Best Practice Guidelines

Measurement, analysis and interpretation of resting heart rate and heart rate variability in athletes

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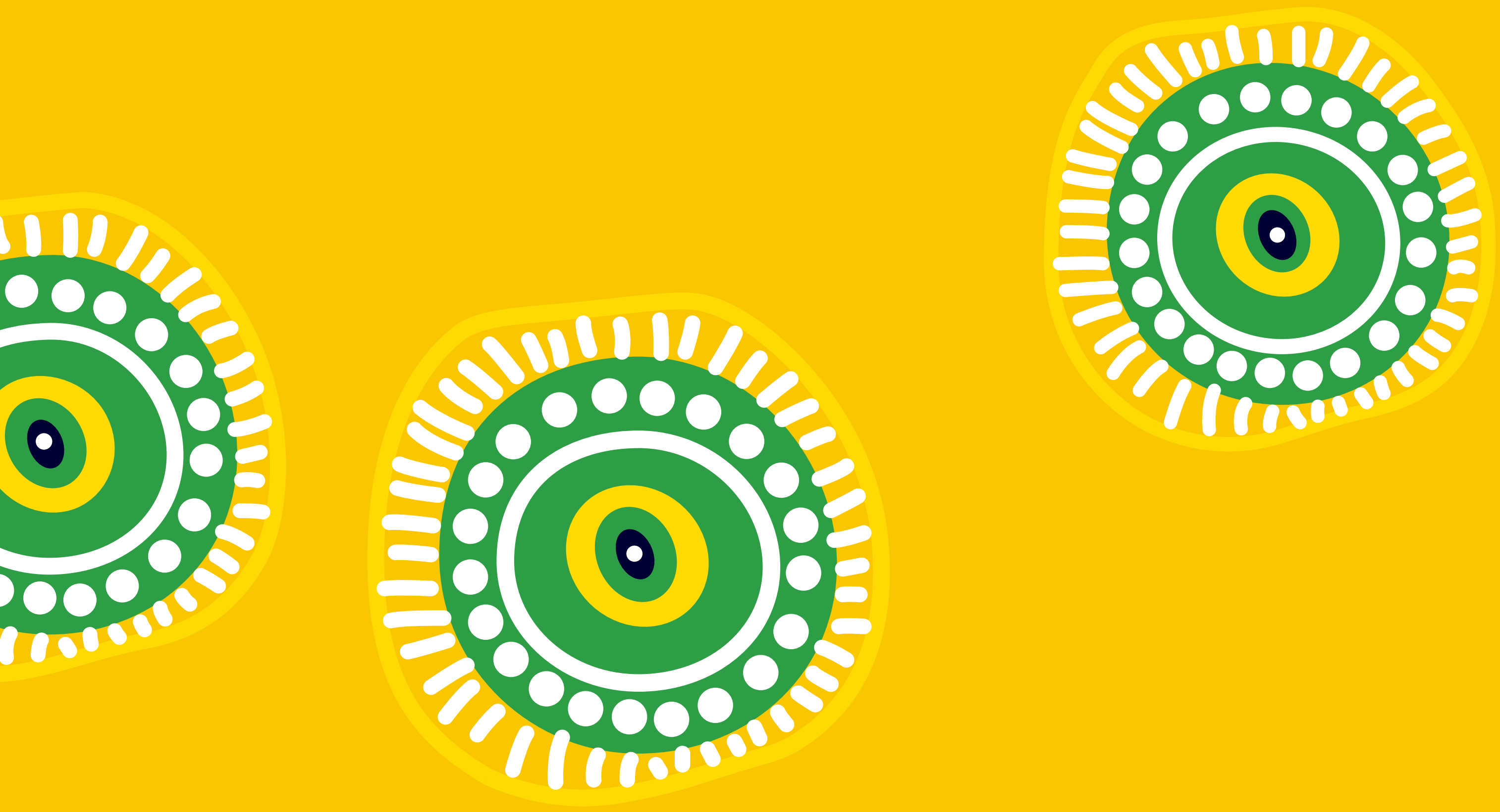

Australian Sports Commission Acknowledgement of Country

The Australian Sports Commission (ASC) acknowledges the Traditional Custodians of the lands where its offices are located, the Ngunnawal people and recognise any other people or families with connection to the lands of the ACT and region, the Wurundjeri Woi-wurrung people of the Kulin Nation, the people of the Yugambeh Nation and the Gadigal people of the Eora Nation.

The ASC extends this acknowledgment to all the Traditional Custodians of the lands and First Nations Peoples throughout Australia and would like to pay its respects to all Elders past, present and future.

The ASC recognises the outstanding contribution that Aboriginal and Torres Strait Islander peoples make to society and sport in Australia and celebrates the power of sport to promote reconciliation and reduce inequality.

Contents

When referencing this document, it should be cited as follows: AIS best practice guidelines for the measurement, analysis and interpretation of resting heart rate and heart rate variability in athletes (2023).

Key recommendations when monitoring Resting Heart Rate and Heart Rate Variability in athletes

Measurement index

Ensure the use of lnRMSSD (see section 2.1.).

Timing of assessment

Both upon waking and nocturnal measures are valid and reliable methods. The method which allows for most consistent high-quality data over time is recommended (see section 2.2.).

Measurement device

Choosing a valid and reliable device is recommended, whether this be from an application, a watch or wearable device (see section 2.3. and Table 1).

Posture

For waking measures, seated or standing postures are preferred over supine postures to counteract the saturation effect. For nocturnal measures a supine posture will and can be used (see section 2.4.).

Duration of assessment

As little as 1 minute can provide valid and reliable measures (see section 2.5.).

Breathing frequency

Breathing freely is recommended (see section 2.6.).

Analysis

Assessment of 7-day rolling averages utilising smallest worthwhile changes are recommended (see sections 3.1. & 3.2.).

Interpretation

A complex area (see section 3.3 and Table 2). Consideration of contextual factors such as, but not limited to, training phase, training load, sleep, nutrition and other recovery factors, menstrual cycle is recommended for more complete understanding.

1. Overview

The aim of this document is to provide best practice guidelines for the measurement, analysis, and interpretation of resting heart rate and heart rate variability (HRV) for the purpose of monitoring athlete stress, acute training responses and/or adaptation to training over time.

HRV is defined as the variability in time between consecutive heart beats or RR wave intervals. The RR wave intervals are constantly fluctuating secondary to the interaction between pulmonary ventilation, blood pressure and cardiac output to maintain blood pressure homeostasis within specific limits [1, 2]. HRV can therefore inform on the responsiveness of the autonomic nervous system (ANS), which in turn informs on the athlete's stress response to training and life demands, physiological adaptation and recovery. Thus, ANS responsiveness (via HRV monitoring) has key implications for athletic performance [3, 4]. HRV is considered a more sophisticated measure of ANS function than heart rate (HR), since it is possible to record the same HR (i.e., average RR interval across a time period) but with different HRV.

While there is opportunity for the application of best practice in the recording of HR/HRV, standardisation should also be considered, such that if you have longitudinal HR/HRV data collected, maintaining current measurement protocols *may* be warranted. Should you choose to modify your measurement protocols in line with the below considerations, comparison between the former and contemporary *absolute* HR/HRV values is unlikely to be valid, however interpretation of trends over time will likely remain comparable.

2. Measurement

2.1 Index of HRV

A number of HRV indices are available for interpretation – see "Heart rate variability: Standards of measurement, physiological interpretation, and clinical use" [1] for comprehensive detail on these indices. The root mean square of successive R-to-R wave differences (RMSSD) is recommended since it is:

1. A pure measure of parasympathetic modulation (as opposed to a composite measure of sympathetic and parasympathetic modulation which is difficult to interpret),
2. Reliable,
3. Minimally impacted upon by subtle changes in breathing frequency (see section "2.6. Breathing frequency"), and
4. Able to be manually calculated if required. For these reasons, RMSSD is the default index of most popular measurement devices which automate some/all elements of HRV measurement.

Additionally, the natural logarithm of RMSSD (i.e. lnRMSSD) is also recommended to reduce non-uniformity of error (or heteroscedasticity) in HRV [5]. In many circumstances, the natural logarithm transformation of RMSSD will need to occur manually.

It should also be noted here that the variables of RMSSD to RR interval ratio and coefficient of variation in RMSSD (RMSSDCV – a measure of the daily variation in RMSSD [6]) can also be calculated to aid the accurate interpretation of HR/HRV in response to positive or negative adaptations to training (see section "3.3. Interpreting meaningful changes in HR/HRV").

2.2 On demand versus automated assessment of HR/HRV

On demand HR/HRV assessment requires the athlete to physically start and stop the HR/HRV recording, and thus the athlete has (almost) full control of the below measurement considerations. With regard to the timing of HR/HRV assessment when assessed on demand, "upon morning waking" is preferred [7, 8]. Specifically, this is immediately upon waking in the morning, but after emptying the urinary bladder (if required).

The aim of upon morning waking HR/HRV assessment is to capture the status of the ANS following a full night of sleep (and therefore recovery) and prior to any significant waking stimuli/daily activities [8]. As such, care should be taken to reduce (or standardise) external stimuli prior to measurement (i.e., emptying the bladder, lights on, noise, etc). Protocol consistency is ultimately the key to ensuring reliable measurements for interpretation.

Currently, several wearable devices are available for the automated collection of HR/HRV (see section "2.3. Measurement device"), whereby the wearable dictates the HR/HRV measurement protocol. The automated assessment of HR/HRV by some contemporary wearable devices will measure HR/HRV during nocturnal periods (see section "2.3. Measurement device"). These nocturnal periods offer a highly standardised environment, however their sensitivity to training-induced changes in ANS function, as well as the stress state of the body from a holistic point of view, may not be as great as that of upon morning waking HRV assessment, since subtle differences in sleep quantity, quality and patterning can independently impact HRV. Additionally, the level of activity completed during the awake period greatly impacts the subsequent nocturnal HRV recording. Consequently, nocturnally-derived HRV may better reflect the state of the ANS on the previous day of training/competition, whereas upon morning waking HRV assessment theoretically better reflects the state of the ANS on the day of training/competition, which may be more important for guiding the impending training/competition effort.

Based on the available evidence, no method (on demand or automated) or time period (upon waking or nocturnal) is deemed more effective than another [9], and therefore, the best method to capture HR/HRV data is considered the most practical one which allows for athlete compliance and consistent high quality data.

2.3 Measurement device

First and foremost, it is important to select a device with known validity and reliability to ensure accurate data are being provided to analyse and interpret. This can be a changing consideration as companies update the hardware and algorithms of their devices, so it is important to ensure you are up to date with the device being used. Refer to Table 1 below for information on measurement device types and considerations.

Table 1. Measurement device types and considerations

Device type	Examples	On demand vs automated	Considerations
Applications	HRV4Training; EliteHRV; ithlete	On demand	Validity/reliability; AMS compatibility; RR intervals collected via chest strap vs photoplethysmography; HRV index (i.e. RMSSD); natural logarithm transformation of RMSSD; ability to access and export raw data; data privacy in the terms and conditions Some measurement device types (and/or their applications) provide a diagnosis (i.e. “your HRV indicates you are excessively fatigued; high intensity training is not recommended today”). These diagnoses have little scientific support, so it is recommended that these diagnostics are ignored (and disabled if possible). Instead, follow the recommendations on HRV trend interpretation in section *2. Analysis and interpretation*.
HR monitors	Garmin; Polar; Suunto; Apple watch	On demand or automated	
‘Wearables’	WHOOP; Oura Ring	Automated (nocturnally-derived)	

2.4 Posture of assessment

Supine, seated and standing postures have been utilised in the on demand collection of HRV. However, seated or standing postures are recommended to avoid the parasympathetic nervous system “saturation” effect, since these postures introduce a minimal level of sustained sympathetic modulation [7, 8, 10]. This of course cannot be implemented during nocturnal measurement. Briefly, HRV saturation refers to a paradoxical phenomenon whereby parasympathetically-modulated HRV (i.e. RMSSD) is reduced as a result of increased parasympathetic activity [8]. It should be noted that parasympathetic saturation is likely limited to high level endurance athletes performing large volumes of training. Where saturation is likely to occur, the use of the RMSSD to RR interval ratio may be useful in aiding interpretation (see section 3.3.). Simply put, HRV determined from seated or standing postures is deemed a more sensitive measure of the autonomic state, and therefore considered more reflective of the stress and adaptative state of the athlete. Seated postures may be considered more comfortable than standing postures and can therefore be recommended.

2.5 Duration of assessment

Evidence suggests that on demand recordings as short as 1 minute provide valid measures of HR/HRV (with the criterion duration being 5 minutes) [11]. Thus, any duration between 1 to 5 minutes can be recommended, however from a pragmatic perspective (i.e., athlete compliance), the shorter the better.

Evidence also suggests that a “stabilisation” period is not required [11], however it can be considered good practice to observe a short (30-60 second) stabilisation period to overcome any effect of waking stimuli (e.g. alarm/noise or emptying the bladder). As such, if on demand assessment are utilised, it is recommended that the athlete is instructed to “rest quietly” for 30-60 seconds before starting the recording.

For nocturnal measures, these can differ dependant on the device, from a given period (e.g., 5 minutes) to the average of the entire night's sleep. However, given the required durations, for valid assessments, most devices meet these criteria.

2.6 Breathing frequency

While some HRV indices are sensitive to subtle changes in breathing frequency, RMSSD is minimally impacted upon, and thus the standardisation of breathing frequency is not required. Instead, it is recommended that the athlete simply "breathe freely".

3. Analysis and interpretation

3.1 Isolated vs 7-day rolling averaged HR/HRV

Evidence indicates that 7-day rolling averaged HRV is more sensitive to training-induced changes in physiological status than isolated (i.e. on the day of measurement) values of HRV [12, 13]. This is because the 7-day rolling average attenuates the natural day-to-day variability in HRV [12]. A minimum of 3 measurements in a 7-day period is required to validly calculate a rolling 7-day average [14].

Pragmatically, the AMS HR/HRV dashboard also includes 4-day rolling averaged HR/HRV to inform on even more acute changes in HR/HRV, and 28-day rolling averaged HR/HRV to inform on more chronic changes in HR/HRV. The need/desire to assess both acute and chronic changes in HR/HRV is theoretically sound, but the optimal number of days that reflect these responses is currently unknown.

3.2 Using statistics to determine ‘meaningful’ changes in HR/HRV

Typical variability in HR/HRV at an individual athlete level can be assessed as a coefficient of variation (CV) to determine whether an observed change is greater than the smallest worthwhile change (SWC). This is calculated as:

> (standard deviation of HR/HRV values over a period of time / mean of HR/HRV values over a period of time) x 100

Unfortunately, the optimal time period in which a CV is calculated is unknown, but should be sufficiently long enough to allow for a true reflection of CV. The AMS HR/HRV dashboard currently uses a rolling 60-day CV, as in most cases, 60 days includes periods of loading and unloading, is not too reactive to acute changes, but also not so long that chronic adaptations influence the daily values, and is therefore reflective of an athletes’ current status [15].

The calculated CV is also used to inform the SWC in HR/HRV. While SWC can be accurately quantified in performance variables (i.e. a x% change in performance time is the difference between podium vs place), the same accuracy cannot occur in the physiologically derived variables of HR/HRV. For this reason, the AMS HR/HRV dashboard calculates within athlete SWC as:

> within athlete CV x 0.5

Finally, as the SWC in HR/HRV is used to determine a meaningful change in HR/HRV, the measure of SWC needs to be applied around a “typical” measure of HR/HRV. Again, the optimal “typical” measure of HR/HRV is unknown, however the AMS HR/HRV dashboard uses a rolling 60-day average of HR/HRV.

Thus, a measure of lnRMSSD will be considered a meaningful increase or decrease if it exceeds the rolling 60-day average of lnRMSSD ± the rolling 60-day SWC. This meaningful change then needs to be interpreted as a positive or negative adaptation to training.

3.3 Interpreting meaningful changes in HR/HRV as positive or negative adaptations to training

The below table is from “Monitoring training status with HR measures: Do all roads lead to Rome?” by Martin Buchheit [8] with modifications from Marco Altini [15]. It provides guidelines for the interpretation of chronic training status based on different scenarios in the changes in HR measures (i.e., HRV, HR, and the HRV/RR interval ratio) with specific reference to training phase and load. It should be noted that this does not contextualise for other factors such as life stressors, sleep, nutrition or other recovery factors, menstrual cycle etc. These factors should ideally be considered for best practice understanding, interpretation, and recommendations.

Table 2. Practical interpretation of training status based on changes in resting HRV and HR

Changes in rMSSD	Changes in HR	Changes in rMSSD/RR ratio	Occurrence	Likely mechanisms	Practical interpretation
↔	↔	↔	Frequent during consistent training periods without excessive changes (increase or decrease) in training load (volume and/or intensity)	Stable physiology - no meaningful change in parasympathetic activity	Coping well with training
↑	↓	Maintained or moderate ↓	Frequent during the building-up phase of elite athletes (high-volume and low-intensity training). Also occurs during overload phases to reflect functional overreaching Can occur during multi-day competition when volume is high and intensity is low	Increase in overall parasympathetic activity	1. If occurring during a phase of overload training, this response can be a sign of functional overreaching. In this context, this increase can be considered a natural/desired response. However, a deload phase should be considered at this point, where HRV should re-normalize 2. If not, this response is typically associated with coping well with training and improved fitness level
↓	↑	Maintained or moderate ↑	Frequent during tapering Can occur during periods of intensified training and during/post competition	Increased sympathetic activity	1. If occurring during tapering, increased readiness to perform 2. If not, accumulated fatigue
↑	↑	Large ↑	May occur at the beginning of a training block, likely observed in previously saturated athletes	Increased sympathetic activity which reverse the saturation phenomenon	1. If occurring during short training blocks, increased readiness to perform 2. If not, accumulated fatigue
↓	↓	Large ↓	Frequent in elite athletes with a long training history	Increase in overall parasympathetic activity that causes saturation	1. Elite athlete/athlete with long training history coping well with training, likely high-volume and low-intensity training 2. If prolonged and not reversed with tapering, can inform on an overtraining state

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