Mastergradsoppgave

# Autonomic recovery during high training loads in female world-class biathlon athletes

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# FULLMAKTSERKLÆRING – MASTERAVHANDLING

Norsk tittel: Autonom restitusjon ved høy treningsbelastning hos kvinnelige topptrente skiskyttere

Engelsk tittel: Autonomic recovery during high training loads in female world-class biathlon athletes

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Dato: 10.06.09 Navn: Egren Emanuelsen

# Autonom restitusjon ved høy treningsbelastning hos kvinnelige topptrente skiskyttere

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## SAMMENDRAG

**Målsetting**: Dette studiet ønsket å se på sammenhengen mellom hvilepuls, hjerte rate variabilitet (HRV), trening impuls (TRIMP), og selvrapportert følelse av utmattelse gjennom tre uker med konkurransetrening hos kvinnelige topptrente skiskyttere. **Metode**: Syv kvinnelige topptrente skiskyttere ble fulgt gjennom en mengdetreningsperiode (DIST), en høy-intensiv treningsperiode (INT), og en moderat treningsperiode (MOD). Utøverne gjennomførte 5 min liggende hvilepuls- og HRV-målinger hver morgen ved hjelp av Polar RS 800 hjertefrekvensmålere, og selvrapportert følelse av utmattelse hver kveld ved hjelp av en utmattingsskala. Treningsbelastningen ble rapportert i treningsdagbøker basert på hjertefrekvens-målinger. Etter en validering av Polar RS800- mot ECG-målinger, ble imidlertid HRV resultatene ekskludert fra videre analyser. **Resultat:** Hvilepuls økte signifikant i DIST og INT, sammenlignet med MOD. Ingen korrelasjoner ble funnet mellom hvilepuls, TRIMP og selvrapportert følelse av utmattelse. Inter-individuelle kryss korrelasjoner viste ingen signifikante sammenhenger mellom hvilepuls og TRIMP. **Konklusjon:** De signifikante sammenhengene mellom hvilepuls og treningsbelastning viser at kvinnelige topptrente skiskyttere blir autonom påvirket av perioder med ekstremt høye treningsbelastninger og av høy-intensive konkurranseperioder. En moderat treningsperiode fører til en signifikant nedgang i hvilepuls, noe som indikerer en autonom restitusjon. De individuelle variasjonene i hvilepuls markerer en individuell påvirking av ulike typer belastninger.

**Nøkkelord:** EKG, hjerte rate variabilitet, hvilepuls, utholdenhetstrening.

# Autonomic recovery during high training loads in female world-class biathlon athletes

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## ABSTRACT

**Purpose**: This study aimed to investigate the relationship between resting heart rate ($HR_{rest}$), heart rate variability (HRV), training impulse (TRIMP), and self-rated fatigue during three weeks of competitive training in female world-class biathlon athletes. **Methods**: Seven female world-class biathlon athletes were monitored during a high volume (long-distance) training period (DIST), an intensive competition training period (INT), and a moderate training period (MOD). The athletes performed 5 min supine $HR_{rest}$ and HRV measurements by use of Polar RS800 heart rate monitors every morning, and self-rated fatigue was recorded every evening by use of a fatigue scale. Training was recorded in training diaries based on HR recordings. After a validation study, comparing Polar measurements with ECG, the HRV results were excluded from the further analysis. **Results:** Resting heart rate increased significantly during DIST and INT, as compared to MOD. No correlations between $HR_{rest}$, TRIMP and self-rated fatigue were found. Inter-individual cross correlations showed no significant relationships between $HR_{rest}$ and TRIMP. **Conclusion:** The significant relationship between $HR_{rest}$ and TRIMP shows that female world-class biathlon athletes are autonomic affected by periods of extremely high training loads and by high intensity competition periods. However, a moderate training period leads to a reduced $HR_{rest}$, indicating an autonomic recovery. The individual variations in $HR_{rest}$ during the three training periods indicate an individual influence by different types of training loads.

**Key Words:** ECG, endurance training, heart rate variability, resting heart rate.

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## INTRODUCTION

Training represents a physical stress which challenges the human body and its homeostasis (Mastorakos et al., 2005). After physical stress, a subsequent adaptation takes place, normally expressed as a training effect (Åstrand et al., 2003: 313-368). To induce endurance training effects, frequency, duration and intensity play key roles (Hickson et al., 1982; Hickson et al., 1985; Wenger & Bell, 1986: Billat, 2001; Laursen & Jenkins, 2002; Rusko, 2003). To achieve maximal adaptive training effects, world-class athletes endure extremely high endurance training loads (Rusko, 2003; Fiskerstrand & Seiler, 2003; Seiler & Kjerland, 2004). It is likely that these training loads have lead to the superior aerobic capacity and endurance capability found in world-class skiers of both genders throughout the last decades (Saltin & Åstrand, 1967; Ingjer, 1991; Saltin, 1997). Based on the abovementioned relationship between training loads, aerobic capacity and performance, it seems reasonable to suggest that world-class athletes respond positively to these heavy training loads, and are able to achieve overcompensation.

In addition to high training loads, different types of endurance training stresses the different physiological factors that are needed to improve performance (Åstrand et al., 2003: 313-368). It is likely, that both the specific effect from each training session, as well as the accumulated effect of all training, determines the training effect.

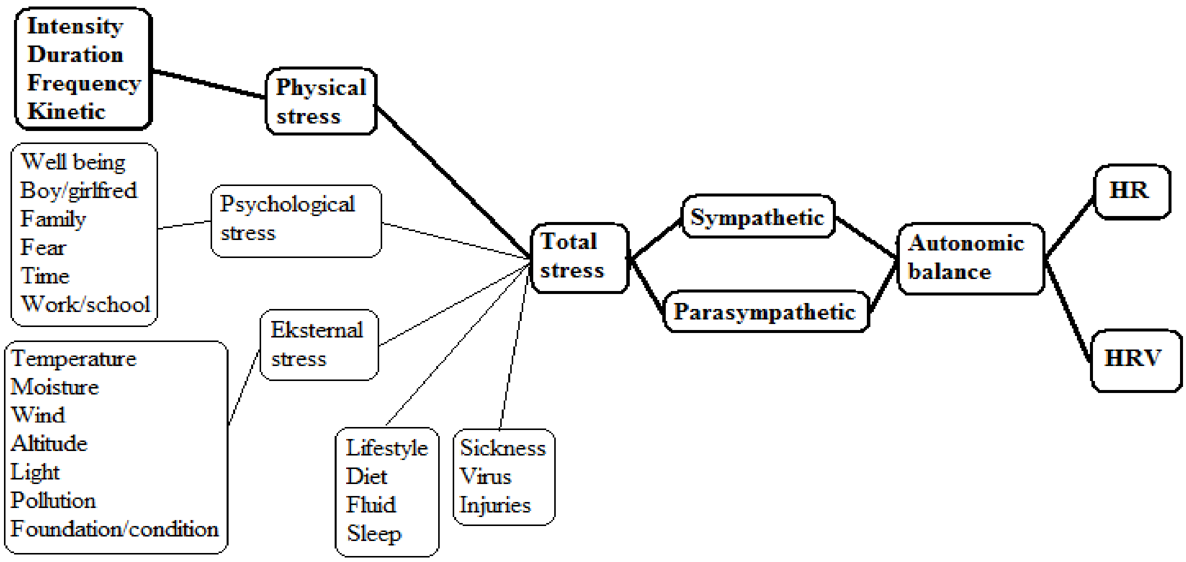



*Figure 1: An attempt to determine the total stress loads for an elite endurance athlete. The relationships between the boldface boxes are studied.*

In addition to physical stress, psychological stress factors also affect the organism's total stress, and Selye (1956) claims that the human body cannot separate between physical and psychological stress factors. Especially during competitions, world-class athletes experience high psychological stress in combination with high physical stress (Rushall, 1992: 43-60). Moreover, the total amount of stress load is also dependent on external factors such as weather, air moisture and temperature. An attempt is made in Figure 1 to summarize the different stressors. The combination of high physical and psychological stress loads can lead to stress-related side-effects and affect the autonomic balance (Hottenrot et al., 2006).

The automatic nervous system (ANS) controls the cardiovascular-, respiratory- and muscular system through the control center in medulla oblongata (Aubert et al., 2003). The balance between parasympathetic activity and sympathetic activity, in the ANS, controls heart rate (HR) during different physical stress loads (Earnest et al., 2004). Resting heart rate ($HR_{rest}$) and heart rate variability (HRV) are used as indexes of sympathetic- and parasympathetic activity, and is regarded to be functions of the synergistic action between these two branches of autonomic nervous system (Achten & Jeukendrup, 2003). These branches act in balance with a number of physiological mechanisms to maintain cardiovascular variables in an optimal range during changing external or internal conditions (Earnest et al., 2004). To investigate and monitor autonomic balance, $HR_{rest}$ and HRV is used as established, noninvasive tools (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. 1996).

To measure cardiac autonomic control and recovery, ECG measurements are regarded the "golden standard" because of the measurements includes the whole QRS complex during the heart beats (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Polar (Polar Electro Oy, Kempele, Finland) have introduced the measurements and analysis of R-R intervals by use of heart rate monitors, and propose that HR and HRV can be measured precisely and accurate during field testing (Laukkanen & Virtanen, 1998). However, HRV measurements are considered more sensitive because you need the accurate time (ms) between each heart beat, while $HR_{rest}$ is more resilient against noise using the mean of heart beats in a determined period (Achten & Jeukedrup, 2003). Validity and reliability tests on HRV by use of the Polar RS 800 HR-monitor have, to the present author´s knowledge, not yet been published; however, similar monitors are considered to measure HRV accurately (Laukkanen & Virtanen, 1998; Gamelin et al., 2006).

Aerobic capacity and endurance training is reported to influence autonomic control. The acute effects of increased stress (i.e., training) loads are increased $HR_{rest}$ and decreased HRV (Kaikkonen et al., 2007). In contrast, the long time effects of training, leading to improved physical capacity, is reported to relate to a decrease in $HR_{rest}$ and an increase in HRV, due to enhanced parasympathetic control (Fronchetti et al., 2007). As a long-term result of training adaptations, endurance athletes have decreased $HR_{rest}$ and increased HRV as compared to sedentary at rest (Kaikkonen et al., 2007; Borresen & Lambert, 2008). Studies have shown that after physical exercise, $HR_{rest}$ decrease and HRV increases slowly toward resting values as a function of time, and depends on the intensity and duration of the exercise (Kaikkonen et al., 2007). The resting level is reached within few minutes if the intensity is low and the duration is short, but the recovery of HR and HRV may last up to days if the intensity is high or the duration is long-lasting (Borresen & Lambert, 2008). A study performed on athletes during the cycle competition Tour of Spain, indicated that HRV may be strongly affected by chronic exposure to heavy exertion, and that training volume and intensity are necessary to explain the degree of these alterations (Earnest et al., 2004). The short- and long-term recovery of HR and HRV in sedentary people has been widely studied (Achten & Jeukendrup, 2003). However, this issue is relatively unexplored in world-class athletes, as well as how total training loads affect $HR_{rest}$ and HRV in these athletes. In addition, little is known on how different types of intensities, durations and frequencies in endurance affect these aspects.

Therefore, the purpose of this study was to investigate the relationships between indicators of autonomic recovery (i.e., $HR_{rest}$ and HRV) to training load and to self-rated fatigue during three weeks of competitive training in seven female world-class biathlon athletes. More specifically, it was hypothesized that the automatic balance would be affected by a period of high training loads and during a competition period compared to a moderate training period. A general relationship between autonomic balance and training load was also suggested.

## METHODS

### Subjects

Seven female world-class biathlon skiers, all members of the Norwegian biathlon team, including World Cup and World Championship medal winners, participated in the study. All the athletes were fully acquainted with the nature of the study before they gave their written consent to participate. The study was approved by the Regional Committee for Medical Research Ethics (REK), Norway.

**Table 1:** Baseline characteristics of seven female world-class biathlon athletes (mean ± SD).

| **Variables** | **mean ± SD** |
|---|---|
| Age (yr) | 26 ± 3 |
| Body height (cm) | 172.3 ± 3.4 |
| Body mass (kg) | 62.5 ± 7.3 |
| $VO_{2max}$ (ml· kg $^{-1}$·min$^{-1}$) | 63.8 ± 2.6 |
| $VO_{2max}$ (l·min$^{-1}$) | 3.78 ± 0.2 |
| Training last six month (hours) | 424.9 ± 40.3 |
| Shooting last six month (number of shots) | 11876 ± 3178.3 |

Training (hours) and shooting (total number of shots) were recorded from May to November. $VO_{2max}$ = maximal oxygen uptake during roller ski skating.

### Overall design of the study

The subjects were monitored sequencely during a six-day high volume (long-distance) training period (DIST), a seven-day intensive training period, including competitions (INT), and a seven-day moderate training period (MOD) (Table 2 and Figure 3). Resting heart rate ($HR_{rest}$) and heart rate variability (HRV; SDNN and pNN50) were recorded during 5 min in the supine position each morning by use of Polar RS800 heart rate monitors. Self-rated fatigue was recorded every evening by use of a fatigue scale. Training was recorded in training diaries based on HR recordings. A modified total training impulse model (TRIMP) was used to calculate total training load (Foster et al., 2001).

## Heart rate monitoring

To measure $HR_{rest}$ and HRV, a heart rate monitor was used (Polar RS 800, Polar Electro OY, Kempele, Finland). Heart rate data (i.e., R-R intervals) was transmitted online from the belt to the watch. The data was further transmitted to a computer program (Polar Pro Trainer 5, Polar Electro OY, Kempele, Finland) which labeled each R-R interval. This software labels all the time values between R-R intervals, but does not show the QRS complex which is needed to determine artifacts and ectopic beats. In an attempt to detect and remove errors, the Polar software possesses an error correction function. This function is supposed to eliminate errors. The error correction function was set to a minimum protection zone of 6 bpm. In addition, a Poincare plot of HRV, where each R-R interval is plotted as a function of the previous interval was displayed for manual editing, and areas of errors were identified and removed by manual deletion done by two independent observers.

Each subject performed the heart rate monitoring every morning during the 20-day period. Two minutes after they woke up, the athletes performed 5 min measurements in the supine position. Time domain analysis was used to calculate HRV. To assess the time domain measures, the standard deviation of the time between all R–R intervals over the given measurement period was analyzed (SDNN, ms), and the number of adjacent R-R intervals differing more than 50 ms expressed as a percentage of all intervals over the given measurement period (pNN50, %). These values were used as indexes on HRV. $HR_{rest}$ was calculated and presented as number of heart rates per minute.

## Validity of resting heart rate and heart rate variability

Since measuring HRV with the Polar heart rate monitor does not give access to each QRS complex when comparing the time between R-R intervals, we included a validation study and compared the Polar monitor to an ECG system (Delsys Myomonitori IV, Boston, US). In this validation we collected $HR_{rest}$ and HRV data simultaneously with Polar and ECG in four subjects lying in a supine position for 5 min. To study the differences between Polar RS 800 and ECG, a difference plot with ECG scores on the x-axis and the difference between the two methods on the y-axis was created (Altman & Bland, 1983). All errors were assigned solely to the Polar heart rate monitors. The modified Bland-Altman plot, in Figure 2, displays considerable lack of agreement between the Delsys ECG and the Polar HR monitor, with discrepancies of up to 400 ms in R-R intervals and ~20% of the Polar values more than 2 SD different from ECG. Moreover, individual plots revealed that while Polar and ECG gave relatively similar scores for the R-R intervals in two subjects, there was great discrepancy for the other two subjects (see Appendix Table I). In addition, the error correction function in the Polar software resulted both in greater agreement and greater disagreement with the ECG signal (see Appendix Figure I, II and II). The unknown discrepancies while measuring R-R intervals with the Polar RS 800 HR monitor may substantially influence the calculations of the HRV variables (e.g., SDNN and pNN50). Data on HRV, measured by the Polar heart rate monitor, are therefore not used further in this study. On the other hand, valid measurements of $HR_{rest}$ were revealed (Table and Figure are shown in the Appendix). As a consequence of these results, we choose to focus on $HR_{rest}$ -values during the rest of the study.

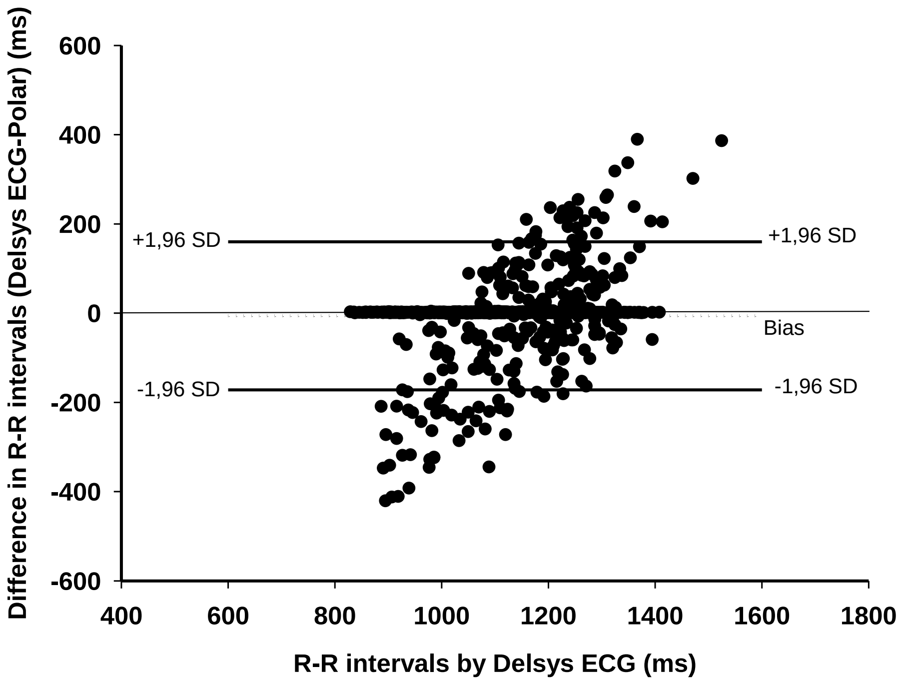



*Figure 2: Modified Bland-Altman difference plot showing bias and limits of agreement for R-R intervals between the Delsys ECG and Polar Heart rate monitor in four well-trained subjects laying in the supine position for 5 min (N = 901 observations). Dotted straight line = bias (average discrepancy between methods). Solid straight line = limits of agreement.*

**Self-rated fatigue**

A self-rated fatigue scale was developed to measure the overall subjective feeling of fatigue during the 20 days of competitive training. Self-rated fatigue was scored on a 1 to 6 point scale (1 = maximal fatigue; 6 = no fatigue) every evening. This index was used as an extra measure of fatigue, in addition to $HR_{rest}$ and HRV, during three weeks of high training loads.

**Maximal oxygen uptake**

All the subjects performed a maximal oxygen uptake ($VO_{2max}$) tests on roller skis, using a G2 skating technique (Nilsson et al., 2004), on a motor-driven treadmill (Bonte Technology**,** Netherlands; belt dimensions of 6 × 3 m), specially designed for roller-ski tests. After a standardized warm-up lasting for 20 min, a $VO_{2max}$ test was performed. The tests were performed at inclinations from 10 to 14 percent, and speed was increased every minute by 1 km $h^{-1}$ until a level that brought the subject to exhaustion, which occurred after 4-8 min. Oxygen uptake was measured continuously, and $VO_{2max}$ was determined by the average of the three highest 10-s consecutive measurements. The following criteria considered the test to be a maximal effort: 1) blood lactate concentration > 8 mmol $L^{-1}$, 2) RER > 1.10, 3) a plateau in $VO_2$ with increasing exercise intensity (Gore, 2000). The measurements of gas exchange values were done via open-circuit indirect calorimetry using Oxycon Pro apparatus (Jaeger, Hoechberg, Germany). To calibrate the $O_2$ and $CO_2$ gas analyzers we used high-precision gases before each measurement (16.00 ± 0.04% $O_2$ and 5.00 ± 0.1% $CO_2$). The inspiratory flowmeter was calibrated with a 3L volume syringe (Hans Rudolph Inc, Kansas City, MO, USA). Blood lactate concentration was determine by blood samples (5 µl), taken from the fingertip (Lactate Pro LT-1710*t,* ArkRay Inc, Kyoto, Japan; validated by Medbø et al., 2000).

**Training**

All training during the study was recorded and quantified by HR recordings during each training session. Training was categorized into 1) low intensity (LIT; ~ 60 and ~82 % of $HR_{max}$), 2) moderate intensity (MIT; ~ 83 to ~ 88 % of $HR_{max}$), 3) high intensity (HIT; > 88 % of $HR_{max}$) and 4) strength- and speed training. To calculate the overall training loads in each training period, a modified TRIMP model was used. Originally, TRIMP was introduced, developed and validated by Banister et al. (1980, 1991 and 1999) for evaluating the overall training loads, based on training duration and intensity. This study used the method introduced by Foster et al. (2001) to categorize endurance training into three intensity zones. Different types of strength- and speed training was also recorded and categorized. TRIMP was calculated by multiplying the accumulated duration spent in each intensity zone by 1, 2, and 3 for the LIT, MIT and HIT, respectively. Strength and speed training was in this study multiplied by 2.

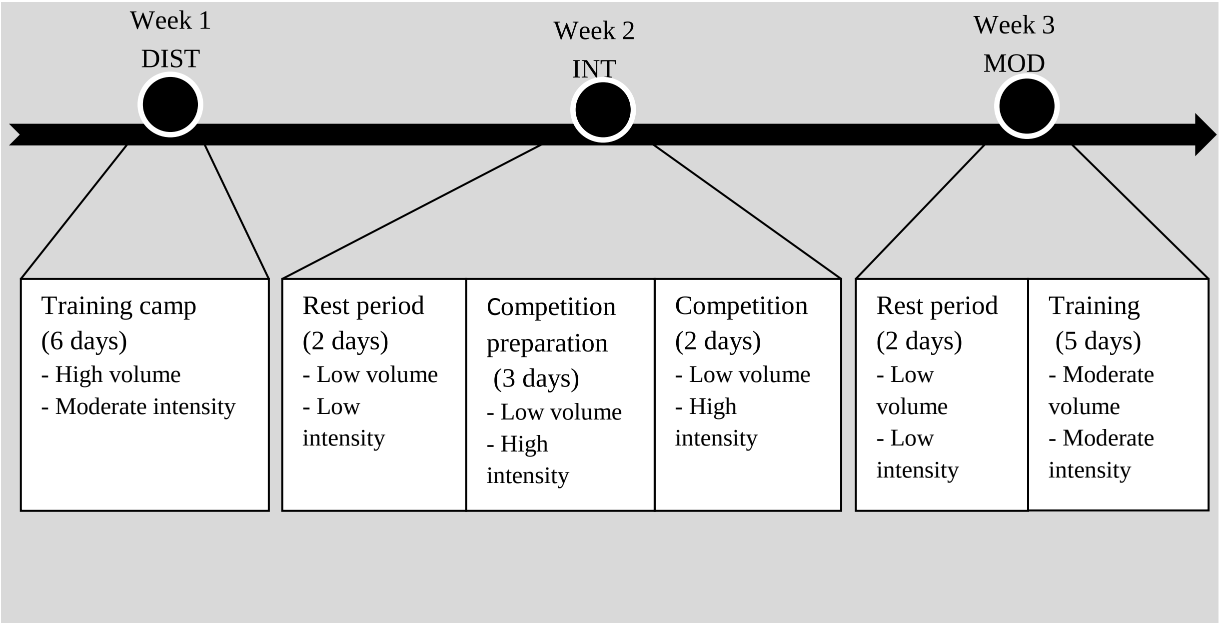



*Figure 3: Three weeks of competitive training. DIST = high volume (long-distance) training period. INT = intensive competition training period. MOD = moderate training period.*

DIST included six days in a training camp where all the subjects experienced high total training volume and one moderate and one high-intensity training session. INT started with two days of rest or recovery training, followed by three days of competition preparation, including two high intensity training sessions. The last three days during the INT-period, all the subjects participated in 2-3 succeeding competitions (1.4 km sprint, 7.5 km individual start and 12.5 km mass start). MOD included two days of rest or recovery training, followed by five days of moderate training, including one high-intensity training sessions.

**Data handling and calculations**

In order to analyze differences between $HR_{rest}$ and fatigue in the different training periods, one score for each person in each period was estimated. The mean score in each period was applied to estimate a representative $HR_{rest}$ score. However, this mean score was calculated using the last five days in each period, to avoid interference from the previous training period. The same method was used to estimate the self-reported fatigue score in each period, despite that the median was used. The median was chosen to best estimate fatigue for each period, because the variable is measured at an ordinal level. *Z*-scores were calculated to compare $HR_{rest}$ and TRIMP within and between subjects graphically.

**Statistical Analysis**

All data were checked for normality by use of the Shapiro-Wilk´s test, and presented as mean and standard deviation (SD) unless otherwise stated. Comparisons for $HR_{rest}$ and TRIMP between the three periods were analysed using repeated measures ANOVA. Possible follow-up testing was carried out by the LSD paired *t*-test procedure. Comparison for fatigue between the three periods was calculated by Friedman´s non-parametric test for related samples. Correlations between variables were tested using both Spearman (self-rated fatigue) and Pearson's product–moment correlation coefficient test ($HR_{rest}$, TRIMP, high-intensity training). Cross-correlations were used to detect time-lags between $HR_{rest}$, TRIMP. Statistical significance was set at $P < 0.05$. All statistical tests were processed using SPSS 15.0 Software for Windows (SPSS Inc., Chicago, IL).

## RESULTS

### Training during the study

Training during the study is given in Table 2. There was significantly higher TRIMP in DIST as compared to INT, while no differences in strength- and speed training were revealed between the periods.

**Table 2**: Training during three training periods in seven female world-class biathlon athletes (mean ± SD).

| Variables | DIST | | INT | | MOD | |
|---|---|---|---|---|---|---|
| | **min** | **%** | **min** | **%** | **min** | **%** |
| LIT (min) | 816 ± 140† | 85.8 | 586 ± 111 | 80.8 | 682 ± 179 | 85.5 |
| MIT (min) | 28 ± 24 | 2.9 | 20 ± 27* | 2.9 | 40 ± 22 | 5.2 |
| HIT (min) | 63 ± 22*† | 6.7 | 86 ± 14* | 12.2 | 18 ± 21 | 2.9 |
| Strength (min) | 46 ± 23 | 4.6 | 28 ± 17 | 4.2 | 53 ± 39 | 6.3 |
| Tot. training (min) | 954 ± 170† | 100 | 721 ± 90 | 100 | 795 ± 198 | 100 |
| TRIMP | 1154 ± 215† | | 944 ± 85 | | 926 ± 205 | |

LIT = low intensity endurance training; MIT = moderate intensity endurance training; HIT = high intensity endurance training; Strength = strength, speed and plyometrics/jumping; Tot. training = total training including LIT, MIT, HIT as well as strength and speed; TRIMP-score = TRIMP in each period; DIST = high volume (long-distance) training period; INT = intensive competition training period; MOD = moderate training period; % = percentage of total training in each period. * = significantly different from the MOD, $P < 0.05$; † = significantly different from the INT, $P < 0.05$.

### Resting heart rate and training loads

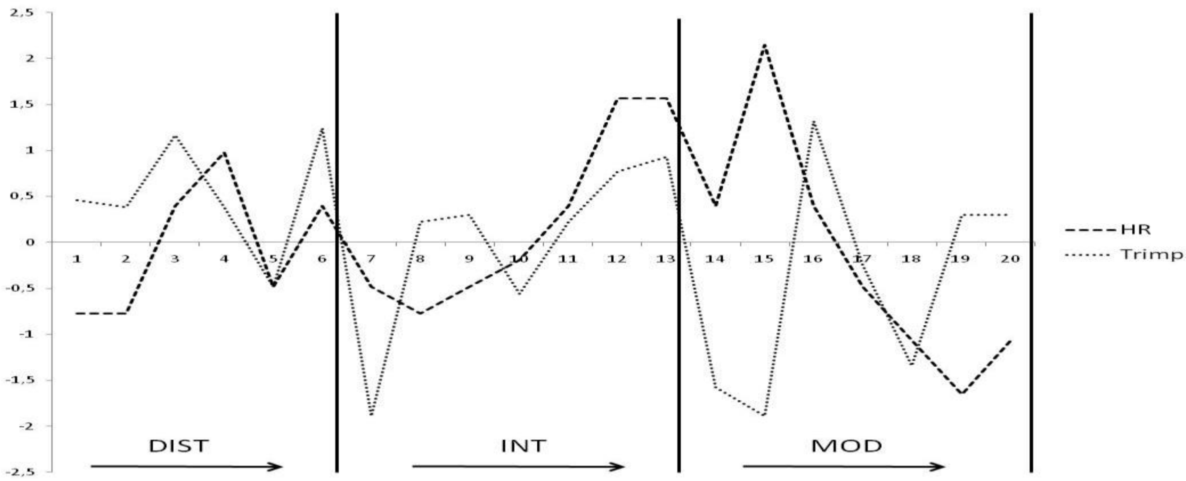
Table 3 shows mean $HR_{rest}$ in the three periods for all seven athletes, as well as mean $HR_{rest}$ in each of the periods. There was significantly lower $HR_{rest}$ in MOD as compared to DIST and INT ($P < 0.05$). Individual day to day variations in $HR_{rest}$ and TRIMP for all subjects are illustrated in Figure 4 A-G. Six out of seven subjects showed higher mean $HR_{rest}$ in the DIST and/or the INT as compared to the MOD (Table 3).

**Table 3:** Resting heart rate during a high volume (long-distance) training period (DIST), an intensive competition training period (INT), and a moderate training period (MOD)in seven female world-class biathlon athletes (mean and range for individual values; mean and SD for all subjects pooled).

| Subjects | DIST | INT | MOD |
|---|---|---|---|
| 1 | 53 (50-56) | 55 (51-58) | 50 (47-54) |
| 2 | 48 (46-50) | 46 (45-48) | 44 (44-46) |
| 3 | 65 (63-66) | 63 (60-65) | 60 (57-63) |
| 4 | 60 (58-65) | 58 (48-67) | 51 (45-55) |
| 5 | 57 (53-59) | 59 (55-65) | 53 (49-57) |
| 6 | 52 (47-55) | 54 (48-58) | 53 (51-55) |
| 7 | 46 (43-47) | 44 (42-45) | 40 (37-46) |
| **Mean** | **54±7** | **54±7** | **50±6*** |

* = significantly lower $HR_{rest}$ in MOD as compared to DIST and INT, $P < 0.05$.

**A**



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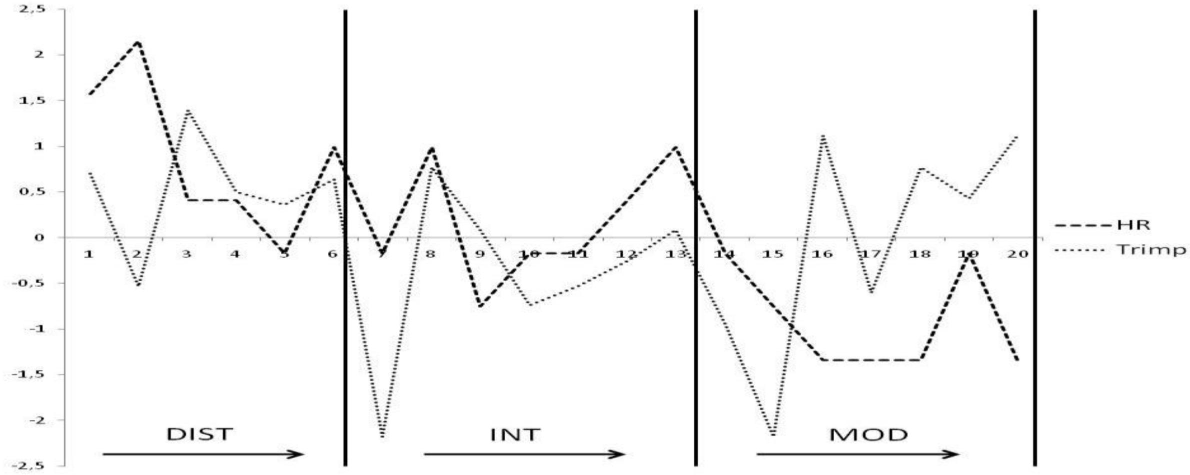

HR
Trimp
DIST
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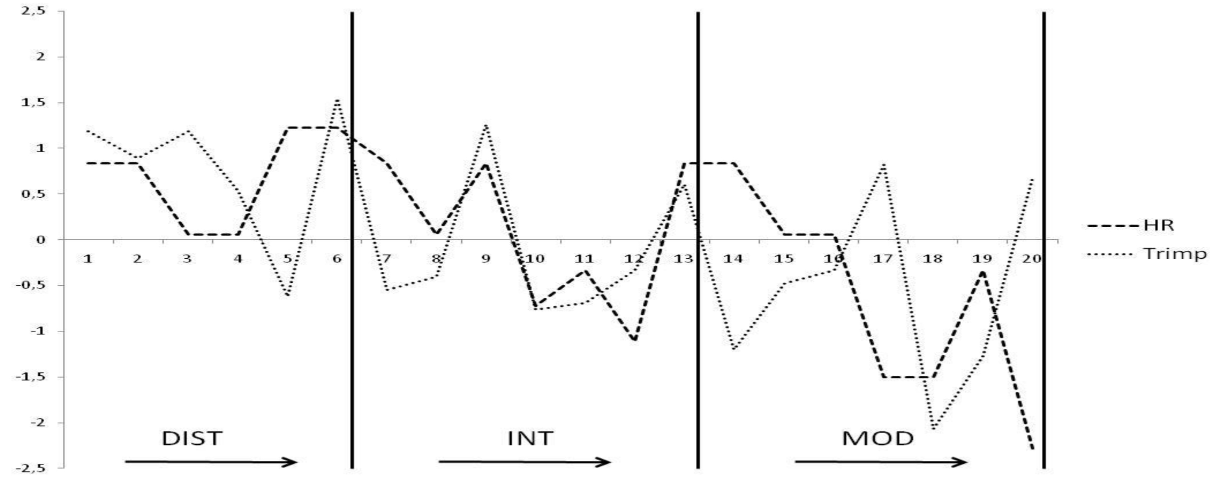

HR
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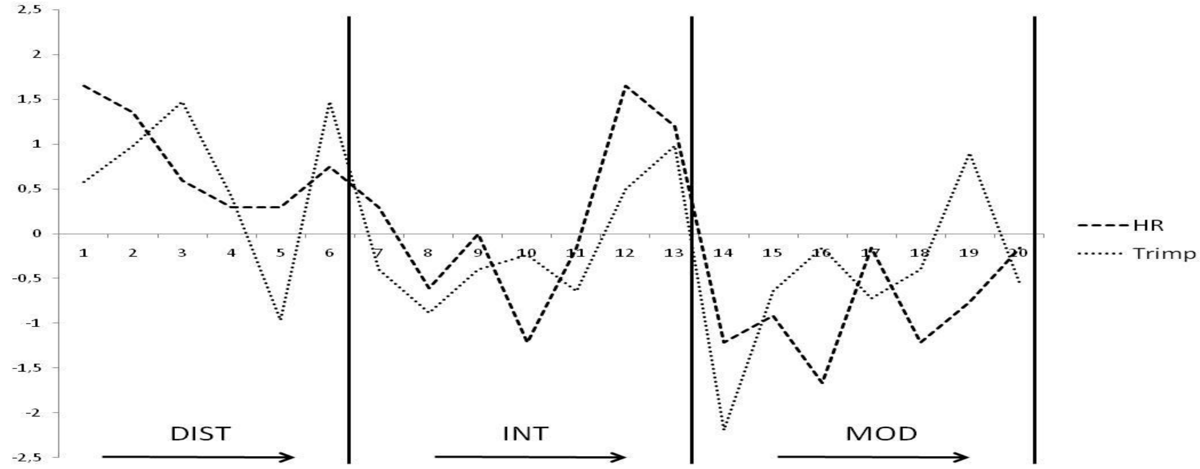

HR
Trimp
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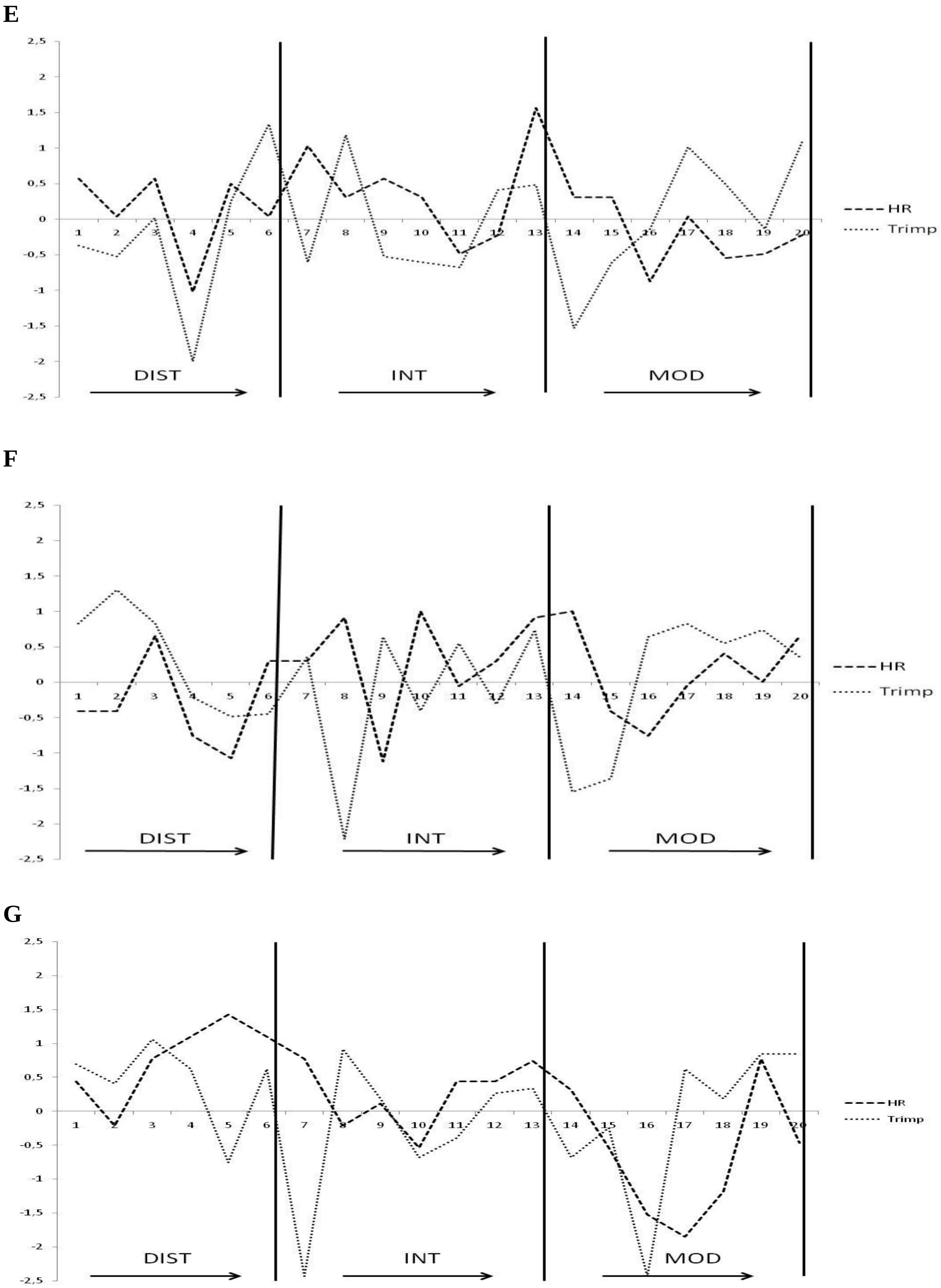


*Figure 4A-G: Day to day variations in $HR_{rest}$ and TRIMP throughout three different periods (showed as z-scores on the Y-axis). The X-axis shows the different days during a high volume (long-distance) training period (DIST), an intensive training period (INT) and a moderate training period (MOD), respectively.*

No general or individual day to day correlations between the variables (i.e., $HR_{rest}$, self-rated fatigue, TRIMP and high-intensity training) were revealed. In addition, inter-individual cross correlations revealed no significant relationships between $HR_{rest}$ and TRIMP.

## DISCUSSION

The major findings in this study were 1) a significantly increased resting heart rate during a period with high total training load (i.e., DIST) and during a high-intensity competition period (i.e., INT), 2) a non-significant day to day relationship between resting heart rate and training load or intensity.

### Resting heart rate and training loads

The findings in this study shows that a period with high total training loads and a high-intensity competition period induce an increased $HR_{rest}$. This indicates an increased sympathetic stress during both DIST and the INT. Interestingly, both DIST and INT had a similar effect on $HR_{rest}$, despite significantly lower TRIMP in INT. The increased $HR_{rest}$ during DIST is in line with other studies showing $HR_{rest}$ to be affected by total training loads (Jeukendrup & Van Diemen, 1998; Hautala et al., 2000; Kaikkonen et al., 2007; Seiler et al., 2007; Borresen & Lambert, 2008). However, autonomic recovery after maximal physical stress (e.g., high intensity training and competitions in the INT) is shown to be slower than after sub-maximal physical stress (Kaikkonen et al., 2007; Seiler et al., 2007; Borresen & Lambert, 2008), and might explain the increased $HR_{rest}$ in the INT. Also in DIST there was a significantly higher amount of HIT than MOD, and this might also explain the increased $HR_{rest}$ in this period. Maximal physical stress cause a high stimulation of the sympathetic nervous system during maximal exercise, which causes a longer deceleration of the HR, and leads to a higher $HR_{rest}$ (Borresen & Lambert, 2008).

Interestingly, all subjects reached their lowest $HR_{rest}$ during the MOD, with one exception. These findings might indicate a re-activation of the parasympathetic system during this period. This recovery-effect is shown despite a relatively high TRIMP in the MOD, and may partly be explained by the high level of fitness in these world-class athletes, which has been shown to have a more rapid recovery of $HR_{rest}$ and a better autonomic control (Seiler et al., 2007). World-class athletes are used to have periods with high training loads, and because of their high performance-level, it is likely that they achieve a subsequent adaptation and training effect. They are therefore suggested to be extremely well suited to tolerate shifting training loads and to recover in more easy or moderate training periods, like shown in the MOD in this study.

Some individual differences in $HR_{rest}$ between the periods were found. For example, some athletes have higher $HR_{rest}$ in the DIST, with a large amount of low intensity and high total training loads, whereas some others have higher $HR_{rest}$ in the INT, with much high- intensity training and 2-3 successive competitions. Also, one athlete had a similar $HR_{rest}$ between the three periods. This indicates that the athletes` $HR_{rest}$ are individually affected by different types of training (e.g., high total training loads and/or several succeeding high-intensity training sessions). Individual variations in $HR_{rest}$ in the different periods may be due to several aspects. For example, $HR_{rest}$ is highly dependent on a variety of mechanisms including training status, psychological influences, and neuroendocrine, musculoskeletal, and cardiovascular responses (Earnest et al., 2004). This shows the importance of individual training guiding, and that each individual should only be compared to its own baseline value when interpreting acute responses of $HR_{rest}$.

The non-significant correlations between $HR_{rest}$ to TRIMP and high-intensity training shown in the present study might be explained by individual variations in $HR_{rest}$ caused by daily variations in training loads, shifting from high one day – to low the next. Moreover, it might be explained by a different recovery-time from different intensities and total training loads. This is further supported by the cross-correlations, showing no time-lags in $HR_{rest}$ related to TRIMP. Therefore, substantial individual response to different types of training, might explain the non-significant relationships shown in this study.

All together, these findings may indicate some interesting aspects. Because these athletes are successful, on a world-class level, it is suggested that they have a fast recovery from the daily training loads and that they over a certain period of time is in autonomic balance. Nevertheless, we find a significant “in- and out of autonomic balance” pattern. This leads to the assumption that these athletes are able to overcompensate from training periods with extremely high training loads.

**Self-rated fatigue**

The variations in self-rated fatigue were small, and did not relate to any parameter (i.e., $HR_{rest}$, TRIMP). No differences between the three periods were found, and on individual level, most of the subjects were totally stable during three weeks of competitive training. This is exceptional considering the high physical and psychological stress loads during this period of measurements. Contrastly, other studies using fatigue ratings shows clear relationships between subjective feelings of fatigue to training loads and $HR_{rest}$ (Iizuka et al., 2008). This leads to the assumption that the subjects in the present study are underreporting their subjective feeling of fatigue. It might also be a psychological factor explaining the lack of variation. Because this study was performed during an essential part of the competitive season, the subjects could have been affected by exaggerated positive thoughts when considering their feeling of fatigue. On the other hand, the small variations in fatigue might also be explained by the short periods and relatively acute autonomic imbalance in DIST and INT. This imbalance might not have affected the athletes` performance levels and feelings of fatigue. The fast recovery of $HR_{rest}$ during MOD and good results in the competitions in the INT supports the latter.

**Limitations of this study**

The present study used only $HR_{rest}$ as an indicator of autonomic balance and recovery due to methodological consideration by using HRV described in the methods. Therefore, this study gives a relatively gross description of the autonomic balance, and the specific sympathetic and parasympathetic nervous influence is not known.

Despite the standardized conditions, psychological factors might have been affecting the subjects differently, leading to different $HR_{rest}$ response. The measurements of $HR_{rest}$ were performed at home or in hotel rooms, and may not be considered as highly standardized as in laboratory conditions. However, this was a necessary trade-off, acquired for achieving $HR_{rest}$ data from female world-class athletes during 20 days of competitive training. Additionally, there may be other factors apart from the variables measured during this study that might affect $HR_{rest}$, such as, insufficient sleep, psychological and physical stress, as well as breathing rhythm, light, noise and temperature (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996: Achten & Jeukendrup, 2003; Song & Lehrer, 2003).

**Conclusion**

Resting heart rate measurements during three weeks of competitive training indicate that female world-class biathlon athletes are affected by periods of high training loads and high-intensity training and competitions. Nevertheless, individual variation in $HR_{rest}$ shows an individual response to different training loads and intensities. The variations in fatigue were small and the overall impression is that the athletes were only acute autonomic affected.

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**FIGURES AND TABELS**

**Tables:**

Table 1: Baseline characteristics of seven female world-class biathlon athletes (mean ± SD).

Table 2: Training during three periods of different physical stress in seven female world-class biathlon athletes (mean ± SD).

Table 3: Resting heart rate during a high volume (long-distance) training period (DIST), an intensive competition training period (INT), and a moderate training period (MOD)in seven female world-class biathlon athletes (mean and range for individual values; mean and SD for all subjects pooled).

**Figures:**

Figure 1: An attempt to determine the total stress load for an elite endurance athlete. The dim boxes are tried standardized in this study, whereas the relationships between the boldface boxes are studied.

Figure 2: Modified Bland-Altman difference plot showing bias and limits of agreement for R-R intervals between the Delsys ECG and Polar Heart rate monitor in four well-trained subjects laying in the supine position for 5 min (N = 901 observations).

Figure 3: Three weeks of competitive training. DIST = long-distance training period. INT = intensive competition training period. MOD = moderate training period.

Figure 4A-G: Day to day variations in $HR_{rest}$ and TRIMP throughout three different periods (showed as z-scores on the Y-axis). The X-axis shows the different days during a high volume (long-distance) training period (DIST), an intensive training period (INT) and a moderate training period (MOD), respectively.

## APPENDIX

### Validity of Polar RS 800

There were clear visual differences in R-R intervals in two out of four subjects, as showed in Figure I and II. Judgments, based on raw data plotted as a time series and in a Bland-Altman plot (Figure 2 in the article), revealed that two of the four subjects showed different patterns measured with the Polar system as compared to ECG. After error corrected the Polar data in the Polar software, three out of four subjects showed different patterns to ECG. ~20% of the points in the Bland-Altman plot were more than 2 SD from the line of identity. Despite these clear visual differences in R-R intervals in two out of four subjects (shown in Figure I and II), it is uncertain if conducting the error correction leads to a more correct result, based on raw data plotted as a time series (e.g., Figure III and Table I, subject 2).

**Table I, Appendix**: Heart rate variables during simultaneous measurement in four subjects.

| **Subject** | **SDNN** | | | **pNN50** | | | **$HR_{rest}$** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Org.** | **Corr.** | **ECG** | **Org.** | **Corr.** | **ECG** | **Org.** | **Corr.** | **ECG** |
| 1 | 138 | 117 | 121 | 25 | 25 | 25 | 42 | 42 | 42 |
| 2 | 120 | 90 | 120 | 20 | 25 | 20 | 54 | 53 | 54 |
| 3 | 136 | 123 | 117 | 30 | 30 | 30 | 52 | 52 | 52 |
| 4 | 67 | 67 | 67 | 38 | 38 | 38 | 56 | 56 | 56 |

Org = Original Polar measurement. Corr = Error corrected Polar measurement. ECG= Original ECG.

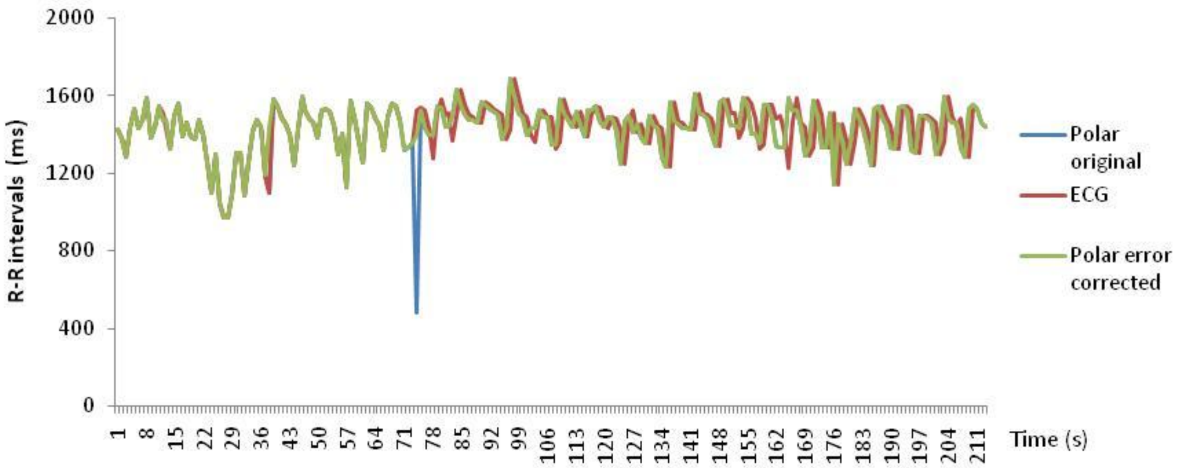


*Figure I, Appendix: R-R intervals (ms) simultaneously collected from Polar RS 800 (original signal and error corrected signal) and ECG, in subject 1, leading to more similar HRV values after error correction.*

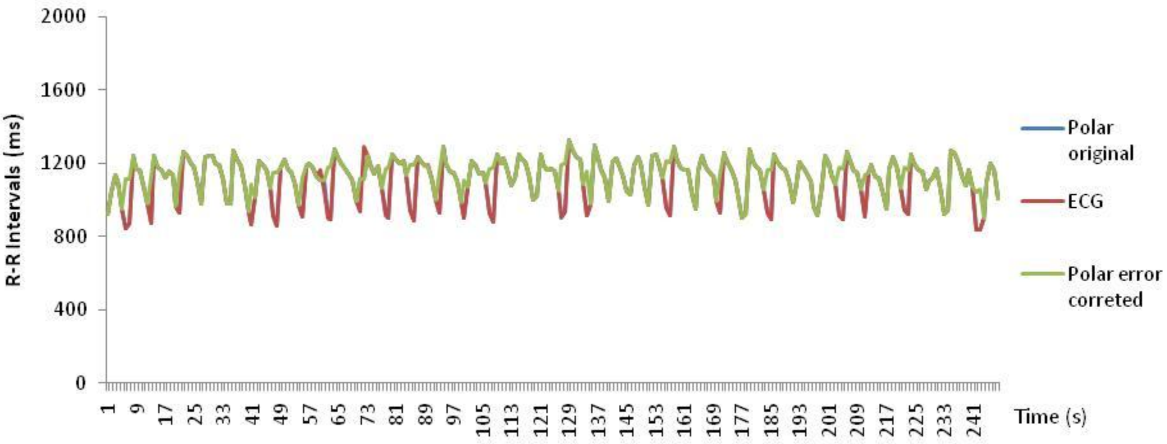


*Figure II, Appendix: R-R intervals (ms) simultaneously collected from Polar RS 800 (original signal and error corrected signal) and ECG, in subject 2. In this case the Polar original follows ECG. However, conducting the error correction leads to incorrect HRV values.*

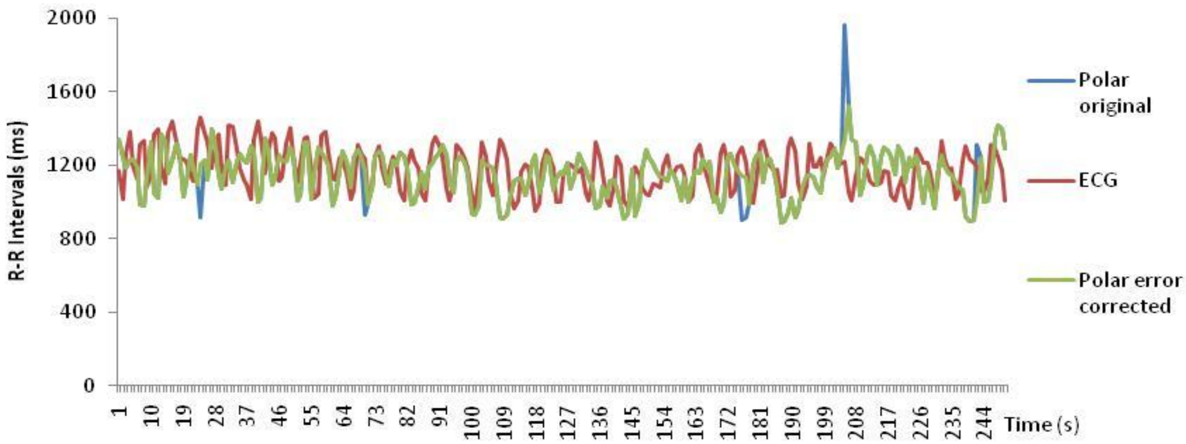


*Figure III, Appendix: R-R intervals (ms) simultaneously collected from Polar RS 800 (original signal and error corrected signal) and ECG, in subject 3, with some differences in R-R intervals.*

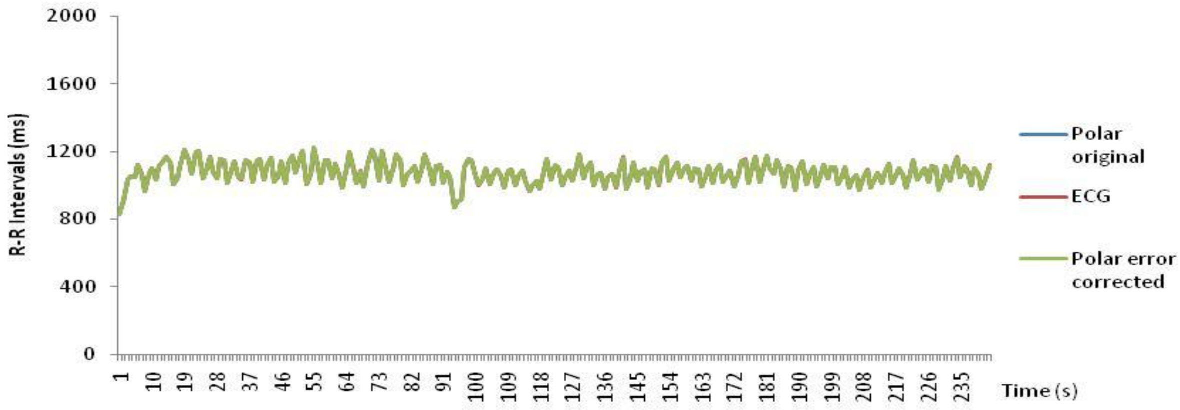


*Figure IV, Appendix: R-R intervals (ms) simultaneously collected from Polar RS 800 (original) signal and error corrected signal) and ECG, in subject 4. In this case the Polar original and error corrected follows ECG.*