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Research article

HEART RATE DURING SLEEP: IMPLICATIONS FOR MONITORING TRAINING STATUS

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ABSTRACT

Resting heart rate has sometimes been used as a marker of training status. It is reasonable to assume that the relationship between heart rate and training status should be more evident during sleep when extraneous factors that may influence heart rate are reduced. Therefore the aim of the study was to assess the repeatability of monitoring heart rate during sleep when training status remained unchanged, to determine if this measurement had sufficient precision to be used as a marker of training status. The heart rate of ten female subjects was monitored for 24 hours on three occasions over three weeks whilst training status remained unchanged. Average, minimum and maximum heart rate during sleep was calculated. The average heart rate of the group during sleep was similar on each of the three tests (65 ± 9, 63 ± 6 and 67 ± 7 beats· min^{-1} respectively). The range in minimum heart rate variation during sleep for all subjects over the three testing sessions was from 0 to 10 beats· min^{-1} (mean = 5 ± 3 beats· min^{-1}) and for maximum heart rate variation was 2 to 31 beats· min^{-1} (mean = 13 ± 9 beats· min^{-1}). In summary it was found that on an individual basis the minimum heart rate during sleep varied by about 8 beats· min^{-1}. This amount of intrinsic day-to-day variation needs to be considered when changes in heart rate that may occur with changes in training status are interpreted.

KEY WORDS: Sleeping heart rate, training response, reliability.

INTRODUCTION

At present there are no specific, accurate, reliable, non-invasive and practical tests available to define training status. Although numerous studies have examined the relationship between exercise training and heart rate (Snyder et al., 1964; Karvonen and Vuorimaa, 1988; Lambert et al., 1998) and other studies (Dressendorfer et al, 1985; Callister et al., 1989; Wilmore et al., 1996) have examined the relationship between morning resting heart rate patterns and training status and overtraining, it is reasonable to conclude that there is no consensus on whether heart rate can predict training status, as defined by changes in the level of cardio-respiratory fitness and performance, with any degree of accuracy. In a study by Dressendorfer et al. (1985), morning heart rates increased by 10 beats· min^{-1} after a 20 day overtraining period after an initial reduction of morning heart rate in the first week. It is however generally accepted that improvements in fitness is accompanied by a lowered heart rate, especially in endurance type training. Pollock (1973) in a review of 18 endurance studies found an average decrease of 7 beats· min^{-1} in resting heart rate after endurance training while Wilmore et al (1996) reported a reduction in resting heart rate of 3 beat· min^{-1} after a 20 week endurance training period.

Jeukendrup et al (1992) suggested that heart rate during sleep may be a more accurate assessment of heart rate compared with palpated morning resting heart rate. The palpated morning heart rate did not change during the two-week period of overtraining, while the mean heart rate during sleep showed a significant ($p < 0.05$) increase and may therefore be a viable marker of overtraining. It is logical to assume that if there is a relationship between heart rate and training status that this will be more evident during sleep when extraneous factors that may influence heart rate are reduced. Surprisingly, there are few studies that have examined the relationship between heart rate during sleep and training status. O'Connor et al (1993) examined the influence of exercise during the day on heart rate during sleep and found no significant difference ($p = 0.14$) in heart rate during sleep on both exercise and non-exercise days before and after a 12 week training period. However, longitudinal studies have found heart rate during sleep to be reduced (Sadamoto et al., 1986) or unchanged (Sedgwick et al., 1974) after several weeks of exercise training. A weakness of all the studies on training status and heart rate during sleep has been that the intrinsic variation of heart rate, during different testing occasions and when training status has remained unchanged, has not been reported. This is an important factor to determine before heart rate data can be interpreted with any degree of accuracy. Accordingly, the aim of this study was to assess the repeatability of monitoring heart rate during sleep under free-living conditions in a group of subjects who kept their training constant, to determine whether this measurement has sufficient precision to use as a marker of training status.

METHODS

Ten female subjects between the ages of 18 to 45 (35.3 ± 7.7 years), were recruited to participate in the study through advertising at a local health club. Each potential participant completed a Health Screen/Activity Questionnaire with questions on personal details, medical history, physical activity and sleep profiles. This was done to ensure eligibility of subjects for the study, to exclude any potential variables such as certain medications that may influence heart rate and to gather information regarding the subject's training status and general sleep profile.

All subjects were pre-menopausal, of average weight (62.2 ± 8.7 kg) and regular exercisers (7.0 ± 2.6 hrs.week) with varying levels of training. Subjects on average trained 4.0 ± 1.3 times per week and had maintained this schedule for more than five years. The subjects were mostly recreational athletes participating in cardiovascular training (circuit, treadmill, aerobics, cycling and swimming) at a gymnasium. Two athletes competed at a provincial level in speedwalking and long distance running respectively. Four of the subjects also did weight training as part of their exercise program. No quantitative assessment was done to assess the subject's level of fitness at the start of the study. None of the subjects currently smoked although two were ex-smokers and none of the women were taking any medication that could affect their heart rate. The only inclusion/exclusion criteria specified was that subjects should be between the ages of 18 and 45 and that they should have no known cardiac pathology. A resting electrocardiogram (ECG) was performed on each subject prior to acceptance into the study to exclude any subjects with unknown cardiac pathology. Prior to the start of the trial an introductory session was held with each participant during which the aim and protocol of the study was explained. All subjects gave their informed consent. The study was approved by the Research Ethics Committee of the University of Cape Town.

The trial consisted of a 24-hour monitoring session conducted on three occasions over a three-week period. Monitoring took place on the same day of each week. Each session consisted of a 24 hour monitoring day that started upon waking before the subject got out of bed. The subjects fitted and activated the heart rate monitors that were set up next to their beds upon waking and before getting out of bed. Heart rate was recorded every minute over the 24-hour period (in total 1440 min) and stored in the heart rate monitor for analysis at a later stage (Polar Vantage XL, Kempele, Finland). The highest and lowest heart rate recorded during this time was defined as the maximum and minimum heart rate respectively.

The starting time of sleep was determined through subjective self-reporting by the subjects. This was verified by comparing the average of the heart rate during the sleep period with the trend of the heart rate during the first 30 minutes prior to the start of the reported sleep time.

Subjects were encouraged to maintain their normal lifestyles whilst being monitored and were also requested to replicate their activity and dietary intakes, including caffeine as closely as possible on each of the three monitoring sessions by using the activity and nutritional records which were given to them as reminders at the orientation session. None of the subjects reported any extreme deviations from their original reported dietary intakes and exercise habits. The testing day was self-selected by each subject to fit in with their own lifestyle. They were then however compelled to test on the same weekday for each of the testing days. The subjects' compliance to the protocol was assessed at each testing session by comparing records of the previous week to the current week and discussing this with the subject. After checking, the subjects were given a copy of the record and reminded to replicate this at the next test session. Subjects were requested not to change their training program in any way during the trial. This was verified through means of the activity records kept. The study was designed to represent a typical field study situation. Therefore the conditions of the study were matched to the conditions in which the monitoring would usually take place with athletes.

Statistics

Results are expressed as mean ± standard deviation (SD) unless otherwise noted. Heart rate data outside the ranges < 30 and > 220 beats· min^{-1} were accepted as noise and were excluded from analysis. The average, minimum and maximum heart rate during sleep and during the daytime for each of the ten subjects and the group were calculated for each of the three trials. The measurement error, defined as the within subjects coefficient of variation ([standard deviation/mean] X 100) was calculated for minimum, average and maximum heart rate during sleep. An analysis of variance with repeated measures was used to determine if there were any differences for these variables on each of the testing days. The intraclass correlation coefficient (ICC) and 95% confidence interval were calculated for the average, minimum and maximum heart rate for the three sessions for all subjects and divided into sleep and daytime periods. The limits of agreement for minimum heart rate were calculated for tests 1 and 2, tests 2 and 3 and tests 1 and 3 (Bland and Altman, 1986). Statistical significance was accepted when $p < 0.05$.

RESULTS

Self-reported physical activity levels and average sleeping time ranged from 4 to 12 hours per week and 5.5 to 9.0 hours per night respectively. Records of current exercise times were compared with hours reported on the initial questionnaire and found to correlate. Subjects reported a mean total in-bed time of 467 ± 27 minutes for the three test sessions. Total in-bed time for each of the three test sessions was 472 ± 52, 493 ± 39 and 437 ± 50 minutes respectively. Intra-subject variability of in-bed time between test sessions was high. The average difference between the highest and lowest amount of sleep for each subject was 17 ± 9 %. Figure 1 depicts a sample of the raw tracing of heart rate recorded over 24 hours for one of the subjects. Similar tracings were recorded for all 10 subjects.

Heart rate data of 504 minutes in total for all subjects and sessions were excluded during analysis as the values fell outside the range of 30 to 220 beats· min^{-1}. This represents a mean loss of data of 1.2 ± 1.1 % (n = 30). No specific pattern could be identified to explain lost heart rate data.

The average heart rate during the 3 days, preceding the 3 nights during which heart rate was recorded during sleep was 83.4 ± 9.8, 83.2 ± 5.4 and 87.2 ± 8.3 beats· min^{-1} respectively. There were no differences between any of these testing days. The minimum and maximum heart rates during the day were also similar for all three testing sessions.

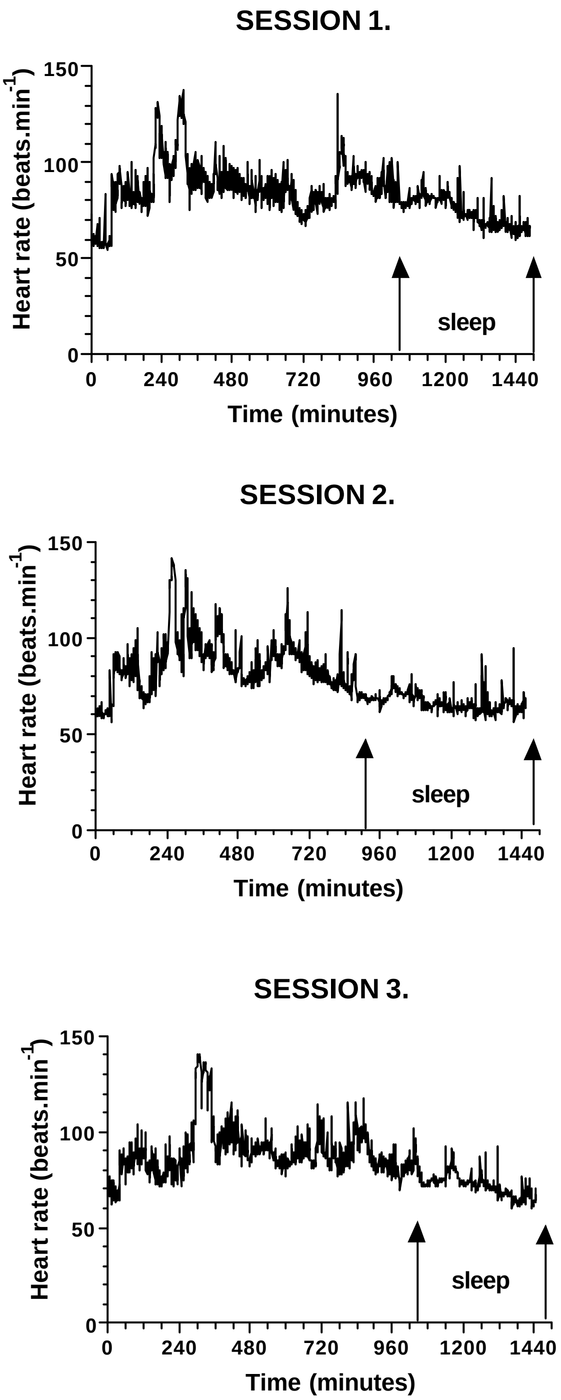

Figure 1. A sample of the raw tracings of heart rate (beats· min^{-1}) for each of the three sessions over 24 hours for subject 1.

Table 1. Descriptive statistics of the average, minimum and maximum heart rate variation (beats· min^{-1}) for sleep for each of the three sessions for each of the ten subjects. Data are expressed as the mean.

Subject	Average Heart Rate			Minimum Heart Rate			Maximum Heart Rate		
	SES1	SES2	SES3	SES1	SES2	SES3	SES1	SES2	SES3
1	74	66	72	60	56	60	98	95	92
2	45	53	51	36	39	42	82	113	85
3	66	59	69	56	52	56	101	98	90
4	69	63	65	59	53	56	106	107	105
5	63	63	64	53	53	53	94	116	100
6	73	76	77	57	64	65	106	100	104
7	62	62	65	51	50	53	103	97	91
8	65	66	69	47	52	57	100	104	107
9	70	69	66	58	57	55	89	100	94
10	58	58	67	47	48	40	91	100	110
Mean	65	63	67	52	52	54	97	103	98
SD	9	6	7	7	6	8	8	7	9

Abbreviations: SES= Session, SD= Standard deviation.

Table 1 describes the average, minimum and maximum heart rate during sleep for each of the ten subjects for each of the three test sessions. There were no significant differences in these measurements between the three tests. Minimum heart rate during sleep varied from 36 to 65 beats· min^{-1} (mean = 53 ± 7 beats· min^{-1}). Maximum heart rate during sleep varied from 82 to 116 beats· min^{-1} (mean = 99 ± 8 beats· min^{-1}). The range for minimum heart rate variation for all the subjects over the 3 testing sessions was 0 to10 beats· min^{-1} (mean = 5 ± 3 beats· min^{-1}), with the range for average heart rate variation between 1 and 10 beats· min^{-1} (mean = 6 ± 3 beats· min^{-1}). The range for maximum heart rate showed a greater variation of 2 to 31 beats· min^{-1} (mean = 11 ± 9 beats· min^{-1}). There were no differences for any of these heart rate measurements. The measurement error was 5.3 ± 3.2% for minimum, 4.9 ± 2.8 for average and 6.7 ± 5.1% for maximum heart rate during sleep.

Minimum heart rate during sleep for the group had the highest intraclass correlation coefficient value (ICC = 0.92: 95% CI of ICC: 0.79 – 0.98) and maximum heart rate during sleep had the lowest value (ICC = 0.55: 95% CI of ICC: 0.17 – 0.84) (Table 2).

The limits of agreement (LOA) for minimum heart rate for tests 1 and 2, 2 and 3 and 1 and 3 were 0 ± 4.1; -1.3 ± 3.9 and -1.3 ± 5.3 beats· min^{-1} respectively (Figure 2).

DISCUSSION

The aim of this study was to assess the repeatability of heart rate during sleep to determine whether this measurement had sufficient precision to use as a marker of training status. An important factor to consider before changes in heart rate data can be interpreted with any degree of accuracy is knowing the intrinsic day–to-day variation in heart rate during sleep. In accordance with this aim the study was designed to determine the intrinsic variation of heart rate during sleep on three different testing occasions within a short period of time, during which the training status of the subjects remained unchanged. Although training status was not measured in this study it can be assumed that it did not change as the subjects were requested to keep their training habits constant during the 3 weeks of the study. Their compliance to training was verified whenever they were tested. All of the subjects had been following a set exercise regime for several years and only two

Table 2. Intraclass Correlation Coefficient (ICC) and 95% confidence intervals for the ICC for average, minimum and maximum heart rates for the three sessions for each of the ten subjects. The data are divided into sleep and daytime.

Variables	ICC for Sleep (95% C.I.)		ICC for Day Time (95% C.I.)	
Average Heart Rate	0.91	(0.76 – 0.97)	0.73	(0.41 – 0.92)
Minimum Heart Rate	0.92	(0.79 – 0.98)	0.79	(0.52 – 0.94)
Maximum Heart Rate	0.55	(0.17 – 0.84)	0.84	(0.61 – 0.95)

were competing at the present time even though five of the subjects had previously competed at a provincial level in their chosen sport.

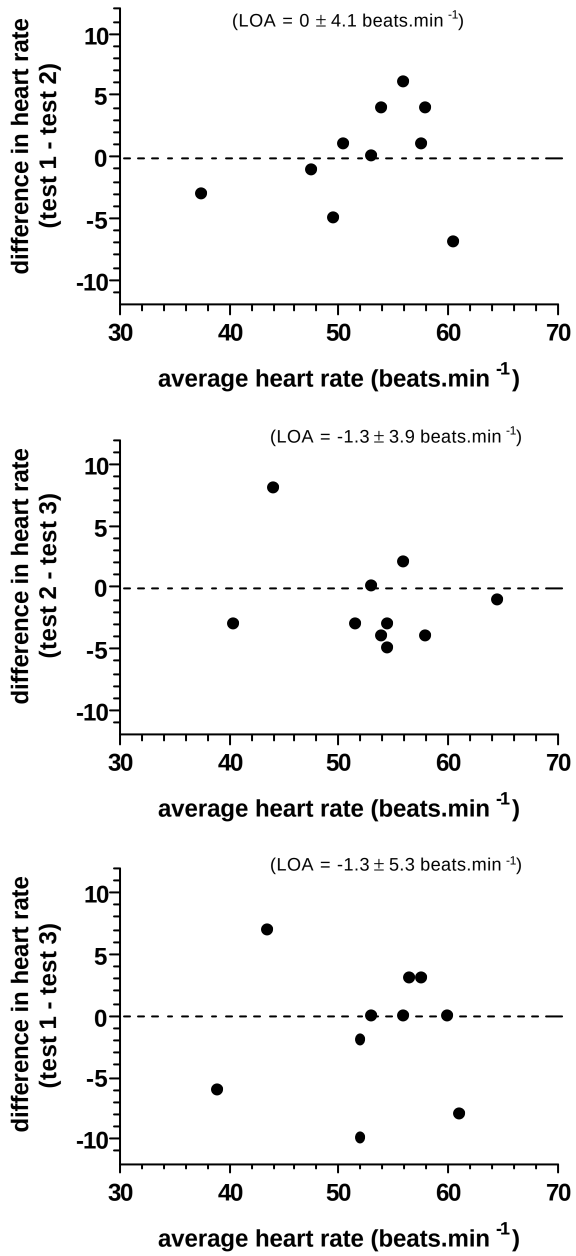

Figure 2. The limits of agreement (LOA) (Bland and Altman, 1986) for minimum heart rate during sleep for test 1 vs. 2, test 2 vs. 3 and test 1 vs. 3.

The most important finding of this study was that monitoring changes in heart rate during sleep has precision to detect changes in heart rate during sleep of about 8 beats· min^{-1}. This was calculated by determining the range of the minimum heart rate during sleep for each of the subjects over each of the three testing sessions. This suggests that changes in the minimum heart rate during sleep needs to be greater than about 10 beats· min^{-1} to be detected with any degree of confidence. A study by Brisswalter and Legros (1994) found that the day-to-day variation in heart rate under controlled, submaximal exercise conditions was 6 beats· min^{-1}. A more recent study by Lamberts et al (2003) also found the day-to-day heart rate variation to be about 5 to 8 beats· min^{-1} under controlled conditions during a submaximal test.

Although the intraclass correlation coefficient (minimum heart rate during sleep) was 0.92 (95% C.I. of 0.79 – 0.98) suggesting that the measurement has “good reliability” (Vincent 1995), from a clinical perspective it is debatable whether this is sufficiently precise to detect relatively small changes in heart rate during sleep that may occur with a change in training status.

The study design may be criticized for the lack of rigor in controlling factors that may have influenced the heart rate. However, the aim of the study was to determine whether heart rate during sleep could be monitored as a marker of training status. Any practical monitoring system needs to be done under relatively free-living conditions. Therefore the subjects were requested to replicate their activities, including sleep as closely as possible on the three monitoring occasions. Subjects were able to replicate their training activities accurately but were less successful in maintaining their exact sleeping habits. No information was obtained on sleeping conditions. This is the degree of control that one might expect in a situation where athletes are monitored under free-living conditions. It may be argued that the repeatability would have been better had the subjects been tested in a controlled laboratory environment and had their stage of the menstrual cycle been controlled (Bisdee et al., 1988; Meijer et al., 1992). However, this method lacks the practical relevance that is needed for athletes.

CONCLUSION

In summary, on an individual basis minimum heart rate during sleep varies by about 8 beats· min^{-1}. This amount of intrinsic day-to-day variation needs to be considered when changes in heart rate that may occur with changes in training status are interpreted.

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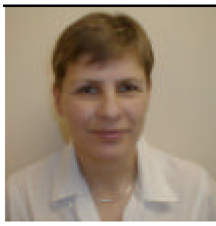

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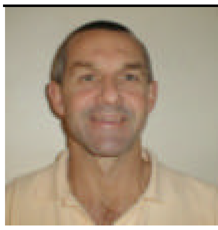

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