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

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From heart rate data to training quantification: a comparison of three methods of training intensity analysis

This is an original investigation with 3 tables and 4 figures. The abstract consists of 230 words and the text 3441 words.

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Running head:

Training intensity distribution quantification

Abstract

Purpose: We directly compared three 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 XC skiers (16 male, 13 female, 25 ± 4 yr, 70 ± 11 kg, 76 ± 7 $mL \cdot min^{-1} \cdot kg^{-1}$ 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 (LIT) range (zone 1), and 3.0/0.33 in the high intensity training (HIT) range (zone 2 & 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 HR based analysis methods.

Key words: XC skiers, endurance training, intensity distribution, time in zone, session goal.

Introduction

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, blood lactate, VO_2)[3-13]. Training dose can also be measured by how the stimulus was *perceived* (session RPE)[12,14-18]. Most high-level endurance athletes maintain a training diary where they report their training. In reality, some combination of all three 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 heart rate (HR) response. One approach is *Time in Zone (TIZ)*[4,5,9-12]. Dedicated software allocates HR registration data to intensity zones defined from cut-offs registered in the software by the athlete/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[12]. A third approach is a hybrid combination of SG and TIZ, called *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 three methods by depicting beat-for-beat HR responses to a typical endurance session lasting ~90 min. The elite athlete performed interval training organized as 5 x 8 min work periods with 2 min recoveries, in addition to a warm-up and cool-down period. Blood lactate concentration during the first, third and fourth rest periods was 3.5, 4.2 and 5.6 $mmol \cdot L^{-1}$ respectively. The session was prescribed as a "zone 3 interval session" based on the 3-zone model (Table 2). The athlete's maximal HR is 200. The TIZ method uses the HR-curve (solid line) to allocate time in different zones. 35 min is distributed in zone 3, plus 48 min in zone 1 and 5 min in zone 2. The SG approach categorizes this *whole* workout as a zone 3 session based on the highest intensity achieved and the accumulated duration at that intensity. The dotted line indicates the SG/TIZ method, giving 40 min in zone 3 and 48 min in zone 1, and is based on the workload actually performed rather than HR alone. Both SG and SG/TIZ methods use lactate values as additional information to determine correct intensity zones (Table 2). Critically, the validity of all three methods for investigating training dose, adaptive response, and performance development, depends on consistent and comparable interpretation of training data among coaches and scientists.

(Figure 1)

Seiler & 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 three 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 three 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 three methods of TID quantification in a large sample of training sessions performed by elite endurance athletes.

Methods

Subjects

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

(Table 1)

Training data collection

Data collection was performed during an altitude training camp in Val Senales (Italy), October 2012. The average length of the data collection period for each athlete was 14 days (range 8-18 days). Athletes were instructed to carry out their normal training and use a HR monitor during every session. In total, complete HR data was 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 2). In the present study athletes were asked to report their individualized 5-zone scale previously established based on physiological testing and field experience. Lab testing includes a standardized incremental submaximal exercise test running at 10.5 % inclination on a treadmill. The test consists of four 5-min 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 s recovery between each stage. This lactate profile test is followed by a VO_{2max} test (described previously[26]). All athletes were tested regularly (during 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 etc., zones can be expected to remain relatively constant over the course of a training year[28], and athletes therefore only use one scale to simplify their daily intensity control regime.

To compare the three 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 ($VT_{1/2}$ & $LT_{1/2}$)[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 2).

(Table 2)

Data analyses

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

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

2 - In the ***session goal*** 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/Table 2). Interval sessions where the intended intensity during the core portion was in zone 2/3 were categorized as zone 2/3 sessions if 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 min. For continuous sessions, an accumulation of >15 min was set as a threshold for categorizing the entire session as zone 2/3.

3 – The ***session goal/time in zone*** approach combines SG and TIZ approaches. For continuous sessions, time in zones was defined using HR curves as a visual starting point (Figure 1/Table 2). 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.

(Figure 2)

Data from each method were further analyzed and compared. Proportion (ratio) of zone 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 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, one *conversion factor* for TID ratio in the LIT (zone 1) range and one *conversion factor* in the HIT (zone 2 and 3 combined) range. The following formula was used for both:

Conversion factor (TIZ→SG) = Ratio SG % / Ratio TIZ %

Conversion factor (SG→TIZ) = Ratio TIZ % / Ratio SG %

Statistical analyses

Total training time is reported as mean ± standard deviation (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 (CI) bounding the difference 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 vs. 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 two methods. The relative underestimation of HIT time (zones 2 and 3 combined) was 21.1 ± 22.4 % (CI: 29.6 - 12.5, $P < .001$) when using TIZ vs. SG/TIZ (Table 3/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/Figure 3).

(Table 3)

(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).

(Figure 4)

Time in high intensity sessions

Mean duration of high intensity training periods was significantly lower in TIZ compared to SG/TIZ, 32.5 ± 8.6 vs. 38.2 ± 6.5 minutes, $P < .001$. TIZ underestimated time spent working in the HIT range by 27.5 ± 43.7 %.

Discussion

This study provides directly comparable data demonstrating differences in quantification of TID using three analysis methods frequently reported in the literature[4-13,19].

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 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 training intensity distribution[10-12,21-24], as well as intensity distribution during long single-day[13] and multi-day 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, zone 2 & 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 $h \cdot yr^{-1}$ /500 training sessions $\cdot yr^{-1}$, 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 1) LIT sessions are often longer than HIT sessions and 2) HIT sessions generally include considerable warm-up and cool-down time, and recovery time between high-intensity bouts. For example, a 6 x 4 min HIT session at 95 % HR_{max}, lactate values >6 $mmol \cdot L^{-1}$, with 2 min recovery, a 20 min warm-up and 15 min cool-down would result in a TIZ distribution of ~20 min HIT and 45 min 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 two TID calculation 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 sub-elite/recreational athletes. Converting TID data from TIZ to SG in junior athletes training ~500 $h \cdot yr^{-1}$ 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/5 $h \cdot wk^{-1}$, including two HIT sessions, gives ~15 % of training time, or 40 % HIT sessions, in TIZ or SG, respectively. These examples suggest that the *conversion factor* identified from elite athlete 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 10-12 hours of additional zone 2/3 training in an athlete training 800 $h \cdot yr^{-1}$. In addition, interval sessions include rest/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 importantly, these methods are frequently used among athletes as self-report in diaries. We have previously showed that when self-reporting training, elite athletes used a “conceptual” routine close to the SG/TIZ method[19]. In the Norwegian XC national 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 XC 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, "time-in-zone" 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], and therefore 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 present study, subjects only performed 13-14 % 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 ~3,000 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 sea level[30], but due to individualized downward adjustment of external load, athletes trained using their normal intensity scale after initial acclimatization. 24 of 29 athletes used the same intensity reference values at sea level and altitude. The remaining athletes reported < 5 $beat \cdot min^{-1}$ lower values in each zone at altitude. Collecting data in 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 2) suggests 82 %/2.5 $mmol \cdot L^{-1}$ as the lower limit, sessions in zone 2 are, due to very high aerobic capacity/lactate threshold, normally conducted with HR ~90 % and lactate 1.5-4.0. The high intensity zones is therefore narrower in elite vs. recreational athletes, and comparing 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. *Session rate of perceived exertion* (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 and colleagues[15,16] introduced the sRPE method to provide a measure of the global perception of intensity of an entire training session. Using sRPE as a basis for session intensity classification, Stellingwerf[18] found that TID in three male elite marathon runners during one year were 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 & Kjerland[12], found 92 % agreement between a 3-zone categorization of sRPE and the 3-zone SG method in junior XC 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 XC national cross-country ski team has formulated as a "success rule" that ~100-140 sessions in zones 2-3 should be integrated into the annual training load of >800hr (personal communication).

Practical applications

In this study we have objectively compared three 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 three 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 present 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 to 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 to 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 10-12 $h \cdot yr^{-1}$ and must be taken into account when evaluating self-reported training diaries using different methods.

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

- In interval sessions, recovery time should be subtracted from zone 2-3 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 provides 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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Table captions

Table 1: Physical characteristics of the subjects, male: N=16, female: N=13.

Table 2: The 5-zone intensity scale used by the Norwegian Olympic Federation. In addition the 3-zone and binary model used in the current study.

Table 3: Training time (hours) 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 hours/570 sessions).

Figure captions

Figure 1: Illustration of intensity distribution using three different methods. Three basic intensity zones are exemplified here. The TIZ method uses the HR curve (solid line) as basis for allocating time in different zones. The SG/TIZ method uses the dotted line indicates in combination with lactate values. The SG 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.

Figure 2: 570 training sessions executed by 29 elite athletes during 8-18 days training camp, along with accompanying HR data, lactate measurements and lactate profile test data, were distributed into three intensity zones via three different methods; HR derived *time in zone*, a categorical *session goal* allocation and a hybrid *session goal/time in zone* distribution.

Figure 3: Training intensity distribution in 570 sessions analyzed with three different methods; TIZ, SG/TIZ and SG.

Figure 4: The figure illustrates how to convert reported training distribution from a "*time based ratio*" method (TIZ or SG/TIZ) to a method of *categorical* allocation of each training session (SG), or vice versa. Panel A: LIT range and Panel B: HIT range.

Table 1

	Male Mean ± SD	Female Mean ± SD
Age (yr)	26 ± 3	24 ± 4
Height (cm)	181 ± 5	168 ± 5
Body mass (kg)	77.6 ± 6.5	61.2 ± 6.6
HR_{max} (beats · min^{-1})	194 ± 8	195 ± 8
VO_{2max} (mL · kg · min^{-1})	79.8 ± 5.0	70.3 ± 5.0
VO_{2max} (L · min^{-1})	6.2 ± 0.5	4.3 ± 0.3

Table 2

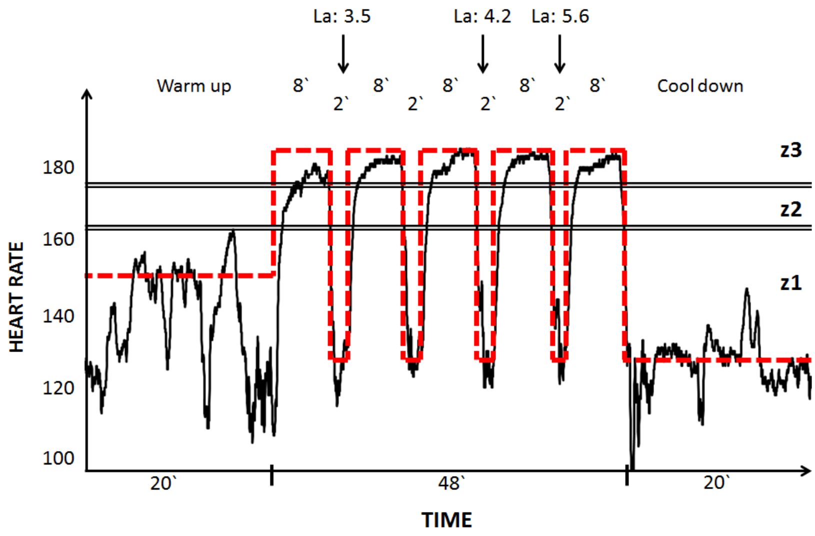
Intensity Zone	Lactate[#] (mmol · L^{-1})	Heart rate (% max)	Three zone model	Binary model
5	6.0-10.0	92-97	Zone 3	HIT
4	4.0-6.0	87-92		
3	2.5-4.0	82-87	Zone 2	
2	1.5-2.5	72-82	Zone 1	LIT
1	0.8-1.5	55-72		

Note. The reference values in this scale are guidelines only, and individual adjustments are required.
[#] measured with lactate pro LT-1710

Table 3

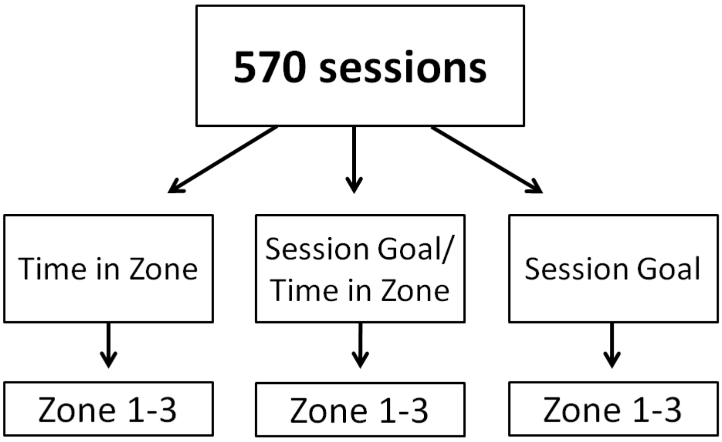
		TIZ (hours)	TIZ (%)	SG/TIZ (hours)	SG/TIZ (%)	SG (no. of sessions)	SG (%)
Mean (n=29)	Zone 1	36.7 ± 8.4	96.1 ± 1.4	36.5 ± 8.3	95.5 ± 1.5	17.0 ± 2.8	86.6 ± 4.8
	Zone 2	1.1 ± 0.5	2.9 ± 1.3	1.4 ± 0.6	3.6 ± 1.5	2.2 ± 1.0	11.1 ± 5.0
	Zone 3	0.4 ± 0.4	1.1 ± 0.9	0.3 ± 0.3	0.8 ± 0.7	0.5 ± 0.6	2.4 ± 2.8
Total (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	

Figure 1



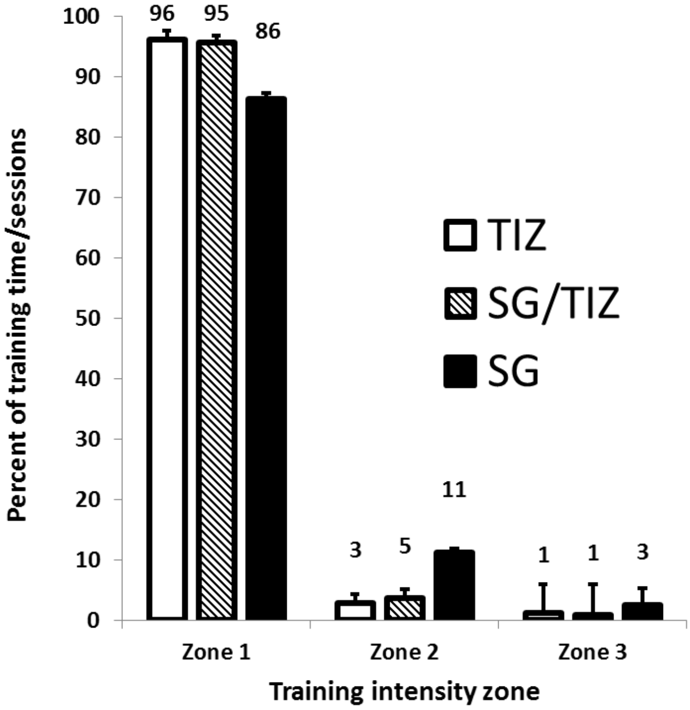
La: 3.5
La: 4.2
La: 5.6
Warm up
8`
2`
8`
2`
8`
2`
8`
2`
8`
Cool down
z3
z2
z1
HEART RATE
180
160
140
120
100
20`
48`
20`
TIME

Figure 2



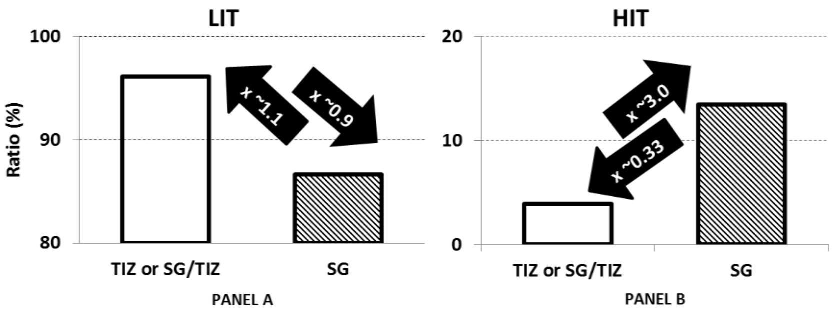
570 sessions
Time in Zone
Session Goal/
Time in Zone
Session Goal
Zone 1-3
Zone 1-3
Zone 1-3

Figure 3



100
90
80
70
60
50
40
30
20
10
0
Percent of training time/sessions
96
95
86
3
5
11
1
1
3
TIZ
SG/TIZ
SG
Zone 1
Zone 2
Zone 3
Training intensity zone

Figure 4


LIT
100
90
80
Ratio (%)
x ~1.1
x ~0.9
TIZ or SG/TIZ
SG
PANEL A
HIT
20
10
0
x ~3.0
x ~0.33
TIZ or SG/TIZ
SG
PANEL B