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Feasibility of Comprehensive, Unattended Ambulatory Polysomnography in School-Aged Children

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Study Objectives: Although unattended ambulatory polysomnography (PSG) is frequently performed in adults, few studies have been performed in children. The objective of this study was to evaluate the feasibility of comprehensive, ambulatory PSG, including electroencephalography, in school-aged children in the home environment.

Methods: A total of 201 children, born premature with birth weights of 500-1,250 grams, currently aged 5-12 years and living in Canada and Australia, underwent unattended ambulatory PSG.

Results: PSG was initially technically satisfactory in 183 (91%) cases. Fourteen studies were satisfactory when repeated, resulting in an overall satisfactory rate of 197 (98%). Artifact-free signals were obtained for ≥ 75% of recording time in more than 92% of subjects, with the exception of nasal pressure, which was satisfactory for ≥ 75% of recording time in only 67% of subjects. However, thermistry signals were satisfactory for ≥ 75% of recording time in 92% of subjects, and some measure of airflow was present for ≥ 75% of recording time in 96% of subjects. Children slept very well, with a long total sleep time (534 ± 73 [mean ± SD] minutes), high sleep efficiency (92% ± 5%), and low arousal index (9 ± 3/h). Parents and children reported a high rate of satisfaction with the study.

Conclusions: This large, international study has shown that comprehensive, unattended, ambulatory PSG is feasible, technically adequate and well-tolerated in school-aged children when performed under research conditions. Further studies regarding the cost efficacy of this approach, and generalizability of the findings to a clinical population, are warranted.

Keywords: polysomnography, sleep study, ambulatory, home, child

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SCIENTIFIC INVESTIGATIONS

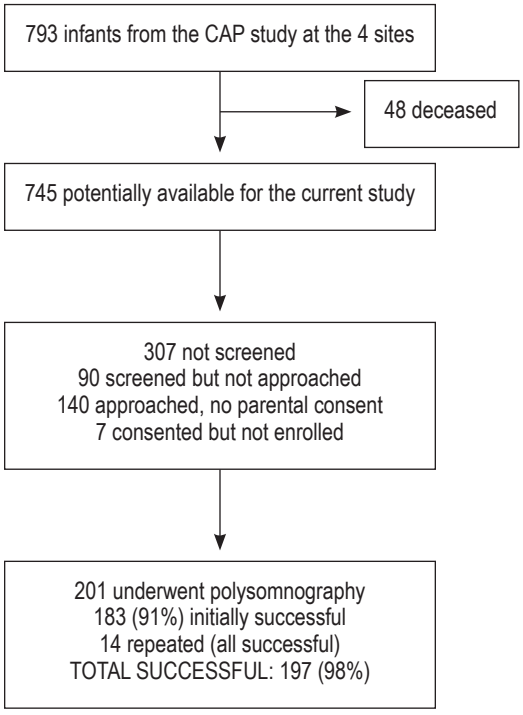
Unattended ambulatory sleep studies are frequently performed in adult patients with suspected sleep disorders. The American Academy of Sleep Medicine (AASM) has published guidelines with recommendations for ambulatory portable sleep monitoring, but these are restricted to adult patients older than 18 years of age.[1] Indeed, the increasing use of ambulatory studies in adults has changed the way clinical sleep medicine is practiced.[2] However, despite the proliferation of ambulatory sleep studies in adults, there have been very few studies evaluating portable monitoring in children. In particular, there have been very few studies in either children or adults evaluating comprehensive, unattended ambulatory polysomnography (type 2 sleep studies) as compared to abbreviated polygraphy, and the AASM task force on portable monitoring noted that there were insufficient data on type 2 portable devices to recommend these types of studies for children.

BRIEF SUMMARY

Current Knowledge/Study Rationale: Ambulatory sleep studies are frequently performed in adults. However, there have been few studies evaluating the feasibility of performing comprehensive, unattended, ambulatory polysomnography in children.

Study Impact: This large, international study has shown that comprehensive, unattended, ambulatory polysomnography is feasible, technically adequate and well-tolerated in school-aged children. However, further study is needed before these results can be translated into the clinical setting.

Figure 1—Study enrollment.



Details of study enrollment are shown. CAP, Caffeine for Apnea of Prematurity trial.

Unattended polysomnography is potentially difficult in children as they tend to move frequently during sleep, resulting in artifact, and young children or those with limited comprehension may remove sensors during the night. The Tucson Children's Assessment of Sleep Apnea study (TuCASA) is the only large study that evaluated comprehensive, unattended polysomnography in children in the home setting.[3] The TuCASA study reported excellent quality overall, but difficulty with obtaining airflow signals, with only approximately 50% of studies having artifact-free airflow signals for at least 6 hours. However, it is not known if findings from this single-center study can be generalized to other settings. We therefore report on the technical quality of a large sample of school-aged children undergoing comprehensive ambulatory polysomnography, including encephalography (EEG), from four centers and two continents. Studies were performed in the research context as part of a study (Caffeine for Apnea of Prematurity - Sleep; CAPS) evaluating the long-term effects of therapeutic caffeine used for apnea of prematurity.

METHODS

A subset of children enrolled in follow-up studies for the Caffeine for Apnea of Prematurity (CAP) trial[4-6] underwent comprehensive, ambulatory polysomnography (**Figure 1**). The original CAP trial randomized more than 2,000 preterm neonates to caffeine or placebo as therapy for apnea of prematurity. Subjects were studied from four of the original CAP sites, chosen based on the recruitment and retention for the parent CAP trial, as well as proximity to an experienced pediatric sleep laboratory: McMaster University Medical Centre, Hamilton, Canada; Sunnybrook Health Sciences Centre, Toronto, Canada; Royal Women's Hospital, Melbourne, Australia; and Mercy Hospital For Women, Melbourne, Australia. The research ethics board at each institution approved the study, and informed consent was obtained from parents/guardians.

Study Group

A total of 201 children, aged 5-12 years, were studied from 8/5/2009 to 7/3/2013. Eligibility criteria for the initial CAP trial included preterm birth with birth weights of 500-1,250 g, absence of major congenital anomalies or syndromes, and considered to be candidates for methylxanthine therapy for apnea of prematurity during the first 10 days of life.

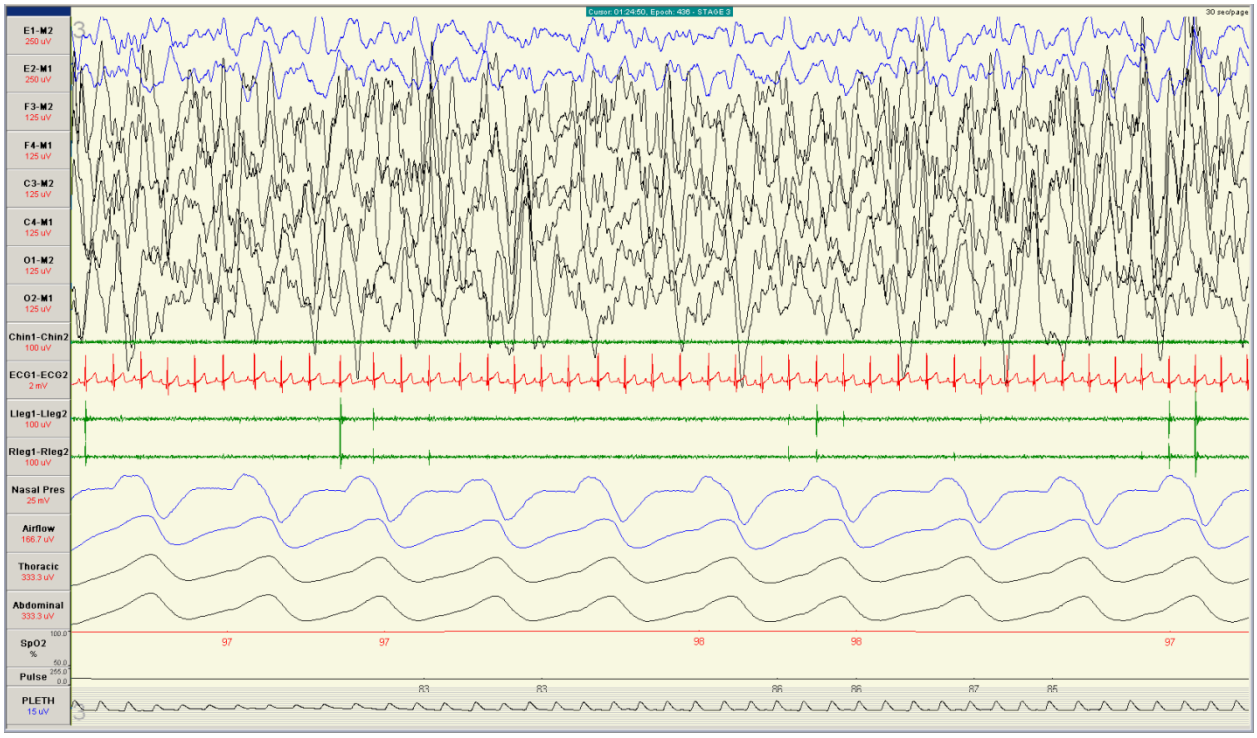
Study Organization

As the principal investigator for the study was in Philadelphia, academic pediatric sleep medicine specialists from the Hamilton-Toronto and Melbourne areas were recruited to supervise local studies. None of these centers had prior experience with ambulatory polysomnography. Personnel from these laboratories were trained in the performance of the study procedures. Studies were performed by 4 technologists. A detailed manual of standard operating procedures with checklists was developed.

A small pilot study to assess validity was performed with 4 healthy non-CAP subjects aged 6-7 years who underwent full laboratory polysomnography, as well as ambulatory polysomnography, on 2 separate nights. The laboratory polysomnography was performed using a Rembrandt polysomnography system (Medcare, Buffalo, NY), whereas the ambulatory polysomnography was performed using a Siesta 802 system (Compumedics, Charlotte, NC). Studies were scored with research personnel blinded to the results of the alternative study.

Ambulatory polysomnography was performed at the child's usual sleep times. A technologist went to the child's home to place the leads, with the exception of two sets of twins who lived in a remote area and were studied in a hotel. Siblings of multiple birth children (twins to quadruplets) were often studied on the same night, by either one or two technologists. The following leads were monitored (Siesta 802, Compumedics): EEG (C4/M1, C3/M2, F4/M1, F3/M2, O2/M1, O1/M2); bilateral electrooculograms; submental and tibial electromyograms; chest and abdominal wall movement by inductance plethysmography; ECG; airflow by nasal pressure and 3-pronged thermistor; microphone; and arterial oxygen saturation (averaged over 4 pulse beats) with pulse waveform. Capnometry was not performed due to the difficulty of obtaining adequate signals in an unattended setting. Parents were asked to record lights off and lights on times. They were supplied with an emergency telephone number to call during the night with questions, as well as a diagram and simple instruction sheet on replacing leads if they happened to notice that any fell off during the night. The recording was terminated by the child's parents or the technologist in the morning after the child awoke for the day, and the equipment was picked up by the technologist. The morning after the study, the sleep technologist, a parent, and the child him/herself completed a brief questionnaire about technical issues and overall satisfaction

Figure 2—Example of an epoch from a technically adequate study.



A 30-sec epoch from a technically adequate study is shown. Nasal press, nasal pressure; Airflow, oronasal airflow by thermistry; Pleth, arterial oxygen saturation plethysmographic pulse waveform.

with the study. In addition to comments, there was an overall Likert scale for parents, and a Wong-Baker "smiley faces" Likert scale for children.

Studies were transmitted electronically to the central reading center where they were scored by a single registered polysomnographic technologist (JT) and then interpreted by a single pediatric sleep medicine physician (CLM), using the AASM pediatric scoring rules.[7] Any differences between the scorer and physician were resolved by consensus. All studies were rated for technical quality. The percentage of total recording time with a satisfactory signal was visually assessed for each polysomnographic channel. A signal was considered satisfactory if the waveform was free of artifact and the data were interpretable. **Figure 2** shows an example of a technically adequate portion of a study. Studies with major technical flaws were repeated if the family agreed. Repeat rules were not specified *a priori*, but in general were studies where power failure occurred, resulting in < 4 h total recording time, or where a major signal was displaced for most of the night (i.e., arterial oxygen saturation, both respiratory effort channels, both airflow channels, or all EEG channels—the latter usually due to displacement of the ground lead).

Data Analysis

Statistical analyses were conducted in Sigmaplot 12.5 (Systat Software, San Jose, CA). Data are shown as mean ± standard deviation. The paired t-test was used to compare data between two conditions. A p value < 0.05 was considered statistically significant.

RESULTS

Laboratory vs Ambulatory Polysomnography

Laboratory vs ambulatory studies in the 4 non-CAPS subjects were performed 3.9 ± 3.5 months apart. Results are shown in **Table 1**. As expected, children slept longer in the home environment, with a trend towards more consolidated sleep, but had similar respiratory parameters compared to the laboratory studies.

Study Group and Data Quality

The study group is shown in **Table 2**. The study sample included 6 (3%) children with moderate to severe cerebral palsy or developmental delays. Of the initial 201 studies, ambulatory polysomnography was initially satisfactory in 183 (91%) cases. Eighteen studies were unsatisfactory (6 with poor oximetry, 5 with reference lead displaced, 4 with general technical failure or power issues, 1 with poor airflow signals, 1 with multiple poor signals, and 1 where the child pulled off the leads). Of these 18 cases, 14 families agreed to repeat polysomnography. In all cases, repeat polysomnography was satisfactory. Thus, 197 studies (98%) were satisfactory with one or two attempts.

Table 3 shows the percentage of total recording time with a satisfactory signal for each channel, based on the final polysomnogram (including the inadequate polysomnogram in the four subjects who did not have the study repeated). Overall, satisfactory signals were obtained for the majority of the channels for ≥ 75% of the night. These numbers were further improved

Table 1—Home vs laboratory polysomnography results (N = 4)

	Laboratory	Home
TST (h)	456 ± 66	542 ± 18 *
Sleep efficiency (%)	87 ± 7	94 ± 1
N1 (%TST)	4 ± 2	5 ± 1
N2 (%TST)	42 ± 8	39 ± 8
N3 (%TST)	31 ± 6	37 ± 13
Rapid eye movement sleep (%TST)	22 ± 4	20 ± 5
Arousal index (N/h)	14 ± 4	9 ± 4
Apnea hypopnea index (N/h)	1.1 ± 1.1	2.0 ± 1.8
SpO_2 nadir (%)	94 ± 1	94 ± 2

* p = 0.046. Data shown as mean ± SD. TST, total sleep time.

Table 3—Final polysomnogram quality (N = 201)

Polysomnographic variable	Satisfactory signal > 95% of recording	Satisfactory signal > 75% of recording
Any EEG channel	93.5	97.0
F3/4	90.0	95.5
C3/4	92.5	96.5
O1/2	87.6	94.5
Any EOG channel	92.0	97.0
E1	91.0	96.5
E2	91.0	96.0
Chin EMG	89.6	94.0
Any tibial EMG	91.0	94.0
Right leg	86.6	92.5
Left leg	87.1	92.5
ECG	90.0	93.0
Any respiratory effort	90.5	97.0
Chest wall	89.6	97.0
Abdomen	86.1	96.0
Any airflow	81.1	96.0
Nasal pressure	49.3	67.2
Thermistor	73.6	92.0
Arterial pulse oximetry	72.6	97.5

Data shown as percentage of studies with a satisfactory signal. EEG, electroencephalogram; EOG, electrooculogram; EMG, electromyogram; ECG, electrocardiogram.

when evaluating signals required for clinical diagnosis, e.g., a satisfactory signal on any respiratory effort channel or on any EEG channel. The only channel with satisfactory signals < 75% of recording time was nasal pressure, which provided a satisfactory signal for > 75% of the recording in only two-thirds of subjects. In most cases, the nasal pressure signal quality fluctuated over the course of the night, rather than being totally absent, and in some cases the signal would disappear for long stretches of time and then reappear spontaneously. The thermistor signal was far more reliable, with a satisfactory signal > 75% of recording time for > 90% of subjects. However, satisfactory combined airflow signals (i.e., either thermistor or nasal pressure signal present) were available for > 75% of the recording for > 95% of subjects.

Sleep Architecture

Sleep architecture is shown in **Table 4**. Overall, children slept very well during polysomnography, with mean total sleep time of 8.9 h, sleep efficiency of 92%, and a normal arousal index.[8-10]

Table 2—Study group (N = 201)

Age (years)	9.2 ± 2
Males	115 (57)
Maternal race *	
White	168 (84)
Asian	20 (10)
Black	11 (6)
Other	2 (1)
Site	
Canada	113 (56)
Australia	88 (44)

Data shown as mean ± SD or N (%). * Race was collected as maternal race from the parent Caffeine for Apnea of Prematurity (CAP) study database.

Table 4—Sleep architecture (N = 201)

Total recording time (min)	635 ± 73
Total sleep time (min)	534 ± 73
Sleep efficiency (%)	92 ± 5
Sleep latency (min)	17 ± 19
Wake after sleep onset (min)	31 ± 22
Stage N1 (% TST)	5 ± 2
Stage N2 (% TST)	38 ± 7
Stage N3 (% TST)	34 ± 8
Rapid eye movement sleep (% TST)	23 ± 5
Arousal index (N/h)	9 ± 3

Data shown as mean ± SD. TST, total sleep time.

Family Perspective

In 34 instances, caregivers noted that a lead had been displaced during the study, but only 12 attempted to replace the lead (nasal cannula in 8 cases; ECG, chest belt, pulse oximeter, microphone in 1 case each). In the other cases, the parent only noticed the loose lead in the morning. No parent called for emergency help.

The median parental satisfaction rating for the study was 1 (mode 1, range 1-5) on the Likert scale ranging from 1-5 (with 1 being best), and the median child rating was 0 (mode 0, range 0-5) on the pediatric Likert scale ranging from 0-5 (with zero being best).

Unique Challenges with Ambulatory Polysomnography

Challenges experienced by the sleep technologists included lack of space to attach the leads, interference from young siblings during the process of attaching the leads, lack of electrical outlets in the vicinity of the child's bed, artifact due to laptop computers and other devices being used in the home, insufficient battery life if the unit became unplugged (e.g., if the child went to the bathroom and the device was not plugged in upon return—a common cause of inadequate studies), children sleeping in bunk beds, and children sleeping with pets. A heat wave in Australia caused problems during that period including sweat artifact and fragmented sleep, as many of the homes did

not have air conditioning. In general, study quality improved over the four years of the study, in particular due to technologists developing special techniques with taping and securing the pulse oximeter and the ground lead.

DISCUSSION

This sizable study of more than 200 children from two different continents has shown that comprehensive ambulatory polysomnography is feasible in school-aged children, results in good technical quality, and is well accepted by children and their families. The study also shows the feasibility of gathering data consistently, and logistically managing a study that includes central PSG reading, with multiple sites that are geographically far apart.

Most studies were of excellent technical quality. The nasal pressure signal was the most problematic sensor, although the combination of nasal pressure and thermistor signals provided an airflow signal for > 75% of the night in more than 95% of studies. As some portable monitors rely on nasal pressure sensors as the only measurement of airflow, this may be particularly problematic for clinical ambulatory polysomnography in children. Potential reasons for the poor nasal pressure signal include nasal secretions and mouth-breathing due to adenoidal hypertrophy, which is common in children; fluctuations in nasal resistance due to the nasal cycle[11]; or the child removing the cannula due to discomfort. As thermistor recordings can result in underestimation of obstructive events, particularly hypopneas, lack of a nasal pressure signal can result in underestimation of the apnea hypopnea index.[12,13] This is of increased concern in children, who are more prone to hypopneas and long periods of partial upper airway obstruction (i.e., obstructive hypoventilation) than complete obstructive apneas.[14] Obstructive hypoventilation may be diagnosed using end-tidal carbon dioxide monitoring, but this is problematic in the home environment as the sensors require frequent technical intervention, and thus was not attempted in this study. Transcutaneous carbon dioxide monitoring is a potential method for detecting obstructive hypoventilation in the home situation, but also has drawbacks including a slow response time and the potential for skin burns. Future studies evaluating the feasibility and utility of capnometry during ambulatory polysomnography would be of interest. Of note, the EEG leads, which are rarely used in ambulatory polysomnography, provided excellent quality for most of the night. As children move frequently during sleep, actigraphy has poor specificity for detecting sleep,[15] and thus EEG signals are useful for polysomnography interpretation, particularly in quantifying total sleep time.

Several studies have evaluated ambulatory polygraphy or polysomnography in children, with varied results. To our knowledge, the only other study evaluating comprehensive polysomnography including EEG measurements was by Goodwin et al., who studied 157 school-aged children in the home.[3] In this study, two technologists went to the home to set up the polysomnogram. The study demonstrated overall excellent PSG quality, similar to the current study. As with the current study, the nasal pressure sensor was the most problematic, with only 52% of studies having scorable signals for at least 6 hours. In contrast to the current study, thermistor signals were also problematic, with scorable signals for at least 6 hours in only 59%. The reason for this difference between studies is unclear.

Other studies have used limited montage monitors in the home setting. Rosen et al. studied a large cohort of children, aged 8-11 years, using a system that included respiratory inductance plethysmography, oximetry, pulse rate, and body position.[16] Devices were placed on the child in the home by a technologist. Ninety-four percent of studies were considered technically satisfactory for ≥ 4 h of recording. In a subset of the study group, ambulatory recordings were compared to laboratory polysomnograms, and it was reported that the ambulatory studies had a sensitivity of 88% and specificity of 98% in diagnosing a laboratory-based apnea hypopnea index > 5/h. Moss et al. had an 89% success rate using limited ambulatory polygraphy in school-aged children, also set up by a technologist in the home.[17] Jacob et al. used a noncommercial polygraphy system that included video recording and was set up in the home by a technologist, and found the quality of data to be comparable to laboratory polysomnography.[18] However, other studies have found ambulatory polygraphy in children to be unsuccessful due to artifact or low specificity.[19,20] Thus, further research in the clinical utility of abbreviated ambulatory polygraphy in children is needed.

Home polysomnography is less intrusive to family function, and results in better sleep, than laboratory polysomnography. However, this study should not be interpreted as indicating that ambulatory polysomnography should replace laboratory polysomnography in children. This study used full, comprehensive polysomnography rather than the usual limited channel portable monitors, which may not provide as much data. Technologists went to the children's home and applied the sensors rather than having families apply the sensors themselves, which probably resulted in better quality studies, but is less cost-effective and utilizes limited resources. Children were school-aged, and these data should not be extrapolated to younger children who may not tolerate the sensors as well. Further, it is possible that different results would be obtained from a clinical sleep-disordered breathing population with more sleep disturbances than the current study group. Finally, the children in the current study were undergoing baseline polysomnograms as compared to studies that required ongoing technical intervention, such as continuous positive airway pressure titrations studies.

In conclusion, this study has shown that unattended comprehensive ambulatory polysomnography is feasible, results in high quality studies, and is well-tolerated by school-aged children and their families. As such, it is a valuable research tool. However, further research is needed in a wider range of ages and clinical conditions, with comprehensive financial modeling, before widespread clinical ambulatory polysomnography can be recommended for all children.

ABBREVIATIONS

AHI, apnea hypopnea index
BMI, body mass index
ECG, electrocardiogram
EMG, electromyogram
EOG, electrooculogram
OSAS, obstructive sleep apnea syndrome

PLMS, periodic limb movements
TST, total sleep time

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