compliance with prescribed interval sessions. Excluded subjects were from MIX (two subjects) and DEC (four subjects) groups. The study was approved by the ethics committee of the Faculty for Health and Sport Science, University of Agder, and registered with the Norwegian Social Science Data Services. All subjects gave their verbal and written informed consent before study participation.

Preintervention Period

Before intervention, a 6-wk preintervention period (PIP) was conducted to familiarize subjects with interval sessions included in the intervention period and with testing protocols (Fig. 1). During the PIP, subjects were instructed to perform only one interval session each week, combined with freely chosen (*ad libitum*) LIT volume. All subjects completed a questionnaire regarding training history the previous year, years of cycling experience, previous peak performance level,
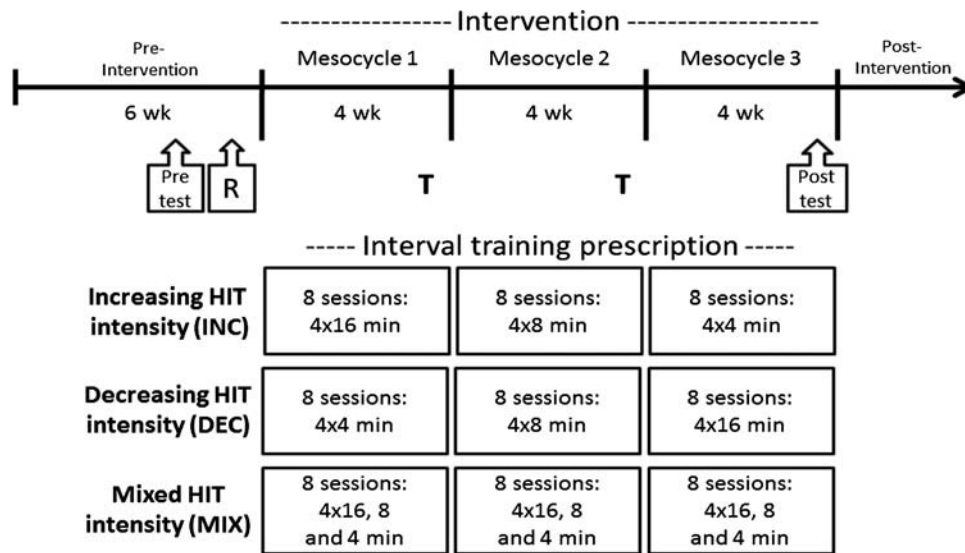
FIGURE 1—Study protocol. A 6-wk PIP, including familiarization to interval sessions, pretesting, and randomization (R), was followed by a 12-wk intervention period divided in three 4-wk mesocycles with different interval session prescriptions for each training group. All groups performed 24 supervised interval sessions, in addition to testing and *ad libitum* LIT. The INC group (*n* = 23) performed 8 interval sessions as 4×16 min in mesocycle 1 (weeks 1–4), 8 interval sessions as 4×8 min in mesocycle 2 (weeks 5–8), and 8 interval sessions as 4×4 min in mesocycle 3 (weeks 9–12). The DEC group (*n* = 20) performed interval sessions in the opposite mesocycle order as INC, and the MIX group (*n* = 20) organized all 24 interval sessions (8 in each mesocycle) in a mixed distribution; sessions 1 as 4×16 min, session 2 as 4×8 min, session 3 as 4×4 min, session 4 as 4×16 min, and so on. In total, during 12 wk, all subjects independent of group performed 8 interval sessions in each 4×16-, 4×8-, and 4×4-min prescriptions, respectively. All subjects were tested (T) in-between cycles during weeks 4 and 8 (results not presented). Posttesting was completed within 5 d postintervention period.

and previous/current injuries and diseases. Pretesting was performed at the end of the PIP (mid-December), and subjects were thereafter randomized into one of three different training groups (INC, DEC, and MIX) matched for 1) age, 2) cycling experience, and 3) $\dot{V}O_{2peak}$.

Intervention Period

Training organization. The training intervention was performed from early January to the end of March (12 wk), corresponding to the early preparation period for these cyclists and consisted of three 4-wk mesocycles. Subjects were instructed to follow a mesocycle week load structure as follows: week 1, medium LIT volume and two supervised interval sessions; weeks 2 and 3, high LIT volume and three supervised interval sessions; and week 4, reduced LIT volume by 50% compared with the previous 2 wk and one HIT session executed as a physiological test (results not presented). In total, each subject was prescribed 24 supervised interval sessions, in addition to laboratory testing, and self-organized *ad libitum* LIT equal to the subject's normal LIT volume. Each intervention group organized interval sessions in a specific periodized mesocycle order or in a mixed distribution during mesocycles 1–3 (Fig. 1).

Interval sessions. All HIT was performed indoors as supervised group interval training sessions and included a 20- to 30-min low-intensity (55%–70% HR_{max}) warm-up, followed by four interval bouts of 4, 8, or 16 min separated by a 2-min rest, and concluded with a 10- to 30-min low-intensity (55%–70% HR_{max}) cooldown. Sessions were performed at

the same time of day throughout the intervention period with room temperature maintained at 17°C–20°C and 50%–60% relative humidity. Subjects manipulated cycling load electronically by adjusting the ergometer with ±3-W precision, and they were provided with continuous feedback regarding their absolute and average power, cadence (rpm), HR, and elapsed time on a large video screen. Revolutions per minute was individually selected. During interval sessions, subjects were instructed to cycle at their maximal sustainable intensity during all four interval bouts (isoeffort) (26,27) such that they 1) completed the described session structure (all four interval bouts completed with only a 2-min rest) and 2) with even or progressive power from first to fourth interval bout. Before each interval session, we estimated the power each subject would be able to maintain during all interval bouts based on previous interval sessions and subject feedback. Mean power, HR (mean and peak), RPE 6–20 (3), and revolutions per minute were quantified at the end of each interval lap. Blood lactate concentration [la⁻] was measured randomly among a subset of 56 subjects at the end of the third and fourth interval bout. Data from all intervention groups pooled together showed that the three different interval prescriptions (4×16 min, 4×8 min, and 4×4 min) induced significantly different mean power, [la⁻], and HR (mean and max) responses. In addition, both RPE and session RPE (sRPE) (9) were significantly different across interval prescriptions despite the same "maximal session effort" approach (Table 1). However, all intervention groups (INC, DEC, and MIX) executed the three different interval prescriptions with similar mean power, [la⁻], HR (mean and

TABLE 1. Physiological and perceptual responses during interval sessions executed as 4×16, 4×8, and 4×4 min during a 12-wk intervention period.

	4×16 min	4×8 min	4×4 min	P^*
Compliance (% HIT sessions)	93.1 (14.2)	96.4 (8.8)	92.5 (13.2)	0.052
Power (W)[a]	276 (25)	308 (29)	342 (33)	<0.001
Power (W·kg^{-1})[a]	3.5 (0.4)	3.9 (0.4)	4.3 (0.4)	<0.001
Percent of PPO (%)[a]	65 (4)	71 (4)	80 (4)	<0.001
Percent of 4 mM lactate power (%)[a]	97 (8)	106 (8)	118 (9)	<0.001
Blood lactate (mmol·L^{-1})[b]	4.7 (1.6)	9.2 (2.4)	12.7 (2.7)	<0.001
Interval lap HR_{mean} (% HR_{peak})[a]	86 (3)	88 (2)	89 (2)	<0.001
Interval lap HR_{peak} (% HR_{peak})[a]	89 (2)	91 (2)	94 (2)	<0.001
RPE (6–20)[a]	15.0 (1.1)	16.2 (0.8)	17.1 (0.9)	<0.001
sRPE 30 min postsession (1–10)	6.3 (1.0)	6.9 (1.0)	7.7 (1.2)	<0.001

All values are calculated as the mean (SD) of up to 24 training sessions in 63 subjects. Compliance is calculated as percent of total interval sessions executed in relation to number of described sessions (24 in each subject).
[a]All values of power, mean/peak HR, and RPE represent a mean of all four interval laps. sRPE was quantified 30 min postexercise.
[b]Blood lactate was measured randomly among a subset of 56 subjects after interval laps 3 and 4, and a total of 531 samples (~10 per participant) were collected.
*One-way repeated-measures ANOVA.

max), RPE, and sRPE. In addition, there was no significant difference in total compliance (% interval sessions completed) among intervention groups.

Training monitoring. All subjects were provided with the Norwegian Olympic committee's online training diary to record their training. The following variables were registered for each training session: 1) total training form duration (endurance, strength, sprint/jump, other), 2) activity form duration (cycling, running, cross-country skiing, etc.), 3) total duration in each endurance training zone (session goal/time in zone method [31]), 4) session goal categorical intensity distribution (31), 5) perceived exertion (1–10) rated 30 min postexercise (sRPE) (8), and 6) self-reported recovery status (1–9) (18). Individualized HR zones were calculated based on the HR_{peak} results from pretesting using a five-zone aerobic intensity scale used by the Norwegian Olympic Federation to prescribe and monitor the training of well-trained endurance athletes: zone 1, 60%–75% HR_{peak}; zone 2, 75%–85% HR_{peak}; zone 3, 85%–90% HR_{peak}; zone 4, 90%–95% HR_{peak}; and zone 5, 95%–100% HR_{peak} (27).

There were no significant differences among groups in any training variable measured as mean during 12 wk (Table 2) and no significant differences in training volume during the intervention period compared with the previous training year. Weekly training volume remained stable across mesocycles 1–3 in all groups (average cycle 1: 9.8 ± 3.2 h·wk^{-1}; cycle 2: 10.0 ± 3.2 h·wk^{-1}; cycle 3: 10.7 ± 3.1 h·wk^{-1}). A self-reported scale for recovery status suggested that subjects were fully recovered every fourth week, as there were no significant differences among the three intervention groups or across 4-wk training cycles in self-reported recovery status (data not shown).

Testing Procedures

Pretesting was completed 2 wk before intervention start. Posttesting was initiated 2–4 d after the last supervised interval session for all subjects and completed within 10 d. Both testing periods were performed for 2 d separated by a minimum of 48 h recovery. Subjects were instructed to perform only LIT for a minimum of 48 h preceding each test and to consume the same type of meal. They were instructed to not eat during the last hour or consume caffeine during the last 3 h preceding testing.

Test day 1. On day 1, four to six submaximal incremental 5-min steps were performed in the laboratory on a bicycle ergometer to identify the workload eliciting 4 mmol·L^{-1} [la$^-$] (Power$_{4mM}$) and gross efficiency (GE). The test started with 5-min cycling at 125 W, and $\dot{V}O_2$, respiratory exchange ratio (RER), and HR were measured during the last 2.5 min, with mean values for this period used for statistical analyses. Blood [la$^-$] was measured after 4.30 min, and RPE was determined at the end of each 5-min step using Borg's 6–20 RPE scale (3). Power was increased by 50 W (25 W if [la$^-$] was >3 mmol·L^{-1}) after 5 min. Testing was terminated when [la$^-$] reached ≥4 mmol·L^{-1}. Power and $\dot{V}O_2$ corresponding to

TABLE 2. Weekly training characteristics and sickness during a 12-wk training period in 63 subjects, randomized to INC, DEC, and MIX training groups.

	All ($N = 63$)	INC ($n = 23$)	DEC ($n = 20$)	MIX ($n = 20$)	P^*
Training volume (h·wk^{-1})	10.1 (2.9)	10.8 (2.6)	9.9 (3.1)	9.6 (2.9)	0.354
Training forms					
Endurance (%)	96.9 (3.7)	97.2 (4.2)	96.6 (3.3)	97.0 (3.7)	0.883
Strength (%)	2.6 (3.5)	2.3 (4.1)	2.7 (3.2)	2.7 (3.1)	0.928
Speed/jumps (%)	0.1 (0.3)	0.0 (0.1)	0.2 (0.4)	0.0 (0.1)	0.198
Other (%)	0.4 (0.9)	0.4 (0.9)	0.5 (0.9)	0.3 (0.8)	0.799
Intensity distribution					
Zone 1 (%)	71.2 (13.7)	72.8 (12.5)	67.7 (15.0)	72.8 (13.7)	0.397
Zone 2 (%)	12.3 (9.0)	11.6 (8.3)	15.9 (9.8)	9.4 (8.1)	0.063
Zone 3 (%)	8.9 (3.8)	9.0 (3.5)	8.4 (3.5)	9.4 (4.6)	0.693
Zone 4 (%)	5.3 (2.5)	4.7 (1.8)	5.3 (2.5)	5.9 (3.0)	0.290
Zone 5 (%)	2.3 (1.4)	1.9 (1.0)	2.7 (1.5)	2.5 (1.7)	0.201
Specific training (%)	81.3 (15.1)	78.0 (17.8)	84.0 (14.0)	82.5 (12.6)	0.408
Sickness (d)	3.8 (3.6)	3.1 (2.4)	3.1 (3.1)	5.2 (4.7)	0.106

Values are presented as mean (SD). Intensity distribution and specific training are calculated as percent of endurance training, and distributed according to session goal/time in zone-method (SG/TIZ) (33). Zone 1 = 60%–75% of HR_{peak}; zone 2 = 75%–85% of HR_{peak}; zone 3 = 85%–90% of HR_{peak}; zone 4 = 90%–95% of HR_{peak}; zone 5 = 95%–100% of HR_{peak}.
*One-way between-groups ANOVA.

APPLIED SCIENCES

4 mmol·L^{-1} [la$^-$] were identified after plotting the true power–lactate curve for each subject, by fitting a polynomial regression model (17). GE was calculated using the method of Coyle et al. (5). Briefly, the rate of energy expenditure was calculated by using gross $\dot{V}O_2$ from the first three 5-min submaximal steps (125, 175, and 225 W), and GE was expressed as the ratio of work accomplished per minute to caloric expenditure per minute.

After 10 min recovery, an incremental test to exhaustion was performed to determine 1) $\dot{V}O_{2peak}$, 2) peak power output (PPO), 3) HR$_{peak}$, and 4) peak blood lactate concentration [la$^-_{peak}$]. The test started with 1 min of cycling at 3 W·kg^{-1} (rounded down to nearest 50 W) and subsequently increased by 25 W every minute until voluntary exhaustion or failure to maintain ≥70 rpm. Strong verbal encouragement was provided throughout the test. $\dot{V}O_{2peak}$ was calculated as the average of the two highest 30-s consecutive $\dot{V}O_2$ measurements. The plateau of the $\dot{V}O_2$ curve and/or the HR ≥95% of known HR$_{max}$, RER ≥1.10, and [la$^-$] ≥8.0 mmol·L^{-1} were used as criteria for the attainment of a valid test (10). PPO was calculated as the mean power during the last minute of the test. HR$_{peak}$ was recorded during the final 5 s before exhaustion, and [la$^-_{peak}$] was measured 60 s postexhaustion. In addition, a theoretical maximal aerobic power was calculated by using submaximal $\dot{V}O_2$ measurements in addition to $\dot{V}O_{2peak}$. Maximal aerobic power was defined as the power where the horizontal line representing $\dot{V}O_{2peak}$ meets the extrapolated linear regression representing the submaximal $\dot{V}O_2$/power relationship. To estimate fractional use of $\dot{V}O_{2peak}$, the previously described $\dot{V}O_2$ corresponding to 4 mmol·L^{-1} [la$^-$] was calculated as percentage of $\dot{V}O_{2peak}$ (%$\dot{V}O_{2peak}$@4 mM).

Finally, after 15 min recovery, a 30-s all-out Wingate test (36) was conducted. The test started with the subject pedaling at a freely chosen cadence less than 120 rpm for 20 s with an ~150-W braking resistance. Then after a 3-s countdown, a braking resistance equivalent to 0.7 N·m·kg^{-1} body mass (Lode Excalibur) or a 0.098 torque factor (Velotron) was applied to the flywheel and remained constant throughout the 30-s test. Cyclists were instructed to pedal as fast as possible from start and were allowed to sit or stand as preferred throughout the test. Strong verbal encouragement was provided throughout. The mean power during 30 s (Power$_{30s}$) was recorded.

Test day 2. On test day 2, subjects performed a 40-min all-out trial. The test started with a 30-min warm-up at a self-selected power output. Thereafter, subjects were instructed to cycle at the highest possible mean power during 40 min. Subjects were blinded to power output and HR but were allowed to see remaining time and rpm. They were encouraged to remain seated during the trial but were permitted to stand and stretch their legs occasionally, and they were allowed to drink water *ad libitum*. Mean power, mean HR (HR$_{mean}$), and HR$_{peak}$ were registered, as well as RPE and [la$^-$], at the end of the test.

Instruments and materials. For each individual, all tests on day 1 were performed on the same Velotron (Racermate,

Seattle, WA) or Lode Excalibur Sport (Lode B. V., Groningen, The Netherlands) cycle ergometer under similar environmental conditions (18°C–22°C/50%–60% relative humidity). Pre- and posttests were performed at the same time of day. Saddle height, handlebar position, and distance between the tip of the saddle and the bottom bracket were adjusted by each subject as desired. Subjects were instructed to remain seated during all tests (except the 30-s all-out test) and allowed to choose their preferred cadence. Both test ergometers are computer controlled and provide <2% margin of error in both accuracy and repeatability, according to the manufacturer. Test day 2 and all interval sessions were performed in groups on their own road racing bicycle mounted on Computrainer Lab^{TM} ergometers (Race Mate, Seattle, WA) calibrated according to the manufacturer's specifications and connected to a central PC running dedicated software (PerfPRO Studio, Hartware Technologies, Rockford, MI).

$\dot{V}O_2$ was measured using Oxycon Pro™ with a mixing chamber and a 30-s sampling time (Oxycon; Jaeger GmbH, Hoechberg, Germany). Gas sensors were calibrated via an automated process using certified calibration gasses of known concentrations before every test. The flow turbine (Triple V, Erich Jaeger) was calibrated using a 3-L calibration syringe (5530 series; Hans Rudolph, Kansas, MO). HR was measured using Polar V800 (Polar Elektro Oy, Kempele, Finland). Blood [la$^-$] were analyzed using a stationary lactate analyzer (EKF BIOSEN; EKF Diagnostics, Cardiff, UK).

Statistical Analyses

Data were analyzed using SPSS 22.0 (SPSS Inc., Chicago, IL) and are presented as mean ± SD or 95% confidence intervals (95% CI). Baseline and training characteristics were compared using a one-way between-groups ANOVA, followed by Bonferroni-corrected *post hoc* tests. A one-way repeated-measures ANOVA was used to compare differences among 4 × 16 min, 4 × 8 min, and 4 × 4 min interval session prescriptions. A univariate general linear model (GLM) (ANCOVA) was used to assess differences in baseline characteristics and changes in test variables among the intervention groups. A GLM repeated-measures model (ANOVA) was used to compare pre- and posttest results in each group. GLM analyses were adjusted for the influence of different covariates (test location and pre-Power$_{4mM}$ (W·kg^{-1})) and conducted to ensure that there were no violations of the assumptions of normality, linearity, and sphericity. All data analyzed by GLM are presented as adjusted values. Because of expectations of small changes in these already well-trained cyclists, the data were further analyzed with effect size (ES) calculated according to Cohen's *d* (0.2 = small, 0.5 = medium, 0.8 = large) (4). Medium or large ES (>0.5) are discussed as tendencies if comparisons are nonsignificant. The frequency distribution of individual response magnitude across training groups was compared using a chi-square test, and ES was calculated with Cramer's *V* with three

categories (4). For all comparisons, statistical significance was accepted as $\alpha \leq 0.05$.

RESULTS

Baseline Characteristics and Body Mass

There were no significant differences among training groups before the intervention period with respect to age, cycling experience, body mass, or any performance or physiological test variables (Table 3). After the intervention, there was a significant body mass reduction in INC (80.3 ± 7.4 vs 79.0 ± 7.6 kg), DEC (79.7 ± 7.8 vs 78.5 ± 7.5 kg), and MIX (79.7 ± 8.9 vs 78.2 ± 8.8 kg) training groups (all $P < 0.05$).

Performance Responses

All training groups improved significantly in all performance measures after the intervention period. The mean (95% CI) improvement before and after the mean power during a 40-min all-out trial (Power$_{40min}$) was 8.0% (5.3–10.6), 7.4% (4.4–10.4), and 4.9% (1.8–8.0) in INC, DEC, and MIX groups, respectively (all $P < 0.05$; Fig. 2). The relative improvement did not differ among groups ($P = 0.307$), but there was a medium ES when comparing difference in absolute values (Table 3) in INC and DEC versus MIX groups. Mean (95% CI) PPO values increased significantly by 7.1% (4.7–9.5), 6.0% (3.4–8.6), and 6.5% (3.9–9.2) in INC, DEC, and MIX groups, respectively (all $P < 0.05$; Fig. 2), with no differences among groups ($P = 0.813$). The MIX and the DEC groups improved significantly in mean (95% CI) Power$_{30s}$ by 2.4% (0.3–4.4) and 2.7% (0.7–4.7), respectively (both $P < 0.05$), whereas a nonsignificant 1.2% (−0.7, 3.1) change occurred in the INC group. The changes in Power$_{30s}$ did not differ among groups ($P = 0.509$).

Physiological Responses

The INC and the DEC groups improved mean (95% CI) Power$_{4mM}$ significantly by 5.8% (2.7–8.9) and 5.9% (2.6–9.2), respectively (all $P < 0.05$).The MIX group showed a nonsignificant change of 2.9% (−0.4 to 6.3) (Fig. 2). The relative changes among groups in Power$_{4mM}$ did not differ ($P = 0.360$), but there was a medium ES when comparing absolute values (Table 3) in the INC group versus the MIX group. All groups significantly improved mean (95% CI) $\dot{V}O_{2peak}$ by 5.8% (3.7–8.0), 4.5% (2.3–6.8), and 3.8% (1.5–6.0) in the INC, DEC, and MIX groups, respectively (all $P < 0.05$; Fig. 2). No significant differences occurred among groups ($P = 0.392$), but there was a medium ES when comparing absolute values (Table 3) in the INC group versus the MIX group.

The DEC group significantly improved mean (95% CI) fractional use calculated as $\dot{V}O_{2peak}$@4 mM by 3.7% (1.2–6.3) ($P < 0.05$). There was a nonsignificant 1.3% (−1.1 to 3.7) and −0.5% (−3.1 to 2.1) change in the INC and MIX groups,

TABLE 3. PRE values and PRE to POST changes in performance and physiological variables during a 12-wk training period with different periodization models in INC, DEC, and MIX training groups.

	All Groups (N = 63)			INC (n = 23)			DEC (n = 20)			MIX (n = 20)			Among Groups—Relative Change		
	Mean PRE (95% CI)	Mean change (95% CI)		Mean PRE (95% CI)	Mean change (95% CI)		Mean PRE (95% CI)	Mean change (95% CI)		Mean PRE (95% CI)	Mean change (95% CI)		P^a	ES^b INC/DEC vs MIX	
Body composition															
Body mass (kg)	79.7 (77.9 to 81.5)	−1.3* (−1.7 to −0.9)		80.3 (76.9 to 83.6)	−1.3* (−1.9 to −0.7)		79.5 (76.6 to 82.4)	−1.2* (−2.1 to −0.4)		79.4 (75.6 to 83.2)	−1.6* (−2.4 to −0.8)		0.809	−0.2/−0.2	
Performance															
Power$_{40min}$ (W)	281 (274 to 288)	19* (14 to 23)		281 (267 to 295)	23* (14 to 32)		279 (269 to 289)	19* (10 to 27)		287 (275 to 299)	10* (4 to 16)		0.267	0.8/0.6	
PPO (W)	413 (406 to 421)	26* (20 to 31)		416 (400 to 431)	30* (19 to 41)		414 (400 to 427)	22* (14 to 31)		413 (400 to 426)	25* (12 to 37)		0.796	0.2/−0.1	
Aerobic															
Power$_{4mM}$ (W)	281 (275 to 288)	13* (8 to 18)		276 (265 to 287)	17* (6 to 28)		283 (273 to 292)	14* (7 to 22)		286 (272 to 300)	6 (−5 to 16)		0.441	0.5/0.4	
$\dot{V}O_{2peak}$ (mL·min^{-1})	4858 (4742 to 4974)	226* (163 to 288)		4941 (4736 to 5146)	299* (191 to 407)		4793 (4585 to 5002)	197* (103 to 290)		4859 (4631 to 5088)	140* (4 to 276)		0.356	0.6/0.2	
$\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1})	61.3 (60.1 to 62.4)	3.9* (3.1 to 4.7)		61.8 (59.5 to 64.1)	4.8* (3.5 to 6.1)		60.6 (58.7 to 62.5)	3.5* (2.0 to 5.0)		61.6 (59.8 to 63.4)	3.0* (1.3 to 4.7)		0.384	0.6/0.2	
MAP (W)	371 (362 to 381)	12* (6 to 19)		376 (361 to 390)	19* (6 to 32)		372 (355 to 388)	3 (−8 to 15)		369 (348 to 390)	12 (0 to 25)		0.332	0.3/−0.4	
% $\dot{V}O_{2peak}$@4 mM (%)	79.2 (77.9 to 80.4)	1.1 (−0.1 to 2.3)		77.3 (74.7 to 80.0)	0.7 (−1.4 to 2.8)		79.4 (77.3 to 81.5)	2.8* (0.6 to 5.1)		80.7 (78.7 to 82.7)	−0.4 (−2.5 to 1.7)		0.090	0.2/0.7	
GE (%)	19.0 (18.8 to 19.3)	−0.4* (−0.6 to −0.2)		18.8 (18.4 to 19.3)	−0.5* (−0.9 to −0.2)		19.3 (18.9 to 19.7)	−0.4* (−0.7 to −0.1)		19.1 (18.7 to 19.5)	−0.2 (−0.7 to 0.2)		0.669	0.3/0.3	
Anaerobic															
Power$_{30s}$ (W)	826 (809 to 842)	16* (7 to 25)		849 (825 to 873)	10 (−6 to 26)		820 (789 to 851)	20* (3 to 36)		812 (778 to 845)	18* (1 to 36)		0.535	−0.2/0.1	

All values are presented as mean (95% CI). Power$_{40min}$, mean power during 40-min all-out trial; Power$_{30s}$, mean power during 30 s all-out test; MAP, maximal aerobic power; Power$_{4mM}$, power corresponding to 4 mmol·L^{-1} lactate; $\dot{V}O_{2peak}$, peak oxygen uptake; %$\dot{V}O_{2peak}$@4 mM, percent peak oxygen uptake corresponding to 4 mmol·L^{-1} lactate; $\dot{V}O_{2peak}$@4 mM, peak oxygen uptake at 4 mmol·L^{-1} lactate.
^{a}General linear model univariate, adjusted for test location and prepower at 4 mmol·L^{-1} lactate (W·kg^{-1}).
^{b}ES calculations according to Cohen's d (0.2 = small, 0.5 = medium, 0.8 = large) (4).
*$P < 0.05$ PRE vs POST within group.
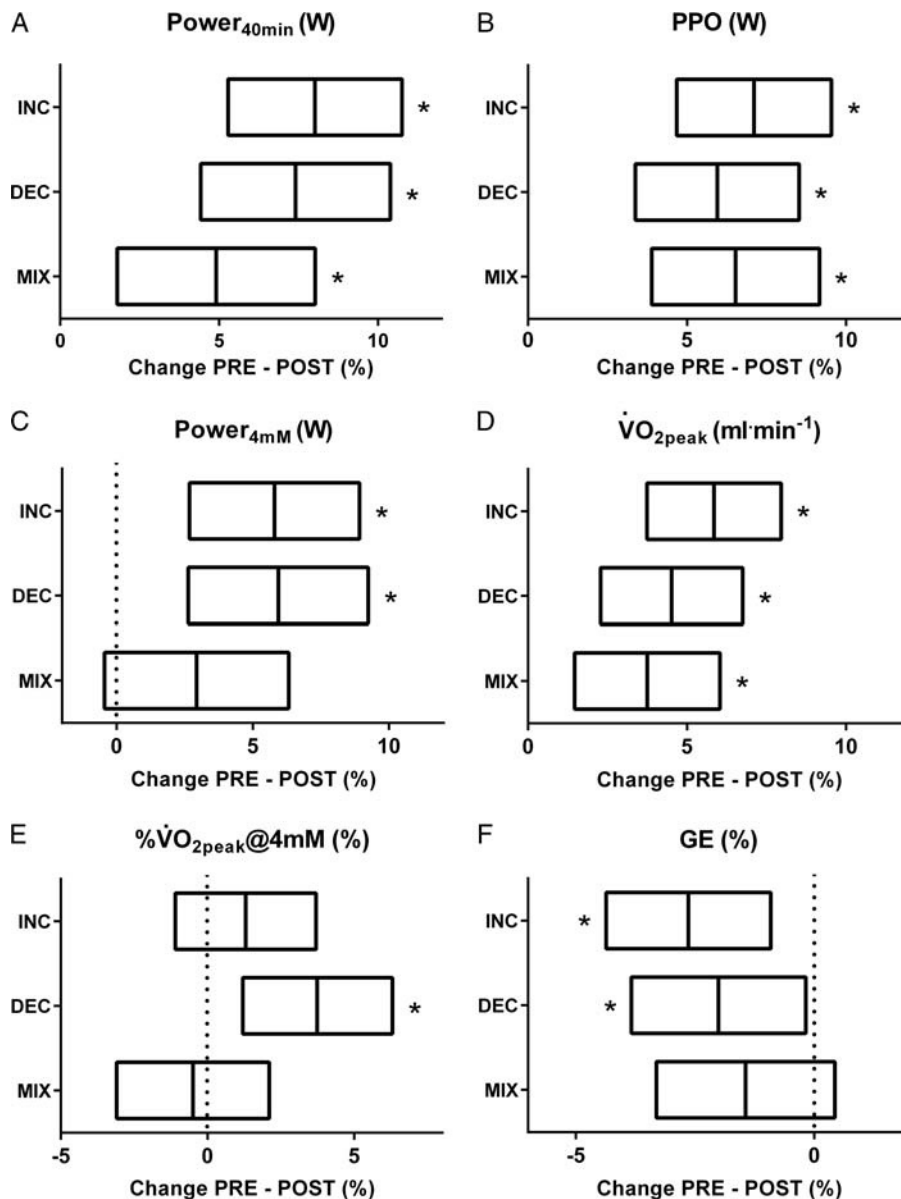
FIGURE 2—The 95% CI for relative change after a 12-wk training period (PRE–POST) in $Power_{40min}$ (A), PPO (B), $Power_{4mM}$ (C), $\dot{V}O_{2peak}$ (D), $\%\dot{V}O_{2peak}@4$ mM (E), and GE (F), in INC ($n = 23$), DEC ($n = 20$), and MIX ($n = 20$) intervention groups. $Power_{40min}$, mean power during a 40-min all-out trial; $Power_{4mM}$, power corresponding to 4 $mmol \cdot L^{-1}$ lactate; $\dot{V}O_{2peak}$ = peak oxygen uptake; $\%\dot{V}O_{2peak}@4$ mM, percent peak oxygen uptake corresponding to 4 $mmol \cdot L^{-1}$ lactate.

respectively (Fig. 2). Although the relative changes among groups did not differ ($P = 0.070$), there was a medium ES when comparing the DEC group versus the MIX group. All groups decreased in GE. Mean (95% CI) relative changes were -2.6% (-4.4 to -0.9) in the INC group ($P < 0.05$), -2.0% (-3.8 to -0.2) in the DEC group ($P < 0.05$), and -1.4% (-3.3 to 0.4) in the MIX group (not significant) (Fig. 2), with no significant differences among groups ($P = 0.642$).

A chi-square test for independence indicated no significant association among training groups and individual performance ($Power_{40min}$) response ($P = 0.146$, Fig. 3). There was, however, a medium ES (4), calculated with Cramer's V with three categories. Approximately 87%, 63%, and 56% of subjects in the INC, DEC, and MIX groups, respectively,

achieved moderate to large gains in performance capacity, whereas ~13%, 37%, and 44% showed nonresponse.

DISCUSSION

The present study demonstrates that, at the group level, the physiological and performance improvements after intensified training were moderate to large in all the training groups used in this study. This indicates that the basic load features of the training were well tolerated and effective. However, the specific HIT periodized mesocycle order or mixed distribution, focusing on manipulating the intensity prescription for interval sessions, had little or no generalizable effect on the adaptive effect of the same overall

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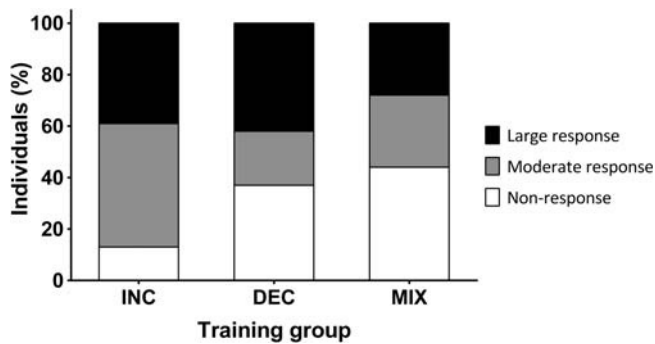
FIGURE 3—Individual response distribution to PRE–POST change (%) in performance (mean power during 40-min all-out trial) after a 12-wk training in INC ($n = 23$), DEC ($n = 19$), and MIX ($n = 18$) intervention groups. Percent change was categorized as nonresponse, <3% change; moderate response, 3%–9% change; or large response, >9% change.

endurance training load. Furthermore, the individual variation in training response did not significantly differ among the three training groups, suggesting similar expected distribution of large, moderate, or nonresponses, respectively, to each prescription.

Performance and Physiological Adaptations

After a 12-wk training period, including two to three interval sessions each week in addition to *ad libitum* LIT, we found that all groups significantly increased performance variables (Power$_{40min}$ and PPO) by 5%–8%. Coinciding with 40-min all-out trial improvements, Power$_{4mM}$ also increased by 3%–6% in all groups. These performance response magnitudes are consistent with previous studies investigating the effect of HIT over similar time frames (15,18,24), or after shorter HIT interventions (2%–6% improvement) (12,30). Furthermore, all groups increased $\dot{V}O_{2peak}$ significantly by 4%–6%, which is in line with the increase in $\dot{V}O_{2max}$ reported in other studies involving well-trained to elite-level cyclists during comparable training periods (15,18,24). Overall, our results demonstrate that the training load prescribed in the present study was effective in improving performance and physiological capacity in well-trained cyclists.

We found negligible changes in the fractional use of $\dot{V}O_{2peak}$ from pre- to posttest, in both the INC (~1%) and the MIX (~0%) groups. The overall small changes in this variable are likely because short-term HIT stimuli are more effective in inducing central cardiovascular adaptations (13). However, the DEC group improved by ~4%.

A small decrease in GE occurred in all groups, despite increased $\dot{V}O_{2peak}$. A relative shift in energetic contribution from carbohydrate to fat could account for a small decrease in GE. For example, a shift in RER from 0.87 to 0.82 at the same oxygen consumption and power output would result in an ~1% decline in GE (from for example, 21.6%–21.4%). However, the decrease in GE observed in the present study was still larger than what could be explained by a shift in

RER toward greater fat use. The main contributor to decreased GE is therefore probably due to higher oxygen consumption, which has also been reported previously (9).

Group Comparisons

Despite large overall progress in all groups, we found no significant differences among groups in adaptive changes from pre- to postintervention, except the fractional use of $\dot{V}O_{2peak}$ where the DEC group tended to improve more than the other groups. The latter may be a compensation of the slightly smaller increase in $\dot{V}O_{2peak}$ in DEC compared with the INC group. Altogether, these results suggest that organizing different interval sessions in a specific periodized "increasing" or "decreasing" mesocycle order or in a mixed intensity distribution results in minor differences in adaptive response when the overall load is the same.

However, although there were no significant differences among groups, the greater microvariation of interval training stimuli (i.e., the MIX group) tended to induce less overall adaptive responses compared with the INC and the DEC groups. We speculate that this tendency could be explained by higher interval session "quality" in the INC and DEC groups who, unlike the MIX group, performed the same eight interval sessions consecutively during each mesocycle. Therefore, subjects in the INC and DEC groups may have been more familiar with their specific sessions and, thus, able to more accurately pace their tolerable power/intensity from the beginning of the first to the end of the fourth interval bout.

We have failed to find any experimental studies for direct comparisons with our results. However, previous experimental studies manipulating HIT organization patterns during timeframes from 2 to 12 wk indicate improved block periodization training adaptations compared with mixed programs (18–20) and superior effects after a polarized TID compared with an HIT block periodization training concept (28). However, in these studies, block periodization was organized as short periods with heavy HIT stimulus followed by periods with LIT focus, or without same total training load among groups, and is therefore not directly comparable to the present study.

Individual Differences in Adaptations Response

Despite excellent overall control of the training program variables, and no differences among groups in overall training load, we quantified large individual differences in adaptive response after 12 wk of training. This finding is consistent with other recent studies (16,34). Furthermore, a response distribution analysis for Power$_{40min}$ revealed no significant differences in the variability of response across groups (Fig. 3). However, we do note that only 56% and 63% of subjects in the MIX and DEC groups achieved >3% improvement, as compared with 87% of subjects in the INC group. Supplementary analyses of variables influencing

the individual effects following different periodization models are needed in future studies.

Methodological Considerations

The main strengths of this study were the structured randomized design, rigorous monitoring of all training variables, and the large group of well-trained endurance athletes. We managed to match the groups for total work (isoenergetic), and all subjects, regardless of group, performed a well-documented training model with two to three weekly interval sessions interspersed with *ad libitum* LIT. On the basis of previous studies using the same model of interval training prescription (26), we anticipated that the different interval duration prescriptions (4×16, 8, and 4 min) would constrain three reasonably discrete work intensities, which would allow us to compare the effects on endurance adaptations when organizing those interval training prescriptions in different periodized mesocycle groups. The distinctive physiological responses to the three interval prescriptions were confirmed by the significant differences in power, [la$^-$], HR, RPE, and sRPE during interval sessions.

This study was conducted as a multicenter trial involving three test locations, which administrated 29, 20, and 20 subjects each, respectively. We are conscious that,

despite our best efforts to standardize them, there could be small methodological differences across centers that may affect the intervention results.

CONCLUSIONS

The present study suggests that organizing different interval sessions in a specific periodized mesocycle order or in a mixed distribution during a 12-wk training period has little or no effect on training adaptation when the overall training load is the same. Although we found a small tendency indicating that a larger microvariation in interval training intensity and duration (i.e., the MIX group) actually induces less adaptation, we overall argue that rigid periodization structures are not supported by the results of this direct intervention study.

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Effects of HIT on physiological and hormonal adaptations in well-trained cyclists.

1   **Effects of HIT on physiological and hormonal adaptions in well-trained**

2   **cyclists**

3

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ABSTRACT

PURPOSE: Investigate development of specific performance adaptions and hormonal responses every 4th week during a 12-week HIT period in groups with different interval training prescriptions.

METHODS: Sixty-three well-trained cyclists were randomly assigned to three groups, performing a 12-week intervention consisting of 2-3 HIT sessions·week^{-1} in addition to *ad libitum* low intensity training. Groups were matched for total training load, but **increasing HIT (INC)** group (*n=23*) performed interval training as 4x16 min in week 1-4, 4x8 min in week 5-8 and 4x4 min in week 9-12. **Decreasing HIT (DEC)** group (*n=20*) performed interval sessions in the opposite order as INC, and **mixed HIT (MIX)** group (*n=20*) performed all interval prescriptions in a mixed distribution during 12 weeks. Cycling-tests and measures of resting blood-hormones were conducted pre, week 4, 8 and 12.

RESULTS: INC and MIX achieved >70% of total change in Power$_{4mM}$ and $\dot{V}O_{2peak}$ during week 1-4, versus only 34-38% in DEC. INC induced larger improvement vs. DEC during week 1-4 in Power$_{4mM}$ (ES: 0.7) and $\dot{V}O_{2peak}$ (ES: 0.8). All groups increased similarly in PPO during week 1-4 (64-89% of total change). All groups' pooled, total- and free-testosterone and free-testosterone/cortisol-ratio decreased by 22±15%, 13±23% and 14±31% (all *P<0.05*), and insulin-like growth factor-1 increased by 10±14% (*P<0.05*) during week 1-4.

CONCLUSIONS: Most of progression in Power$_{4mM}$, $\dot{V}O_{2peak}$ and PPO was achieved during weeks 1-4 in INC and MIX, and accompanied by changes in resting blood-hormones consistent with increased but compensable stress load. In these well trained subjects, accumulating 2-3 h·week^{-1} performing longer 4x16 min work bouts at best effort induces greater adaptions in Power$_{4mM}$ and $\dot{V}O_{2peak}$ than accumulating ~1 h·week^{-1} performing best effort intervals as 4x4 min.

48

INTRODUCTION

50   A famous Norwegian coach of World Champions from 4 different endurance sports said "elite

51   endurance athletes must train a lot and they must train smart". This advice is simple, but

52   research over several decades suggests that translating it into best practice is quite complex.

53   Elite endurance athletes organize their training around a high volume of low-intensity training

54   (LIT, defined as a workload eliciting a stable blood lactate concentration ([la$^-$]) of less than 2

55   mMol$^.$L^{-1}). This high volume of LIT is infused with smaller proportions of both moderate-

56   (MIT, 2-4 mMol$^.$L^{-1} [la$^-$]) and high-intensity training (HIT, >4 mMol$^.$L^{-1} [la$^-$]). Training within

57   these three intensity categories, LIT, MIT, and HIT, is usually distributed either in a

58   *pyramidal* or *polarized* model (27, 32). Most retrospective studies on elite endurance athletes

59   report a pyramidal training distribution with approximately ≥80% LIT, 5-15% MIT and ≤10%

60   HIT throughout the preparation phase, e.g. (2, 25, 34). However, short term experimental

61   studies demonstrate superior responses to a polarized, compared to a pyramidal model (20,

62   31). This finding aligns with the more polarized pattern observed among international medal

63   winning athletes in the pre-competition and competition period (3, 34). Adding or

64   manipulating HIT, in combination with a high volume of LIT, has been found to induce 2-

65   12% average performance improvements in groups of well-trained cyclists of varying

66   performance levels over timeframes from a few weeks to three months (18, 23, 29, 33). The

67   primary physiological adaptations reported during these relatively short intervention periods

68   are increases in power output at lactate threshold (LT) and maximal oxygen uptake ($\dot{V}O_{2max}$).

69   Importantly, these effects are often only reported as net changes from pre- to post-

70   intervention period. There is still limited evidence available concerning the time-course of

71 adaptive development during a longer training cycle, and how this development trajectory

72 might be influenced by the organization and execution of the HIT component during the

73 training cycle.

74

75 During standardized HIT sessions, we have previously observed that relatively small changes

76 in exercise intensity are associated with large changes in tolerable accumulated exercise

77 duration (29, 33). Data from these studies and others raise important questions about how

78 work intensity and accumulated duration of HIT interact to signal physiological adaptation.

79 For example, Helgerud et al, 2007 (13) found that a total accumulated HIT duration of ~10-15

80 min at ~90-95% of maximal heart rate (HR_{max}) had a greater impact on endurance

81 performance than accumulating ~25 min at ~85% HR_{max} during a 3 session·week^{-1} interval

82 training program lasting 8 weeks. However, other studies conclude that accumulating ~30-45

83 min at ~90% HR_{max} twice per week is a more effective HIT prescription than accumulating

84 15-20 min at ~95% HR_{max} (26, 29). Discrepancies in reported results might be explained by

85 the characteristics of the added HIT stimuli, baseline performance level, age and small sample

86 sizes.

87

88 Conceptually, optimization of endurance training can be seen as an attempt to maximize

89 positive adaptive signaling effects of training frequency, volume, and intensity adjustments

90 while managing accompanying psychological and physiological stress loads at tolerable

91 levels. Testosterone (T) and cortisol (C) have been suggested to be important mediators of the

92 adaptive response to endurance training, and considered as useful biomarkers of anabolic and

93 catabolic hormonal control, respectively (4, 5, 11, 14, 39). However, the relationship between

94 the time-course of training adaptations during a training cycle and the parallel time-course of

95 potential changes in resting T and C is not well established. Pre to post intervention

96 comparisons do not paint a consistent picture. For example, a 14-day mesocycle with frequent

97 HIT sessions induced both endurance adaptions and increases in serum T concentration in

98 male junior triathletes (39). In contrast, others have reported significant adaptive responses to

99 a training program that also induced declining T and increasing C concentrations indicative of

100 an increased catabolic state (14). Discrepancies among studies may be due to differences in

101 the baseline training status of participants, or the training dose administered. Further, a

102 decrease in the ratio between free testosterone and cortisol (FTCR) has been proposed as a

103 marker of the overtraining syndrome (1, 10), although doubt has been cast as to whether

104 FTCR is able to differentiate between functional overreaching and overtraining (36, 37). In

105 addition, increased human growth hormone (HGH) has been reported in endurance trained

106 subjects, and elevated 24 h HGH secretion rates combined with increased plasma levels of

107 insulin-like growth factor-1 (IGF-I) have also been found to correlate positively with $\dot{V}O_{2max}$

108 (8, 21). This finding is consistent with the observation that a one-year exercise training

109 program approximately doubled resting HGH concentration in untrained women (38).

110 However, the effect of multiple training-cycles with different intensities and accumulated HIT

111 duration on hormonal responses in well-trained endurance athletes remains to be thoroughly

112 investigated.

113

114 The aims of the present study were therefore to compare the influence of three different 12-

115 week training programs differing in HIT load intensification structure on: 1 - the development

116 of specific endurance adaptations, 2 - the potential interactions among the different HIT

117 prescriptions, and 3 - the time-course of changes in resting anabolic and catabolic hormones

118 over 12 weeks divided in three mesocycles.

119

120

METHODS

This study was conducted as a multicenter trial, with all participants completing a 12-week

training period, divided in three 4-week cycles. These data were collected in parallel with data

from a newly published study where the main purpose was to compare the effects of different

periodized HIT models in well-trained endurance athletes (33).

Subjects

Sixty-nine experienced male competitive cyclists (age: 38±8 years, $\dot{V}O_{2peak}$: 62±6 mL·kg$^-$

^{1}·min^{-1}, training experience: 6±4 years) completed the intervention period, with 63 included in

the final analyses. Six subjects were excluded due to absence from post-testing, and/or <70%

compliance with prescribed interval sessions. Based on peak power output (PPO), training

volume and cycling experience, subjects were categorized as well-trained (15). The study was

approved by the ethics committee of the Faculty for Health and Sport Science, University of

Agder, and registered with the Norwegian Social Science Data Services (NSD). All athletes

provided their written informed consent to participate in the study.

Pre-intervention period

A 6-week pre-intervention period was conducted in order to ensure an approximately equal

training status, and familiarize subjects with testing protocols and interval sessions included in

the intervention period (Figure 1). Subjects were instructed to perform only one interval

session each week, combined with *ad libitum* LIT volume. Pre-testing was performed at the

end of the pre-intervention period (mid-December), and subjects were thereafter randomized

in a stratified manner based on age, cycling experience and peak oxygen uptake ($\dot{V}O_{2peak}$) into

one of three different training groups; increasing HIT (INC) (n=23), decreasing HIT (DEC)

(n=20) or mixed HIT (MIX) (n=20) group.

146

Intervention period

The training intervention was performed from early January to the end of March, and
consisted of 12 weeks, divided in three 4-week cycles. Subjects were instructed to follow a
training load structure within each cycle as follows; week 1; medium LIT volume and two
supervised interval sessions, week 2 and 3; high LIT volume and three supervised interval
sessions, week 4; reduced LIT volume by 50% compared to the previous two weeks and 1-2
laboratory testing sessions. All interval sessions was performed indoors as supervised group
training, and included a 20-30 min low-intensity (55-70% HR_{max}) warm-up, followed by four
interval bouts of either 4, 8 or 16 min separated by 2 min rest, and concluded with 10-30 min
low-intensity (55-70% HR_{max}) cool-down. During interval sessions, subjects were instructed
to cycle at their maximal sustainable intensity during all four interval bouts (*isoeffort*) (28, 29)
such that they completed the described session structure (all four interval bouts completed
with only 2 min rest), and with consistent or slightly progressive power output from the 1st to
the 4th interval bout. In total, each participant was prescribed 24 supervised interval sessions
during the 12-week intervention period, in addition to testing and self-organized *ad libitum*
LIT. Figure 1 shows the study design and interval session prescriptions in each group during
the intervention. INC group performed eight interval sessions as 4x16 min in cycle 1, eight
interval sessions as 4x8 min in cycle 2 and eight interval sessions as 4x4 min in cycle 3. DEC
group performed interval sessions in the opposite cycle order as INC, and MIX group
organized all 24 interval sessions (eight in each cycle) in a mixed distribution; session 1 as
4x16 min, session 2 as 4x8 min, session 3 as 4x4 min, session 4 as 4x16 min and so on.

- - Figure 1 - -

171   Although all sessions were performed with *isoeffort* instructions, the different interval session

172   prescriptions differing in interval bout duration and total accumulated HIT duration, induced

173   significantly different power output, [la⁻], heart rate (HR) and rating of perceived exertion

174   (RPE) responses (Table 1). During each interval session, independent of prescription, there

175   were significant increased HR and RPE responses from interval bout 1 to 4 (data not

176   presented). The evolution of power output was, in keeping with the instructions given to

177   subjects, maintained relatively constant over the 4 interval bouts. However, sub-analyses

178   revealed that relatively few subjects (n=6) typically showed a decreasing power development

179   over 4x16 min, whilst in contrast, 23 of 63 subjects typically reduced their power output by

180   the end of 4x4 min sessions. Data in Table 1 are presented as average values during all four

181   interval bouts for all three groups pooled. There were no differences across groups, although

182   different interval prescriptions (4x16 and 4x4 min) were performed in opposite sequence

183   (cycle 1 and 3) for INC and DEC, respectively.

184

185   - - Table 1 - -

186

187   **Testing procedures**

188   *Cycling test*

189   Testing weeks included a laboratory-based cycling-test, which were conducted pre-

190   intervention, and at week 4, 8 and 12 during the intervention period (see Figure 1). Subjects

191   were instructed to perform only LIT during the 48 h preceding each test and to consume the

192   same type of pre-test meal. Subjects were not permitted to eat during the last hour, or

193   consume caffeine during the last 3 h preceding each test.

194

195   Briefly, four to six steady state submaximal 5-min steps were performed on a bicycle

196   ergometer to identify the workload eliciting 4 $mMol^.L^{-1}$ [la$^-$] (Power$_{4mM}$) and gross efficiency

197   (GE). The test started at 125 W, increased 50 W (25 W if [la$^-$] was $\geq$3 $mMol^.L^{-1}$) every fifth

198   minute, and terminated when [la$^-$] reached $\geq$4 $mMol^.L^{-1}$. Our purpose of reporting Power$_{4mM}$

199   was not to determine LT or maximal lactate steady state (MLSS), but having a fixed value for

200   measurements of changes during different test periods. Thereafter, an incremental test,

201   starting at 3 $W^.kg^{-1}$ and subsequently increased by 25 W every minute until voluntary

202   exhaustion, was performed to determine $\dot{V}O_{2peak}$ and PPO (calculated as mean power output of

203   the last completed minute). Finally, a 30 s all-out Wingate test was performed to identify

204   mean power during 30 s (Power$_{30s}$). A detailed description of all testing protocols, instruments

205   and materials has recently been described elsewhere (33).

206

207   *Serum hormone concentrations*

208   Venous blood samples were collected from a sub-group of twenty-nine subjects to assess

209   hormonal responses (INC; n=9, DEC; n=10, MIX; n=10). For each testing session (pre, week

210   4, 8 and 12) all subjects reported to the laboratory between 07.00 and 09.00 AM in a rested,

211   fasted state, and were only allowed to perform LIT 48 h preceding blood-tests. Approximately

212   10 mL venous blood was collected from an antecubital vein using Vacutainer tubes (Becton

213   Dickinson, Franklin Lanes, USA). Samples were stored at room temperature (20-22°C) for

214   30-60 min before being centrifuged for 10 min at 3000 rpm (StatSpin Express 4, Beckman

215   Coulter, USA). The supernatant serum was pipetted into 1 mL aliquots and immediately

216   frozen at −20°C until analyses. Serum was analyzed for total testosterone (TT), free

217   testosterone (FT), C, IGF-1, IGF-BP3, HGH, sexual hormone binding globulin (SHBG) and

218   prolactin (PRL). The FTCR was calculated using the method of Banfi & Dolci (2006) (1).

219   Given the sensitivity of resting HGH to natural variations or dietary status (although subjects

220 were in a fasted state), subjects with extreme outlier values (identified through boxplot

221 analyses in SPSS) were excluded from HGH analyses. Four, 1 and 3 subjects were excluded

222 from the INC, DEC and MIX group, respectively. Sub-analyses were executed to ensure that

223 this sub-group of 29 subjects (both pooled and divided in intervention groups) was

224 representative to the main findings of specific performance responses in the present study (not

225 presented).

226

227 **Statistical analyses**

228 Data were analyzed using SPSS 22.0 (SPSS Inc, Chicago, IL, USA) and are presented as

229 mean ± standard deviation (SD) or 95% confidence intervals (95% CI). Training

230 characteristics and differences in blood hormone responses between groups were compared

231 using a one-way between-groups analysis of variance (ANOVA). A GLM repeated measures

232 model (ANOVA) was used to assess statistical differences in physiological test variables and

233 blood hormones from pre to week 4, 8 and 12 within each group. Statistical comparisons

234 were followed by Bonferroni post hoc corrections if there was a significant within-group

235 difference. A univariate General Linear Model (GLM) (analysis of covariance (ANCOVA))

236 was used to assess differences in physiological baseline characteristics and delta changes (pre

237 – week 4, week 4 – 8 and week 8 – 12) in physiological test variables between each training

238 group. For physiological test-variables, GLM analyses were adjusted for the influence of

239 different covariates (test-location and pre Power$_{4mM}$ (w$^.$kg^{-1})), and presented as adjusted

240 values. Effect size (ES) was calculated according to Cohen's d (0.2=small, 0.5=medium,

241 0.8=large) (7). Medium or large ES (≥0.5) are discussed as tendencies if comparisons are non-

242 significant. A total of <2% of all data variables were missing, and treated as "last observation

243 carried forward". For all comparisons, statistical significance was accepted as α ≤0.05.

244

RESULTS

Body mass

There were no significant differences in body mass among groups at pre. After 12 weeks, there was a significant body mass reduction in INC (80.3±7.4 vs. 79.0±7.6 kg), DEC (79.7±7.8 vs. 78.5±7.5 kg) and MIX (79.7±8.9 vs. 78.2±8.8 kg) (all $P<0.05$). All physiological and performance adaptions are further presented as absolute values, hence relative values with respect to body mass are therefore slightly different.

Training characteristics

There were no differences among groups in any training variables at pre. Weekly training volume did not change in the three cycles and was 9.8±3.2, 10.0±3.2, and 10.7±3.1 h·week^{-1} in cycles 1-3, respectively. For detailed training characteristics see Sylta et al (2016) (33). The only difference among groups was the intensity x accumulated duration of HIT within cycle 1-3 (Table 1, Figure 1 and Figure 2, A-C). INC, DEC and MIX completed on average 95±5%, 94±8% and 93±9% of their 24 prescribed interval sessions, respectively. Overall, the 3 HIT prescriptions were executed with even pacing, as prescribed. Mean power output was within +/- 3 W from work bout 1 to 4 within each prescription. However, at the individual level, execution of the 4x4 min prescription was more often associated with a negative pacing pattern (observed in ~1/3 of subjects) where power output declined >2% from the first to last work bout.

Adaptation time-course

Of the total change in Power$_{4mM}$ and $\dot{V}O_{2peak}$ during 12 weeks, INC achieved 98±80% and 70±80%, and MIX 147±74% and 92±74%, respectively, while DEC achieved only 34±83% and 38±91%, during the first 4 weeks of intensified training (Figure 2). However, changes in

270   PPO during cycle 1 were similar, $77\pm52\%$, $64\pm86\%$ and $89\pm88\%$ of total change in INC, MIX

271   and DEC groups, respectively. There was a significant change in $Power_{30s}$ in DEC during

272   cycle 1. Only small changes occurred during 12 weeks in all groups with respect to GE, and

273   will not be any further discussed. See Table 2 for more details.

274

275   Individual adaption variation was very large in all test variables in this cohort. For example,

276   overall mean improvement in PPO from pre to week 12 was $6\pm7\%$ ($P<0.05$). However, the

277   individual range was from -9 to 36%, a range which is representative for all test variables

278   presented.

279

280   - - Figure 2 - -

281

282   - - Table 2 - -

283

284   **Group comparisons**

285   During cycle 1, INC and MIX significantly increased PPO, $Power_{4mM}$ and $\dot{V}O_{2peak}$ (all

286    $P<0.05$), while DEC significantly increased PPO and $Power_{30s}$ (all $P<0.05$). There were no

287   significant differences in delta changes in any test variables across INC (4x16 min), DEC

288   (4x4 min), or MIX (Table 2 and Figure 3). However, INC (4x16 min) revealed a moderate ES

289   compared to DEC (4x4 min) when comparing delta changes in $Power_{4mM}$ (ES: 0.7) and

290    $\dot{V}O_{2peak}$ (ES: 0.7). A similar analysis of PPO and $Power_{30s}$ revealed no differences between

291   INC and DEC.

292

293   During cycle 2, DEC increased significantly in $Power_{4mM}$ ($P<0.05$). No further significant

294   changes were observed in any test variables in INC (4x8 min), DEC (4x8 min), or MIX (all

295   *P*>0.05), and there were no significant differences in delta changes between groups (Table 2,

296   Figure 3).

297

298   During cycle 3, DEC significantly increased $\dot{V}O_{2peak}$ (*P*<0.05). No further significant changes

299   were observed for any test variables in INC (4x4 min), DEC (4x16 min), or MIX (all

300   *P*>0.05), and there were no significant differences in delta changes between groups (Table 2,

301   Figure 3). However, in this final 4-week cycle, DEC (4x16 min) revealed a moderate ES

302   compared to INC (4x4 min) when comparing delta changes in both Power$_{4mM}$ (ES: 0.5) and

303    $\dot{V}O_{2peak}$ (ES: 0.5).

304

305   - - Figure 3 - -

306

307   **Blood hormones**

308   The sub-sample of 29 subjects assessed for anabolic and catabolic hormonal responses in

309   addition to physiological tests were representative of the total sample in terms of both

310   adaptive time-course and group comparisons. There were no significant differences among

311   INC, DEC and MIX at pre for any blood hormone measured.

312

313   Pooling the three training groups, TT, FT and FTCR decreased by 22±15%, 13±23% and

314   14±31%, respectively by the end of the first 4-week training cycle (all *P*<0.05). IGF-1

315   increased 10±14% (*P*<0.05). In contrast, comparing pre to week 12, TT, IGF-1 and IGF-BP3

316   increased 24±31%, 11±18% and 8±13%, respectively (all *P*<0.05, Figure 4).

317

318   Hormonal changes are presented in Figure 4 as delta changes in each group across 12 weeks.

319   Most important findings are:

320   •   TT decreased 27±15%, 25±14% and 16±15% during cycle 1 in INC, DEC and MIX

321   groups, respectively (all $P<0.05$), and returned to pre-intervention levels by the end of

322   cycle 2 ($P>0.05$ vs. pre). MIX group had 42±24% elevated TT at the end of cycle 3

323   compared to pre ($P<0.05$).

324   •   FT decreased 24±15% in INC during cycle 1 ($P<0.05$) and returned to pre-

325   intervention level by cycle 3. The decline in FT was significantly higher in INC

326   compared to DEC (24±15% vs. 1±29%) during cycle 1 ($P<0.05$, ES: 1.0).

327   •   FTCR decreased 22±27%, 12±25% and 8±41% during cycle 1 in INC, DEC and MIX

328   groups, respectively (all $P>0.05$). A comparison of INC (4x16 min) (22±27%) vs.

329   DEC (4x4 min) (12±25%) during cycle 1, revealed an effect size of 0.4 ($P>0.05$). A

330   comparison of DEC (4x16 min) (decreased 4±20%) vs. INC (4x4 min) (increased

331   18±34%) in the final cycle revealed a significant difference ($P<0.05$, ES: 0.9).

332   •   HGH increased 38±80% in INC (4x16 min) compared to 19±45% in DEC (4x4 min)

333   during cycle 1 ($P>0.05$, ES: 0.5).

334

335   - - Figure 4 - -

336

Discussion

338 This study can be summarized with three key findings:

339   1. HIT performed during the initial 4-weeks of training appears to have larger impact on

340   specific performance outcomes than what occurs later in the periodized mesocycles.

341   Both INC (4x16 min) and MIX reached ≥70% of total development in Power$_{4mM}$ and

342        $\dot{V}O_{2peak}$, while DEC (4x4 min) reached ≥89% of total development in PPO and

343   Power$_{30s}$ already during cycle 1.

344   2. Performing 2-3 weekly HIT sessions with an interval prescription of 4x16 min, seems

345   to induce greater adaptions in Power$_{4mM}$ and $\dot{V}O_{2peak}$ compared to the same frequency

346   of 4x4 min prescription whether prescribed early or late in a 12-week periodization

347   plan.

348   3. The first 4 training weeks, which were associated with the largest progression in

349   Power$_{4mM}$, $\dot{V}O_{2peak}$, PPO and Power$_{30s}$ in specific groups, were also characterized by

350   decreases in anabolic hormones in all groups. In training cycles 2 and 3, resting

351   hormone values rebounded to baseline levels or even increased, but this rebound was

352   accompanied by smaller adaption magnitude.

353

354   Our first key finding is that ≥70% of the progression in Power$_{4mM}$ and $\dot{V}O_{2peak}$ was achieved

355   already during the initial 4 weeks of training for both INC (4x16 min) and MIX group, while

356   DEC (4x4 min) reached ≥89% of total development in PPO and Power$_{30s}$ in cycle 1. During

357   this period, all groups increased ~2-6% in Power$_{4mM}$, $\dot{V}O_{2peak}$ and PPO, a magnitude

358   comparable to previous studies of similar length (18, 24).

359

360   To stimulate improvements in endurance capacity in already well-trained athletes it appears

361   necessary to increase the total training volume (3, 9, 25), increase intensity of the aerobic

362   endurance training (17, 19) or reorganize HIT training in, for example, block periods to

363   provide an adequate stimuli (23, 24). In the present study, subjects increased the HIT

364   frequency from 1 weekly session during the pre-intervention period, to 2-3 weekly sessions

365   during the intervention period. On average, this intensification provided a sufficient stimulus

366   to elicit physiological improvements in Power$_{4mM}$, $\dot{V}O_{2peak}$ and PPO (Figure 2/Table 2). This

367   finding alone is not surprising. However, most previous training intervention studies present

368   only pre to post results during similar timeframes (13, 23, 26, 29, 31). We therefore argue that

369   by providing a time-course with more frequent testing (e.g. every 4th week) more accurate

370   prediction of training effects over more extended timeframes can be achieved. Bearing in

371   mind that most of the positive effect in specific variables was achieved already during the

372   initial 4 weeks of training intensification, our results highlight that extrapolating short term

373   adaptation rates from a training intervention involving HIT to even modestly longer time

374   frames is ill-advised. In this context, it is interesting that 4-week cycles are quite commonly

375   used in elite endurance sport, often characterized by 3-week training load builds and 1-week

376   load reductions. Our findings are also consistent with training descriptions of elite endurance

377   athletes, who use HIT consistently but relatively sparingly when examined over an entire

378   training year (3, 25, 34).

379

380   **Group comparisons**

381   Our second key finding is that accumulating 2-3 $h \cdot week^{-1}$ at the "lower" end of the HIT range

382   performing intervals as 4x16 min, tended to elicit superior adaptions in $Power_{4mM}$ and $\dot{V}O_{2peak}$

383   compared to accumulating ~1 $h \cdot week^{-1}$ at the "higher" end of the HIT range performing a 4x4

384   min interval prescription.

385

386   During the first training cycle, a 4x16 min "*isoeffort*" interval training prescription (INC

387   group) tended to induce greater adaptations in $Power_{4mM}$ and $\dot{V}O_{2peak}$ compared to a 4x4 min

388   interval prescription (DEC group). The ES of the relative improvement in $Power_{4mM}$ and

389   $\dot{V}O_{2peak}$ revealed a moderate effect of 4x16 min vs. 4x4 min prescription. Even in the final

390   cycle when, in theory, much of the short-term adaptation potential had been realized, we

391   found a similar tendency. These results are in line with previous findings from our research

392   group. Both Seiler et al (2013) (29) and Sandbakk et al (2013) (26) found that a HIT

393   prescription accumulating more minutes at a slightly lower intensity level compared to a 4x4

394   min prescription, induced greater overall adaptive response, inclusive $\dot{V}O_{2max}$, in recreational

395   to well-trained athletes. The present study was however performed on a much larger group of

396   well-trained subjects (n=69) during a longer time-frame. Furthermore, a case study of a

397   professional cyclist suggests that increasing HIT time by slightly decreasing intensity during

398   2-3 weekly interval sessions, in combination with an increase in total training volume,

399   increased $\dot{V}O_{2max}$ from 82 to 90 $ml^{.}kg^{-1.}min^{-1}$ during a 3-month period (30). However, in

400   contrast to our results, Helgerud et al (2007) (13) observed that 4x4 min intervals at 90-95%

401   HR_{max} lead to larger improvements in endurance capacity compared to LT training at ~85%

402   HR_{max}. The training groups in the study by Helgerud and colleagues were however matched

403   for total work (*isoenergetic*) in contrast to our "maximal overall effort" (*isoeffort*) model.

404   Consequently, the LT training sessions were only modestly longer in accumulated duration

405   than the 4x4 min sessions. This form of matching is not consistent with how athletes manage

406   intensity and accumulated duration in their daily training. We argue that matching training for

407   overall effort is more representative of this process in well trained athletes.

408

409   During cycle 1, DEC was the only group which significantly improved in both PPO and

410   Power$_{30s}$. This may be because those variables are more specific to a 4x4 min interval

411   prescription due to higher power output (Table 1). PPO performed as an incremental test is a

412   function of both aerobic and anaerobic energy supply. Therefore, an individual can increase in

413   PPO without any change in aerobic energy supply. Due to no or only small aerobic adaptions

414   in DEC during cycle 1, we speculate that the observed increase in PPO was a result of

415   anaerobic energy supply adaptions.

416

417   **Blood hormones**

418   The third key finding is that large progression in Power$_{4mM}$, $\dot{V}O_{2peak}$, PPO and Power$_{30s}$ in

419   specific groups during the first 4 weeks was accompanied with a decrease in anabolic

420   hormones in all groups, which thereafter rebounded to baseline levels in cycles 2 and 3, when

421   adaption magnitude was reduced.

422

423   During the first 4-week cycle, both TT, FT and FTCR decreased significantly. Although an

424   anabolic response (increased T/decreased C) is most likely expected together with

425   physiological adaptions, reduced serum concentrations of T (measured in a fasted rested state)

426   after a successful period of intensive training have also been observed elsewhere (5,

427   12). However, an acute increase in the circulating concentration of T is also a normal

428   observation directly after high intensity endurance exercise (35). Up-regulation of T has been

429   suggested to be associated with increased androgen receptor expression (AR) (22). Therefore,

430   we speculate whether increased expression of AR can partially explain the present temporary

431   reduction (measured after 4 weeks) in serum T, due to increased binding of T to AR and

432   therefore increased uptake of T in muscle cells (16). Speculating further, this increased T

433   uptake could, in turn, amplify the intracellular signal for endurance adaptation. The present

434   results suggest that in well trained cyclists, a modest reduction in T levels during intensified

435   training need not predict decreased performance.

436

437   For all groups pooled together during the entire 12-week training period, we observed a

438   significant increase in both TT and IGF-1/BP3. The observed anabolic response was

439   accompanied by improvements in key components of performance, such as PPO, Power$_{4mM}$

440   and $\dot{V}O_{2peak}$. This is in agreement with previous findings that have demonstrated that training

441   periods with frequent HIT sessions increase T levels (39), and that increased IGF-1 correlates

442   positively with improvements in $\dot{V}O_{2max}$ (8, 21).

443

When comparing between groups, superior adaptations in $Power_{4mM}$ and $\dot{V}O_{2peak}$ were

observed in INC (4x16 min) compared to DEC (4x4 min) during the first training cycle.

Simultaneously, we also observed a large ES and a significant difference when comparing the

decrease in FT in INC and DEC group, which may indicate a functional, controlled

overreaching in INC group, and may explain absence of physiological adaption in DEC. On

the other hand, decreased T in combination with increased C has been proposed as an early

marker of the overtraining syndrome, and a change in FTCR of >30% as a boundary to

diagnose overtraining (36, 37). In the present study, FTCR decreased by 22% after

performing cycle 1 with 4x16 min interval prescription (INC), compared to 12% after a 4x4

min interval prescription (DEC) (ES: 0.4). This pattern was confirmed during the final cycle,

where a 4x16 min interval prescription (DEC) was followed by a 4% decreased in FTCR,

compared to an 18% increase after a 4x4 min interval prescription (INC) (ES: 1.0). This

suggests that the 2-3 weekly sessions of 4x16 min were very demanding, but may be

necessary to stimulate large aerobic enhancements in already well-trained cyclists. The latter

is supported by the fact that superior endurance adaptations have been observed after

implementing periods with very demanding HIT blocks, compared to a more even distribution

of the same training volume and exercise intensity distribution (23). Although FTCR

decreased, we found a 38% increase in the anabolic hormone HGH in INC (4x16 min) vs.

19% in DEC (4x4 min) group (moderate ES) during cycle 1. It has been suggested that

circulating HGH may act as a positive stimulus for expansion of plasma volume and

erythropoiesis (6). Altogether, the hormonal data from the first training cycle indicate that

differences in hormonal changes induced by the different HIT training cycles may contribute

to the observed differences in adaptations between the training groups.

467

Methodological considerations

This present intervention period aimed to simulate a preparation period leading up to the competition period, and not peak performance. We assume that athletes switch their training-focus after a similar period, for example by competing regularly. The intention with interval sessions was therefore mainly to build general aerobic performance capacity. Performed intensities differed in all interval prescriptions (Table 1). The 4x16 min was executed at an average power output just below $Power_{4mM}$ and almost all subjects managed to achieve a constant or slightly increasing power output evolution from first to fourth interval bout. We suggest that the 4x16 min intensity is near power output at LT or MLSS, but still in the lower range of the HIT zone, and therefore almost exclusively sustained through aerobic metabolism. However, the 4x4 min prescription was executed 15-20% above $Power_{4mM}$ and therefore in the upper range of the HIT zone or near maximal aerobic intensities. In addition, subjects more often failed our "steady or increasing" prescription during 4x4 min intervals, indicative of more "anaerobic" intracellular metabolic conditions that may not be conducive to optimal adaptive signaling of aerobic metabolic adaptations. These differences may explain why we observed different specific performance adaptions comparing a 4x16 min vs. 4x4 min interval prescription, especially during cycle 1.

CONCLUSION

The results of the current study suggest that most of the progression in $Power_{4mM}$, $\dot{V}O_{2peak}$, PPO and $Power_{30s}$ during a 12 week HIT intervention were achieved already during the initial 4 weeks of training. However, the magnitude of adaption was dependent on the specific interval training prescription, independent of timing of prescription. Accumulating 2-3 h per week performing intervals as 4x16 min appears to induce greater adaptions in $Power_{4mM}$ and $\dot{V}O_{2peak}$ compared to accumulating ~1 h per week performing intervals as 4x4 min. Resting

493 levels of anabolic hormones were found to first decline and then rebound over 12 weeks, with

494 the period of decline associated with greater adaption.

495

504

510

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626

627 **FIGURE LEGENDS**

628

629 **FIGURE 1:** Study protocol. A 6-week pre-intervention period, consisting of *ad libitum* LIT

630 and one prescribed interval session each week, in addition to pre-test and randomization (R),

631 was followed by a 12-week intervention period divided in three 4-week cycles with different

632 interval session prescriptions for the **increasing HIT (INC)** (n=23) **decreasing HIT (DEC)**

633   (n=20) and **mixed HIT (MIX)** (n=20) groups. Testing was performed pre-intervention,

634   during week 4, 8 and 12. Figure redrawn from Sylta et al (2016) (33).

635

636   **FIGURE 2, A-C:** Mean (SD) high-intensity training (HIT) duration each week during a 12-

637   week training period in (A) increasing HIT (INC) (N=23), (B) decreasing HIT (DEC) (N=20)

638   and (C) mixed HIT (MIX) (N=20) training group. T=test. See Figure 1 for detailed interval

639   training prescriptions during each cycle. **D-L:** Mean and 95% CI for delta changes in peak

640   power output (PPO), peak oxygen uptake ($\dot{V}O_{2peak}$) (ml·min^{-1}) and power at 4 mMol·L^{-1} lactate

641   (Power$_{4mM}$) at pre, after 4, 8 and 12 weeks of training in INC (D/G/J), DEC (E/H/K) and

642   MIX (F/I/L) training group, respectively. * $P<0.05$ for changes from pre.

643

644   **FIGURE 3:** Mean and 95% CI for delta changes (%) in (A) power at 4 mMol·L^{-1} lactate

645   (Power$_{4mM}$) and (B) peak oxygen uptake ($\dot{V}O_{2peak}$) (ml·min^{-1}) in increasing HIT (INC),

646   decreasing HIT (DEC) and mixed HIT (MIX) training group, during cycle 1 (week 1-4), cycle

647   2 (week 5-8) and cycle 3 (week 9-12), respectively. Values inside boxes represent interval

648   training prescriptions during each cycle. * $P<0.05$ for changes within cycle.

649

650   **FIGURE 4:** Mean change in blood hormones at pre, after 4, 8 and 12 weeks of training in

651   increasing HIT (INC) (N=9), decreasing HIT (DEC) (N=10) and mixed HIT (MIX) (N=10)

652   training group, respectively. * $P<0.05$ for changes from last observation, # $P<0.05$ for

653   changes from pre.

654

TABLE 1. Physiological and perceptual responses during interval sessions executed as 4x16, 4x8 and 4x4 min during a 12 week intervention period.

	4x16 min	4x8 min	4x4 min	P-value*
Power (W)[§]	276 (25)	308 (29)	342 (33)	<0.001
Power ($W \cdot kg^{-1}$)[§]	3.5 (0.4)	3.9 (0.4)	4.3 (0.4)	<0.001
Percent of PPO (%)[§]	65 (4)	71 (4)	80 (4)	<0.001
Percent of $Power_{4mM}$ (%)[§]	97 (8)	106 (8)	118 (9)	<0.001
Percent of $Power_{40min}$ (%)[§]	95 (5)	106 (5)	117 (6)	<0.001
Blood lactate ($mMol \cdot L^{-1}$)[#]	4.7 (1.6)	9.2 (2.4)	12.7 (2.7)	<0.001
Interval bout HR_{mean} (% HR_{peak})[§]	86 (3)	88 (2)	89 (2)	<0.001
Interval bout HR_{peak} (% HR_{peak})[§]	89 (2)	91 (2)	94 (2)	<0.001
RPE (6-20)[§]	15.0 (1.1)	16.2 (0.8)	17.1 (0.9)	<0.001
sRPE 30min post session (1-10)[β]	6.3 (1.0)	6.9 (1.0)	7.7 (1.2)	<0.001

All values are calculated as the mean of means (SD) of up to 24 training sessions in 63 subjects. [§] All values of power, heart rate (HR) and rate of perceived exertion (RPE) represent a mean of all 4 interval laps. Reference values for Power at 4 $mMol \cdot L^{-1}$ blood lactate ($Power_{4mM}$) are mean of 4 tests performed at pre, week 4, 8, and 12. Reference value for 40 min time-trial power ($Power_{40min}$) is mean of pre and post test results. [#] Blood lactate was measured randomly among a subset of 56 subjects after interval lap 3 and 4, and a total of 531 samples (~10 per participant) were collected. [β] Session RPE (sRPE) was quantified 30 min post exercise. * One way repeated measure ANOVA comparing responses to HIT prescriptions. There were no significant differences in responses across intervention groups, although different interval prescriptions (4x16 and 4x4 min) were performed in opposite sequence (cycle 1 and 3) for INC and DEC, respectively.

1 **TABLE 2:** Pre-intervention values and absolute mean changes from last cycle in performance

2 and physiological variables in the Increasing HIT (INC) (N=23), Decreasing HIT (DEC)

3 (N=20) and Mixed HIT (MIX) (N=20) groups during the 12 week intervention period. All

4 values are mean (95% CI).

	Mean Pre	Mean change, Pre-Cycle 1	Mean change, Cycle 1-2	Mean change, Cycle 2-3
Power$_{4mM}$ (W)				
INC	277 (266, 287)	16 (6, 25)*	2 (-4, 9)	-2 (-10, 6)
DEC	283 (274, 293)	5 (-5, 15)	5 (-3, 14)	4 (-5, 13)
MIX	287 (273, 302)	8 (0, 17)	-2 (-8, 4)	-1 (-11, 8)
$\dot{V}O_{2peak}$ (ml·min^{-1})				
INC	4947 (4749, 5146)	196 (77, 316)*	97 (-18, 211)	-10 (-142, 121)
DEC	4794 (4594, 4994)	83 (-51, 217)	48 (-124, 220)	71 (-118, 260)
MIX	4858 (4609, 5108)	137 (9, 266)*	-7 (-148, 134)	10 (-183, 202)
Gross eff. (%)				
INC	18.8 (18.4, 19.3)	-0.3 (-0.7, 0.2)	-0.3 (-0.7, 0.2)	0.0 (-0.4, 0.4)
DEC	19.3 (18.9, 19.7)	-0.2 (-0.7, 0.3)	-0.1 (-0.6, 0.3)	0.0 (-0.4, 0.4)
MIX	19.1 (18.7, 19.5)	0.1 (-0.4, 0.5)	-0.4 (-0.9, 0.2)	0.0 (-0.5, 0.6)
PPO (W)				
INC	418 (403, 433)	22 (14, 30)*	3 (-6, 11)	4 (-4, 12)
DEC	414 (401, 427)	21 (8, 34)*	3 (-7, 12)	-1 (-7, 6)
MIX	417 (402, 433)	14 (1, 27)*	1 (-10, 12)	6 (-10, 21)
Power$_{30s}$ (W)				
INC	852 (827, 878)	10 (-5, 24)	0 (-13, 12)	1 (-15, 17)
DEC	824 (787, 862)	21 (1, 42)*	0 (-11, 11)	0 (-15, 15)
MIX	820 (773, 867)	19 (-8, 45)	0 (-17, 16)	-4 (-22, 14)

5 Power$_{4mM}$ = Power corresponding to 4mMol·L^{-1} lactate, $\dot{V}O_{2peak}$ = Peak oxygen uptake, PPO =

6 Peak Power Output, Power$_{30s}$ = Mean power during 30 s all out test. * = *P*<0.05 vs. last cycle.

7 There were no sig. between-group differences in relation to pre values or mean changes.

Figure 1
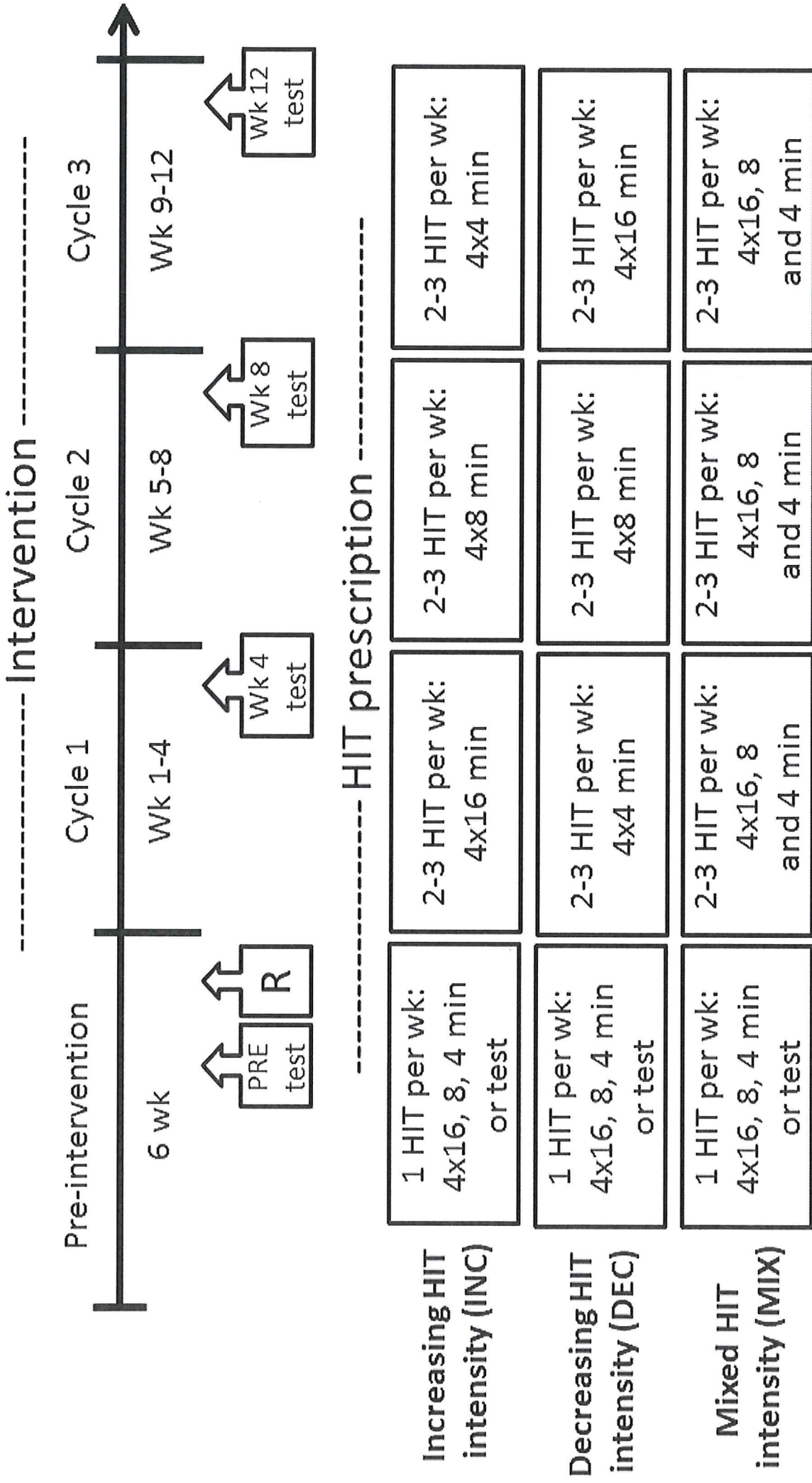
Figure 1
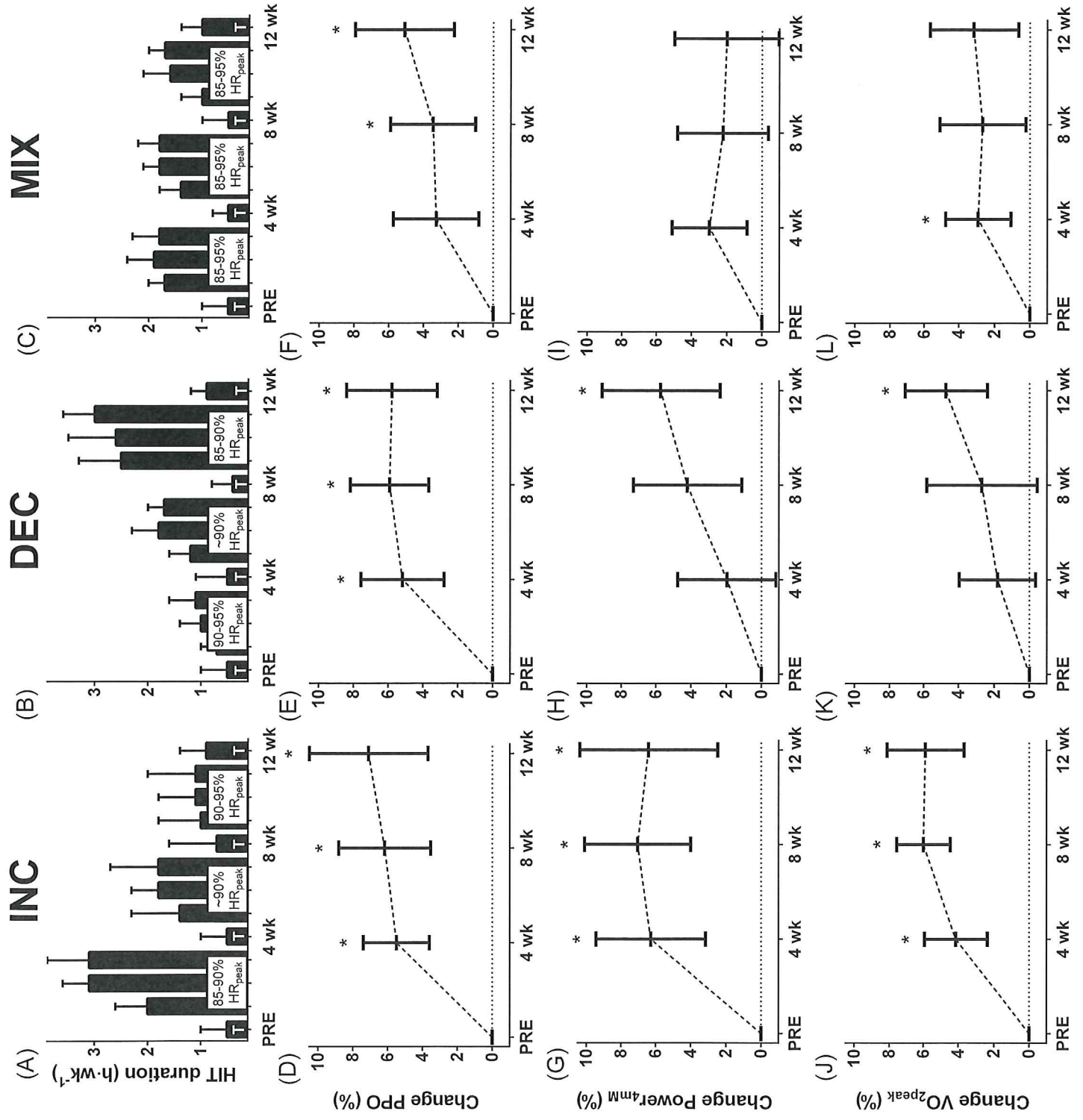
Figure 2

Figure 3

Figure 4

Total testosterone

Free testosterone

Cortisol

Free testosterone-cortisol ratio

Insulin-like growth factor-1

Human growth hormone
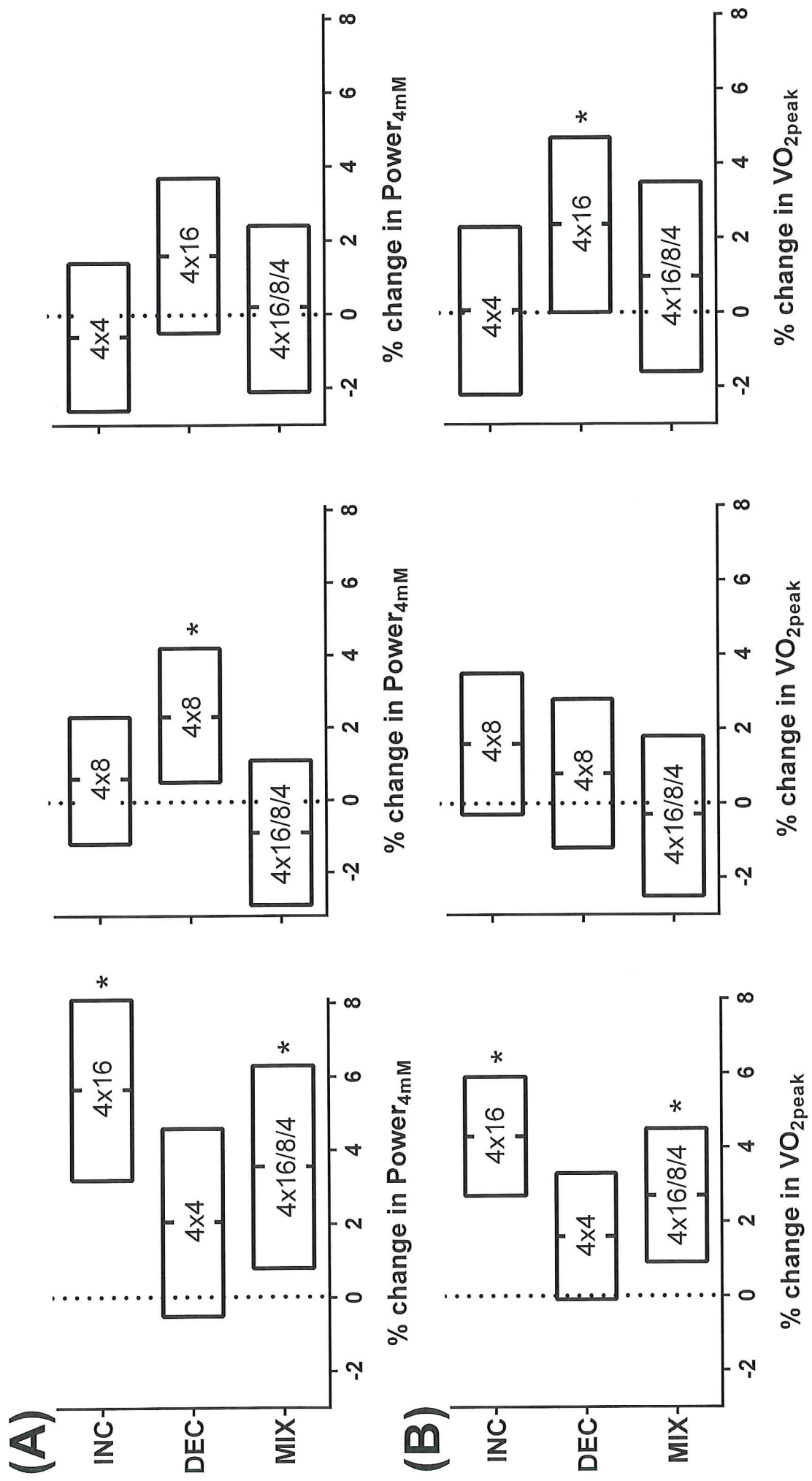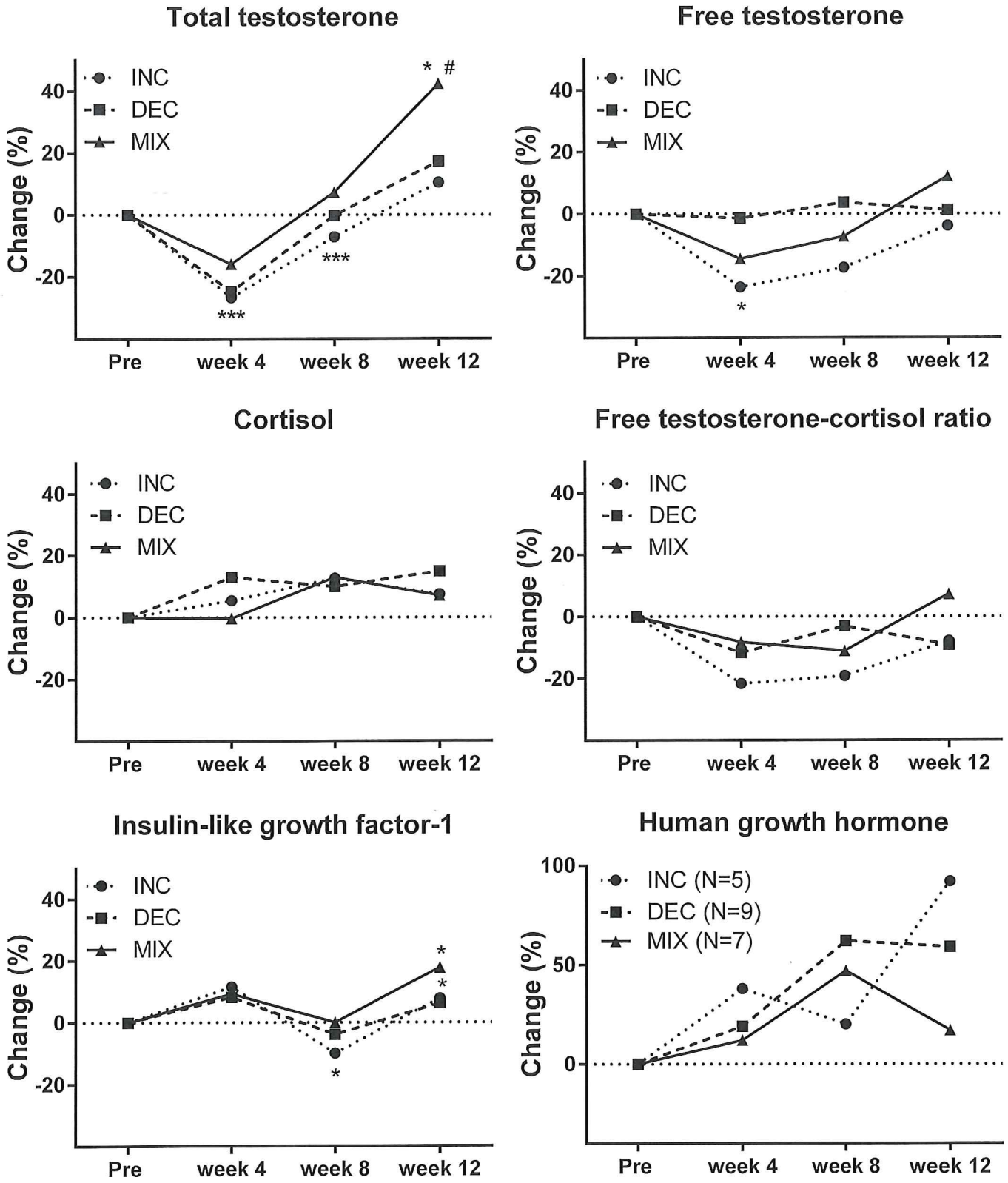
Index describing all collected data, *study III*

Appendix I: An overview of all collected data during *study III.*

Background data

Questionnaire:
- Age, work, children etc.
- Cycling experience (years, best performance)
- Training history

Restitution scales, day by day:
- Sleep duration
- Sleep quality
- Motivation to train
- Appetite
- How did you feel today?
- Overall recovery status
- How did your legs feel?
- Muscle soreness

Training/activity monitoring

OLT diary:
- Training volume, frequency, intensity distr. (SG/TIZ + SG)
- Training forms
- Activity forms (specific)
- Rest: sick/injured/plan
- Restitution (8 scales)

POLAR diary:
- Training volume, freq., intensity distr. (TIZ).
- Day by day activity monitoring (five zones)

HIT session's:
During each interval bout:
- Watt (total/per kg)
- HR mean/max
- RPE (general, muscular)
- RPM
- Lactate (~600) (lap 3&4)

Qualitative data:
- Own experiences after each 4 week cycle

Performance/ physiological tests

Pre, cycle 1, cycle 2 and post.
Performance test's:
- 40 min TT (only pre/post). Total & each 10 min: Watt, distance, HR mean/max, RPE(G/M), RPM (N=30), lactate.
- PPO/TTE
- Wingate: peak/mean30s/ fatigue/tot work.
- Development HIT sessions
- SJ/CMJ

Physiological tests:
Lactate profile tests (n=~280): 125→375 W: VO_2, HR, RPE(G/M), lactate, RPM.
- CC, gross/delta efficiency, metabolic (F/KH), LT_1, LT_2, %LT HR/VO_2/RPE
VO_{2max} tests (n=~280):
- MAP, VO_{2peak}, HR, RPE(G/M), VE, lactate, HR drop. 14 min post: lactate.
HR_{rest} (N=30)

Body composition (IN Body, N=50):
- Weight, height, fat (kg/%), SMM (kg), BMI etc.

Blood tests (N=30):
- Total/free testosterone, SHBG, IGF-1, IGF-BP3, HGH, cortisol and PRL.

RED's

Pre/post (N=21):
- Diet reg. (3x3 d)
- RMR/BP (sit/rise)
- HR_{rest}
- Questionnaire
- DXA (post)
- Blood tests (Total cholesterol, LDL, HDL, Triglycerides, Glucose, T-3, S-Insulin)

Tapering (n=15):
- Training monitoring
- Testing (all tests)

Informed consent, *study I*

Forespørsel om bruk av data til forskningsprosjektet

Best practice for endurance training among Norwegian cross country skiers.

Bakgrunn og hensikt

Dette er en forespørsel til deg om å delta i en forskningsstudie hvor hensikten er å øke vår kunnskap om hva som kjennetegner treningen til våre beste langrenns utøvere for å kunne utvikle dere videre, samt gi råd til andre utøvere som ønsker å nå det samme nivået. I løpet av denne og andre treningssamlinger vil det bli samlet inn data om deg og din trening. Dette innbefatter bl.a treningsdagbok, pulsdata, fysiologiske data, testresultater, evalueringer av dine økter osv. Dette er en forespørsel til deg om tillatelse til å benytte disse dataene til et forskningsprosjekt.

Utholdenhetstrening innebærer manipulering av belastningsfaktorene varighet, intensitet, aktivitetsform og frekvens på kort og lang sikt. Dessverre er beste praksis for disse variablene blant godt trente utøvere dårlig dokumentert. Det er nå ønskelig å benytte langrennslandslaget til datainnsamling hvor Norge har en stor gruppe av internasjonalt suksessrike utøvere. Du er en av disse, og ut i fra dine fantastiske resultater må man anta at du har gjort særdeles mye riktig i treningen din. Denne kunnskapen vil på sikt være med på å skape økt innsikt og forståelse i hva som skal til for å nå et internasjonalt topp nivå i din idrett, og vil være verdifull for deg og neste generasjons utøvere som ønsker å ta over hegemoniet. For å bidra til at dagens/kommende utøvere får et best mulig treningsopplegg, og at Norge fortsetter å utvikle topputøvere er det nødvendig at treningen til våre beste utøvere blir kartlagt.

Hva innebærer studien for deg?

Alt du gjennomfører av trening på denne (og evt senere) samlinger vil bli «observert» og data samlet inn. Din pulsklokke samles inn daglig for avlesning, det gjennomføres fysiologiske tester på mølla og oppfølging underveis på økter (eks laktatmålinger), samt at du må føre daglig treningsdagbok (papirformat) som blir samlet inn jevnlig. Data og informasjon fra dine økter og treningsdagbøker vil bli registrert og systematisert, og det er ønskelig å bruke dette til forskning senere.

Data vil bli samlet inn av ditt vanlige støtteapparat fra langrennslandslaget og Olympiatoppen (OLT). I tillegg har OLT i samarbeid med Universitet i Agder (UiA) ansatt en doktorgradsstipendiat, Øystein Sylta, på prosjektet. Professor Stephen Seiler ved UiA står ansvarlig for forskingsprosjektet, og fagsjef for trening ved OLT Espen Tønnessen er medansvarlig.

Mulige fordeler og ulemper

Ved å delta i studien får du en systematisk og fullstendig oversikt over egen trening og tester i det aktuelle tidsrommet, som kan gjøre deg og støtteapparatet mer bevisst slik at treningsprosessen blir enda bedre. Ditt bidrag vil også ha stor verdi for andre topputøvere, og for trenere som arbeider med utvikling av utøvere på topp internasjonalt nivå. Det kan oppfattes som en ulempe at du som deltaker i forskningen blir bedt om å dele dine treningsdata/treningsdagbok i løpet av samlingen.

Hva skjer med informasjonen om deg?

Informasjonen som blir registrert om deg skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysningene vil bli behandlet uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger. En kode knytter deg til dine data gjennom en navneliste. Det er kun autorisert personell

knyttet til prosjektet som har adgang til navnelisten og som kan finne tilbake til deg. Så langt som mulig skal det søkes å publisere resultatene slik at ikke identiteten til inkluderte kommer frem, ved at data publiseres på gruppenivå, og ikke som enkeltutøver. Som offentlig kjent person kan det likevel være at enkelte personer vil kunne gjenkjenne din identitet.

Dataene som fremkommer i studien vil bli benyttet i doktorgradsarbeidet og artikler i internasjonale tidsskrifter, men vil også bli presentert på nasjonale og internasjonale konferanser og seminarer, og i forelesninger på høgskoler og universitet.

Hvis du sier ja til å delta i studien, har du rett til å få innsyn i data som er registrert på deg. Du har videre rett til å få korrigert eventuelle feil i de dataene vi har registrert. Dersom du trekker deg fra studien, kan du kreve å få slettet innsamlede opplysninger. Opplysningene blir senest slettet 2023.

Frivillig deltakelse
Det er frivillig å delta i studien. Du kan når som helst og uten å oppgi noen grunn trekke ditt samtykke. Dette vil ikke få konsekvenser for ditt videre samarbeid med OLT. Dersom du godtar at dine treningsdata kan brukes ber vi deg fylle ut svararket under. Ved spørsmål kontakt:

Stipendiat Øystein Sylta ved Universitetet i Agder
Mail: oystein.sylta@uia.no
Tlf: + 47 92 25 27 92

Prosjektleder Professor/Dekan Stephen Seiler ved Universitetet i Agder
Mail: stephen.seiler@uia.no
Tlf: +47 38 71 14 97/ + 47 91 61 45 87

Fagsjef for trening Espen Tønnessen ved Olympiatoppen:
Mail: espen.tonnessen@olympiatoppen.no
Tlf: + 47 99 09 87 67

Samtykke til deltakelse i studie

JEG GODTAR AT MINE DATA BENYTTES
Jeg har mottatt skriftlig informasjon og **godtar at mine data** benyttes til forskningsprosjektet, forskning og statistiske fremstillinger i internasjonale tidsskrifter

NAVN (med blokkbokstaver):_____

Dato   Underskrift

Informed consent, *study III*

Forespørsel om deltakelse i forskningsprosjektet

«Eksperimentell forskning:
Effekten av ulike periodiseringsmodeller blant sub elite syklister»

Bakgrunn og hensikt
Dette er et spørsmål til deg om å delta i en forskningsstudie hvor hensikten er å undersøke effekten av ulike periodiseringsmodeller innen utholdenhetsidrett.

Dette vil bli undersøkt ved å gjennomføre et eksperimentelt treningsforsøk hvorav de intensive øktenes **rekkefølge og variasjon** vil bli «manipulert» i etterfølgende sykluser som del av grunntreningen til godt trente syklister. Effekten vurderes på bakgrunn av endringer i prestasjonsvariabler, fysiologiske variabler, perseptuelle endringer og stress hormoner som følge av de ulike syklusene og intervensjonsperioden som helhet.

Studien bygger videre på hva vi vet om effekten av ulike treningsmodeller basert på tidligere forskning og erfaringer fra praksisfeltet.

Hva innebærer studien?
Intervensjonsperioden har en varighet på 12 uker, i tillegg til tilvenningsperiode, testing og formtoppingsperiode, og det planlegges med start av intervensjonsperioden uke 1 2015.

Treningsmodellen i intervensjonsperioden tar utgangspunkt i en *polarisert* tilnærming hvorav det legges opp til 2-3 intensive økter (HIT) pr uke (sone 3-5) i tillegg til 4-5 rolige økter (LIT - sone 1-2). Selve intervensjonens hovedhensikt er å manipulere intensitet og varighet på HIT øktene i tre ulike modeller. Fra deskriptive studier og praktiske erfaringer vet vi at det er vanlig med en progressiv og periodisert oppbygning av den intensive treningen, hvorav HIT øktene blir hardere og kortere inn mot sesongstart (fra sone 3 til sone 5).

I inneværende studie deles selve intervensjonsperioden opp i tre sykluser, hver med varighet på fire uker. Antallet HIT økter pr uke vil være hhv 2-3-3-1 innad i hver fire-ukers syklus.

Det legges opp til følgende periodiseringsmodeller:

1. Tradisjonell modell; sykluser med HIT økter i hhv sone 3 – 4 – 5
2. Reversert modell; sykluser med HIT økter i hhv sone 5 – 4 – 3
3. Hybrid modell; sykluser med HIT økter i hhv sone 3/4/5 – 3/4/5 – 3/4/5

De ulike periodiseringsgruppene vil ha likt totalt gjennomsnittlig volum, intensitetsfordeling og antallet HIT økter i løpet av hele intervensjonsperioden.

Studiens rammer vil bare forhånds bestemme innholdet på HIT økter i tillegg til å begrense andel alternativ trening (<30 %). Øvrig treningsinnhold står du fritt som forsøksperson til å bestemme selv. Innad i hver syklus anbefales det ca. 10 % progressiv økning i totalt volum pr uke de tre første ukene og en restitusjonsuke som inneholder én test dag og ca. 50 % reduksjon i totalt volum.

Alle HIT økter starter med 15min oppvarming og 10min nedkjøring og gjennomføres felles på sykkelrulle under veiledning og standardisert datainnsamling. Sone 3 kjøres som 4 x 16min, sone 4 som 4 x 8min og sone 5 som 4 x 4min. Øktene skal gjennomføres «så hardt som mulig», men innenfor øktens rammer. Belastningen (watt) innad i hvert drag skal være steady state (utenom første minutt) og

det skal være progressiv eller lik belastning fra drag til drag. Pauselengden er 2 min og gjennomføres med lett tråkk (50-100w).

Det legges opp til en tilvenningsperiode på fire uker i forkant av intervensjonsperioden, i tillegg til test uker pre og post. For utvalgte deltakere vil det også gjennomføres en formoppkjørings periode etter intervensjonsperioden med påfølgende test. Total varighet på studien vil være 18-20 uker.

Mulige fordeler og ulemper
Som forsøksperson har du følgende fordeler av å delta på studien:

- Får delta på et vitenskapelig fundamentert treningsopplegg, med randomisering i tre treningsgrupper som alle sannsynligvis er effektive.
- Får delta på et prosjekt i samarbeid med Olympiatoppen og anvender dermed deres kunnskap og viten om effektiv trening.
- Mulighet til å bidra til å skaffe kunnskap for å utvikle toppidretten.
- Får gjennomføre et stort testbatteri med mulighet til å få et meget nyansert bilde av egen kapasitet.
- Deltakelse på 2-3 intensive fellesøkter pr uke under kyndig veiledning. Øktene kjøres på sykkelruller med nøyaktig wattmåling.
- Mulighet for kjøp av pulsklokke (Polar V800) til halv pris hvis du fullfører prosjektet.
- Kan selv bestemme total treningsmengde i tillegg til HIT øktene.
- Får testet ut effekten av et formoppkjøringsopplegg som del av siste testperiode.

Eventuelle ulemper:

- Må møte til fellesøkter/tester i løpet av perioden.
- Kan bare trene de HIT øktene som intervensjonsopplegget tilsier.
- Anstrengende treningsøkter og tester krever god innsats og motivasjon.
- Risiko for evt overbelastning som følge av treningsopplegg.

Hva skjer med testresultater, prøver og informasjonen om deg?
Alle testresultater, prøver og informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysningene og prøvene vil bli behandlet uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger. En kode knytter deg til dine opplysninger og prøver gjennom en navneliste. Det er kun autorisert personell knyttet til prosjektet som har adgang til navnelisten og som kan finne tilbake til deg. Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres.

Frivillig deltakelse
Det er frivillig å delta i studien. Du kan når som helst og uten å oppgi noen grunn trekke ditt samtykke til å delta i studien. Dette vil ikke få konsekvenser for din videre behandling. Dersom du ønsker å delta, undertegner du samtykkeerklæringen på siste side. Om du nå sier ja til å delta, kan du senere trekke tilbake ditt samtykke uten at det påvirker din øvrige behandling. Dersom du senere ønsker å trekke deg eller har spørsmål til studien, kan du kontakte:

Prosjektleder Øystein Sylta ved Universitetet i Agder
Mail: oystein.sylta@uia.no
Tlf: + 47 92 25 27 92

Professor/Dekan Stephen Seiler ved Universitetet i Agder
Mail: stephen.seiler@uia.no
Tlf: +47 38 71 14 97/ + 47 91 61 45 87

Appendix III

Fagsjef for trening ved Olympiatoppen Espen Tønnessen
Mail: espen.tonnessen@olympiatoppen.no
Tlf: + 47 99 09 87 67

Ytterligere informasjon om studien finnes i kapittel *A – utdypende forklaring av hva studien innebærer.*

Ytterligere informasjon om biobank, personvern og forsikring finnes i kapittel B *– Personvern, biobank, økonomi og forsikring.*

Samtykkeerklæring følger etter kapittel B

Kapittel A- utdypende forklaring av hva studien innebærer

Ved behov for ytterligere informasjon om hva studien innebærer henvises det til vedlegg 1 (bakerst i dette dokumentet), *Project description.*

Kapittel B - Personvern, biobank, økonomi og forsikring

Personvern
Opplysninger som registreres om deg er relatert til din trening/generell helsetilstand og dine testresultater. Som forsøksperson må du registrere all gjennomført trening og helsestatus (som følge av treningen) daglig i Olympiatoppens elektroniske treningsdagbok. I tillegg vil vi som prosjektledere samle inn data på deg tilknyttet gjennomføring av alle HIT økter og omfattende test data ifm testperiodene.

Utfyllende informasjon vedrørende datainnsamling henvises til vedlegg 1.

Utlevering av materiale og opplysninger til andre
Hvis du sier ja til å delta i studien, gir du også ditt samtykke til at blodprøver utleveres til et analyselaboratorium i Sveits, Bern. Ansvarlig person er Dr. Michael Vogt.

Rett til innsyn og sletting av opplysninger om deg og sletting av prøver
Hvis du sier ja til å delta i studien, har du rett til å få innsyn i hvilke opplysninger som er registrert om deg. Du har videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du trekker deg fra studien, kan du kreve å få slettet innsamlede prøver og opplysninger, med mindre opplysningene allerede er inngått i analyser eller brukt i vitenskapelige publikasjoner.

Finansiering
Studien er finansiert gjennom forskningsmidler fra Olympiatoppen i tillegg til Universitetet i Agder.

Forsikring
Som deltaker i studien er du forsikret gjennom Universitetet i Agders forsikringsordninger.

Informasjon om utfallet av studien
Som deltaker har du rett på å få utfyllende informasjon om utfallet av studien gjennom lesing av publiserte artikler, foredrag etc.

Samtykke til deltakelse i studien

Jeg er villig til å delta i studien

(Signert av prosjektdeltaker, dato)

Jeg bekrefter å ha gitt informasjon om studien

(Signert, rolle i studien, dato)

Informed consent, *study II*

Appendix IV

Til: Forsøkspersonen
Fra: Espen Tønnessen (Olympiatoppen)

Informasjonsskriv om treningsfilosofiprosjektet i langrenn
Bakgrunn og hensikt med studien:

Hva er det som ligger til grunn for at noen utøvere blir bedre enn andre? Skyldes det medfødte egenskaper, sterkere ønske og vilje til å vinne, tålmodighet, støtte og oppfølging fra familie, venner, klubb og forbund, eller skyldes det rett og slett at de trener bedre enn andre? Sannsynligvis er det en rekke forhold som må fungere over lang tid før en kan ta steget opp på seierspallens øverste trinn. I mitt doktorgradsarbeid ønsker jeg å få mer dyptgående og helhetlig kunnskap om hva som skal til for å oppnå internasjonale resultater i typiske aerobe utholdenhetsidretter.

Ut i fra dine fantastiske resultater må man anta at du har gjort særdeles mye riktig. Hensikten med studien er å få en grundig og helhetlig beskrivelse og forståelse av din treningsprosess fra talent til internasjonal langdistanseløper. Denne kunnskapen vil på sikt være med på å skape økt innsikt og forståelse i hva som skal til for å nå et internasjonalt nivå i din idrett, og vil være verdifull for neste generasjons utøvere som ønsker å ta over hegemoniet. Hensikten med studien er altså ikke å bekrefte eller avkrefte hypoteser, men snarere å skape nye gode hypoteser innenfor problemområdet. Resultatene fra studien vil også kunne danne grunnlag for ny begrepsforståelse innenfor fagfeltet.

Metode:

I studien vil jeg foreta intervju av deg, treneren din og andre personer som (vi/du tror) har betydd mye for din idrettslige utvikling. Intervjuene vil bli tatt opp på lydbånd og skrives ut ordrett, og for deretter å bli analysert etter visse kriterier. Disse vil oppbevares trygt, og makuleres når undersøkelsen er ferdigstilt. Intervjuet vil vare en til to timer.

Jeg vil også analysere treningsdagbøkene dine ved at treningstid, treningsintensitet og treningsinnholdet registreres i et nettbasert databaseverktøy.

For å sikre pålitelige og gyldige data, er det ønskelig med en kontinuerlig dialog med deg gjennom hele studien. I felleskap skal vi komme frem til det endelige forskningsresultatet. Du vil få muligheten til å lese gjennom intervjuet, manuset og analysene av treningsdataene når de foreligger.

Dataene som fremkommer i intervjuet og fra treningsdagbøkene vil bli behandlet konfidensielt. Som offentlig kjent person kan det være at enkelte personer allikevel vil kunne gjenkjenne din identitet. For å sikre din rett til privatliv vil du få muligheten til å lese igjennom og godkjenne manuset i avhandlingen før det blir publisert.

Ved å delta i studien får du en systematisk og fullstendig oversikt over egen treningsutvikling, fra ungdom til avsluttet karriere. Ditt bidrag vil også ha stor verdi for fremtidige talentfulle og ambisiøse utholdenhetsutøvere, og for trenere som arbeider med utvikling av talentfulle utøvere i din idrett.

Appendix IV

Informert samtykke

Dataene som fremkommer i studien vil i hovedsak bli benyttet i mitt doktorgradsarbeid, men vil også bli presentert på nasjonale og internasjonale konferanser og seminar, og i forelesninger på høgskoler.

I henhold til etiske retningslinjer for forskning på mennesker er det anbefalt å få et skriftlig samtykke på at du frivillig deltar i dette prosjektet.

Jeg, _____, bekrefter at jeg har mottatt informasjon og samtykker herved i å delta i prosjektet, og har muligheten til å trekke meg når som helst uten noen som helst form for konsekvenser.

Oslo,_____

_ _ _ _ _ _ _ _ _ _ _ _ _ _ _   _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
Forsøksperson   Espen Tønnessen
                                                       Fagsjef for trening i Olympiatoppen

Jeg, Espen Tønnessen, forplikter meg kun til å bruke dataene fra studiet til de formålene som er skissert i avtalen/informasjonsskrivet.

På forhånd hjertelig takk for at du vil stille opp!

Dersom det er noe som du lurer på kan du kontakte meg på mail eller telefon:
- E-mail: espen.tonnessen@olympiatoppen.no
- Mobil: 99 09 87 67

Vennlig hilsen

_ _ _ _ _ _ _ _ _ _ _
Espen Tønnessen
Fagsjef fortrening i Olympiatoppen

Confirmation of research clearance from NSD, *studies I-III*

Appendix V

Norsk samfunnsvitenskapelig datatjeneste AS
NORWEGIAN SOCIAL SCIENCE DATA SERVICES

Øystein Sylta
Institutt for folkehelse, idrett og ernæring
Universitetet i Agder
Serviceboks 422
4604 KRISTIANSAND S

Vår dato: 07.08.2012   Vår ref:30922 / 3 / HIT   Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 25.06.2012. All nødvendig informasjon om prosjektet forelå i sin helhet 02.08.2012. Meldingen gjelder prosjektet:

30922	*Best Practice for Endurance Training among Norwegian Olympic and World Championship Medal Winners*
	A study of duration, intensity distribution, activity form, frequency, changes in physiological variables and lactate profile during the season, training monitoring and the effect of different models for periodization.
Behandlingsansvarlig	*Universitetet i Agder, ved institusjonens øverste leder*
Daglig ansvarlig	*Øystein Sylta*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, eventuelle kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/forsk_stud/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://www.nsd.uib.no/personvern/prosjektoversikt.jsp.

Personvernombudet vil ved prosjektets avslutning, 31.07.2016, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Vigdis Namtvedt Kvalheim

Hildur Thorarensen

Avdelingskontorer / District Offices:
OSLO: NSD. Universitetet i Oslo, Postboks 1055 Blindern, 0316 Oslo. Tel: +47-22 85 52 11. nsd@uio.no
TRONDHEIM: NSD. Norges teknisk-naturvitenskapelige universitet, 7491 Trondheim. Tel: +47-73 59 19 07. kyrre.svarva@svt.ntnu.no
TROMSØ: NSD. SVF, Universitetet i Tromsø, 9037 Tromsø. Tel: +47-77 64 43 36. nsdmaa@sv.uit.no

Kontaktperson: Hildur Thorarensen tlf: 55 58 26 54
Vedlegg: Prosjektvurdering

Personvernombudet for forskning

Prosjektvurdering - Kommentar

NASJONALT SAMARBEIDSPROSJEKT
Personvernombudet forstår det slik at prosjektet skjer i samarbeid mellom Universitetet i Agder og Olympiatoppen (OLT), med førstnevnte som behandlingsansvarlig institusjon. Ombudet forutsetter at ansvarsforhold, sikring og evt. eierskap av data er avklart mellom de to institusjonene, og anbefaler at forholdet formaliseres.

FORMÅL OG UTVALG
Prosjektets formål er å øke kunnskapen om hva som kjennetegner treningen til våre mest suksessfulle utøvere innen utholdenhetsidrett, og systematisere deler av OLT's database med testresultater og treningsdata. Utvalget består av ca. 30-50 tidligere og nåværende idrettsutøvere på høyt internasjonalt nivå innen typiske aerobe utholdenhetsidretter. Rekruttering skjer ved at OLT tar kontakt med utøverne med forespørsel om deltakelse.

INFORMASJON OG SAMTYKKE
Det innhentes skriftlig samtykke basert på skriftlig informasjon. Personvernombudet finner informasjonsskrivet tilfredsstillende, såfremt følgende endring foretas:

- det må fremgå at dato for prosjektslutt er 31.07.2016, og personopplysninger vil bli oppbevart i ti år etter dette for eventuelle oppfølgingsstudier, undervisning og veiledning.

Vi ber om å få tilsendt revidert skriv før dette distribueres til utvalget.

DATAMATERIALETS INNHOLD
Data som innhentes inkluderer treningsdata og testresultater. Dataene er tidligere innhentet som del av OLT's oppfølging av utøverens treningsprosess. Videre vil prosjektleder analysere dataene og om nødvendig gjennomføre samtaler og observasjoner for å kvalitetssikre at dataene blir riktig fremstilt.

Personvernombudet tar høyde for at det kan bli registrert sensitive personopplysninger om helseforhold, jf. personopplysningsloven § 2 nr. 8 c). Personvernombudet finner at denne behandlingen kan finne sted med hjemmel i personopplysningsloven § 8 første ledd og § 9 a) (samtykke).

INFORMASJONSSIKKERHET
Materialet registreres og oppbevares på pc i nettverkssystem tilknyttet virksomheten. Det oppgis at datamaskiner beskyttes av brukernavn og passord. Datamaterialet vil være knyttet til direkte personidentifiserende opplysninger via kode som viser til en koblingsnøkkel.

PROSJEKTSLUTT
Enkelte personer vil kunne være indirekte identifiserbare i det endelige datamaterialet. Dette vil skje via avtale med den enkelte, og vedkommende vil få anledning til å lese igjennom egne opplysninger/sitater og godkjenne disse før publisering.

Prosjektslutt er oppgitt til 31.06.2016. Vi vil da ta ny kontakt. Datamaterialet oppbevares frem til 2026 for mulige oppfølgingsstudier, undervisning og veiledning til andre utøvere, og anonymiseres etter dette.

Vi gjør oppmerksom på at bruk av materialet til annet enn forskning, kan medføre konsesjonsplikt til Datatilsynet - dette gjelder eksempelvis dersom materialet skal brukes til undervisningsformål. Vi legger til grunn at Datatilsynet kontaktes dersom dette blir aktuelt.

Confirmation of research clearance from REK, *study III*

REK
REGIONALE KOMITEER FOR MEDISINSK OG HELSEFAGLIG FORSKNINGSETIKK

Region:	Saksbehandler:	Telefon:	Vår dato:	Vår referanse:
REK sør-øst	Hege Holde Andersson	22845514	17.10.2014	2014/1532/REK sør-øst B
			Deres dato:	Deres referanse:
			19.08.2014	

Vår referanse må oppgis ved alle henvendelser

Øystein Sylta
Universitetet i Agder

2014/1532 Eksperimentell forskning: Effekten av ulike periodiseringsmodeller blant sub-elite syklister

Vi viser til søknad om forhåndsgodkjenning av ovennevnte forskningsprosjekt. Søknaden ble behandlet av Regional komité for medisinsk og helsefaglig forskningsetikk (REK sør-øst) i møtet 17.09.2014. Vurderingen er gjort med hjemmel i helseforskningsloven § 10, jf. forskningsetikklovens § 4.

Forskningsansvarlig: Universitetet i Agder, Høgskolen på Lillehammer, Norges Teknisk-Naturvitenskapelige Universitet, Olympiatoppen, Haus des Skisportes
Prosjektleder: Øystein Sylta

Prosjektleders prosjektomtale
Hensikten med studien er å gi ny kunnskap om effekten av ulike periodiseringsmodeller innen utholdenhetsidrett. Dette vil bli gjennomført gjennom et eksperimentelt studie hvor metoden innebærer å manipulere rekkefølge og variasjon i tre etterfølgende fire ukers sykluser (total 12 ukers intervensjon) som del av grunntreningen blant sub-elite syklister. Det planlegges med tre ulike intervensjonsmodeller hvorav intensitet og rekkefølgen på de intensive treningsøktene vil variere: 1 - tradisjonell modell 2 - reversert modell 3 - hybrid modell Total treningsbelastning vil være lik i alle modeller i løpet av intervensjonsperioden. Effekten vurderes på bakgrunn av endringer i prestasjonsvariabler, fysiologiske variabler, perseptuelle endringer og stress hormoner som følge av de ulike syklusene og intervensjonsperioden som helhet. Resultatene av studien vil være av betydning for vår inneværende viten om ulike periodiseringsmodeller innen utholdenhetsidrett.

Komiteens vurdering
Slik komiteen oppfatter prosjektet er formålet å gi ny kunnskap om effekten av ulike periodiseringsmodeller innen utholdenhetsidrett. Komiteen vurderer at prosjektet, slik det er presentert i søknad og protokoll, ikke vil gi ny kunnskap om helse og sykdom som sådan. Prosjektet faller derfor utenfor REKs mandat etter helseforskningsloven.

Det kreves ikke godkjenning fra REK for å gjennomføre prosjektet. Prosjektet kommer inn under de interne regler som gjelder ved forskningsansvarlig virksomhet. Det er institusjonens ansvar å sørge for at prosjektet følger gjeldende reguleringer for behandling av helseopplysninger. Ettersom prosjektet forutsettes gjennomført i samsvar med gjeldende reguleringer, vil dette ikke være til noe hinder for at resultatene kan publiseres.

Vedtak
Etter søknaden fremstår prosjektet ikke som medisinsk eller helsefaglig forskning, og prosjektet faller derfor utenfor helseforskningslovens virkeområde, jf. § 2

Klageadgang
Du kan klage på komiteens vedtak, jf. forvaltningslovens § 28 flg. Klagen sendes til REK sør-øst B.
Klagefristen er tre uker fra du mottar dette brevet. Dersom vedtaket opprettholdes av REK sør-øst B, sendes
klagen videre til Den nasjonale forskningsetiske komité for medisin og helsefag for endelig vurdering.

Med vennlig hilsen

Grete Dyb
førsteamanuensis dr. med.
leder REK sør-øst B

Hege Holde Andersson
Komitésekretær

Kopi til: - *Universitetet i Agder ved øverste administrative ledelse*
           - *Førsteamanuensis Bent Rønnestad, Høgskolen på Lillehammer*
           - *Øyvind Sandbakk, NTNU*
           - *Fagsjef Espen Tønnessen, Olympiatoppen*
           - *Forsker Michael Vogt, Haus des Skisportes*

Confirmation of research clearance from NSD, *study III*

Appendix VII

Øystein Sylta

Institutt for folkehelse, idrett og ernæring Universitetet i Agder

Serviceboks 422

4604 KRISTIANSAND S

Vår dato: 18.01.2016	Vår ref: 45021 / 3 / MSS	Deres dato:	Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 06.10.2015. Meldingen gjelder prosjektet:

45021	*Effekten av å periodisere intensiv trening blant sub-elite syklister på prestasjons-, fysiologiske-, perseptuelle- og hematologiske variabler i løpet av en 12 ukers treningsperiode*
	Sekundært forskningsspørsmål: - Endringer og kartlegging av energitilgjengelighet, kroppssammensetning, benmineraltetthet, blodtrykk, ulike blodparametere, samt treningsavhengighet som følge av 12 ukers intensiv utholdenhetstrening blant godt trente syklister.
Behandlingsansvarlig	*Universitetet i Agder, ved institusjonens øverste leder*
Daglig ansvarlig	*Øystein Sylta*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 01.10.2017, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Vigdis Namtvedt Kvalheim

Marie Strand Schildmann

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Kontaktperson: Marie Strand Schildmann tlf: 55 58 31 52
Vedlegg: Prosjektvurdering

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektet er igangsatt og datainnsamlingen er allerede gjennomført. Personvernombudet finner dette beklagelig. Behandlingen av personopplysninger skulle vært meldt i god tid og senest 30 dager før oppstart.

Prosjektet er lagt frem for REK, som fant at det falt utenfor helseforskningslovens virkeområde.

Formålet med prosjektet er å gi kunnskap om effekten av ulike periodiseringsmodeller innen utholdenhetsidrett. Dette er allerede gjennomført gjennom en eksperimentell studie som del av grunntreningen til sub-elite syklister. Effekten er vurdert på bakgrunn av endringer i prestasjonsvariabler, fysiologiske variabler, perseptuelle endringer og stresshormoner. I tillegg er det gjennomført målinger av energitilgjengelighet og variabler som kan assosieres med lav energitilgjengelighet; beinmineraltetthet, kroppssammensetning, blodtrykk, treningsavhengighet, samt ulike blodparametere. Dette er i tillegg utført på 20 langdistanseløpere i en oppfølgende data-innsamlings periode. Studien som er gjennomført på langdistanseløpere vurderes ikke i denne sammenhengen, men skal meldes inn som eget prosjekt.

Utvalget er informert skriftlig og muntlig om prosjektet og det er innhentet skriftlige samtykker til deltakelse. Informasjonsskrivet er godt utformet, men vi bemerker at dato for prosjektslutt og hva som da vil skje med datamaterialet, ikke fremgår. Vi finner likevel at beskrivelsen av hva datamaterialet skal brukes til legger klare føringer.

Data samles inn gjennom treningsøkter og tester på sykkel. I tillegg samles helsevariabler inn gjennom papirbasert spørreskjema, samt ved bruk av ergo-spirometri, blodprøver, måling av kroppssammensetning og DXA.

Det behandles sensitive personopplysninger om helseforhold, jf. personopplysningsloven § 2, punkt 8 c).

Personvernombudet legger til grunn at forsker etterfølger Universitetet i Agder sine interne rutiner for datasikkerhet.

Det forutsettes at blodprøver slettes så snart analyser er gjennomført (innen tre måneder), eller at de alternativt lagres ut prosjektperioden i en godkjent forskningsbiobank ved UiA.

Forventet prosjektslutt er 01.10.2017. Ifølge prosjektmeldingen skal innsamlede opplysninger da anonymiseres. Anonymisering innebærer å bearbeide datamaterialet slik at ingen enkeltpersoner kan gjenkjennes. Det gjøres ved å:
- slette direkte personopplysninger (som navn/koblingsnøkkel)
- slette/omskrive indirekte personopplysninger (identifiserende sammenstilling av bakgrunnsopplysninger som f.eks. bosted/arbeidssted, konkurranseresultater, alder og kjønn)