Received: 19 November 2020 | Revised: 24 December 2020 | Accepted: 28 December 2020

DOI: 10.1111/apa.15740

ACTA PÆDIATRICA
NURTURING THE CHILD
WILEY

BRIEF REPORT

Video-based actigraphy is an effective contact-free method of assessing sleep in preterm infants

Xi Long[1,2] | **Javier Espina**[2] | **Renée A. Otte**[2] | **Wenjin Wang**[1,2] | **Ronald M. Aarts**[1] | **Peter Andriessen**[3,4]

[1]Department of Electrical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands

[2]Philips Research, Eindhoven, The Netherlands

[3]Department of Neonatology, Máxima Medical Center, Veldhoven, The Netherlands

[4]Department of Applied Physics, Eindhoven University of Technology, Eindhoven, The Netherlands

Correspondence: Xi Long, Department of Electrical Engineering, Eindhoven University of Technology, P.O. Box 513, 5600 MB, Eindhoven, The Netherlands.
Emails: x.long@tue.nl; xi.long@philips.com

Sleep is essential for brain development, but being in a neonatal intensive care unit exposes preterm infants to multiple stimuli and care activities that disrupt their sleep. Monitoring can increase infants' sleep duration and quality by modifying nursing and caretaking behaviours.[1] Actigraphy has been validated as a non-invasive and cost-efficient method that can measure activity levels and assess paediatric sleep over long periods.[2] However, attaching relatively large sensors to a preterm infant's fragile skin may cause discomfort and disrupt their sleep. Contact-free video-based actigraphy quantifies body movement during long-term sleep assessments and does not require a sensor. It has successfully monitored sleep-wake patterns in adults,[3] but has not been tested on preterm infants. We evaluated its feasibility and performance in identifying sleep-wake states in preterm infants in a neonatal intensive care unit.

This observational pilot study focused on five preterm infants during routine care in the neonatal intensive care unit of the Máxima Medical Center, Veldhoven, The Netherlands. The ethical committee approved the study protocol, and written, informed parental consent was provided. A uEye Monochrome video camera (IDS GmbH), placed inside the infant's incubator (Figure S1), produced 736 × 480 pixel images eight times a second. According to Prechtl's rules,[4] behavioural sleep and wake states, including caretaking, were manually scored for each 30-s epoch by a paediatric sleep expert, who reviewed the videos and the synchronised chest-impedance respiratory signals when necessary. A spatiotemporal recursive search algorithm[3] detected motion, unaffected by illumination changes, from the video frames. Video-based actigraphy was computed in a similar way to actigraphy, by counting the non-zero motion values for each epoch. The activity count was then statistically compared between the sleep and wake epochs. A linear discriminant model that has successfully been used in sleep classification[5] was used for automatic sleep-wake detection, based on the video-derived activity count. It was implemented using MATLAB (MathWorks).

During each cross-validation round, data from four infants were used to train the model and the data from the remaining infant were used to test the model. A number of metrics were used to evaluate detection performance, by comparing the results with human annotations. Sensitivity and specificity were the proportion of correctly detected wake and sleep epochs, respectively. Precision was the proportion of detected wake epochs that were true awake states. We also measured overall accuracy and Cohen's kappa coefficient, which compensated for chance agreements. These metrics were calculated for each infant and group means were produced.

The preterm infants had a mean ± SD gestational age and postmenstrual age of 30.1 ± 2.9 and 31.7 ± 2.9 weeks, respectively (Table 1). The mean length of the videos was 5.6 ± 0.7 h per infant and they were awake for 9.9% ± 5.8% of the time. Significantly lower activity counts were observed when they were asleep (15.3 ± 32.6) than awake (112.4 ± 90.3). An overall accuracy of 91.9% ± 5.1% and a Cohen's kappa coefficient of 0.51 ± 0.15 were calculated with a high specificity (96.6% ± 2.7%) and relatively low sensitivity (52.5% ± 20.4%) and precision (62.1% ± 16.7%). The detection of sleep and awake performances showed noticeable, relatively large variations across the infants. Cohen's kappa ranged from 0.33 to 0.73, overall accuracy from 85.6% to 96.5%, sensitivity from 41.3% to 88.6% and precision from 41.9% to 78.3%. Detection was better

TABLE 1 Characteristics of the five preterm infants and sleep-wake detection results

	Preterm infant					
	1	2	3	4	5	Mean ± SD
GA, week	30.4	33.9	27.4	31.7	27.0	30.1 ± 2.9
PMA, week	31.3	34.4	29.0	34.9	29.1	31.7 ± 2.9
Epoch, number	686	605	606	633	799	665.8 ± 81.4
Wake percentage[a], %	18.7	12.4	5.8	4.6	7.9	9.9 ± 5.8
Activity count[b]						
Sleep	11.9 ± 36.0	26.1 ± 43.9	16.5 ± 34.1	19.8 ± 25.7	5.6 ± 18.1	15.3 ± 32.6
Wake[*]	103.8 ± 88.3	91.0 ± 78.3	199.2 ± 58.3	112.0 ± 88.6	107.2 ± 98.0	112.4 ± 90.3
Sensitivity, %	42.2	41.3	88.6	41.4	49.2	52.5 ± 20.4
Specificity, %	97.3	91.9	97.0	97.9	98.8	96.6 ± 2.7
Precision, %	78.3	41.9	64.6	48.0	77.5	62.1 ± 16.7
Accuracy, %	87.0	85.6	96.5	95.3	94.9	91.9 ± 5.1
Cohen's kappa	0.48	0.33	0.73	0.42	0.58	0.51 ± 0.15

Abbreviations: GA, gestational age; PMA, postmenstrual age; SD, standard deviation.

[a]Including caretaking.

[b]Activity count by video-based actigraphy, where the mean ± standard deviation was computed for each infant.

*$p < 0.0001$ (Mann–Whitney *U* test) between sleep and wake epochs for all patients.

for younger preterm infants, with a postmenstrual age of less than 30 weeks.

Video-based actigraphy has been reported to be an effective measure of activity levels and sleep and wake patterns, similar to actigraphy using an Actiwatch (Philips Respironics).[2] It has the added advantage of contact-free monitoring. However, both methods failed to identify being asleep with increased activity or being awake with reduced activity.[2] These states are often more common in older preterm infants, as seen in patient two (Table 1). This would lead to relatively large differences between older and younger infants, as we observed. That is why age-appropriate personalised approaches should be used to improve the detection of sleep-wake states.

Our preliminary study used limited data from only five infants, with a few hours per infant. A larger dataset with a wider age range and longer recording time and polysomnography-based scoring are necessary to verify the proposed automatic sleep-wake detection model. The motion detection also picks up other activity outside the incubator, such as nursing staff, and this can result in sleep being misclassified as wakefulness. Therefore, methods that exclusively detect infant movements need to be investigated. We used a monochrome camera that required sufficient illumination. An infrared camera should be used to monitor infants in the dark, for example in a covered incubator.

For assessing sleep in preterm infants, using a video camera has the potential to recognise the movement of specific body parts and monitor vital signs, such as the respiratory rate and heart rate, and therefore provides a fully fledged sleep-wake detection system.

ACKNOWLEDGEMENTS

The authors would like to thank the anonymous reviewers and a text editor Annette Whibley for their help in improving the manuscript.

CONFLICT OF INTEREST

At the time of writing, XL, JE, RAO and WW were employed by Royal Philips, a commercial health technology company. The company had no influence on the study and on the decision to publish. The other authors have no conflicts of interest to declare.

ORCID

Xi Long https://orcid.org/0000-0001-9505-1270

REFERENCES

1. Park J. Sleep promotion for preterm infants in the NICU. Nurs Womens Health. 2020;24:24-35.
2. Sung M, Adamson TM, Horne RS. Validation of actigraphy for determining sleep and wake in preterm infants. Acta Paediatr. 2009;98:52-57.
3. Heinrich A, Aubert X, de Haan G. Body movement analysis during sleep based on video motion estimation. Conference Proceedings of the 15th International Conference on e-Health Networking, Applications and Services. Lisbon, Portugal; 2014:539-543
4. Prechtl HF. The behavioural states of the newborn infant (a review). Brain Res. 1974;76:185-212.
5. Fonseca P, Long X, Radha M, et al. Sleep stage classification with ECG and respiratory effort. Physiol Meas. 2015;36:2027.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Long X, Espina J, Otte RA, Wang W, Aarts RM, Andriessen P. Video-based actigraphy is an effective contact-free method of assessing sleep in preterm infants. *Acta Paediatr*. 2021;00:1–2. https://doi.org/10.1111/apa.15740