Can Sleep and Wakefulness Be Distinguished in Children by Cardiorespiratory and Videotape Recordings?*

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Polysomnography, including EEG recording, is the standard method to diagnose obstructive sleep apnea (OSA) in children and adults. Diagnosis of OSA would be considerably simplified if it was shown that sleep could be distinguished from wakefulness without EEG recordings. Therefore, we compared sleep/wakefulness classification using a simplified cardiorespiratory-video (CRV) method with standard polysomnography in 20 children undergoing in-hospital evaluation for OSA. The channels for the simplified montage were chosen because they (1) were suitable for unattended, home recordings, (2) allowed the diagnosis of apneas, hypopneas, desaturation, and movement/arousals, and (3) did not require attachment to the head or face that might disturb the child's sleep. Sleep staging by the two methods was blinded to results of the other method. We evaluated 21,832 30-s epochs—1,092 ± 111 (SD) per child. Across 20 subjects, 79.7 ± 7.1% of the epochs were sleep. The simplified montage agreed with polysomnographic classification of sleep/wakefulness for 93.8 ± 2.5% of the epochs. Of all sleep epochs, 97.7 (96.4, 98.1%) median (interquartile range), were correctly classified; sleep predictive value of the CRV method was 95.2 ± 2.8%. Of all epochs classified as wakefulness by polysomnography, 80.1 ± 12.8% were correctly classified by the CRV method. The wakeful predictive value was 88.7 ± 2.6%. Kappa values averaged 0.8 ± 0.1, indicating that agreement between the CRV method and polysomnography did not occur by chance and that the level of agreement was excellent. Thus, sleep can be distinguished from wakefulness in children being evaluated for OSA using a combination of cardiorespiratory and videotape recordings. These results suggest that the CRV method would be useful in a pediatric laboratory setting where EEG recordings are not always possible. They also suggest that overnight, unattended CRV recordings in a child's own home could correctly distinguish sleep from wakefulness.

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Key words: children; OSA; polysomnography; sleep/wakefulness classification

The standard method for documenting obstructive sleep apnea (OSA) in children is overnight polysomnography with a technician attending. For the assessment of pediatric OSA, the essential diagnostic elements that should be quantitated include the following: obstructive, mixed, and central apnea; partial airway obstruction; hemoglobin desaturation; sleep vs wakefulness; and sleep disturbance. Nocturnal polysomnography quantitates these elements but involves extensive instrumentation in a laboratory environment. The complex recordings have important disadvantages when applied to young children: (1) the electrodes required for sleep staging can disturb sleep; (2) some children will not tolerate electrodes applied to the head and face; (3) the unfamiliar setting of the sleep laboratory may disturb sleep; and (4) complex recordings require the presence of an experienced technician.1,2

A first step toward validating a less complex test for OSA is to demonstrate that such a test can distinguish sleep from wakefulness. Previously, several techniques have been developed to distinguish sleep (S) from wakefulness (W) without EEG recordings: cardiorespiratory variability,3-7 computerized movement detectors (actigraphy),8-13 and videotape recordings.14,15 However, these methods do not incorporate all the needs of a pediatric laboratory for the assessment of OSA. Some are not portable, while others provide no information on breathing8-13 or have been validated only in normal infants.14

Therefore, a cardiorespiratory-videotape (CRV) re-
recording method that would accurately distinguish S from W and would fulfill the essential diagnostic elements for pediatric OSA was evaluated. In the present study, the accuracy of this simplified CRV method for S/W classification was compared with full polysomnography in 20 children being evaluated for OSA in our sleep laboratory.

**Materials and Methods**

*Subjects*

The study population consisted of 20 pediatric patients referred to the Montreal Children’s Hospital Sleep Laboratory to rule out OSA due to adenotonsillar hypertrophy. The first 12 children were consecutive patients who came to the laboratory for testing. The last eight children were selected because they had an apnea/hypopnea index greater than or equal to 5. None of the children had neuromuscular or craniofacial disorders that predispose to OSA. The mean (±SD) age was 5.6±3.1 years with a range of 2 to 12.5 years (Table 1). There were 15 boys and 7 girls. Eighteen of the children were white and 2 were black. Eighteen subjects were within normal limits in the weight for height curve, whereas one subject was below the fifth percentile and one subject was above the 95th percentile. Four children had an apnea/hypopnea index less than 1, the upper limit of normal in children (Table 1). In children, an apnea/hypopnea index less than 1 is considered normal. Two children had mild OSA and were not given specific treatment. Fourteen children with apnea/hypopnea indexes greater than 3 had adenotonsillectomy. All data were collected as part of clinical evaluations; therefore, no ethics committee or parental consent for research was required.

**Polysomnography**

In-hospital, overnight, 15-channel recordings were obtained in each subject. Four channels were dedicated to sleep staging (EEG, right and left electro-oculogram, and submental electromyogram). The remaining channels were EEG, heart rate, arterial oxygen saturation, pulse waveform, transcutaneous oxygen, transcutaneous carbon dioxide, end-tidal carbon dioxide, and arm electromyogram. The sum, thorax, and abdominal signals were obtained from a respiratory inductive plethysmograph (RIP) (Respironograph; Non-Invasive Monitoring System Inc; Miami). All signals were recorded on a computerized polysomnograph (Ultrasom; Nicolet; Madison, Wis). Use of computerized polysomnography allowed a technician to view either the full 15-channel recording or a cardiorespiratory montage consisting of the seven channels underlined above. The seven channels for the cardiorespiratory montage were chosen because they were (1) suitable for unattended, home recordings; (2) allowed the diagnosis of apnea, hypopnea, and movement/arousals; and (3) did not require attachments to the head or face that might disturb the child’s sleep.

Apneas and hypopneas were identified using the RIP sum amplitude, a signal available on both the full polysomnographic and CRV montages. A qualitative diagnostic calibration was used to calibrate the sum signal. Apneas and hypopneas were classified as central, mixed, or obstructive based on the presence or absence of chest and abdominal RIP excursions. Apneas were identified as a decrease to less than 20% of the RIP sum. Hypopneas were counted only if the RIP sum signal decreased by at least 50% and if the event was accompanied by hemoglobin desaturation. The use of RIP has been found to be an accurate means of detecting apnea and hypopnea in adults and children. The correlation coefficients for the comparison of these two methods was 0.97. Hemoglobin desaturations were defined as decreases of greater than or equal to 4% of baseline arterial oxygen saturation. Central apneas were counted if duration exceeded 20 s or if a shorter apnea was associated with hemoglobin desaturation.

Movement/arousals were defined according to the standard adult criteria with two modifications. First, movement/arousals of greater than 1 s were included. Second, changes in any two recorded signals were counted as a movement/arousal. Mograss et al assessed the accuracy of tabulating movement/arousals using only the cardiorespiratory montage vs standard polysomnography. Of all movement/arousals tabulated by polysomnography, 92.9±7.6 (SD) were detected by the cardiorespiratory montage alone.

Apnea/hypopnea, desaturation, and movement/arousal indexes were calculated as the number of events per hour.

**Audiovisual Recordings**

The sound and appearance of each subject was recorded using a videorecorder (S-VHS; Panasonic AG 1970) with a time-date generator (Panasonic IWJ 810) synchronized to the nearest second with the computerized polysomnograph. Two low-light, ceiling-mounted security cameras (Panasonic WVBC 604) provided the video signals. As the cameras were sensitive to infrared light, it was possible to record in complete darkness using an infrared lighting system (Safelight Filter; Kodak; Rochester, NY). Audio signals were obtained from a unidirectional microphone (Beyerdynamic MCE86N) positioned approximately 2 feet above the subject’s head.

**Protocol**

To determine the accuracy of a seven-channel CRV method for classifying S/W, each record was scored three times, once using standard polysomnography by one technician and twice using the CRV method by two other polysomnographic technicians. The latter two scorers had rather different levels of experience. One scorer was a registered polysomnography technician with 4 years of experience in pediatric polysomnography; the other was a respiratory therapist with 6 months of experience in pediatric polysomnography. To maintain blinding of the CRV scorer, each scoring started at the beginning of the recording and continued until the end of the recording. Only those epochs with EEG recordings available to stage sleep were included in the comparison.

One technician scored sleep stages, and therefore S/W, according to standard criteria using the 15-channel montage (polysomnographic method). A 30-s epoch was staged as W if it contained greater than 15 s of alpha activity. Movement time was scored if more than half of the epoch was obscured by movement artifacts. Each epoch scored as W or movement time was classified as W (Fig 1). Each 30-s epoch scored as rapid eye movement (REM) or non-REM sleep was classified as S.

The other two technicians classified S and W by observation of the seven-channel cardiorespiratory channels plus videotape (CRV

**Table 1—Ages and Polysomnography Results for 20 Children Evaluated for OSA**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age, yr</strong></td>
<td>5.6</td>
<td>3.1</td>
<td>2-12.5</td>
</tr>
<tr>
<td><strong>Apnea/hypopnea index</strong></td>
<td>8.1</td>
<td>8.2</td>
<td>0-31</td>
</tr>
<tr>
<td><strong>Desaturation index</strong>*</td>
<td>0.7</td>
<td>(0.7,3)</td>
<td>0-15</td>
</tr>
<tr>
<td><strong>Movement/arousal index</strong></td>
<td>17.6</td>
<td>7.8</td>
<td>6.9-31.7</td>
</tr>
<tr>
<td><strong>Mean CO2</strong>*</td>
<td>45</td>
<td>(45.48)</td>
<td>42-51</td>
</tr>
</tbody>
</table>

*The data for these variables were not normally distributed and are therefore presented as the median and IQR.*

CHEST / 109 / 3 / MARCH, 1996 681

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method). Each subject's videotape was reviewed in fast forward mode (six times real time) and all occurrences of behavioral W were tabulated. Subsequently, the seven-channel cardiorespiratory recording was analyzed for S vs W on an epoch-by-epoch basis. An epoch was classified as wakeful if a behavior characteristic of W was observed on the videotape (eg, crying, vocalization, eyes open, purposeful movements), and/or if greater than 15 s of movement artifact were observed on at least two cardiorespiratory channels (Figs 2 and 3). As previously defined, evidence of movement artifact included irregularity and/or increased amplitude of the RIP and pulse waveform signals, electromyographic artifact on the ECG signal, and tachycardia.22

Data Analysis

For the evaluation of S/W classification, the 15-channel montage was regarded as the gold standard and the seven-channel CRV re-

![Figure 1](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21728/)

**Figure 1.** Two 30-s epochs scored for sleep by polysomnography. The first 30-s epoch was scored as light sleep (stage 2) due to the presence of spindles. The second 30-s epoch was scored as wakefulness due to the presence of low-voltage, fast EEG frequencies, movement artifact, and electromyographic activity. The vertical line separates the two epochs. EKG=electrocardiogram.

![Figure 2](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21728/)

**Figure 2.** Sleep/wakefulness classification using the CRV method. The same epochs are shown as in Figure 1. On the seven-channel montage, the first 30-s epoch was staged as sleep due to the regularity of the cardiorespiratory channels. The second 30-s epoch was staged as wakeful because of movement artifact lasting more than 15 s. EKG-electrocardiogram.
Figure 3. Top: this videotape frame shows the appearance of the child during the first epoch. Absence of movement and eyes closed are consistent with sleep. Bottom: this videotape frame during the second epoch shows movement of the arm and a change in body position consistent with wakefulness.

cording as the test method. Each epoch could thus be classified in one of four ways (Fig 4).

For each subject, the following measures of agreement and test characteristics were calculated (Fig 4): accuracy, \( (SS+WW) / total \) epochs; the percentage of sleep epochs correctly classified as sleep by the CRV method, \( SS / (SS+WS) \); the sleep predictive value, \( SS / (SS+SW) \); the percentage of wakeful epochs correctly classified as wakefulness, \( WW / (WW+SW) \); and the wakeful predictive value, \( WW / (WW+WS) \). We also calculated the kappa value that adjusts concordance for chance agreement when one state (sleep) occurs much more frequently than another (wakefulness).27

To give each patient in the study equal weight, measures of
agreement by subjects were first calculated. The results for the 20 subjects are summarized as mean±SD for normally distributed data or as median (interquartile range, IQR) for data not distributed normally.

**Results**

A total of 21,832 30-s epochs were analyzed for S/W (1,089±111 [SD] epochs per subject). Within the group, measures of OSA severity (apnea/hypopnea and desaturation indexes) varied widely. Likewise, there was marked variability in the movement/arousal index, a measure of sleep disturbance. Across 20 subjects, 79.7±7.1% of the epochs were polysomnographically staged as sleep.

**Interscorer Agreement for the CRV Method**

The two CRV scorers agreed on S/W classification for 95.6±2.5% of epochs. A paired t test was used to test for differences in agreement between the two CRV scorers. Because no statistically significant differences in agreement were found between the CRV scorers, measures of agreement and test characteristics are presented subsequently by comparing the average of the two scorers to polysomnographic scoring.

**Polysomnography**

**Sleep** | **Wakefulness**
---|---
**Cardio-respiratory plus videotape (CRV) method**

<table>
<thead>
<tr>
<th>Sleep</th>
<th>Wakefulness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoch classified as sleep by both methods</td>
<td>Epoch misclassified as wakeful by the CRV method</td>
</tr>
<tr>
<td>SS</td>
<td>WS</td>
</tr>
<tr>
<td>SW</td>
<td>WW</td>
</tr>
</tbody>
</table>

**Figure 4.** Four ways an epoch could be classified. The CRV method was assessed against polysomnography. Please see text for further details.

| % sleep epochs | 79.7 | 65-91 |
| % sleep epochs correctly classified by the CRV method as sleep | 93.8 | 88.3-97.7 |
| Sleep predictive value | 97.7 | 88.3-99.6 |
| % of wakeful epochs correctly classified | 95.2 | 88.8-99.4 |
| Wakeful predictive value | 80.1 | 45.8-94.9 |
| Kappa coefficient | 0.5 | 0.5-0.9 |

*Percent of sleep epochs correctly classified by the CRV method as sleep.*

The data for this variable are not normally distributed and are therefore presented as the median and IQR.

*Percent of wakeful epochs correctly classified by the CRV method as wakeful.*

*Agreement between the CRV method and polysomnography for sleep/wakefulness classification after correcting for chance agreement.

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**Analysis of CRV Method Errors**

Epochs that were misclassified as W by the CRV method accounted for 2.2% of total study epochs and were most frequently in stage 1 sleep, followed by stage 2, and REM sleep, respectively. Stages 1, 2, and REM accounted for 15±9, 5±7, and 4±5 epochs per study, respectively. Most misclassified stage 1 epochs contained about half wakeful EEG activity and half stage 1 EEG activity. Similar errors have been observed with the actigraphic method that bases S/W discrimination on body movement.

The epochs misclassified as sleep by the CRV method accounted for 0.5% of total study epochs and...
occurred primarily when the child was resting quietly, breathing regularly, and lying with the eyes closed or not visible to the cameras. During such epochs, the only polysomnographic indication of W was alpha rhythm or low-voltage, mixed-frequency EEG activity.

The accuracy of the CRV method did not correlate with apnea/hypopnea, desaturation, or movement/arousal indexes (r=0.01 to 0.08, p=0.37 to 0.48).

**Discussion**

The present study demonstrates that S can accurately be distinguished from W in children being evaluated for OSA using a CRV method. The total concordance of 93.8% indicates an excellent agreement between the CRV method and polysomnography. The high level of agreement between the two CRV scorers with different levels of experience suggests that the scoring rules are reproducible. The kappa values, which account for agreement beyond chance, confirm this excellent agreement.27 Our results indicate that the CRV method allows clinicians and investigators to be confident that the vast majority of S is correctly classified and that an epoch classified as S is very likely to be S.

EEG S staging is not essential for the evaluation of OSA. Douglas et al.28 evaluating the clinical value of polysomnography in adult OSA, found that “recording sleep electrophysiologically was of no diagnostic value because it did not modify clinical patient management. In fact, one recent study suggested that the distribution of sleep stages in children with OSA was normal.29 However, it is important to be sure that the evaluation period includes REM sleep because OSA in children is often much worse in REM sleep. For instance, in 54 consecutive, nocturnal in-laboratory evaluations of OSA, the apnea/hypopnea index was 6.5 (0.8 to 18.9) vs 0.8 (0.2 to 4.1) events per hour, median (IQR) (p<0.001), in REM vs non-REM sleep, respectively. In these 54 children studied in our sleep laboratory, there were 156±62 of REM sleep epochs. There were only two children that had less than 40 epochs of REM sleep. Neither had OSA; both had low total sleep time and low sleep efficiencies related to anxiety in the laboratory environment. Thus, nocturnal polysomnography for pediatric OSA will invariably include REM sleep. Although apnea and desaturation events may cluster in REM sleep, this fact has little impact on treatment decisions such as that for or against adenotonsillectomy.

Although we agree with Douglas et al.28 that recording S electrophysiologically may not be necessary, we disagree with their conclusion that apnea/hypopnea index should be scored per time in bed. This method would lower both apnea/hypopnea index and desaturation index by including wakeful time in the denominator. In the 20 children described in this study, half of the children slept less than 81% of the time they were in bed (Table 2). Use of our CRV method would increase precision, especially in children who often spend a significant amount of time awake during laboratory recordings.

**Nonelectrophysiologic S/W Discrimination**

Although experience in older children is more limited, evaluations of non-EEG methods to assess S in infants have resulted in good agreement. Prechtl et al.30 showed that S state in term newborn infants could be distinguished on behavioral criteria and it is widely accepted that “behavioral observations are necessary to differentiate between states of sleep and wakefulness in the infant.”30,31 Anders and Sostek14 subsequently validated the use of time-lapse video recording to stage S in normal infants finding an overall correlation of 0.79. Their method is convenient for long-term recordings and minimally disturbs the infant.

Several groups of investigators have used cardiac and/or respiratory variability measures to determine S/W state in infants with good results.3-7 However, these studies have generally been limited to normal neonates or infants. Because movement/arousals and W are often associated with increases in heart rate, respiratory rate, and their variability,22 the present results suggest that such systems would also perform well in infants and/or children with apnea or airway obstruction.

Computerized movement detectors (Actigraph; Ambulatory Monitoring; Ardsly, NY) have been used to classify S and W in infants and children.8-13 These devices are easy to apply, enable recording for prolonged periods, and minimally disturb S. However, actigraphy would not meet the essential diagnostic requirements for OSA unless it was used in conjunction with cardiorespiratory and/or videotape recordings.

In children, there is less information available on S/W discrimination without EEG. Stradling et al.32 using a computerized video movement analysis system, found less nocturnal movement after tonsillectomy than before. Although they excluded prolonged W periods by manual review of videotapes, they did not validate S/W classification against polysomnography. Subsequent to this series of 20 subjects, we have developed a computerized, video-based movement detection system (SleepVision; Martinex; Montreal) for S/W discrimination that shortens the analysis time for an overnight study to approximately 30 min.33,34

**Study Critique**

As reviewed above, there is much literature to suggest that our findings are concordant with those of neonates and infants. However, because adults and
adolescents may more commonly lie quietly in bed but be awake, the CRV method should be evaluated in these other age ranges. Further studies to determine the accuracy of the CRV method in normal children and other diagnostic groups are needed.

Although no data on normal children have been obtained, it might be expected that the ability to separate S from W would be more difficult in children with OSA. Typically, children with OSA have more sleep disruption, and more brief movement/arousals terminating apneas and hypopneas. In our subjects, we found no relation between apnea/hypopnea indexes or movement/arousal indexes and the accuracy of S/W classification.

A final critique would suggest that a simplified method of discriminating S and W is useful only if the accompanying respiratory abnormalities are also classified. However, several studies have found that the use of the RIP sum signal is an accurate method of identifying apneas and hypopneas. Jacob et al. found a correlation coefficient of 0.97 between an abbreviated cardiorespiratory montage and full polysomnography. Whyte et al. evaluated apnea/hypopnea in 22 adults subjects based on a reduction in thoracoabdominal movement compared with a flow signal. They obtained a correlation of 0.99. Brouillette et al. found that all central apneas and 92% of obstructive apneas were correctly classified with the RIP method. Gould et al. and Cantineau et al. have shown that use of the RIP sum signal to calculate the apnea/hypopnea index correlates better with hemoglobin desaturation than does an apnea index based on an oronasal thermistor, a method often used in adult polysomnography. Our inclusion of hypopneas only if they were associated with desaturation made the classification of hypopneas more rigorous.

CONCLUSIONS

In summary, a CRV method for distinguishing S and W showed excellent agreement with standard polysomnography. Similar cardiorespiratory and videotape equipment is widely available. The recordings are easier to obtain and to score than polysomnography and do not require, but could use, specialized computerized processing. Because there are no electrodes attached to the face or head, sleep and breathing may be more representative of the child's usual patterns.

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