Polar Sleep Plus^{TM}

Research and Technogy

CONTENTS

1 Introduction

People spend roughly one third of their lives asleep, but scientists still do not have a single theory for why we sleep. They do, however, have extensive knowledge regarding the mechanisms that control sleeping and waking up and on what happens during sleep. Sleep plays a critical role in people's overall health and well-being. In their everyday lives, people observe that following a good night's sleep, they feel more alert, more energetic, happier, and better able to function. Getting a good night's sleep routinely is central to many functions of the body and the brain. These functions include, for instance, immune function, appetite regulation, memory, and learning.[1] In the 24/7 society we live in today, many people voluntarily compromise their health by building up a sleep debt for months and years on end. Over time, a lack of sufficient sleep increases the risk for several chronic health problems including cardiovascular, metabolic, respiratory, and mental problems.[1]

The Polar Sleep Plus^{TM} feature automatically detects the duration, quality, and timing of sleep based on an acceleration measurement. Tracking sleep over time helps identify how daily habits affect sleep and what changes in habits could improve sleep. Sleep Plus^{TM} is developed by Polar, and the patent publication EP3366206A1 is related to it.

2 Background

This section focuses on the following questions: How is sleep regulated? What is sleep, and how is it measured? What can an individual do to improve sleep?

2.1 Sleep regulation

Sleep-wake rhythm is regulated by interaction of two body systems: *the homeostatic sleep drive* and *the circadian rhythm*.[2] The homeostatic sleep drive balances wakefulness and sleep. After sufficient sleep, an individual typically feels alert in the morning. The pressure to sleep accumulates during the day and makes an individual feel tired and ready for sleep in the evening. During the night, the pressure to sleep gradually dissipates, and the likelihood of waking up increases. The circadian rhythm is an internal system that regulates the feelings of sleepiness and wakefulness over a 24-hour period. The circadian rhythm is controlled by an area of the brain that responds to light. Therefore, an individual is most alert while the sun is shining and is ready to sleep when it is dark outside. In addition to the light-dark cycle other factors, including social schedules, cognitive pressure, and motivation influence sleep-wake rhythm.[2]

2.2 Sleep architecture

Normal sleep architecture is characterized by two types of sleep. These types are referred to as *non-rapid eye movement (NREM)* sleep and *rapid eye movement (REM)* sleep.[3] In an adult, a normal night's sleep usually consists of four or five sleep cycles, each of them including NREM and REM sleep. During NREM sleep, most physiological activities slow down, but body movements can still occur. NREM sleep is further divided into three stages: the two lightest stages together are called light sleep and the deepest stage is called deep sleep. During REM sleep, the brain is active, and many physiological activities speed up to daytime levels, whereas the body hardly moves. REM sleep is the stage of sleep during which most dreams occur. Different sleep stages serve many specific functions. In general, while deep sleep is linked to restoration of the body, REM sleep is linked to restoration of the mind. If a healthy individual meets his/her sleep need on daily basis, (s)he typically gets a proper proportion of each sleep stage.[3]

2.3 Sleep measurement

Polysomnography is considered to be the gold standard for measuring sleep and diagnosing sleep disorders. The method requires an expert in the field and specialised equipment. A sleep technician attaches small electrodes to the head to record eye movements, muscle tone, and brainwave patterns. Based on these signals the sleep technician classifies manually each 30- second epoch of sleep into different sleep stages.

While the polysomnography remains the gold standard method to assess sleep, wrist accelerometry offers a more viable tool for assessing sleep-wake patterns.[4] A major advantage of accelerometry is that it allows an indivudal's sleep to be measured in their own home over extended periods of time. Accelerometry is commonly used both in scientific studies and in clinical settings. Basically, a wrist accelerometer records acceleration caused by hand movements. This information is automatically analyzed by established algorithms in order to classify each 30- or 60-second epoch of either sleep or wakefulness.

Validations against polysomnography have shown that wrist accelerometry is a reasonably valid and reliable tool for assessing sleep-wake patterns in healthy individuals.[5,6] Wrist accelerometry has also proved to be a useful method for estimating those aspects of sleep quality that can be derived from sleep-wake classification within the detected sleep period. Accelerometry appears to provide a valid estimate of total sleep time and total wake time during the sleep period, while its validity for estimating sleep onset latency remains suboptimal.[5] Sleep onset latency refers to the amount of time it takes to fall asleep. As a rule, accelerometry does not allow for the assessment of sleep architecture parameters, i.e. the percentages of time spent in different sleep stages.

2.1 Sleep need

The National Sleep Foundation has provided age-related sleep duration recommendations for healthy individuals with normal sleep patterns.[7] The recommended sleep duration for adults is between 7 and 9 hours a day. There are substantial differences in sleep need between individuals. Some individuals may sleep less or more than the recommended times with no adverse effects. Deviating far from the normal range, however, is rare and individuals who habitually sleep too little or too much may show signs or symptoms of health problems.

2.2 Sleep hygiene

Typical complaints related to sleep are difficulty falling asleep, staying asleep, and early morning awakenings. These difficulties can be caused by, for example, an inconsistent sleep-wake rhythm or scheduling high-intensity workouts too close to bedtime. For a healthy person, lifestyle and daily routines are key determinants of good sleep. Table 1 shows practical recommendations intended to promote healthy sleep. These recommendations are known as *"sleep hygiene"* and they represent scientific thinking about maintaining healthy sleep patterns.[8,9]

Table 1. Practical tips for improving sleep.[8,9]

Improve your sleeping environment
- Keep your bedroom dark, cool, and as quiet as possible
- Make sure that your mattress and pillows are comfortable
Stick to a consistent sleep schedule
- Go to bed and wake up at the same time, even during weekends
Limit naps
- Keep afternoon naps short and avoid napping after 5 p.m.
Establish evening routines
- Practice relaxing activities before bedtime
- Avoid stressful and stimulating activities before bedtime
Take notice of evening meals and fluid intake
- Avoid eating foods that cause indigestion
- Limit fluids before bedtime
Avoid stimulants
- Avoid caffeine for four to six hours before bedtime
- Avoid alcohol and nicotine for roughly two hours before bedtime
Exercise regularly
- Exercise regularly, but try to schedule high-intensity workouts earlier in the day

Not all sleep problems are temporary and treated with good sleep hygiene. Sometimes sleep difficulties may signify the presence of a sleep disorder such as sleep apnea, restless legs syndrome, narcolepsy, or some other clinical sleep problem. If adjusting daily routines does not improve sleep, it may be a good idea to consult a physician or a sleep specialist.

3 Polar Sleep Plus™

Sleep Plus™ is a feature that tells the user how much and how well (s)he has slept. It objectively measures the timing, duration and quality of sleep based on a wrist-acceleration measurement. The measurement is automatic and does not require any effort from the user. Sleep Plus also gives the user verbal feedback on the duration and quality of last night's sleep.

3.1 Benefits

Sleep Plus provides the following benefits:

- The user gets objective information on the timing, duration and quality of his/her sleep
- The user can record his/her own perception of how well (s)he slept
- The user can track his/her weekly sleep-wake rhythm
- Over time the user can learn how his/her lifestyle and daily routines affect sleep

3.2 Objective sleep parameters

Sleep Plus automatically detects when the user falls asleep and when (s)he wakes up. All the user needs to do is wear his/her device in the evening and overnight. Detection of sleep is based on recording a 3D-acceleration signal at a frequency of 50 Hz from the non-dominant wrist. The proprietary algorithm developed by Polar analyses characteristics of raw acceleration signals. The primary output of the scoring algorithm is the sleep-wake classification with a resolution of 30 seconds.

Sleep Plus gives a visual representation of the user's sleep and when interruptions to his/her sleep happened during the night. It also provides the user with a set of sleep parameters calculated from the sleep-wake information. They indicate how much time the user was asleep during the night, and how continuous his/her sleep was. The Sleep Plus parameters are listed in table 2.

As the Polar sleep algorithm automatically recognizes the time when the user falls asleep and wakes up, it may sometimes make a mistake. For instance, reading a book or watching TV close to bedtime can sometimes be mistaken as sleep. Therefore, the user is able to adjust the fell asleep and woke up time in Flow service. Consequently, all parameters characterizing sleep are recalculated.

Table 2. Polar Sleep Plus parameters

Parameter	Definition
Fell asleep time (hh:mm)	Time when the user has fallen asleep
Woke up time (hh:mm)	Time when the user has woken up
Sleep time (h min)	Time elapsed between Fell asleep time and Woke up time
Interruptions (h min)	Total time spent awake according to sleep-wake classification
Actual sleep (h min)	Total time spent in asleep according to sleep-wake classification
Actual sleep (%)	Actual sleep expressed as a percentage of Sleep time
Continuity (scale 1–5)	An estimate of sleep continuity based on the pattern of interruptions and sleep bouts during the night

3.3 Subjective sleep rating

In the morning, 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 find out the optimal amount and quality of sleep (s)he needs.

3.4 Feedback about last night's sleep

In the morning, the user gets a verbal feedback on the duration and quality of his/her last night's sleep. The feedback considers three parameters: sleep time, actual sleep percentage, and sleep continuity.

Sleep time tells the duration of the period between the when the user fell asleep and when (s)he woke up. The feedback compares sleep time to 'preferred sleep time' setting in order to evaluate how well the user has met the hours of sleep (s)he wants to get each night. As sleep need is individual, the user is recommended to set his/her preferred hours of sleep in Polar Flow service when taking Polar watch in use and adjust it when needed. The default value for the preferred sleep time setting depends on age, and it is 8 hours for adults according to the National Sleep Foundation's recommendations.[7] The feedback interprets that the user has met his/her preferred sleep time well enough when his/her sleep time is no more than 15 min shorter than that.

In addition to sleep time, the feedback considers two sleep quality parameters. One of the two parameters is the percentage of actual Sleep. It tells the time spent asleep between the time the user fell asleep and when (s)he woke up. In theory, the maximum value for actual sleep is 100%. In practice, however, there are numerous short and long interruptions during a normal night's sleep. Interruptions of 90 seconds or more are called long interruptions, and they can be usually recalled in the morning. Anything shorter than that are known as short interruptions, and the user does not usually remember these in the morning. As sleep efficiency is known to decrease with aging, Polar sleep feedback uses age-related cut-off values for interpretation of actual sleep.[10]

Another sleep quality parameter that is considered in the feedback is continuity. It is a unique parameter developed by Polar. Continuity ranges from 1 to 5, and it is displayed with an accuracy of one decimal. The user gets also a verbal interpretation with a five-step scale: fragmented – fairly fragmented – fairly continuous – continuous – very continuous. A high value of continuity relates to sleep with occasional interruptions and a large amount of sleep accumulating from long sleep bouts. In contrast, a low value of continuity relates to many interruptions and a large amount of sleep accumulating from short sleep bouts. Continuity parameter is based on the assumption that sleep must be uninterrupted for a certain period in order to be restorative and even a very brief interruption disturbs the restorative process.[11] Another assumption behind Polar sleep continuity parameter is that long interruptions impair sleep more than short interruptions.

3.5 Sleep-wake schedule

Polar Flow service keeps a record of sleep in a longer term. Keeping a regular sleep-wake schedule is one of the most important strategies for sleeping better. Weekly and monthly summaries in Flow service help the user evaluate how well (s)he has stuck to a regular schedule. The user also sees how sleep time, actual sleep percentage, and continuity compare to his/her own typical level. The typical level is a rolling average of one month.

4 Validity

Two independent studies have validated the Sleep Plus algorithm against polysomnography in children, adolescents[12], and adults[13].

In a study by Pesonen and Kuula[12], 17 children (age 11.0 ± 0.8 years) and 17 adolescents (17.8 ± 1.8 years) wore a Polar wrist device and a polysomnography device in their own home for one night. The mean difference between the polysomnography and Sleep Plus for fell asleep time was 5 min in the children and 13 min in the adolescents. Mean difference for woke up time was 0 min in the children and -1 min in the adolescents. None of the differences was statistically significant. A 30-s epoch to epoch comparison against the polysomnography showed excellent sensitivity, adequate specificity, and excellent accuracy for Sleep Plus. There were notable differences in sensitivity, specificity, and accuracy between individuals. The authors concluded that Polar algorithm measures sleep at a level generally accepted in research and clinical context.

In a study by Parent and colleagues[13], 19 women and 16 men (age 27±4 years; VO_2max 47±9 ml/kg/min) underwent in-home sleep assessments for three separate nights. The first night served as screening for sleep apnea. The second and third nights were randomized to take place after a day with an interval run (6 × 3 min at $VO_2 \geq 80\%$ second ventilatory threshold) within 6 hours prior to bedtime or a rest day. After both days, a comparison of Sleep Plus to the polysomnography showed excellent sensitivity, adequate specificity, and excellent accuracy. The authors stated that Polar algorithm recognized sleep and wake accurately in healthy adults and could be used to follow sleep time in health programs.

The results of the above validation studies are in line with sensitivity, specificity, and accuracy percentages we calculated from a dataset used for algorithm development.[14] The dataset comprised 56 measurements from 31 healthy volunteers (11 men: age 35.7 ± 4.7 years; BMI 24.8 ± 2.3 kg/m^2 and 20 women: age 33.1 ± 7.7 years; BMI 24.4 ± 4.7 kg/m^2).

Sleep Plus data from Polar Flow have been used to exprole sleeping habits in couple large global samples. One study utilized a dataset with 17,355 Polar users with 242,989 nights to explore wordwide trends in sleep duration and timing in the transition to adulthood.[15] Another study focused on predicting the sleep efficiency based on exercise information using large data sets collected from Polar users.[16] In addition, a sample of 121,223 Polar users has been used to demonstrate sex differences in sleep schedules over the globe.[17]

5 Limitation

The main challenge of Polar Sleep Plus algorithm, as any acceleration-based method, is to identify quiet wakefulness from sleep because identification of wake and sleep is based entirely on movement. The Sleep Plus feature does not include sleep stages, whereas some consumer devices relying on movement do show sleep stages. However, accelerometry as a measurement method has not been validated for measuring sleep stages and sleep experts are not convinced that the wrist movements could indicate whether one is in deep sleep or lighter stages of sleep.[5] In 2019, Polar lauched the Sleep Plus Stages feature that includes also sleep stages. Sleep Plus Stages combines information on acceleration and the heart's beat-to-beat intervals, both measured from a wrist.

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