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The Analysis of Pediatric Sleep Lab Inefficiencies

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Mechanical Engineering Senior Design Report

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Abstract

The goal of this project is to develop a children's sleep apnea test for home use. This design is to be of cost and quality improvement to what is currently on the market. It is important to fully understand the background of this sleep disorder in order to create this improvement. Knowing what sleep apnea is, as well as the different types, is what is used to create the methods such as S.C.O.P.E.R. Each letter is used to observe one portion or aspect of the human body and how it functions with regards to sleep apnea. The data taken from the test is used in determining sleep apnea, the severity, and necessary treatment. On the side of cost, the price of a sleep test, depending on whether it is a home test or not is taken into consideration for the patient's insurance. This includes anywhere from speaking to a specialist before setting up a sleep test to analyzing the data from said sleep test. These things are all taken into account when designing a sleep test for home use.

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Introduction

Sleep apnea is a disorder that affects millions of americans, with many cases going undiagnosed each year. The current methods of determining sleep apnea, such a sleep lab tests and home tests, help when getting treatment, especially in children. However there is still a demand to improve this type of testing so that more people can be diagnosed and get treatment for this sleep disorder.

Project definition

Background

Sleep apnea is a sleeping disorder that causes the person's breathing to stop in short intervals throughout the night. The breathing can stop anywhere from a few times a night to hundreds of times. When the breathing stops at these times, the person is partially awakened from their deep sleep so they can breath again. Over time, the the quality of sleep goes down, which can cause multiple health complications for the person's long-term health.

The main types of sleep apnea are: obstructive apnea, mixed apnea, and central apnea. Obstructive sleep apnea is the most common form of sleep apnea. This is caused by partial or total blockage of the airways when asleep. This occurs when the throat muscles relax and the tongue or fatty tissues fall back into the airway and block the airflow. Central apnea is when the brain fails temporarily to signal the muscles that control breathing.

There are multiple symptoms of sleep apnea which ultimately leads to one being tested for having sleep apnea. Symptoms include snoring, awakening with dry mouth, morning headache, insomnia, hypersomnia, attention problems, and irritability. Although each symptom alone is not a definite indication of a person having sleep apnea, a combination of these can produce the need for testing.

The amount of people who are affected by sleep apnea are not entirely defined, as hundreds of cases go undiagnosed each year. One estimate states that in America, among 30-60 year olds, there are 4% men and 2% women who have obstructive sleep apnea. Another study shows in the same age group,that 4-24% of men and 2%-9% of women have obstructive sleep apnea. According to the National Heart, Lung, and Blood institute, at least 12-18 million people suffer from sleep apnea. With regards to symptoms and causes,70% of patients who have sleep apnea are overweight and african-americans, hispanics, native americans, and pacific islanders are at the highest risk of being diagnosed with sleep apnea. For children, about 1% to 10% have sleep apnea. Symptoms for children are mild and most outgrow this condition. Additionally, sleep apnea in children is more commonly caused by enlarged tonsils and adenoids.

Once a person is suspected to have sleep apnea they are given testing to determine if and/or the severity of the sleeping disorder. Testing is done by one of two ways: monitoring overnight in a sleep lab (polysomnography) or using a home sleep test. When a doctor receives the results of a sleep test, or even while monitoring the individual during the sleep test, they use a method known as S.C.O.P.E.R. to interpret the data. S.C.O.P.E.R. stands for sleep, cardiovascular, oximetry, position, effort, and respiration. These are the parameters observed as such during testing:

- Quantity of sleep: the amount of time a person is actually asleep during the study. This is done by measuring the brainwaves of the patient.
- Arousals and/or awakenings: these occur spontaneously over the course of the sleep period, and the patient is mostly unaware that they occur. In a sleep test, the amount of times this happens is recorded. Anywhere from 5 to over 100 arousals/awakening can occur in one night for a patient who suffers from sleep apnea.
- Chest movement: the chest is observed to see if the patient is making an effort to breathe or how much of an effort to breathe is made

- Sleep Efficiency: TRT, called sleep deficiency, is the ratio between the total sleep time and the total recording time. Depending on the severity of the sleep disorder, this number can greatly diminish over time
- Sleep Onset Latency: this is the number of minutes between the time the light is turned off to when the patient falls asleep. For a normal person the time is usually about 15 minutes, but when it is shorter, this can indicate sleep deprivation, common in those with sleep apnea.
- Sleep Stages: There are 4 stages of sleep followed by the REM (rapid eye movement) stage, which is the state of "deep sleep":
    - Stage 1: The lightest stage of sleep which should occur in the beginning, and only be about 5% of the total sleep time
    - Stage 2: This stage is also fairly light, however it accounts for about 55-60% of the total sleep time
    - Stage 3 & 4: These are the "deep sleep" stages and they each account for 20% of the total sleep time. If either stage is absent or shortened, the patient will not feel rested the following day.

By observing the structure of these stages, it can be determined whether or not the patient is getting the restorative sleep needed.

Mechanical malfunction: In a patient that has sleep apnea, a possible cause would be physical barriers in the airway. When the soft structures in the back of the throat collapse in the airway, this reduces the amount of air that goes into the lungs and, subsequently, the amount of oxygen that goes into the bloodstream. Reduction in the amount of oxygen going into the bloodstream is what causes the brain to arouse or wake the patient.

In order to observe these parameters, raw data needs to be collected and interpreted. For this multiple sensors are placed on the body with regards to each of these parameters:

- Breathing- thermistor, placed under the nose or cannula, which is placed in the nostrils
- Pulse ox- usually a finger clamp, which records beats per minute and the blood oxygen level
- Electrocardiogram (EKG/ECG)- measures heart rate
- Electroencephalogram (EEG)- measure brain waves
- Respiratory Effort- thoracic sensor that goes in the abdominal area
- Leg movement- accelerometer that measures leg movement
- Electrooculogram- signal pads that measure eye movement
- Chin muscle tone- pads that measure chin movement
- Microphone- records snoring

Process

Getting to a sleep test is the farthest thing from being easy and straightforward. According to the American Sleep Apnea Association (ASAA), the patient has to first schedule an appointment with his PCP who will recommend him to a sleep physician who will then schedule a sleep test for them and then another appointment to go over the results. This is a very long wait for a disorder that plagues a patient daily, not to mention the price they must pay.

Per ASAA, upon sleep abnormality or deprivation, a patient usually visits his primary care physician and explains the symptoms he is facing, the physician then refers the patient to a sleep doctor, who assesses the situation before sending the patient to the sleep lab where the sleep test is done. The patient then does a sleep study called a polysomnography; a polysomnography, as defined by WebMD, is an overnight, onsite test where the patient is hooked up with many electrodes that measure various aspects during sleep. These electrodes are designed to measure SCOPER (Sleep, Cardiovascular, Oximetry, Effort, Respiration) continuously over the course of the study. According to Alaska Sleep Clinic, the results are a series of graphs each showing a single aspect of SCOPER where night time technicians start searching and pointing out abnormalities (Example below). This information is then transferred to a daytime technician who then interprets the information (example below) and sends it to the sleep physician to give his final verdict on the diagnosis. The test requires 6.5-7 hours of continuous sleep to yield accurate results, but could be redone if sleep was not enough. Another sleep study according to the American Sleep Association (ASA) is the in-home study (example below), which is a test the patient does over 3 nights at the comfort of his own home. This test is made up of a portable device that records data, a cannula that measures nasal and oral airflow, elastic bands that go across the chest to measure respiratory effort, and a pulse oximeter used put on as a clip on the patient’s finger to measure oxygen levels in the blood. The patient connects all the equipment to their designated areas on the body for 3 nights. The results will be recorded and saved by the portable device simultaneously with sleep to be then analyzed by a sleep technician who interprets the results and provides the information to the sleep specialist who comes up with a diagnosis or recommendation, according to the University of Tennessee Medical Center.

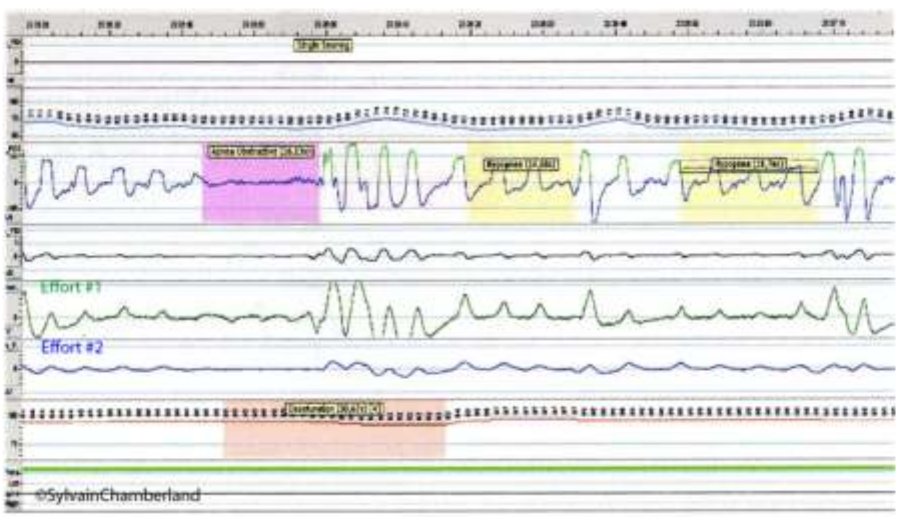

Figure 1: Example of lab results from a sleep test

Diagnostic sleep study report

Name: Doe, John	**DOB:** 1/21/1973	**Age:** 39 YRS	**Sex:** Male
Height: 73"	**Weight:** 205 lbs	**BMI:** 27	**Test:** #136
Test Date: 8/9/2012		**Referring physician:** Dr. Acula	

Mr. Doe is a 39 year-old male referred by Dr. Smith with symptoms of snoring and excessive daytime sleepiness. His bed partner reports that Mr. Doe has apnea episodes and wakes up gasping for breath several times during the night. The patient is 73 inches tall and 205 pounds with a BMI of 27.0. He is significant for a Mallampati class 3 oropharynx.

The medical history is significant for hypertension. His current medications are Lisinopril and Prilosec. The patient's normal bedtime is 10:30 pm. A full in-lab Diagnostic Polysomnography was ordered to rule out the diagnosis of obstructive sleep apnea (OSA).

Apnea/hypopnea index	18.8
Total respiratory events	104
Central apneas	12
Central hypopneas	
Mixed apneas	1
Obstructive apneas	91
Obstructive hypopneas	0
RERA count / RERA index	0 / 0.0/hr
RDI	0.0

Respiratory events by body position	
Supine AHI	31.5
Lateral AHI	35.4
Prone AHI	0.0

Oxygen saturations	
Mean SpO2	96%
Lowest SpO2 during sleep	84%

Limb movements	
Leg movements	562 / 81.2
PLMS	453 / 65.4
PLMS Arousals	55 / 7.9

Sleep times	
Lights out	10:07:44 PM
Lights on	5:25:02 AM
Total bed time (min)	437.3
Total sleep time (min)	357.0

Sleep efficiency	81.6%
Sleep latency (min)	11.6
REM latency (min)	33.1
WASO (min)	**27.2**

	REM	NREM	Arousals	Awakenings	Ar + Aw	Ar + Aw Index
Respiratory events recorded in each category:	0	16	21	6	27	3.9
Snore:	11	25	58	15	73	10.5
Spontaneous:	10	12	28	3	31	4.5
Total:	21	53	107	24	131	18.9
Arousal Index	18.0	12.2	15.5	3.5	18.9	—

Figure 2: Example of interpreted results from a sleep test

Figure 3: Example of what a Home Sleep Test (HST) would look like

After the diagnosis is done by sleep specialist, and there is any sign of a severe abnormality, the patient is then required to do the sleep test again, but this time with a CPAP (Continuous Positive Airway Pressure) device, which is used to treat sleep apnea. The results are then analyzed and interpreted again to confirm the diagnosis, as stated by Alaska Sleep Clinic. According to VeryWell, the price of a sleep study itself ranges from $1,000 to $10,000, for example, a sleep study at Stanford University costs $8500. This is all dependent on the situation, location, and facility. Insurers usually cover most of the costs depending on one's coverage. On the other hand, according to the ASA, in-home testing usually costs between $150 to $500 covered fully by most insurers. If one has insurance, the reimbursement code for this test is ICD-10 with CPT Codes varying with the situation and age and listed below according to the American Academy for Sleep Medicine (AASM). CPT Codes for a normal polysomnography are many more than the ones for a at home sleep test which may imply the at home sleep test is not sufficient to accurately identify sleeping disorders. The list of codes used for both in home and normal sleep tests are listed below.

CPT Codes	Description
95782	Polysomnography; younger than 6 years, sleep staging with 4 or more additional parameters of sleep, attended by a technologist
95783	Polysomnography; younger than 6 years, sleep staging with 4 or more additional parameters of sleep, with initiation of continuous positive airway pressure therapy or bi-level ventilation, attended by a technologist
95800	Sleep study, unattended, simultaneous recording; heart rate, oxygen saturation, respiratory analysis (e.g., by airflow or peripheral arterial tone), and sleep time
95801	Sleep study, unattended, simultaneous recording; minimum of heart rate, oxygen saturation, and respiratory analysis (e.g., by airflow or peripheral arterial tone)
95803	Actigraphy testing, recording, analysis, interpretation, and report (minimum of 72 hours to 14 consecutive days of recording)
95805	Multiple sleep latency or maintenance of wakefulness testing, recording, analysis and interpretation of physiological measurements of sleep during multiple trials to assess sleepiness
95806	Sleep study, unattended, simultaneous recording of, heart rate, oxygen saturation, respiratory airflow, and respiratory effort (eg, thoracoabdominal movement)
95807	Sleep study, simultaneous recording of ventilation, respiratory effort, ECG or heart rate, and oxygen saturation, attended by a technologist
95808	Polysomnography; any age, sleep staging with 1-3 additional parameters of sleep, attended by a technologist
95810	Polysomnography; age 6 years or older, sleep staging with 4 or more additional parameters of sleep, attended by a technologist
95811	Polysomnography; age 6 years or older, sleep staging with 4 or more additional parameters of sleep, with initiation of continuous positive airway pressure therapy or bilevel ventilation, attended by a technologist
94660	Continuous positive airway pressure ventilation (CPAP), initiation and management

Note: Use the Technical Component (TC) modifier when only the technical component is billed and the 26 (professional component) modifier when only the professional component is billed.

Table 1: Insurance CPT codes for a normal sleep test (polysomnography)

Code	Description
G0398	Home sleep study test (HST) with type II portable monitor; unattended; minimum of 7 channels: EEG, EOG, EMG, ECG/heart rate, airflow, respiratory effort, and oxygen saturation
G0399	Home sleep test (HST) with type III portable monitor; unattended; minimum of 4 channels: 2 respiratory movement/airflow, 1 ECG/heart rate and 1 oxygen saturation
G0400	Home sleep test (HST) with type IV portable monitor; unattended; minimum of 3 channels

Table 4: Insurance CPT codes for a Home Sleep Test (HST)

There are many inefficiencies and delays that come from the previous steps. Firstly, According to The Sleep Disorder Clinic it is a minimum of 4-6 weeks before a patient can see a sleep specialist and an extra 30-90 days to be scheduled for a sleep study according to Vol. 169 of the American Journal of

Respiratory And Critical Care Medicine and that number will continue to increase, a recent study done by Merritt Hawkins shows an increase of 30% increase in the period to schedule an appointment; then after the sleep study is done, it usually takes between 1-2 weeks to process results and come up with a verdict for a polysomnography. As for the home sleep test, it still requires a recommendation from a sleep specialist and after the 3-night analysis, it takes 2-4 weeks to come up with a diagnosis. This will lead to prolonged effects from obstructive sleep apnea, as sleep apnea becomes worse with time a patient can go from moderate to severe sleep apnea in that timeframe; in addition to side effects such as high blood pressure, diabetes, and depression according to ASAA and hence the issue with scheduling and time. The equipment of the polysomnography although accurate is overwhelming, many sensors are placed to get the most accurate and detailed reading which could inhibit sleep for some patients, and if patients do not get at least 6.5-7 hours of sleep, they will have to redo the test on a different night. For the home sleep test, it is a bit different, yes there is much less equipment needed to hook up, and the patient is in the comfort of his own home, however it is a 3-night test and if a patient does not feel comfortable the first night, he will grow increasingly frustrated the second and the third which may harm the data. Also, the data collected from the home sleep test is best accurate when the patient suffers from severe sleep apnea, while its accuracy decreases as the severity decreases. Hence, a person that may have already done a home sleep test, might have to do a polysomnography to validate results which adds an extra step and in turn adds unanticipated wait time for the diagnosis. A huge inefficiency for sleep tests according to the National Center For Biotechnology are children; children are considered very challenging when it comes to sleep studies as they do not want to cooperate out of discomfort or fear; this results in inaccurate data that will not be sufficient to diagnose sleep apnea. The sleep test for children is preferred by the child himself, but as stated above could only diagnose the child if he is suffering from severe sleep apnea. Finally, the cost of a polysomnography and although mostly covered by insurance, is an expensive price to pay or even pay partially pay, factoring in the sleep physician, the sleep study and everything else that is required, the patient will have to pay over $10,000 for the whole process if he does a traditional polysomnography; and while the home sleep test is much cheaper, approximately $1000 total, it will not always guarantee the result needed for diagnosis.

Project Scope

The scope of this project is to come up with a device that will solve most if not all these inefficiencies. The home system is a very interesting system that could be enhanced to yield more positive results. The goal of the project is to come up with a device that will be able to function as a polysomnography that could be done at home with the least amount of connections possible. The target price for this device is $50 for manufacturing to reduce the price the consumer must pay to use the product. Also by achieving this goal, the 1-3 month wait period for a normal sleep test becomes a couple of days, as it is also intended to be able to gather all results in one night as the technician connects to the device via WIFI for analysis and interpretation.

Data Features

When reading data from a sleep study, it is important to correctly identify the data from the study. The process of scoring the data will give an idea if there is a presence of sleep apnea. Unless otherwise stated, all scoring data and information in this section is taken from The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications version 2.2.

The tests and equipments used are as follows: electroencephalogram (EEG), electrooculogram (EOG), electromyogram (EMG), Electroencephalogram (EEG) measures brain waves, pulse oximeter (Pulse-Ox), cannula, and electrocardiogram (ECG).

Electroencephalogram (EEG)

Electroencephalogram (EEG) measures brain waves. This a primary source of measurement when determining sleep stages. The sampling rate is desired at 500 Hz but at a minimum is 200 Hz. The data is run through filters: a low-frequency filter of 0.3 Hz and a high-frequency filter of 35 Hz. The EEG outputs a frequency waveform. A few different waves are possible.

Electrooculogram (EOG)

Electrooculogram (EOG) measures eye movement.The sampling rate is desired at 500 Hz but at a minimum is 200 Hz. The data is run through filters: a low-frequency filter of 0.3 Hz and a high-frequency filter of 35 Hz. The EOG outputs a few different waveforms.

Electromyogram (EMG)

Electromyogram (EMG) measures chin movement. The sampling rate is desired at 500 Hz but at a minimum is 200 Hz. The data is run through filters: a low-frequency filter of 10Hz and a high-frequency filter of 100 Hz. The EMG produces a type of waveform called a Low Chin EMG Tone. To establish a baseline EMG activity in the chin derivation, the value is no higher than in any other sleep stage, usually at lowest level of the entire recording. It also produces a Transient Muscle Activity which shows short irregular bursts of EMG activity and usually lasts a duration of less than 0.25 seconds and is superimposed on low EMG tone with maximal in association with REM. This may be seen in EOG or EEG too.

Pulse Oximeter (Pulse-Ox)

A pulse oximeter (Pulse-Ox) measures two variables, pulse in heart beats per minute and blood oxygenation in percentage. A normal beats per minute sits in the range of 60 to 90 bpm. Normal blood oxygenation percentage is between 95 and 100 percent.

Cannula

A cannula measures one variable, breathing. It does this via changes in air pressure. It is generally a prefered method as opposed to thermistor. A cannula more sensitive but it can be less comfortable. It generates one signal, in the shape of a waveform.

Electrocardiogram (ECG)

An electrocardiogram (ECG) uses a series of electrodes placed on the chest. These electrodes measure electric potential. When the heart muscle activates, a change in electric potential occurs which is measurable. The ECG measures the number of peaks, which represent heart activity, and then plots those peaks against time. The useful data that can be interpreted from this is the heart rate in beats per minute.

Heart rate is used to help diagnose sleep apnea. Score is added for a sustained sinus heart rate of greater than 90 bpm for adults. Score is added for a sustained heart rate of less than 40 bpm for adults through 6 year olds. Score is added for asystole (a period of time when the heart does not beat) for cardiac pauses greater than 3 seconds for ages 6 years through adult. Score is added for a narrow complex tachycardia (a rapid heart rate) with a rhythm lasting a minimum of 3 consecutive beats at a rate of greater than 100 bpm with a QRS duration of less than 120 msec. Score is added for an atrial fibrillation (an irregular, usually rapid, heartbeat) if there is an irregular ventricular rhythm associated with replacement of consistent P waves by rapid oscillations that vary in size, shape, and timing.

Pediatric Data

There are slight differences in adult and child sleep cycles. An adult has several sleep stages and they are denoted as such: Stage W (wakefulness), Stage N1 (NREM1), Stage N2 (NREM2), Stage N3 (NREM3), Stage R (REM). For the purpose of a sleep study, an epoch is assigned as a 30 second interval. From this, each epoch is assigned a sleep stage. Occasionally, more than one stage will exist in an epoch. If this happens, it will be assigned to whichever stage takes up more of it. Remain N1 until sign of another sleep stage. Sleep onset is the first epoch rated as anything other than wakefulness.

When we turn our attention to pediatric sleep studies, the scoring is slightly different. Pediatric sleep staging rules to score sleep and wakefulness in children 2 months and older. Electrode placement is slightly different to account for a child's size. Children also have an additional stage N after N3.

Sleep Stage Scoring

The data is split into 30 second intervals called epochs. Each epoch is assigned a sleep stage based on the guidelines laid out in the AASM Manual. For this, the sleep lab technicians look for the types of waveforms mentioned above, specifically for the EEG, EOG and EMG.

Wakefulness

Features and characteristics of wakefulness are distinct. An EOG will show a patient may have rapid eye blinks at about 0.5 - 2 Hz. When viewing an EMG it will have variable amplitude but usually higher than during sleep stages. When the patient's eyes are open, the EEG will show that the pattern consists of low amplitude activity (chiefly alpha and beta rhythm) in occipital region. When the eyes are closed but still the patient is awake most people demonstrate alpha rhythm (posterior dominant rhythm) in the occipital region, or similar to when eyes are open.

The patient is considered in this wakeful stage if more than 50% of epoch (or 30 second interval) contains either for individuals that produce an alpha rhythm with eyes closed EEG, alpha rhythm over the occipital region or, for all individuals, eye blinks, rapid eye movements associated with normal high chin muscle tone, or reading eye movements, or both of these criteria.

Stage N1

This is the first stage the patient is considered asleep. Features and characteristics of this stage are slightly different. An EEG will have a low-amplitude, mixed-frequency signal, or LAMF. An EMG will also be variable, but lower than W stage. The EEG may have Vertex waves, but this is not required for this stage. The EOG may show SEM as it is often in stage 1, but it is not required for N1.

Scoring this stage comes down to a few considerations. If person has alpha rhythm the EEG will show alpha rhythm replaced by LAMF for more than 50% of epoch. If person does not have alpha rhythm, one of the following will happen: the EEG will have a range of 4 - 7 Hz with slowing of background freq by >/= 1 Hz from those in Wakefulness, the EEG will show Vertex sharp waves, the EOG will show slow eye movements. If majority of epoch meets N1 criteria, LAMF EEG, in absence of evidence for another sleep stage it is scored as stage N1, following epochs with LAMF EEG without evidence of other sleep stages.

Stage N2

Features and characteristics of stage N2 include: K-complex, EOG: usually no eye movements, but some slow eye movements (SEM) may be present, EMG: variable amplitude, but usually lower than Wakefulness and may be as low as in REM.

Score as stage N2 if no criteria for stage N3, and either one or more K-complexes unassociated with arousals or one or more sleep spindles occur during the first half of that epoch or the last half of the previous epoch, or if both of these events occur. If majority of epoch meets criteria or stage N2. If the waveforms in the A or B above are followed by an arousal in the same or subsequent epoch, the segment preceding the arousal is N2. Continue to score epochs with LAMF that don't have K-complexes, Sleep Spindles or arousals, if they come after epochs with either K-complexes unassociated with arousals or Sleep Spindles. Epochs following N3 epochs that do not meet N3 criteria if no intervening arousal & epoch does not meet Wakefulness or REM criteria.

Stage N3

Features and characteristics of stage N3 are as follows: the EEG will show slow wave activity or sleep spindles may be present, eye movements are not typical and this is reflected in the EOG, the EMG will have a variable amplitude, but often lower than stage N2 and may be as low as in REM. This stage is scored as N3 when 20% or more of epoch consists of slow wave activity, irrespective of age.

Stage N

This stage applies to pediatric sleep studies. Scoring for this stage is that if all epochs of NREM sleep contain no recognizable Sleep Spindles, K complexes or high amplitude 0.5 - 2 Hz slow wave activity, score all epochs as stage N. If some epochs of NREM sleep contain Sleep Spindles or K complexes, score N2. If in the remaining NREM epochs, there is no slow wave activity comprising more than 20% of the duration of epochs, score as N. If some epochs of NREM sleep contain greater than 20% slow wave activity, score as N3. If there is no K complexes or Sleep Spindles in the remaining NREM epochs, score as N. If NREM is sufficiently developed that some epochs contain sleep spindles and K complexes and others contain sufficient amounts of slow wave activity, then score as an adult.

Arousals

Arousals are an abrupt shift in EEG frequency including alpha, theta, and/or frequencies greater than 16 Hz (but not Spindles) with a duration of at least 3 seconds and preceded by at least 10 seconds of stable sleep. If during REM, requires a concurrent increase in submental EMG lasting at least 1 second.

Conclusions

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APPENDIXA : EEG Waveforms

Based on frequencies:

- slow wave has a frequency of 0.5 - 3.0 Hz and minimum amplitude of 75 µV peak in frontal derivations
- delta wave has a frequency of 0 - 3.99 Hz
- theta wave had a frequency of 4 - 7.99 Hz
- alpha wave has a frequency of 8 - 13 Hz
- beta wave: greater than 13 Hz

The EEG will display the Posterior Dominant Rhythm (PDR) trains of sinusoidal alpha waves in occipital region. Dominant reactive EEG rhythm in relaxed wakefulness. This is slower in infants & young children. Attenuates with eyes opening or attention. Breakdown by age is a follows:

- 3 - 4 months: 3.5 - 4.5 Hz
- 5 - 6 months: 5 - 6 Hz
- 3 years: 7.5 - 9.5 Hz
- 9 years: mean of 9 Hz
- 15 years: mean of 10 Hz
- Adults: 8 - 13 Hz

Low-amplitude, Mixed-frequency (LAMF) with frequency range mostly 4 - 7 Hz.

Vertex Sharp Waves (V waves) are sharply contoured waves over central region with a duration of less than 0.5 sec (as measured at base of wave) and are distinguishable from background activity. Maximal over central region.

K-complex is a well-delineated, negative, sharp wave immediately followed by a positive component for a total duration of over 0.5 sec. It stands out from the background and is usually maximal in amplitude when recorded using frontal derivations. For an arousal to be associated with K complex, the arousal must be either concurrent with K-complex or commence no more than 1 sec after termination of K-complex. It can be considered Slow Waves if it meets the definition.

Sleep Spindle is a train of distinct sinusoidal waves with a frequency 11 - 16 Hz (most commonly 12 - 14 Hz) and a duration greater than or equal to 0.5 seconds. It is usually maximal in amplitude in the central regions.

Slow Wave Activity is characterized by a frequency range of 0.5 - 2 Hz with peak to peak amplitude greater than 75 µV. It is measured over frontal regions referenced to the contralateral ear or mastoid (F4-M1, F3-M2).

Sawtooth Waves are trains of sharply contoured or triangular, often serrated waves with a frequency of 2 - 6 Hz and maximal in amplitude over central portions of head. These waves appear often after a burst of REM.

Major Body Movement is movement and muscle artifact obscuring the EEG for more than half an epoch to the extent that the sleep stage cannot be determined.

APPENDIX B: EOG Waveforms

Eye blinks are conjugate vertical eye movements have a frequency of 0.5 - 2 Hz and are present in wake stage

Reads eye movements trains of conjugate eye movements which is a slow phase followed by a rapid phase in the other direction and is present in wake stage.

Slow eye movements (SEM) are conjugate, reasonably regular, sinusoidal eye movements with an initial deflection usually lasting greater than 500 msec.

Rapid eye movements are conjugate, irregular, sharply peaked eye movements with an initial deflection usually lasting less than 500 msec and may appear in REM or Wake stages.