# Home (Level 2) polysomnography is feasible in children with suspected sleep disorders

Russo, Kylie; Greenhill, Janet; Burgess, Scott

*Published in:*
Sleep Medicine

*DOI:*
10.1016/j.sleep.2021.10.024

Sleep Medicine 88 (2021) 157–161

Contents lists available at ScienceDirect

Sleep Medicine

journal homepage: www.elsevier.com/locate/sleep

Original Article

# Home (Level 2) polysomnography is feasible in children with suspected sleep disorders

Kylie Russo [a], Janet Greenhill [b], Scott Burgess [b, *]

[a] Bond University, Australia
[b] Queensland Children's Lung and Sleep Specialists, Australia

ARTICLE INFO

*Article history:*
Received 12 August 2021
Received in revised form
12 October 2021
Accepted 13 October 2021
Available online 22 October 2021

*Keywords:*
Obstructive sleep apnoea
Polysomnography
Sleep
Children
Ambulatory
Diagnostic screening

ABSTRACT

*Aim:* To audit the feasibility and patient experience of home polysomnography (sleep study) for the investigation of a sleep disorder in children.
*Methods:* The signal quality and outcomes of a Level 2 (home) polysomnography in young people undergoing investigation between September 2020 and January 2021 in a single centre was reviewed. A successful home polysomnogram was defined as a study with ≥6 h of sleep and all channels (EEG, thoraco-abdominal bands, calculated airflow, and pulse oximetry) present for at least 90% of the study time. Feedback from the guardian and young person was collected following the study using a questionnaire.
*Results:* Fifty-five patients, aged 4 months to 18 years, were included. A successful polysomnogram, on the first attempt, was achieved for 48/55 (87%) subjects. There were no differences in success when accounting for neurodevelopmental conditions, OSA severity or age. The majority (76%) of guardians felt that their child slept the same or better than normal and only 12% found having the study conducted at home difficult. Following the study, only 8% would have preferred a hospital sleep study in retrospect.
*Conclusions:* Home polysomnography produced a technically adequate study for the majority of subjects. Most families also found the experience of having a home sleep study to be positive. These data support the use of home sleep studies as an alternative to an in-patient sleep study, in appropriate circumstances, for young people undergoing investigation of a sleep disorder.


## 1. Introduction

Paediatric sleep disorders are important and common conditions. Sleep disordered breathing, which includes obstructive sleep apnoea (OSA), has an estimated prevalence of 1–5% [1] and restless legs syndrome/periodic limb movement disorder has an estimated prevalence of 2% [2]. OSA has been associated with impairments of memory, learning, behaviour, growth, quality of life and cardiovascular health [3]. Restless sleep disorders have been shown to result in sleep disruption, impaired cognitive function, reduced mood, and poorer quality of life [4].

The reference standard for the investigation of paediatric sleep disorders is a polysomnogram (PSG, also known as a sleep study) [5]. A Level 1 PSG is performed in hospital, under the supervision of trained medical staff and includes the measurement of multiple physiological signals which allows a comprehensive assessment of sleep quality, breathing, oxygenation and movement. However, such studies are labour intensive and costly.

A Level 2 sleep study refers to an unattended PSG study (no medical staff present) and is performed outside of a sleep laboratory, typically in the patient's home [5]. It still includes the measurement of at least 7 physiological signals which allow a similar assessment of sleep quality, breathing, oxygenation and movement. Although some more technically demanding measures such as carbon dioxide ($CO_2$) levels and video are often absent.

There are a small number of studies which have examined the feasibility and utility of Level 2 sleep studies for the assessment of OSA in children [6–8]. These studies reported that 81%–91% of the studies were acceptable based on differing criteria. Ioan, Weick [6] described a clinical sample of 57 children aged 3–16 years. Of these, 8 (14%) subjects were developmentally delayed, and the median age was 7 years. Failure was defined as <5 h of data or ≥75% artefact in one or more major signals. It was reported that 81% of subjects

* Corresponding author. Queensland Children's Lung and Sleep Specialists, 639 Stanley Street, Woolloongabba, Queensland, 4102, Australia.
*E-mail address:* scott@qclass.com.au (S. Burgess).

https://doi.org/10.1016/j.sleep.2021.10.024

had a technically acceptable study and all but one had an interpretable study. Marcus [8] described the outcome for 201 children aged 5–12 years who were being followed up as part of a neonatal research study. It included few children with medical comorbidities. An adequate study, >4 h of data and signals present for >75%, occurred in 91% of subjects. Goodwin, Enright [7] reported the outcomes of home sleep studies in 157 children aged 5–12 years recruited from the community. Children with significant medical or developmental disorders were excluded. The authors reported that 91% of subjects had at least 5 h of interpretable data.

There has been significant progress in sleep monitoring equipment with improved signal quality, smaller light-weight equipment, and leadless technology such as Bluetooth being incorporated into devices. A calibrated signal derived from bands worn around the subject's chest and abdomen has been shown to produce a calculated airflow signal which in adults was comparable with airflow measured by face mask and pneumotachometer [9]. This is important as direct airflow monitoring is often disliked by children and is one of the more commonly lost signals.

The principal aim of this study was to assess the feasibility of a Level 2 diagnostic sleep study in a clinical cohort of children in an Australian centre. The secondary aims were to assess the consumer experience and preference for a home or hospital study.

## 2. Materials and methods

### 2.1. Setting

The study was conducted in a private paediatric sleep clinic in Brisbane, Australia. The clinic has access to a 5-bed in-patient sleep laboratory. Australia provide universal healthcare to all citizens. However, there is a significant waiting time of >12 months for a non-urgent sleep studies in most government run hospitals, especially following the Covid-19 pandemic. Access to private hospital facilities requires the family to hold private health insurance or pay an additional fee which can be significant. Thus, there is a need for diagnostic services that do not require admission to hospital.

### 2.2. Population

This clinical audit describes the outcome of consecutive children who underwent a Level 2 sleep study between September 2020 and January 2021. All children were reviewed by a clinician prior to their sleep study. All patients were offered a choice of a hospital or home sleep study.

### 2.3. Home polysomnography (PSG)

Ambulatory PSG was performed using a Nox-A1 device (Nox Medical, Iceland). Monitored signals included frontal, central, and occipital electroencephalogram (EEG: FpZ, F4, C4, O2, A1 & A2), two electrooculograms (EOG), chin electromyogram (EMG), electrocardiogram, respiratory inductance plethysmography (RIP) of chest and abdominal movement, pulse oximetry (Nonin 3150 with one of 3 age-appropriate sized probes), audio, position/movement and leg electromyograms when clinically indicated. Airflow was assessed using cRIP flow, a calculated signal derived from the respiratory bands. The equipment was applied in the clinic by a sleep physician (SB), typically between 5PM and 6PM, and the patient returned to their own home or a local hotel depending on their distance from the clinic. Guardians started the studies manually at the child's normal bedtime. Guardians were provided with verbal and written instructions on the device. They were encouraged to contact the physician at any time and were provided with an on-call mobile number. All of the leads connect to a battery powered device worn on the child's chest and are bundled together to prevent a choking hazard and the wrist worn oxygen saturation monitor connects to the main device via Bluetooth. Studies were scored by an experienced sleep scientist (JG) according to rules of the American Academy of Sleep Medicine [10]. Mild OSA was defined as an obstructive apnoea/hypopnoea index (OAHI) > 1 and < 5 events/hr, moderate OSA if the OAHI was ≥5 and < 10 events/hr and severe OSA if the OAHI was ≥10 events/hr. A diagnosis of periodic limb movement disorder was made if the number of periodic limb movement series was >5 per hour of sleep.

### 2.4. Signal quality

The Noxturnal software rates signal quality and calculates the percentage of the study for which there was an adequate signal for the oximeter, airflow, abdominal and thoracic respiratory effort. This assessment was confirmed manually by SB. If either respiratory band signal was absent or a poor signal for >10% of sleep time then the RIP bands were rated as inadequate. The EEG, EOG, chin EMG and leg EMGs were assessment for quality manually by SB. To be acceptable all 3 EEG signals needed to be present and sufficiently free of any artefact for =>90% of sleep such that sleep stages could be evaluated. The EOG was assessed as adequate if there was an artefact free signal present for ≥90% of sleep time and REMs could be identified. Chin EMG was assessed as adequate if present for ≥90% of the recording and there was appropriate differentiation between wake, REM sleep and NREM sleep.

### 2.5. Criteria for success

Studies with ≥6 h of sleep and key channels (EEG, RIP bands, cRIP airflow and pulse oximetry) present for at least 90% of sleep time were deemed successful.

### 2.6. Evaluation of home PSG

Guardians completed a questionnaire including lights off, presence of audible snoring, how the young person slept compared with normal, how easy the study was and whether in retrospect they would have preferred a hospital or home sleep study if cost had not been a factor.

### 2.7. Statistical analysis

Statistical analysis was performed using SPSS version 26. Descriptive statistics for clinical characteristics and home PSG results are expressed as median and range (or mean and SD if parametric) and questionnaire responses are displayed as frequencies and percentages. Questionnaire data are represented as proportions without missing data items. Non-parametric statistical tests of association (chi-square analysis) between variables were undertaken to explore failed home PSG recordings according to age, sex, OSA severity and the presence of neurodevelopmental comorbidities. A significance Level of $p < 0.05$ was used.

### 2.8. Ethics

Ethical approval was obtained from the Mater Misericordiae Human Research Ethics Committee (Ethics no: EXMT/MML/73550).

## 3. Results

A total of 55 children were scheduled for a Level 2 home PSG study during the study period (140 subjects had a Level 1 study during the same time). The reason for choosing a home study over a hospital study was not documented. Cost was a significant factor for many families. Although 41% of those undertaking a home study held private health insurance and other factors such as their child sleeping in their own bed and/or avoiding a hospital admission during the Covid-19 pandemic were also mentioned informally. The most common indication for a sleep study was investigation of possible OSA and participants had a mean age (SD) of 7.8yrs (4.4yrs). Participant characteristics are presented in Table 1 and Fig. 1. Twenty-one children (39%) had neurodevelopment disorders: Down syndrome in 1 [2%], Prader Willi Syndrome in 4 [7%], autistic spectrum disorder (ASD) in 5 [9%], attention deficit hyperactivity disorder (ADHD) in 4 [7%], ASD + ADHD in 6 [11%] and ASD + significant global developmental delay in 1 [2%].

### 3.1. Waiting time for home PSG

The median time from referral to the initial sleep service clinic appointment was 15 days (range: 1–115 days) and the median time from clinic appointment to sleep study was 12 days (range: 0–172 days). Overall patients waited for a median time of 27 days from referral to their sleep study (range: 1–191 days). An outlier from regional Queensland waited 172 days to come to Brisbane because of Covid-19 travel restrictions.

### 3.2. Home PSG

One subject did not tolerate the application of equipment, the remaining 54 subjects underwent a home sleep study. The median total sleep time (TST) was 540 min (IQR: 494–585 min) and an overall sleep efficiency of 89.7% (IQR: 86–94%) (Table 2).

### 3.3. Success rates of home PSG

A total of 48/55 (87%) patients fulfilled the criteria for successful home PSG. The reason for failure included: complete refusal in 1 (1.8%), TST < 6 hrs in 2 (3.6%), <90% signal quality in 3 (5.5%; due to $SpO_2$ artefact in 2 patients and $SpO_2$ and EEG absence/artefact in 1 patient) and <6hr of TST and <90% signal quality in 1 (1.8%; due to EEG absence/artefact). The child who did not tolerate application of equipment was 4yrs and had an anxious temperament. His mother attempted to apply the equipment when the child was asleep, but this was unsuccessful. The percentage of TST with artefact free oxygen saturation, RIP bands and EEG for the remaining subjects is summarised in Fig. 2. Four of seven patients with a suboptimal study had an ASD diagnosis and either anxiety or developmental delay. All children <4years of age had a successful home PSG. Overall, there was no difference in the success rates of typically developing children versus children with neurodevelopment conditions (p = 0.19), children <4yrs versus children >4yrs (p = 0.58), or OSA severity (no OSA, p = 0.19; mild, p = 0.58; moderate, p = 0.13; severe p = 0.09).

**Table 1**
Participant characteristics.

| | |
|---|---|
| Males, n (%) | 37 (67%) |
| Age in years, mean (SD) | 7.8 (4.4) |
| <4 years of age, n (%) | 8 (15%) |
| Private health insurance, n (%) | 22 (41%) |
| Lives >100 km from clinic, n (%) | 7 (13%) |
| Neurodevelopmental disorder, n (%) | 21 (39%) |
| Indication for sleep study, n (%)[a] | |
| Snoring, possible OSA | 46 (84%) |
| Restless sleep | 5 (9%) |
| Investigation of somnolence | 8 (15%) |
| Cause of moaning in sleep | 1 (2%) |

[a] Multiple indications per child for undertaking sleep studies may have been provided and therefore the total is higher than 100%; SD=Standard deviation; OSA=Obstructive sleep apnoea.

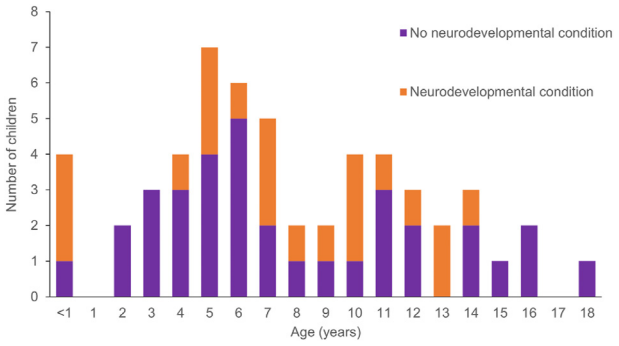


**Fig. 1.** Age and neurodevelopmental condition.

### 3.4. Other signals

The two children who removed their head leads also removed the leads for EOG and chin EMG. In additional there were two children for whom the chin EMG did not provide good differentiation between sleep stages and 4 children who either lost or had artefact effecting the left EOG for >10% of the sleep time. The absence of an adequate chin EMG or left EOG did not critically affect sleep staging and these factors were not taken into account when assessing the overall quality of the study. Leg EMG was measured in 26 children. There were 7 children for whom one or both of the leg EMGs were at least intermittently absent.

### 3.5. Clinically utility of home PSG

Of the seven patients whose study was deemed unsuccessful, four were found to have moderate or severe OSA. One patient, who was initially referred for investigation of moaning in sleep (possible catathrenia), was only observed to moan at sleep onset and transitions (while awake) and not during sleep and therefore catathrenia could be excluded. Thus, although not ideal, these five studies provided clinically useful data and these subjects did not require further diagnostic testing. Overall a clinical diagnosis was confidently made in 53 patients (96%).

### 3.6. Acceptability of home PSG

Fifty-one guardians (93%) completed the questionnaire. Compared with their normal sleep: 2% felt their child slept much better, 22% better, 52% the same, 20% worse and 4% much worse. Guardians felt that having the study at home was very easy 16%, easy 33%, neither easy or difficult in 39%, difficult in 10% and very difficult in 2%. Most guardians still preferred a home sleep study (75%) compared with no preference (18%) or a hospital study (8%).

## 4. Discussion

This audit of a clinical population of children undergoing a home sleep study found that the overwhelming majority (87%) had a successful study. For the remaining subjects the home study often

**Table 2**
Level 2 polysomnography results (n = 54).

| | Median | IQR | Range |
|---|---|---|---|
| Total recording time (min) | 565 | 511–602 | 248–677 |
| TST (min) | 540 | 494–585 | 226–668 |
| Sleep efficiency (%) | 90 | 86–94 | 60–97 |
| NREM 1 (% of TST) | 4.1 | 2.6–6.0 | 0.1–20 |
| NREM 2 (% of TST) | 41 | 35–46 | 25–82 |
| NREM 3 (% of TST) | 26 | 22–31 | 10–41 |
| REM (% of TST) | 27 | 23–30 | 4–43 |
| Arousal index (number/hr of TST) | 8 | 6–10 | 3–66 |
| Obstructive apnoea/hypopnoea index (number/hr of TST) | 0.6 | 0.2–2.4 | 0–91 |
| Central apnoea/hypopnoea index (number/hr of TST) | 1.7 | 1.0–3.2 | 0–38 |
| Mean oxygen saturation (%) | 97 | 96–98 | 73–99 |
| Lowest oxygen saturation (%) | 91 | 87–92 | 51–95 |
| Oxygen desaturation index (number/hr of TST) | 1.9 | 0.7–4.5 | 0–62 |
| Periodic limb movement index [a] | 2.5 | 0.0–6.0 | 0–17 |
| | **n** | **%** | |
| Total OSA | 21 | 39 | |
| Mild OSA | 10 | 19 | |
| Moderate OSA | 6 | 11 | |
| Severe OSA | 5 | 9 | |
| Periodic limb movement disorder [a] | 7 | 28 | |
| Central sleep disorder | 3 | 6 | |

[a] Limb movement measured in 25 subjects; TST = Total sleep time; NREM=Non-rapid eye movement sleep; REM = Rapid eye movement sleep; OSA=Obstructive sleep apnoea.

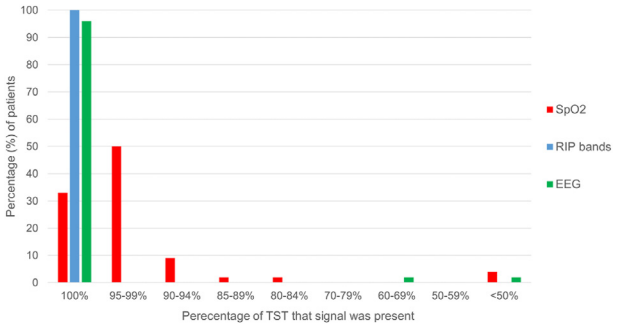


**Fig. 2.** Percentage of sleep time in which polysomnography signals were artefact free. TST = Total sleep time.

provided sufficient information, leaving only 2 subjects (4%) in whom further investigation was required. The criteria used for success in this study were more stringent than in previous studies; 6 h of sleep and key signals present for ≥90% of sleep. Despite this, the data were comparable with previous studies by Iona [6] who reported 81% of studies were technically adequate and 98% interpretable and both Goodwin [7] and Marcus [8] who reported an adequate sleep study in 91% of subjects.

Subjective sleep quality and satisfaction with having a home sleep study were also high. A significant proportion of guardians (76%) reported that their child slept as well or better than usual and only 8%, in retrospect, would have preferred to have had a hospital sleep study if cost had not been a factor.

There are numerous reasons why a Level 2 study was adequate for most subjects. There have been technical advances in ambulatory sleep equipment. The device used is worn on the subject's chest and oximetry connects via Bluetooth technology allowing fewer cords and no connection to devices separate to the subject. This also increases the safety of home sleep studies with fewer choking hazards. In a previous study problems encountered included limited power outlets nears the child's bed, the device becoming unplugged when the child went to the toilet or interference from household devices [8], problems not experienced with more modern equipment. The calibrated airflow signal was also extremely robust and provided an airflow signal in all subjects while the respiratory bands remained in place. The respiratory bands are easily adjusted to fit the child well and remained in place in all subjects with the exception of the child who did not allow any equipment to be applied and one of the children who woke and pulled off all equipment.

It is important to highlight that the investigators had performed more than 200 ambulatory studies prior to this audit. During this time mistakes were made, and procedures were adapted. The most vulnerable signal is oxygen saturation and probes were always securely fastened with tape at set-up. Guardians were provided with clear verbal instructions, a laminated instruction sheet and spare equipment. After-hours calls were uncommon, but the on-call physician was contacted numerous times, most often regarding the oximetry signal. Prior practice of guardians applying at least some of the equipment at home was found to be less successful. Assessing signal quality prior to the subject returning home helped ensure that all equipment/leads had been configured and applied correctly.

The aim of this project was to assess feasibility and not clinical accuracy of home sleep studies. The equipment used in this study is the same as may be used in a hospital sleep study. However, it is conceded that subjects did not have a measure of $CO_2$, direct measurement of airflow or video. A study involving direct comparison of subjects undergoing a Level 1 and 2 study would be required to exclude differences in diagnosis or OSA severity. Ambulatory studies were only offered when the young person had an adequate domestic setting, a guardian who could supervise the study and would not require monitoring by a healthcare professional. During the period of the audit all subjects met these criteria. Some complex patients (for example those with a significant neuromuscular disorder or those receiving respiratory support) will require $CO_2$ and/or clinical

monitoring. It is important to recognise that home sleep studies will not be appropriate for all subjects who require investigation of a sleep disorder because of the nature of the study required, clinical complexity and/or social reasons.

A strength of this study is that it included a population of young people typical of those seen in a sleep clinic, including a broad range of ages (babies through to teenagers) and the majority had an underlying comorbidity including neurodevelopmental, intellectual, or mental health challenges. Ioan also included a clinical cohort of children aged 3-16 y, of whom 14% had neurodevelopmental conditions [6]. Whereas both Marcus [8] and Goodwin [7] included children with few comorbidities aged 5–12 years. Younger subjects and those with significant co-morbidities were sometimes more challenging to set-up or had problems with equipment during the night. However, many did not, and some guardians reported that they believe their child did better in their own home than they would have done in hospital. This audit suggests that young age or neurodevelopmental problems should not necessarily exclude subjects from having a home sleep study. A proportion of home sleep studies will be unsuccessful and thus the ability to repeat studies or perform a Level 1 study will be essential in any service offering home sleep studies.

In summary, successful Level 2 paediatric studies are aided by appropriate subject selection, high quality equipment, trained staff, and on-call support. Level 2 studies are significantly less expensive to perform than Level 1 studies. Although, the financial advantages of Level 2 over Level 1 studies will depend upon how sleep services are funded in the respective healthcare system. This audit demonstrates that Level 2 studies are feasible for a significant proportion of young people requiring a diagnostic study and may even have advantages for those who might sleep better at home than in hospital. Home sleep studies could be used to increase capacity and Level 1 studies could be reserved for young people who require a more complex investigation or who would be better managed in an inpatient setting.

## Funding

Self-funded

## Authors contribution

The project with conceptualised by SB. The investigation was conducted by SB and JG. The data were analysed by SB and KR. The manuscript was written by KR and SB with input from JG.

## Conflict of interest

None conflicts of interest.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: https://doi.org/10.1016/j.sleep.2021.10.024.

## References

[1] Marcus CL, Brooks LJ, Draper KA, et al. Diagnosis and management of childhood obstructive sleep apnea syndrome. Pediatrics 2012;130(3):e714–55.
[2] Picchietti D, Allen RP, Walters AS, et al. Restless legs syndrome: prevalence and impact in children and adolescents–the Peds REST study. Pediatrics 2007;120(2):253–66.
[3] Urquhart DS, Hill EA, Morley A. Sleep-disordered breathing in children. Paediatr Child Health 2017;27(7):328–36.
[4] Allen RP, Picchietti DL, Garcia-Borreguero D, et al. Restless legs syndrome/Willis-Ekbom disease diagnostic criteria: updated International Restless Legs Syndrome Study Group (IRLSSG) consensus criteria–history, rationale, description, and significance. Sleep Med 2014;15(8):860–73.
[5] Pamula Y, Nixon GM, Edwards E, et al. Australasian Sleep Association clinical practice guidelines for performing sleep studies in children. Sleep Med 2017;36(Suppl 1):S23–42.
[6] Ioan I, Weick D, Schweitzer C, et al. Feasibility of parent-attended ambulatory polysomnography in children with suspected obstructive sleep apnea. J Clin Sleep Med 2020;16(7):1013–9.
[7] Goodwin JL, Enright PL, Kaemingk KL, et al. Feasibility of using unattended polysomnography in children for research–report of the Tucson Children's Assessment of Sleep Apnea study (TuCASA). Sleep 2001;24(8):937–44.
[8] Marcus CL, Traylor J, Biggs SN, et al. Feasibility of comprehensive, unattended ambulatory polysomnography in school-aged children. J Clin Sleep Med 2014;10(8):913–8.
[9] Finnsson E, Jónsson SÆ, Ragnarsdóttir H, et al. Respiratory inductance plethysmography for the reliable assessment of ventilation and sleep apnea phenotypes in the presence of oral breathing. Sleep Med 2019;64:S115–6.
[10] American Academy of Sleep Medicine. The AASM manual for the scoring of sleep and associates events: rules, terminology and technical specifications. 6 ed. Darien, IL: American Academy of Sleep Medicine; 2020., Version 2.