White Paper

Comparison of the Circadia Contactless Sleep Monitor Against Gold Standard Polysomnography

CIRCADIA

Contents

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Performance of the Circadia Contactless Sleep Monitor Against Gold Standard Polysomnography Sleep Monitoring

Summary

The Circadia Contactless Sleep Monitor provides a sleep tracking system at 1/10th the cost of the current gold standard sleep monitoring technique of polysomnography (PSG), where patients are connected to numerous sensors and wires overnight. The Circadia monitor is able to contactlessly collect body vitals throughout the night, thus eliminating the patient discomfort caused by PSG.

This white paper validates the accuracy of the Circadia Contactless Sleep Monitor, by comparing its automated sleep stage predictions to those recorded by PSG. The Circadia Monitor was found to have a mean prediction accuracy of 78% across 11 participants. The highest prediction accuracy achieved for a single participant was 85%, and the monitor was found to have a 94% accuracy in detecting deep sleep. Thus, we demonstrate the suitability of the Circadia Contactless Sleep Monitor as an unobtrusive and affordable sleep tracking system.

Figure 1. The Circadia Contactless Sleep Monitor

Introduction

Sleep is vital for optimal mental and physical health. We spend almost a third of our life asleep, and a lack of it can have severe consequences. Sleep deprivation has been shown to directly increase the risk of various health problems, such as heart disease, diabetes, cancer and stroke. There are also dire short term consequences of sleep deprivation, including reduced productivity and alertness, and a significantly increased risk of accidents[1,3,4].

Therefore, the rising the number of sleep disorders, including insomnia, narcolepsy and obstructive sleep apnea (OSA), is concerning in terms of the overall health of the population and the impact on the economy due to expensive treatments and reduced productivity.

Sleep is generally categorised into different sleep stages, known as: Wake, Light Sleep, Deep Sleep and Rapid Eye Movement (REM), which progress cyclically throughout the night in periods of approximately 90 minutes. Figure 2 shows the proportion of the night that a healthy individual spends in each of these sleep stages. Abnormalities in the sequence and duration of these stages can be indicators of poor sleep health, therefore analysis of a patient's sleep stages throughout the night is often used to diagnose sleep disorders[2].

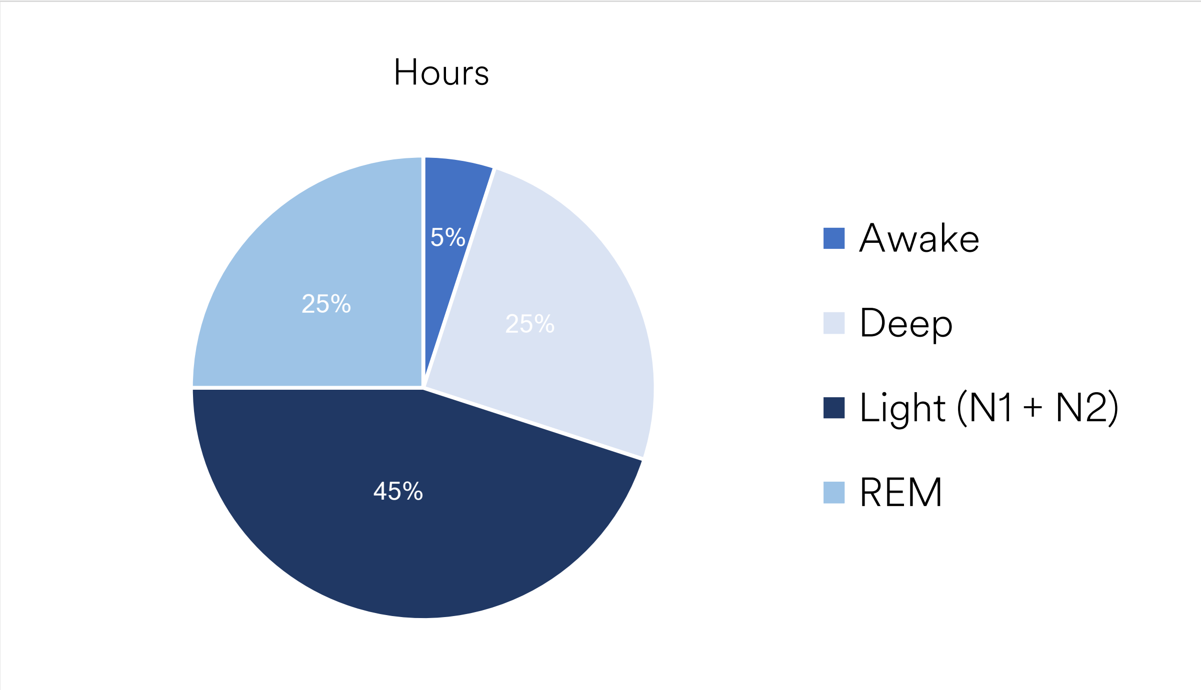

Figure 2. Pie chart showing the average percentage of the night spent in each sleep stage (Awake, Light, Deep, REM) by a typical healthy adult[2].

Current Sleep Monitoring Methods

Currently, the gold standard method of monitoring sleep stages is polysomnography (PSG). This involves connecting a patient to sensors overnight, which analyse various bodily functions, including brain activity, eye movement, heart rhythm and breathing rate. Once the data is collected, it is visually inspected by a sleep technician and each 30-second interval of sleep is categorised into one of 4 possible sleep stages. A visual representation of the sequence of these sleep stages across time, called a hypnogram, is often produced.

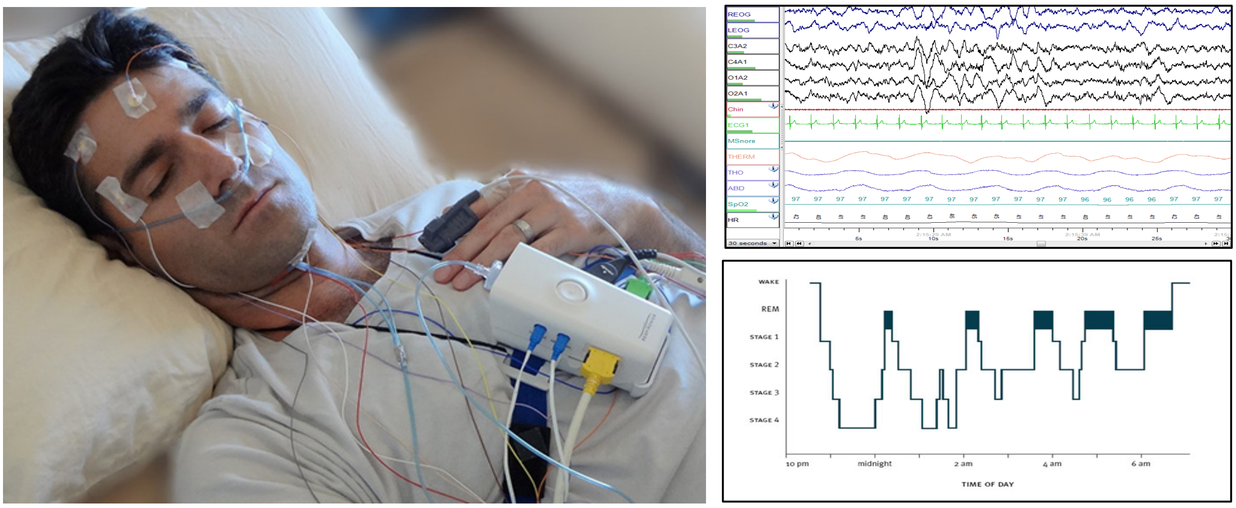

Figure 3. Left: Typical set up of overnight polysomnography (PSG). Sensors include EEG (brain), ECG (heart), EMG (muscle activity), EOG (eye movement) **Top right:** Output data of PSG sensors, which is visually scored into sleep stages by a sleep technician. **Bottom right:** Typical hypnogram showing sequence and duration of sleep stages throughout the night.

Although PSG provides an accurate measurement of sleep behaviour, it is an incredibly time consuming and expensive process. One night of PSG testing costs up to $2,000, and the visual scoring of the output data by a sleep technician takes on average 2-3 hours. Furthermore, the manual scoring of sleep stages introduces human error and subjectivity.

Furthermore, PSG studies are often conducted in a sleep lab, which further increases cost and removes patients from their usual sleeping environment, thus disrupting their quality of sleep.

Although, PSG testing can be conducted at participants' homes, sleep quality is still disrupted by the highly invasive nature of the PSG set up, which includes hooking patients up to various wires and sensors, see Figure 3. This interferes with the clinical understanding of a patients' sleep health, which is used to inform their diagnosis and treatment.

Actigraphy is an alternative sleep monitoring tool, which collects movement data through a wrist-worn device to assess sleep behaviour. Although it is less cumbersome than PSG, it is costly ($800 per device), and lacks the accuracy of PSG as it cannot distinguish between different sleep stages. Questionnaires are also used to aid a clinician's understanding of patients' sleep behaviour, however these are highly subjective and cannot be used to accurately collect sleep quality metrics.

There is, therefore, a great need for a sleep monitoring solution which can match the accuracy of PSG, but at a lower cost and with increased patient comfort.

The Circadia Solution

The Circadia Contactless Sleep Monitor offers a completely non-invasive sleep monitoring system for use in the home environment, at 1/10th the cost of PSG testing. The device is small and portable and can be mounted above a bed or placed on a nightstand, as shown below, therefore there is minimal disturbance to the patient and they can be comfortably monitored in their own bedroom. Furthermore, the affordability of the Circadia Contactless Sleep Monitor means it is more feasible for patients to be monitored for multiple nights of sleep, and thus a more accurate understanding of their sleep behaviour can be gained.

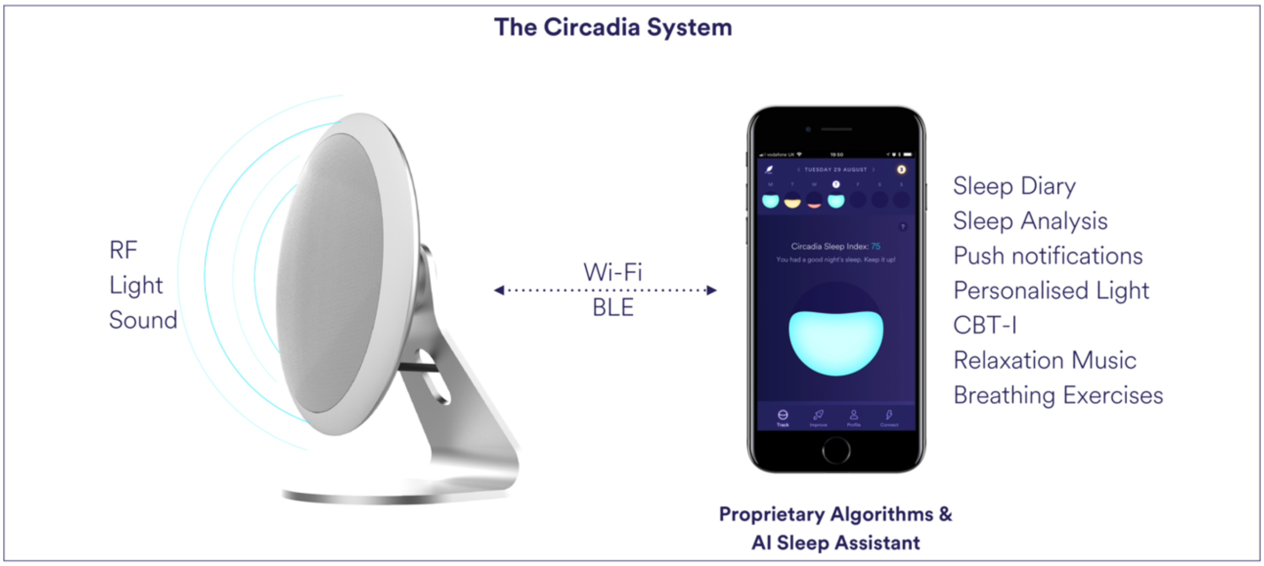

Figure 3. The Circadia Contactless Sleep Monitor and Mobile App

The Circadia Contactless Sleep Monitor contactlessly collects respiration and body movement data throughout the night, from up to 8 feet away. This data is fed into machine learning algorithms which provide automated predictions of sleep stages, from which a hypnogram can be produced. Thus providing the same outputs as PSG, but without the cost, human error and subjectivity associated with manual sleep scoring.

Testing the Circadia Contactless Sleep Monitor Against Polysomnography (PSG)

The accuracy of the Circadia Contactless Sleep Monitor and sleep stage estimation algorithm were validated through comparison against the gold standard polysomnography (PSG). 11 healthy adult participants were recruited, and the Circadia Contactless Sleep Monitor and PSG were used in parallel to record their sleep overnight, in a home setting, for between 8-11 hours. The Circadia Contactless Sleep Monitor was placed 1m above the subject, with a 60 degree field of view. The PSG machine contained channels for EEG (brain activity), EOG (eye movement) and ECG (heart rhythm), amongst others.

Figure 5. Set up of participants during the study. Polysomnography equipment is strapped to the participant. The Circadia Contactless Sleep Monitor (bottom left) is collecting data wirelessly from the nightstand.

Each 30-second epoch of PSG data was scored into sleep stages by a qualified sleep technician. To train the Circadia Contactless Sleep Monitor sleep staging algorithm, the PSG derived sleep stages and Circadia Monitor data were fed into a machine learning algorithm. Using leave-one-subject-out cross-validation, data from the Circadia Contactless Sleep Monitor was used to predict sleep stages for each 30-second epoch of sleep, for all participants. The resulting sleep stage datasets were then compared epoch-by-epoch to determine the level of concordance between PSG and the Circadia Sleep Monitor.

Results

A high level of similarity was found between the sleep stages estimated by the Circadia Contactless Sleep Monitor and by PSG. The Circadia Contactless Sleep Monitor was found to have a mean prediction accuracy of 78% across all 11 participants, and the highest accuracy achieved in a single participant was 85%. Table 1, below, shows the prediction accuracy achieved by the Circadia Contactless Sleep Monitor for each participant. It is evident that the Circadia Monitor provided consistently accurate sleep stage predictions, when compared to PSG.

Table 1. Accuracy of sleep stage by the Circadia Contactless Sleep Monitor, per participant.

Participant	Prediction Accuracy
0	76.3%
1	70.3%
2	74.8%
3	74.0%
4	76.1%
5	78.1%
6	77.6%
7	70.7%
8	79.3%
9	84.5%
10	84.7%

A high level of accuracy was also found when looking at individual sleep stages. Figure 6 shows the fraction of the night spent in each of the four sleep stages (wake, light sleep, deep sleep, REM) as measured by PSG (right) compared to the prediction made by the Circadia Contactless Sleep Monitor (left). The figure shows great similarity between the sleep stage estimations from the two different methods, validating the accuracy of the Circadia Contactless Sleep Monitor and sleep stage estimation algorithm.

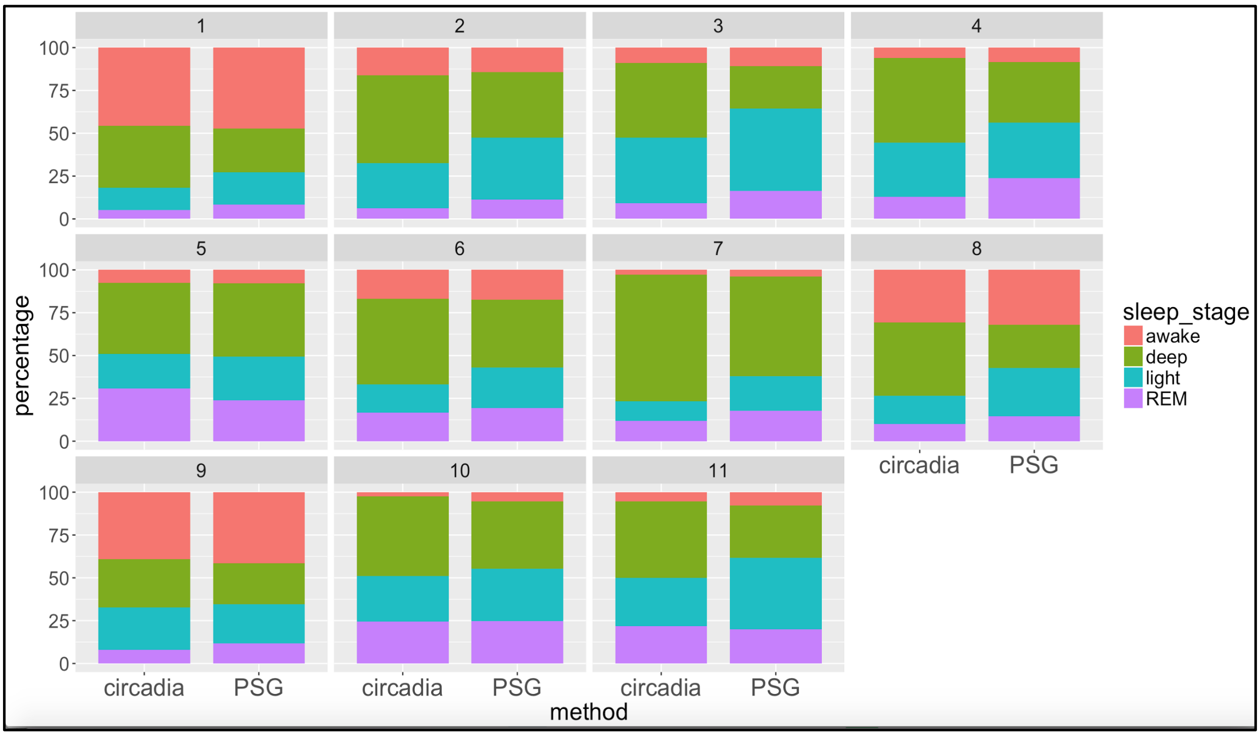

Figure 6. Proportion of the night spent in each of the four sleep stages (wake, light sleep, deep sleep, REM) as measured by PSG (right) compared to the prediction made by the Circadia Sleep Monitor (left). Data is shown per participant.

As shown above, the Circadia Contactless Sleep Monitor was able to predict the proportion of the night that participants spent in each sleep stage very accurately. The hypnograms below (Figure 7) show that the Circadia Contactless Sleep Monitor was also able to predict the sequence and duration of these stages with great similarity to PSG. A hypnogram is a graphical representation of an individual's progress through sleep stages over time. Figure 7 shows two representative hypnograms from participants 9 and 10 over the course of the night. Other hypnograms of the remaining nine participants were left out for brevity. The orange hypnograms were created from PSG data, and the blue hypnograms are based upon predictions from the Circadia Contactless Sleep Monitor. The great similarity between the orange and blue hypnograms, in terms of timing and length of sleep stages, once again highlights the accuracy of the Circadia Contactless Sleep Monitor as a sleep monitoring tool.

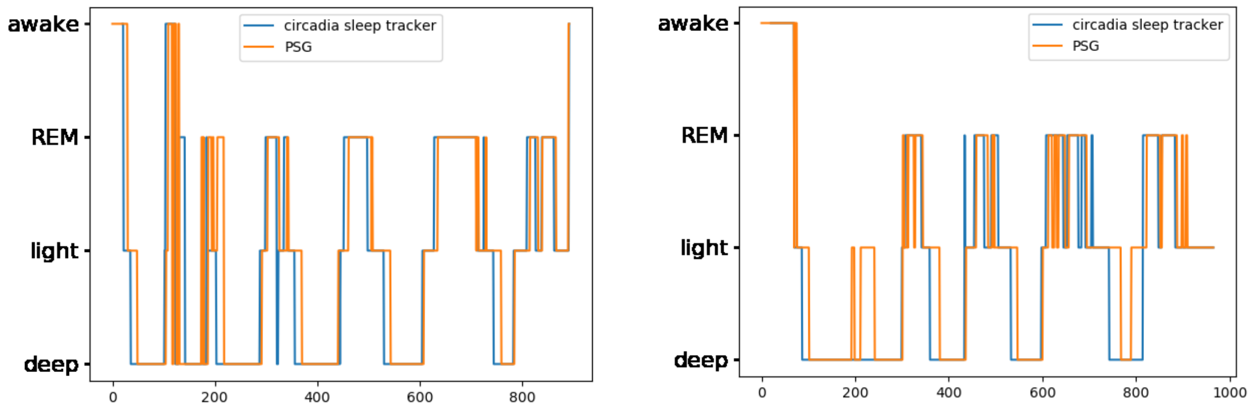

Figure 7. Hypnograms for two representative individuals (**left:** participant 9, **right:** participant 10). Comparison of PSG data (orange) and Circadia Contactless Sleep Monitor prediction (blue).

Although a mean prediction accuracy of 78% was obtained across all participants, the accuracy of predictions made by the Circadia Sleep Monitor varied between sleep stages. The accuracies with which the Circadia Contactless Sleep Monitor could detect each sleep stage is shown in Table 2. As shows, deep sleep and wake were found to be the stages which the Circadia Contactless Sleep Monitor could most accurately detect, and both had mean prediction accuracies of approximately 94%.

Table 2. Circadia Contactless Sleep Monitor sleep staging prediction accuracy, for each of the four sleep stages.

Sleep Stage	Prediction Accuracy
Wake	94.1%
Light	58.8%
Deep	93.6%
REM	61.1%

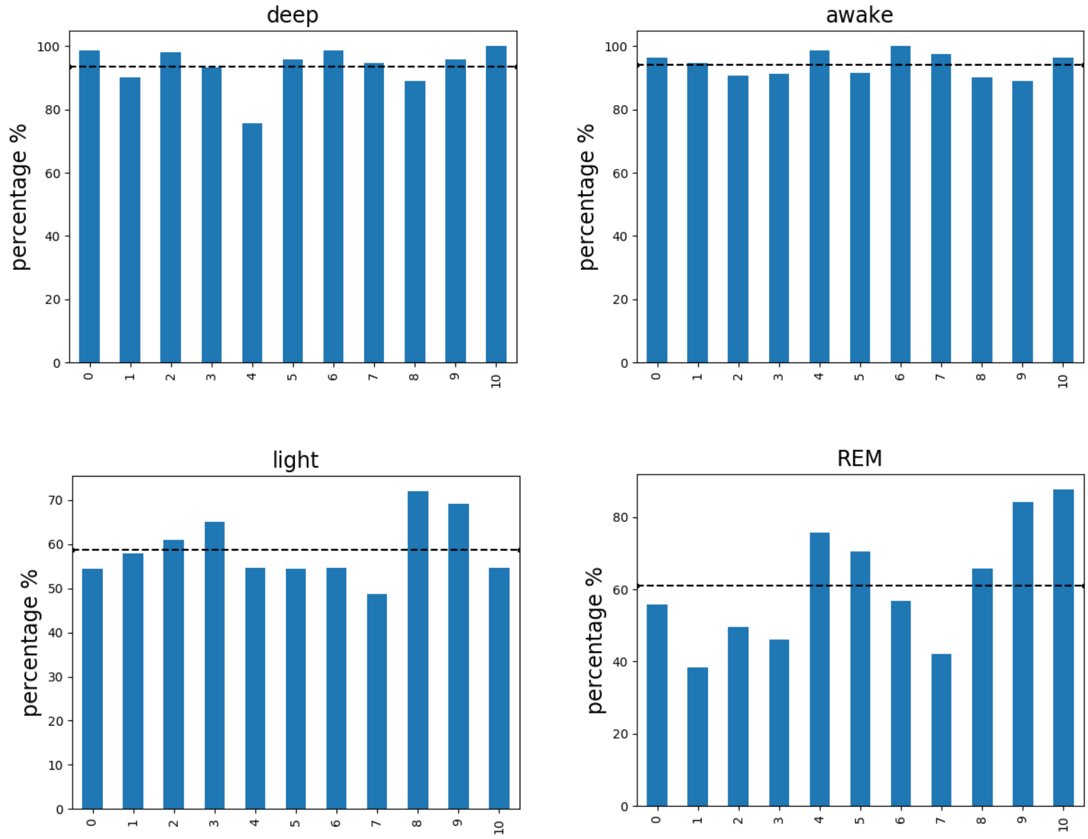

Figure 8. Circadia Contactless Sleep Monitor sleep staging prediction accuracy for each of the four sleep stages, shown per participant. Dotted lines represent mean prediction accuracy for each stage.

This variation in sleep stage detection accuracy can also be seen in Figure 8, which shows the accuracy with which each of four sleep stages was detected in individual participants. This figure not only shows once again that deep sleep and wake were the most accurately predicted stages, but also that the REM prediction accuracy, in particular, varied strongly between individuals. However, taking into account the small number of participants in this study (n=11), we expect REM prediction accuracy to improve significantly once a larger dataset is collected.

Conclusion

Overall, we were able to show that the Circadia Contactless Sleep Monitor is highly accurate at predicting sleep stages, compared to the gold standard polysomnography (PSG). This accuracy is evident in terms of estimating the proportion of night spent in each stage, and the length and timing of each stage. This accuracy, combined with the affordability and patient-comfort of the Circadia Contactless Sleep Monitor, demonstrates its ability as a reliable and convenient sleep monitoring system.

Future Development

This paper demonstrates the ability of the Circadia Contactless Sleep Monitor to predict sleep stages, using respiration and body movement data, with an average accuracy of 78%. Leave-one-participant-out cross-validation was used to train the machine learning algorithm on a group of datasets collected under similar conditions. The current study determined the accuracy of the Circadia Contactless Sleep Monitor based on output sleep stage predictions. For further validation we plan to compare raw data from individual channels, such as respiration rate, between PSG and the Circadia Contactless Sleep Monitor.

Further work is being performed to indicate how generalizable the algorithm is to a larger population, and, with the collection of data from a larger sample, we expect generalizability and accuracy to increase. Accuracy is set to increase even further with the addition of heart rate monitoring and the implementation of that data into the sleep staging algorithm.

Furthermore, our technology has the ability to distinguish data collected from two individuals in close vicinity to each other, thus introducing the potential for the Circadia Contactless Sleep Monitor to simultaneously track the sleep of two people in the same room.

References

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