POLAR.

PIONEER OF WEARABLE SPORTS TECHNOLOGY

White Paper

Polar Sleep Plus Stages

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Contents

1 Introduction

Sleep is vital to overall health and well-being. It plays a critical role in cardiovascular, immune, hormone, and brain functions as well as metabolism and appetite regulation.[1] Even though most people acknowledge that sleep is important, many people simply sleep too little. Over time, insufficient sleep increases the risk for several chronic health problems, including cardiovascular disease, obesity, diabetes, and depression, to mention but a few.[1]

Adequate recovery is an integral component of training process and performance development in athletes. Sleep has been recognized as an effective recovery strategy.[2,3,4,5] It is fundamental for both the physical and mental restoration. Several hormonal responses relating to physical restoration take place during sleep. Sleep is also the time period during which a number of processes linked to memory, learning, cognition, vigilance, mood, and motivation occur.

Sleep loss can slow down training adaptation. While total sleep deprivation has been shown to negatively affect exercise performance, the effects of partial sleep restriction have been more conflicting.[6] The extent, influence, and specific mechanisms of sleep loss affecting exercise have remained unclear. However, the adverse effects of sleep loss on cognitive performance are clear, meaning that inadequate sleep can impair performance in sports that require high levels of cognitive functioning.[6] Ability to follow a personal training plan is an important determinant of success. Inadequate sleep may increase the risk of injury and illness and thus reduce participation in planned training.[2]

Despite the importance of sleep, athletes are often unable to achieve the recommended amount of sleep during training or competition periods. [2,4,5,6] Factors known to negatively affect sleep include competitions, early morning training, increased training load, traveling, jet lag and altitude. There is growing evidence that increased sleep duration and improved sleep quality are associated with improved performance and better competitive success.[2,3] Thus, athletes may benefit from sleep optimization and extension.

This paper describes Polar Sleep Plus Stages feature developed by Polar. The patent publication WO2018154136A1 is related to the feature. Sleep Plus Stages complements Polar's previous sleep analysis with sleep stages and sleep score. The sleep score is a single number, that provides a glanceable summary of sleep amount and quality. The feasible and automatic sleep measurement allows to track sleep on a regular basis, which helps follow long-term sleep habits and identify the factors that may affect sleep.

2 Background

Both the amount and quality of sleep can be assessed with objective metrics. Most common methods to assess sleep in science and clinical

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practise are polysomnography, accelerometry and questionnaires. Whereas the polysomnography remains the 'gold standard' method to assess sleep, accelerometry seems to be the preferred method in athletes.

2.1   Polysomnography

Polysomnography is an expensive method that requires specialised laboratory equipment, making it impractical for regular tracking. It measures brain activity, eye movements and muscle activity with surface electrodes attached to the head. Based on these signals a sleep technician classifies each 30-epoch of sleep into different sleep stages according to the American Academy of Sleep Medicine rules. The sleep stages are visualized as a hypnogram, a graph representing the sleep stages as a function of time. A typical night's sleep is composed of roughly 90-min cycles divided into periods of rapid eye movement sleep (REM) and non-rapid eye movement sleep (non-REM).[7] Non-REM sleep is further divided into three different stages that differ in terms of how deep the sleep is.

Light sleep
Light sleep is the term that refers to the two lightest stages of non-REM sleep. When we fall asleep we first enter to the lightest stage of sleep and then proceed to other sleep stages. Adults spend about half or more of their nights in light sleep. This stage of sleep is though to play a role in memory consolidation.

Deep sleep
The deepest stage of non-REM sleep is often called deep sleep or slow-wave-sleep. Deep sleep is considered the sleep stage during which the body actively repairs and restores itself. The pituitary gland releases growth hormone during this sleep stage. Growth hormone is necessary for muscle growth, repair, and bone building, which is essential to athletic recovery following exercise sessions. Deep sleep also promotes the right balance between anabolic and catabolic hormones, which accelerates muscle adaptation and growth. In addition, deep sleep has properties that support the immune system and affect certain aspects of memory and learning.

REM sleep
As deep sleep restores the body, REM sleep has considered to restore the mind. REM sleep is characterized by vividly recalled dreams and rapid movements of the eyes. During this stage, brain activity is quite similar to that during waking hours. It has been proposed that the high brain activity is associated with memory consolidation and learning of motor skills. Thus, both non-REM and REM sleep are fundamental for training adaptation and proper physical and cognitive functions during exercise performance.

2.2   Sleep amount

The National Sleep Foundation (NSF) has provided practical recommendations for daily sleep duration for different age groups.[8] Recommended daily sleep duration for healthy adults is between 7 to 9 hours. On average, this amount of sleep on a regular basis is considered to be appropriate for health and well-being. The recommendations acknowledge the individual variability by defining the range of hours that 'may be appropriate' for some people. For some adults 6 hours may be enough, and some adults may need 10 hours of sleep.

Though the recommendations identify the rule-of-thumb amounts experts agree upon, it is important to pay attention to an individual's own sleep need. For example, athletes have suggested to need more sleep than the hours recommended for the general public.[2] Moreover, sleep needs also vary between days for the same individual, depending on e.g. health status, training and environment.

2.3   Sleep quality

The NSF has provided evidence-based recommendations and guidance regarding indicators of good sleep quality for healthy people at different ages.[9] According the consensus paper, those parameters that reflect sleep continuity (or sleep fragmentation) can be used as measures for sleep quality at most ages. Sleep continuity refers to a group of those sleep parameters that indicate

amount and number of wake bouts during the night. Shorter sleep latencies, fewer awakenings, reduced wake after sleep onset, and higher sleep efficiency indicate good sleep quality.

In addition to continuity parameters, the experts also judged whether the percentages of time spent in different sleep stages could be used as measures for sleep quality. They concluded that deep sleep and REM sleep can be used as measures for sleep quality in adults. Reduced deep sleep and elevated REM sleep do not indicate good sleep.

3   Polar Sleep Plus Stages

The Sleep Plus Stages feature automatically measures the amount and quality of sleep and illustrates sleep structure in detail. It gathers sleep time and the components of sleep quality into one easily glanceable value, the sleep score. The score compares the previous night's sleep to the science-based indicators of a good night's sleep.

3.1   Benefits

Sleep Plus Stages provides the following benefits:

- The user can see how his/her sleep proceeded over the course of the night and how much time (s)he spent in each sleep stage and in interruptions.
- The user gets Sleep score that shows how well (s)he slept compared to the indicators of a good night's sleep based on the current sleep science.
- The user gets feedback on how well (s)he slept compared to his/her usual night's sleep.
- With regular sleep tracking the user can learn to identify the factors that may affect his/her sleep.

3.2   Measurement method

Polar sleep measurement does not require any effort from the user. Only thing (s)he needs to do is to wear his/her watch and make sure that 'Continuous HR tracking' setting is on. Sleep Plus Stages automatically recognizes when the user

falls asleep and when (s)he wakes up. The Sleep Plus Stages algorithm utilizes accelerometry and photoplethysmography measured from the non-dominant wrist. Characteristics of raw 3D-acceleration signals reveal hand movements, which is the foundation for Polar's sleep detection. Photoplethysmography is an optical technique that detects pressure pulses traveling through blood vessels. According our own studies it detects the heart's beat-to-beat intervals accurately enough when the user is resting or sleeping and does not move his/her hand. Measurement of the times between successive heart beats and analysis of their variation is used for classification of sleep into the different sleep stages.

3.3   Sleep structure

The total duration between fall asleep and wake up times is called sleep time. Polar sleep algorithm classifies each 30-s epoch during this period into light sleep, deep sleep, REM sleep or interruptions (figure 1). Light sleep corresponds to the two lightest stages of non-REM sleep. Deep sleep corresponds to the deepest stage of non-REM sleep. Interruptions in sleep correspond the bouts when the algorithm has detected the user awaken briefly from his/her sleep. Whether the user remember these interruptions or not depends on their duration. The shorter ones the user doesn't usually remember. The longer ones, lasting 90 seconds or more, the user can remember.

In addition to the parameters shown in figure 1, Polar's sleep breakdown includes two parameters derived from the interruptions and sleep bouts during the night. These parameters are actual sleep and sleep continuity. Actual sleep means the time the user actually spent asleep, thus equalling sleep time minus interruptions. Actual sleep can be presented as both duration and a percentage of sleep time. Sleep continuity evaluates how continuous sleep was based on the pattern of interruptions and sleep bouts during the night. The scale is 1-5, where 1 reflects fragmented sleep and 5 very continuous sleep.

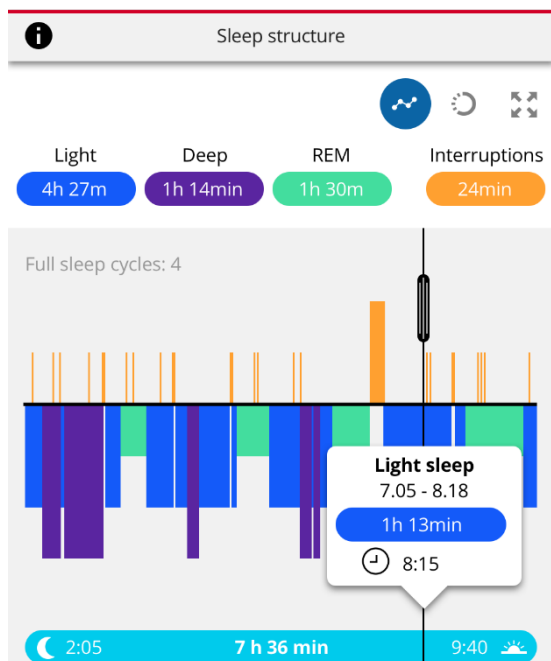Polar Research and Technology

Figure 1. An example of Polar sleep structure view. Different sleep stages are shown in different colours. Thin and thick yellow bars indicate short and long interruptions in sleep, respectively. This example shows four full sleep cycles. A typical sleep cycle progresses from light to deep sleep and then back to REM sleep.

3.4 Sleep score

Sleep Plus Stages combines the amount and quality of sleep into one easily glanceable value, sleep score (figure 2). The six components of the sleep score are grouped under three themes: sleep amount, sleep solidity, and sleep regeneration. Polar research has used the NSF's recommendations and guidance as a foundation for selecting and evaluating the components of the sleep score.[8,9] The sleep score value is an average of its components, and its scale is 1–100.
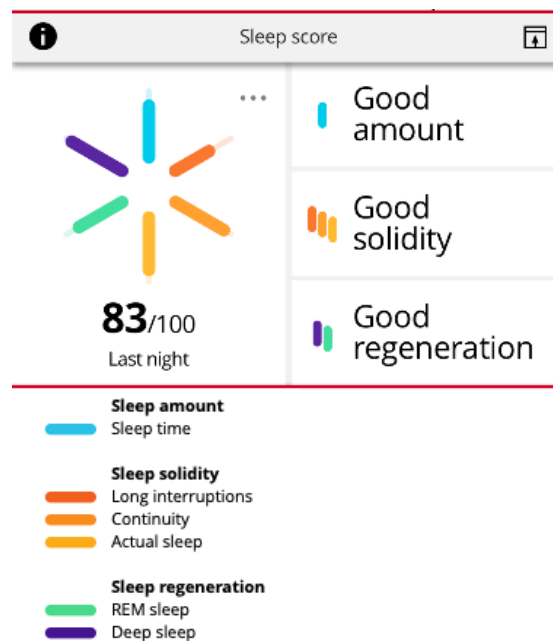

Figure 2. An example of Polar sleep score view. Here, the sleep score value is 83 out of 100. The score consists of six components that are grouped under three themes: sleep amount, sleep solidity and sleep regeneration. In this exmaple, each theme is evaluated as 'Good'.

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 duration recommendations. The user can set his/her preferred sleep time in Polar Flow. The default value for it is 8 hours for adults based on the NSF's recommendations. It is important to adjust the setting to match with the user's individual sleep need. 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. On average adults have about 15 minutes of long interruptions in sleep.

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- The scale for continuity is from 1 to 5. Five represents sleep without any interruptions and gives the maximum score. For adults, the average value is 3.2.
- An actual sleep value close to 100% gives the maximum score. The average value of actual sleep for adults is about 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. According to Polar Flow database and multiple scientific studies the amount of REM sleep is on average about 21 % of sleep time for adults.[10]
- The deep sleep amount of roughly 17% gives the maximum score. The amount of deep sleep is on average about 15% of sleep time for adults by our database and the literature.[10]

3.5   Verbal feedback

In addition to the sleep score, the user gets textual feedback on its three themes (sleep amount, sleep solidity, and sleep regeneration). Each theme is evaluated against the characteristics of a good night's sleep with a three-step scale: poor - moderate - good.

As sleep need and sleep structure are highly individual, each theme is also evaluated against the user's usual level with a five-step scale: much below usual - below usual - usual - above usual - much above usual. Corresponding visual comparisons are available also for the six individual components of the sleep score. Comparing sleep to the own usual level can help the user to learn how daily choices and lifestyle habits affect sleep.

3.6   Sleep-wake schedule

The user can see his/her sleep rhythm from Polar weekly and monthly sleep graphs. Sticking to a regular schedule is the foundation of a healthy sleep structure, as it keeps the internal sleep regulatory clock synchronized with a 24-hour rhythm. In addition, a practical way to improve sleep in athletes and the general public is to follow 'sleep hygiene' recommendations intended to promote healthy sleep (e.g. avoid caffeine, exercise regularly, manage stress, reduce bedroom noise).[11,12]

3.7   Subjective sleep rating

After getting enough sleep one should feel alert and energetic to perform well in daily duties and other activities. The user can record his/her own perception of how well (s)he has slept by rating the previous night's sleep with a five-step scale: very poorly - poorly - okay - well - very well. This may help the user to discover the optimal amount and quality of sleep (s)he needs. Sleep rating is not considered in the sleep score calculation.

4   Validity

Polar launched the Sleep Plus feature in 2017 and the Sleep Plus Stages in 2019. Polar research has developed both algorithms and they have been validated against polysomnography, the gold standard in sleep science and medicine.

The Sleep Plus utilizes a 3D acceleration measurement to automatically detect fell asleep time, woke up time, and interruptions in sleep. The algorithm has been validated in children, adolescents and adults with healthy sleep.[13,14] Comparisons of 30-s epochs were used to determine accuracy of Polar's detection of sleep and wakefulness with the polysomnography. The study in children and adolescent also included Actiwatch 2 (Philips Respironics), an accelerometer mainly targeted to clinicians and researchers.[13] Altogether, results from the validation studies suggest that Sleep Plus detects sleep and wakefulness (i.e. interruptions) with excellent accuracy, being as accurate as the current, commonly used wrist-worn devices in

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research and clinical practice. The results regarding the Sleep Plus feature also apply to the Sleep Plus Stages feature.

An independent study in Canada has been conducted to validate the Sleep Plus Stages algorithm against the polysomnography. Sleep Plus Stages utilizes accelerelometry and photo-plethysmography to indirectly detect sleep stages whereas in polysomnography an expert defines sleep stages based on electroencephalography (brain activity), electrooculography (eye movements), and electromyography (muscle activity). Unpublished results suggest that the Sleep Plus Stages algorithm is able to detect sleep stages with a reasonable degree of accuracy in heathy adults with normal sleep patterns. Further, according to our own analysis, the Sleep Plus Stages algorithm works reasonably well also in children and adolescents.

5   Limitations

As the measurement is fully automatic, it may detect sleep time inaccurately for some nights. If the user is very restless and moves a lot during sleep, Sleep Plus Stages may falsely detect that the user is awake when (s)he actually is asleep. It is also possible for Sleep Plus Stages to falsely recognize sleep. This can typically happen if the user is not moving but not asleep for long periods of time.

Sleep Plus Stages estimates sleep stages indirectly based on signals measured from a wrist. Sometimes it might happen that, for example, the wrist strap is not tight enough, and the signal from the optical sensor is noisy. Then the algorithm cannot recognize sleep stages and the Polar hypnogram includes periods of unrecognized state.

Sleep Plus Stages is developed and validated in healthy people with normal sleep patterns. It is not capable of indicating sleep problems and may not work accurately in people with sleep disorders.

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