Polar Nightly Recharge

September 30, 2019

Polar Research and Technology

Content

1 Introduction

Night-time recovery from training and stress is a central element of performance development, optimal daytime functioning, wellbeing, and health. Regular trainers typically combine training with work, family, and other commitments, and they may not always reserve enough time for recovery.

Stress is an unavoidable part of life. To understand what stress means from a scientific perspective, more specific terms are needed. The term **stressor** refers to stressful events or circumstances that may be real or imagined threats to an individual's equilibrium and wellbeing. The term **stress response** refers to physiological changes, such as quickened heart rate or breathing rate induced by hormonal and neural control in response to stressors. This response, often called **the 'fight-or-flight' response**, is helpful in times of physical danger. Regardless of its source, the body responds to all stress the same way, which may lead to a prolonged stress response. Overall stress and/or inadequate recovery can decrease an individual's readiness and tolerance for training and increase his/her risk of injury.[1, 2] In addition, chronic stress is linked to various health problems, such as heart problems, high blood pressure, diabetes, anxiety, and insomnia, to mention but a few.[3] Stress can affect health directly, through adverse physiological changes, and indirectly, through its effects on behaviour. Under stress, we are less likely to eat healthily, exercise regularly, or get enough sleep.

Therefore, it is important to allow enough time for recovery, both on a daily basis and in the longer term. Recovery is regarded as a multifaceted restorative process relative to time. When the stressor is no longer present, the stress response subsides and the normal state returns. In other words, **the 'rest-and-digest' system** takes dominance over the fight-or-flight system.

This paper describes the Nightly Recharge feature that assesses recovery based on an automatic overnight measurement. It combines information on the status of the autonomic nervous system (ANS) and nightly sleep. Based on these measurements, it gives tips for exercise, sleep and regulating energy levels. The feature is targeted at regular trainers who want to make optimal choices every day to reach their own training goals and maintain overall wellbeing.

2 Background

The roles of the ANS and sleep in stress and recovery have been extensively studied in many disciplines. Measurement of the heart's beat-to-beat intervals provides valuable information on the functioning of the ANS as well as sleep.

2.1 Autonomic nervous system

The status of the ANS reflects the body's recovery process. Mental stress as well as strain coming from training affect the functioning of the ANS.[4,5,6] The ANS controls vital functions, such as heart rate, blood flow, and digestion, beyond our conscious control. It consists of two branches: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). Both branches play a crucial role in adjusting bodily functions to respond to external and internal demands. The SNS is called the 'fight-or-flight' system as it facilitates behavioral activation in response to stressors. Activation of the SNS results in, for example, an increase in heart rate. The PNS

is called the 'rest-and-digest' system as its activation conserves energy. It facilitates homeostasis of the body. Activation of the PNS is high during rest and sleep resulting in, for example, a decrease in heart rate.

It is well documented that a mental stressor or an acute bout of aerobic exercise induce a shift of the ANS balance towards increased activation of the SNS and decreased activation of the PNS.[7,8,9] In the case where there is enough time for recovery after the stressful event, the opposite changes happen and the ANS balance returns to its usual level. In the case where numerous stressful events occur frequently with incomplete recovery in between, which is often the case with work stress or training overload, the ANS balance may remain disturbed for a longer period of time.[10, 11] The time-course of the recovery process is individual. A consensus has not been established on what time period should be used to capture meaningful changes in the ANS function.

2.2 Nightly sleep

Sleep is an integral part of optimal recovery from training and daily hassles. The restorative properties of sleep depend on the amount and quality of sleep. Sleep recommendations are different for different age groups. On average, adults need 7 to 9 hours of sleep for optimal daytime performance and health.[12] However, sleep needs vary between individuals as well as between days for the same individual.

There is no single parameter that would indicate sleep quality. Sleep quality can, however, be defined as a combination of several parameters reflecting different aspects of sleep.[13] One aspect of sleep quality is continuity (or fragmentation). It refers to a group of those sleep parameters that indicate amount and number of wake bouts during the night. Another aspect of sleep quality is sleep structure.

Sleep consists of two major types: REM (rapid eye movement) sleep and non-REM sleep. Non-REM sleep can be further divided into three stages that differ in terms of how deep the sleep is. The deepest stage of non-REM sleep, often called deep sleep, is considered the sleep stage during which the body actively repairs and restores itself. Deep sleep also has properties that support the immune system and affect certain aspects of memory and learning. As deep non-REM sleep restores the body, REM sleep is considered to restore the mind. It has been shown to facilitate memory and learning. Thus, both non-REM and REM sleep are important to how well we can learn new things and what we can remember.

Insufficient sleep is associated with an increased risk of mortality and with problems and illnesses related to the respiratory, cardiovascular, and metabolic systems as well as mental health.[14] Although sleep is considered critical to optimal training adaptation, performance, injury prevention, and overall health, many athletes fail to achieve the recommended amount of sleep during training or competition periods.[15,16,17] There is growing evidence that suggests that longer and better quality sleep are associated with better athletic performance and success.[17,18,19]

2.3 HRV as a recovery assessment tool

A measurement of heart rate variability (HRV) is considered a reliable means to indirectly estimate the ANS control of the heart.[20] It also provides a tool to measure sleep and determine sleep stages in real life settings.[21] HRV refers to variation in the time between successive heart beats. Measuring HRV requires the accurate detection of the heart's contraction and it is typically assessed based on an electrocardiogram. However, recent technological advancements have made it possible to assess the beat-to-beat intervals at rest accurately enough with optical wrist and finger sensors.[22] As this technology detects pressure pulses traveling through blood vessels, a term pulse rate variability is often used instead of HRV. In this white paper, we use the term heart rate variability also for pulse rate variability.

Studies assessing the ANS response to stress and recovery in working population or athletes, have measured heart rate and HRV at rest, during an orthostatic test, during or after exercise, during or after working hours and during sleep.[4, 5, 6]

3 Description of Nightly Recharge

The Nightly Recharge feature shows the nightly recharge status that is based on an automatic overnight measurement. The nightly recharge status reflects how the user was able to recover from stress caused by training and other aspects of life. The nightly recharge status considers how the user's ANS status and sleep compared to his/her usual night (figure 1).

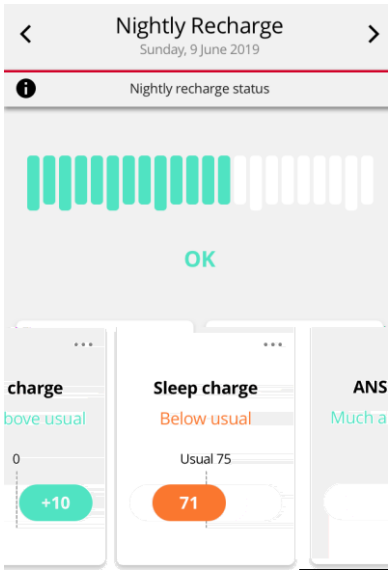

Figure 1. The nightly recharge status combines automatically measured information on the ANS and sleep. The ANS charge and the sleep charge compare the previous night's measurements to the user's usual level formed from the past 28 days.

3.1 Benefits

The Nightly Recharge feature provides the following benefits:

- The user can see how his/her body was able to recover from overall stress, coming from training and other aspects of life, based on automatic overnight measurements
- The user gets an exercise tip every day telling if (s)he should take it easy or go for it
- The user gets personalized tips on how to improve sleep and regulate energy levels on days with the poor/very poor nightly recharge status
- The user can learn what (s)he can do to improve her/his nighttime recovery

3.2 ANS charge

The ANS charge (meaning **A**utonomic **N**ervous **S**ystem charge) reflects how ANS functioning during the early hours of sleep compared to the user's usual night. In other words, the previous night's ANS measurements are compared to the user's usual levels calculated from the past 28 days. The ANS charge is formed from heart rate, HRV and breathing rate. The three parameters are measured during a 4-hour period starting at 30 minutes after falling asleep. Most weight is given to heart rate and least weight to breathing rate. Combining the three parameters allows to capture changes in the ANS balance. Heart rate reflects combined activation of the SNS and PNS. The selected HRV parameter, called RMSSD (Root Mean Square of Successive Differences in beat-to-beat intervals), reflects activation of the PNS in particular. Feasible techniques to measure breathing rate over many nights have not been available until recently, and therefore longitudinal studies on stress and breathing rate during sleep are lacking. However, according to our own findings, breathing rate adds meaningful information to the ANS charge.

The rationale for selecting the 4-hour period is that it has been used in several studies.[e.g. 23,24,25,26,27,28] Further, studies using hour-by-hour analysis have shown that ANS measurements during the early hours of sleep in particular reflect insufficient recovery from work and exercise.[29,30,31] This is supported by our own unpublished findings that the selected 4-hour period during the early hours of sleep is more sensitive to reflect recovery than the whole sleep period.

Selection of measurement conditions is always a matter of application. Nightly Recharge utilizes the nighttime measurements to assess recovery as sleep is the best period to automatically measure and interpret heart rate, RMSSD and breathing rate in real life settings. Sleep is a somewhat controlled and repeatable condition in terms of signal quality, posture, mental state, environment and time of day. As ANS and sleep measures are highly individual, it is meaningful to interpret them against individual variation. As a rule of thumb, frequent measurements are required to accurately assess

the normal ranges of individual variations. The automatic overnight measurement does not require any effort from the user and can be done routinely every night.

Heart rate (4-h average)

As an adult, the normal range for resting heart rate is from below 60 to 100 bpm. In athletes, heart rate at rest and during sleep can be closer to 40 bpm. The ANS charge utilizes a heart rate average of 4 hours. This value can vary substantially between nights for the same individual. The 4-hour heart rate average is also expressed as the corresponding beat-to-beat interval length in milliseconds (ms). For example, an average heart rate of 60 bpm corresponds to an average beat-to-beat interval length of 1000 ms (or 1 s).

Heart rate variability (4-h average)

The average heart rate of 60 bpm does not mean that each beat-to-beat interval would be exactly 1000 ms. Instead, the intervals vary substantially. In Nightly Recharge, HRV is measured with a parameter called RMSSD. It was selected as it reflects the parasympathetic control of the heart in particular and it is commonly used to assess stress and recovery, especially in athletes. A RMSSD of 4 hours can vary greatly from individual to individual, ranging from values anywhere between 20 and 150 ms. Therefore, it is meaningful to interpret RMSSD values against the user's own data. The higher the parasympathetic control of the heart, the higher the RMSSD value.

Breathing rate (4-h average)

Breathing rate can also be captured from the heart's beat-to-beat intervals. A phenomenon called respiratory sinus arrhythmia refers to the shortening of beat-to-beat intervals during inhalation and lengthening of them during exhalation. This pattern of fluctuations allows the calculation of the breathing rate. Typical breathing rate values for a healthy adult at rest range from 12 to 20 breaths per minute. Within an individual, the 4-hour average of breathing rate is typically quite stable from night to night but when it does deviate from its usual level it adds meaningful information to the ANS charge.

Interpretation

The scale of the ANS charge is from -10 to +10 with usual level being from -2 to +2. The scale and its interpretation limits are individual and they are based on the average and multiples of standard deviation of the measurements from the past 28 days. Outliers are excluded when forming the scale. The higher the ANS charge, the higher the dominance of the parasympathetic branch of the ANS compared to the user's usual level. As mentioned earlier, the ANS charge reflects changes in the both branches of the ANS as heart rate reflects the PNS and SNS control and RMSSD specifically reflects the PNS control.

3.3 Sleep charge

The sleep charge reflects how well the user slept compared to his/her usual night. The previous night's sleep score is compared to the user's usual level calculated from the past 28 days.

Sleep score

The sleep score combines sleep time and five sleep quality parameters into one number (figure 2). The components of the sleep score are grouped under three themes: sleep amount, sleep solidity, and sleep regeneration. The components have been selected and evaluated based on the National Sleep Foundation's recommendations and guidance for sleep duration and quality.[12,13] The sleep score value is an average of its components, and its scale is 1–100.

Figure 2. The sleep score consists of six components. Each component is scored between 1 and 100. The sleep score is an average of its components.

Sleep amount looks at how long the user has slept. Sleep time is compared to the optimal sleep time based on your preferred sleep time setting and the age-related sleep duration recommendations. An adult gets the maximum score from this component when (s)he has slept for at least 8 h and met his/her preferred sleep time.

Sleep solidity looks at sleep quality in terms of the pattern and amount of interruptions in sleep. It consists of three components: Long interruptions, Continuity, and Actual Sleep.

- A night without any long interruptions gives the maximum score for this component. There are about 15 minutes of long interruptions in sleep during an average night of an adult.
- The scale for continuity is from 1 to 5. Five represents sleep without any interruptions and gives the maximum score. The average value for adults is 3.2.
- An actual sleep value close to 100% gives the maximum score. For adults, an average value is 93%.

Sleep regeneration looks at sleep quality in terms of the proportions of restorative sleep stages: REM sleep and deep sleep.

- The REM sleep amount of 25% gives the maximum score from this component of the sleep score. Higher or lower percentages decrease the score. The amount of REM sleep is on average about 21% of sleep time for adults.
- The deep sleep amount of roughly 17% gives the maximum score. Higher percentages do not improve the score. On average, deep sleep counts for about 15% of sleep time for adults.

The sleep score is a part of the Polar Sleep Plus Stages feature that has been described in more detail in a separate white paper.

Interpretation

The sleep charge compares the sleep score to the user's sleep scores from the past 28 days. The user's usual level is a 28-day average ± roughly 3 units. It is important to understand that in the case where the user starts using Nightly Recharge when (s)he is getting less sleep than (s)he needs, his/her baseline does not represent the ideal level for the user.

3.4 Nightly recharge status

Nightly recharge status shows how the user was able to recover from training and stress during the night. It combines information on the ANS charge and the sleep charge. Six different statuses are: very good, good, OK, compromised, poor, or very poor (figure 3). 'The green statuses' (very good, good, and OK) indicate that the user has recovered well. Compromised, 'the yellow status' indicates slightly weakened recovery. It is given, for instance, if the sleep charge is much below the user's usual level and the ANS charge is at the usual level or higher than that. 'The red statuses' (poor and very poor) indicate that the user has not recovered well. The ANS charge has more weight than the sleep charge in interpreting that something is up. For instance, if the ANS charge is much below the user's usual level, the nightly recharge status is in red regardless of what the sleep charge is.

There are several factors that affect the nightly recharge status. Physical stress is one source of stress to the body. In addition to training, there are many other factors that can cause stress and affect the nightly recharge status. The most important factors known to negatively affect functioning of the ANS and/or sleep include mental stress (e.g. work or an upcoming competition), intense emotions, alcohol, caffeine and other stimulants, traveling, environmental changes (e.g. high altitude or hot climate), illness, and medication.[e.g. 1,5,32,33,34,35] The effects of these factors on the ANS charge and the sleep charge are individual and depend on duration and timing of the stressful situation. It is good to remember that people are stressed by different situations and their coping skills differ.

When the user starts using Nightly Recharge, (s)he needs to wear his/her watch for three nights before (s)he will get the nightly recharge status. As the ANS charge and the sleep charge are formed by comparing the parameters to the user's usual level, the nightly recharge status becomes more reliable the more measurements have been done over the past 28 days. It is important to understand that if (s)he is sick or very stressed at that time, his/her usual level actually reflects an "unusual" situation. However, as the user's usual level is updated continuously, it starts to reflect the user's normal

situation when (s)he has been better for a couple of weeks.

Figure 3. The nightly recharge status has six different statuses that are formed by combining information on the ANS charge and the sleep charge.

3.5 Daily tips

Based on the measured data, the user gets personalized daily tips for exercise, sleep, and regulating energy levels.

Exercise

The exercise tip is given every day and it tells the user if the day in question is a good day to train or if it would be better to train lightly or rest. The tips are based on the nightly recharge status, the ANS charge, the sleep charge and cardio load status. See more information on cardio load status from a separate white paper. If the user wants more detailed training guidance, (s)he can select the FitSpark training guide. It offers ready-made training sessions that are designed to match the user's fitness level, training history and the nightly recharge status.

Sleep

If the user did not sleep as well as (s)he usually does, (s)he gets a sleep tip. It tells the user how to improve the aspects of sleep that were not as good as usual. Good habits (i.e. "sleep hygiene") that are known to help maintain healthy sleep patterns are the basis of the sleep tips.[36] Besides the sleep charge and its component, sleep rhythm over a longer period, cardio load status, and exercise on the previous day affect the tips.

Energy level

If the ANS charge or the sleep charge is much below usual, the user gets a practical tip for regulating his/her energy levels. The tips suggest several ways to calm down or feel more energetic. Tools for regulating energy levels include, for instance, a breathing exercise, power nap, and mini breaks.

4 Validity

There is no gold standard method for assessing recovery. Therefore, it is challenging to validate Nightly Recharge scientifically. However, Nighty Recharge is based on up to date scientific knowledge of stress and recovery, and it utilizes generally accepted tools for measuring ANS functioning and nightly sleep in real-life settings.

A measurement of HR and HRV provides a valid tool to indirectly estimate the ANS control of the heart. Most studies have used short-term measurements of HRV at rest or during an orthostatic test to assess recovery. Night-time measurements have been less used due to lack of feasible technology. Recent developments in optical measurement technology have made it possible to measure the heart's beat-to-beat intervals accurately enough from the wrist. Automated signal processing and analysis of the beat-to-beat data is a common challenge for customer-targeted devices and solutions. However, combining information on heart rate, heart rate variability and breathing rate smartly makes the ANS measure less prone to ectopic beats and technical artifacts.

Polar automatic sleep measurement has been validated against polysomnography, the gold standard in assessing sleep. Polysomnography measures brain activity, eye movements and muscle activity with a large set of sensors attached to the head. Classification of sleep into different sleep stages requires that a sleep technician analyses these signals in 30-second epochs according to the American Academy of Sleep Medicine rules.

In 2017, Polar launched a Sleep Plus feature. The algorithm utilizes a 3D acceleration measurement that has been validated in children, adolescents and adults with healthy sleep.[37,38] Results from the validation studies suggest that Sleep Plus detects sleep and wakefulness as accurately as the current, commonly used wrist-worn devices in research and clinical practice. In 2019, Polar launched a Sleep Plus Stages feature. It

complements Polar sleep analysis with light, deep and REM sleep stages. The new algorithm incorporates measurements of acceleration and the heart's beat-to-beat intervals. The unpublished results of an independent validation study have demonstrated that the algorithm was able to determine sleep stages with a reasonable degree of accuracy in heathy adults with normal sleep patterns. Further, according to our own analysis, the algorithm works reasonably well also in children and adolescents.

5 Limitations

Nightly Recharge cannot separate sources of stress. It evaluates how well the user has recovered from an overall stress coming from different sources. Nightly Recharge is not able to recognize chronic stress. It is possible that the user starts tracking his/her recovery during a stressful period. Chronic stress is not revealed by the Nightly Recharge status as each night's measurements are compared to the user's usual level – that actually is unusual in this case.

6 Nightly Recharge vs. Recovery Pro

Nightly Recharge is most suitable for regular trainers who are not trying to test their limits in terms of their ultimate training loads. We recommend Training load Pro and Recovery Pro for those athletes who want to maximize their performance. That feature helps them find the right balance between training and recovery and thus avoid over- or undertraining. Recovery Pro combines objective (Orthostatic test) and subjective measures (questions on perceived recovery) with training history. Based on these factors it determines the balance between training load and recovery both in short term (today) and long-term and guides the user accordingly.

It is worth mentioning that not only ANS measurements, but also their interpretations differ between Nightly Recharge and Recovery Pro. Both features compare the ANS measurements to personalized usual levels. In Nightly Recharge, the basic principle of the ANS charge states that increased HR and decreased HRV indicate poor recovery while decreased HR and increased HRV indicate good recovery. In Recovery Pro, cardio recovery is evaluated with a HRV measurement in a lying on a bed and a standing position (Orthostatic test). Cardio recovery is considered to be incomplete if HRV values are either below or above their normal ranges. This is because several studies have reported both, increased and decreased HRV values during extremely strenuous training loads (see a separate white paper).

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