Respiratory Motion Visualization and the Sleep Apnea Diagnosis with the Time of Flight (ToF) camera.

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Abstract: - A new non-invasive method for diagnosis of sleep apnea, this diagnosis method is based on respiratory motion visualization with a Time of Flight (ToF) camera. The 3D movie taken with this camera visualizes the patient movements while he/she is sleeping, and the respiratory motion is extracted, analyzed and displayed in real time. This method can also be useful in sport medicine or for YOGA practice a. s. o. This low cost non-invasive method can be used for sleep apnea diagnosis evaluation, helping patients and physicians to do further investigations for suspected critical cases.

Key-Words: - sleep apnea, time of flight, TOF, respiratory motion, respiratory force.

1 Introduction

The name "apnea" cames from the Greek "απνοια": from α – privative and πνεειν, to breathe i.e. it is a technical term for suspension of external breathing.

Under normal conditions, humans cannot store much oxygen in their body. Prolonged apnea leads to severe lack of oxygen in the blood circulation. Permanent brain damage can occur after as few as three minutes and death will inevitably ensue after a few more minutes unless ventilation is restored. However, under special circumstances such as hypothermia, or apneic oxygenation, much longer periods of apnea may be tolerated without severe consequences. When a person is immersed in water, physiological changes due to the mammalian diving reflex enable somewhat longer tolerance of apnea even in untrained persons. Tolerance can in addition be trained. The ancient technique of free-diving requires breath-holding, and world-class free-divers can indeed hold their breath underwater for more than nine minutes. Apneists, in this context, are people who can hold their breath for a long time.

Untrained humans cannot sustain voluntary apnea for more than one or two minutes. The reason for this is that the rate of breathing and the volume of each breath are tightly regulated to maintain constant values of CO2 tension and pH of the blood. In apnea, CO2 is not removed through the lungs and accumulates in the blood. The consequent rise in CO2 tension and drop in pH result in stimulation of the respiratory centre in the brain which eventually cannot be overcome voluntarily.

Sleep apnea is a sleep disorder characterized by pauses in breathing during sleep. Each episode, called an apnea, lasts long enough so that one or more breaths are missed, and such episodes occur repeatedly throughout sleep. The standard definition of any apneic event includes a minimum 10 second interval between breaths or 3 or more consecutive breaths missing. For children whose breath frequency is higher, the apneic event is shorter by a few seconds.

The sleep apnea disorder is so common that it wasn't considered to be a disorder till 1965 when the first reports appeared in the medical literature of what is now called obstructive sleep apnea, when it was independently described by French and German investigators.

An accurate clinical picture of adult obstructive sleep apnea syndrome was first described in literature by Charles Dickens in the description of Joe, "the fat boy" in his novel "The Pickwick Papers".
If you are snoring, you have a big chance to have sleep apnea, but not everyone who snores has this condition.
Another common sign of sleep apnea is fighting sleepiness during the day, at work, or while driving. You may find yourself rapidly falling asleep during the quiet moments of the day when you're not active.

You may also have memory or learning problems and may not be able to concentrate or you may feeling irritable, depressed, or have mood swings or personality changes.
For children, the sleep apnea can cause hyperactivity, poor school performance, and aggressiveness.
If you would like to know how severe the problem is, a sleep study is the most accurate test for diagnosing sleep apnea. It captures what happens with your breathing while you sleep. This can be done in a sleep center or sleep lab, which may be part of a hospital, but you may have to stay overnight in the sleep center.

Fig. 1. A patient with all PSG sensors attached at St_ Louis Children's Hospital.

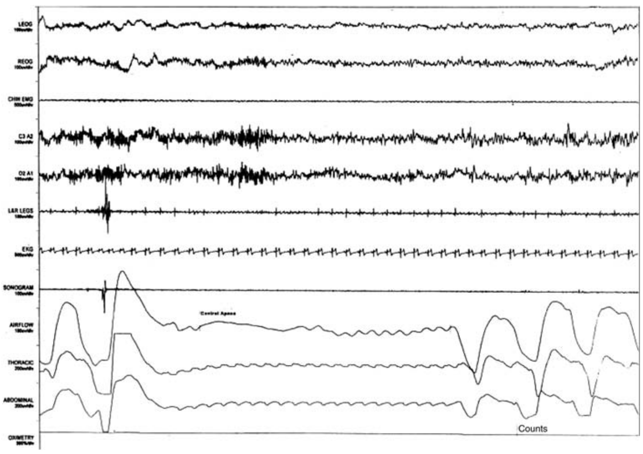

Fig. 2. This is a PSG showing central apnea [1].

Then you’ll receives a polysomnogram (poly-SOM-no-gram), or PSG which is the most common study for diagnosing sleep apnea. This test records:

- Brain activity
- Eye movement and other muscle activity
- Breathing and heart rate
- How much air moves in and out of your lungs while you're sleeping
- The amount of oxygen in your blood

A PSG is painless. You will go to sleep as usual, except you will have sensors on your scalp, face, chest, limbs, and finger. The staff at the sleep center will use the sensors to check on you throughout the night.
A sleep specialist (sometimes a pulmonologist) reviews the results of your PSG to see whether you have sleep apnea and how severe it is. He or she will use the results to plan your treatment.

Clinically significant levels of sleep apnea are defined as five or more episodes per hour of any type of apnea (from the polysomnogram). There are three distinct forms of sleep apnea: central, obstructive, and complex (i.e., a combination of central and obstructive) constituting 0.4%, 84% and 15% of cases respectively. Breathing is interrupted by the lack of respiratory effort in central sleep apnea; in obstructive sleep apnea, breathing is interrupted by a physical block to airflow despite respiratory effort. In complex (or "mixed") sleep apnea, there is a transition from central to obstructive features during the events themselves.

The individual with sleep apnea is rarely aware of having difficulty breathing. Sleep apnea is recognized as a problem by others witnessing the individual during episodes or is suspected because of its effects on the body (sequelae). Symptoms may be present for years (or even decades) without identification, during which time the sufferer may become conditioned to the daytime sleepiness and fatigue associated with significant levels of sleep disturbance [2].
The management of obstructive sleep apnea was revolutionized with the introduction of continuous positive airway pressure (CPAP), first described in 1981 by Colin Sullivan and associates in Sydney, Australia.

The availability of an effective treatment stimulated an aggressive search for affected individuals and led to the establishment of hundreds of specialized clinics dedicated to the diagnosis and treatment of sleep disorders. Though many types of sleep problems are recognized, the vast majority of patients attending these centers have sleep disorder breathing. [3] Some treatments involve lifestyle changes, such as avoiding alcohol or muscle relaxants, losing weight, and quitting smoking. Many people benefit from sleeping at a 30 degree elevation of the upper body or higher, and also from the lateral positions (sleeping on a side), as opposed to supine positions (sleeping on the back). Some people benefit from various kinds of oral appliances to keep the airway open during sleep.

2 Respiratory motion visualization.

The main purpose of our research was to visualize in real time the respiratory motion regardless the position of the body. The patient can freely move in the bed, can turn and sleep in any position; the respiratory motion is recorded with video cameras and processed in real time. Of course it is preferably to use a single camera but it is not a major problem to use more than one.
The cheapest solution was to use web cameras but we preferred the ToF cameras for two simple reasons: it is easier to implement the algorithm for a 3D camera (ToF cameras are 3D), and a major producer announced a future price of under $200.

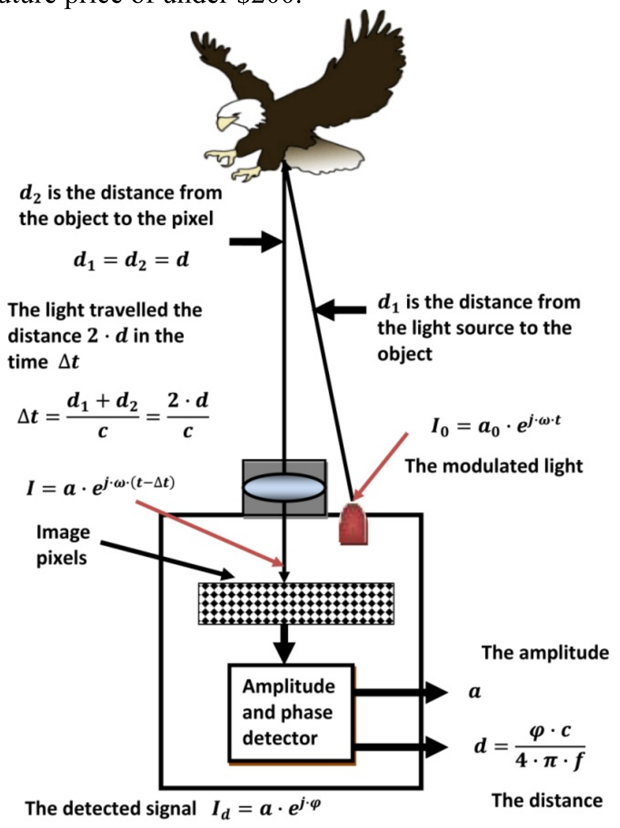

Fig. 3. Illustration of the Time of Flight cameras working principle.

The Time of Flight camera is a new type of 3D camera. With this camera we get two images. One is the usual amplitude image and the other is a distance image. [4]
The camera has its own illumination source - an infrared light. The camera can be used in absolute darkness and because its I.R. illumination source is invisible for the human eye and it does not disturb the investigated subjects.
Each pixel of the camera measures the incoming reflected light and the distance to the objects in the scene. This information is obtained by using amplitude - modulated light. The amplitude and phase of the modulating wave are detected by a phase detector. In this way only the modulated light is detected, and the background light is rejected.
The ToF camera principle is represented in Fig. 1. The distance to the object is given by the relation (1), where the phase difference between the emitted and reflected wave is φ, c is the speed of light and f the modulation frequency [5].

$$d = \frac{\varphi}{4\pi} \cdot \frac{c}{f} \quad (1)$$

For each camera pixel i from the detected light signal $i(t)$ is obtained and the amplitude $a(t)$, phase $\varphi(t)$ and the distance $d(t)$ are computed using (1).
From the amplitude image it is difficult to measure the respiratory motion but from the distance image the thorax and abdomen movements are recorded with 4-30 images per second depending on the exposure time. From this movie we can compute the volume change of each body part, and we can plot the time variation of the volume of the thorax and abdomen. Not all the time the movement of the thorax and abdomen are in phase, and there are situations when their movements have opposite phases. This happens when is an obstruction of the breathing airways, for example during an obstructive apnea crisis. This movement is produced by the contraction of the diaphragm muscle. We used this anti phrase thorax and abdomen respiratory motion (Fig. 4 – 2) to detect obstructive sleep apnea.

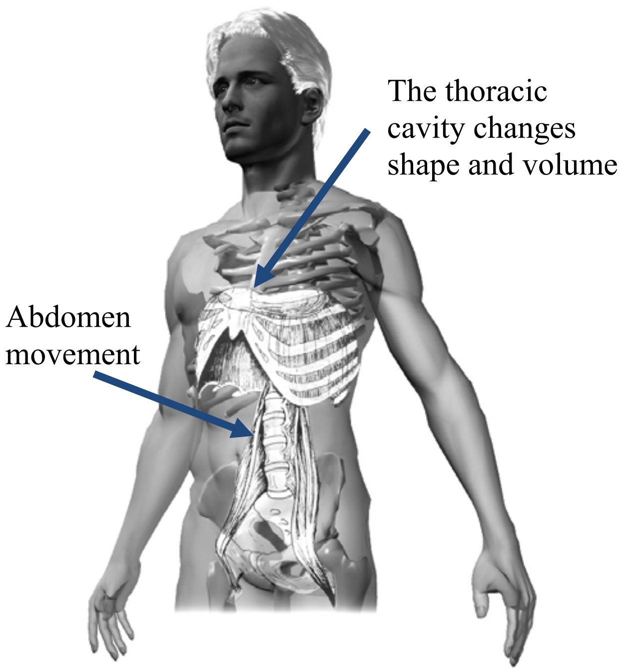

Fig. 4. The volume of the air inhaled and exhaled change the shape of the thorax and abdomen.

In mammals, breathing in (or inhaling), is usually an active movement, involving the contraction of the diaphragm muscle. This is known as negative pressure breathing.
In amphibians, the process used is called positive pressure breathing. Muscles lower the floor of the oral cavity, enlarging it and drawing in air through the nostrils.

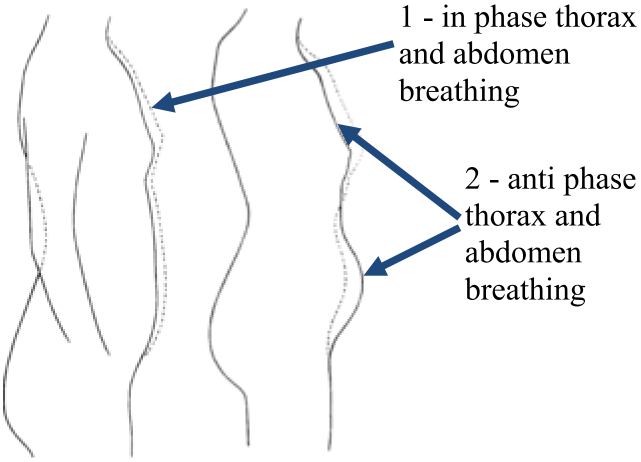

Fig. 5. The body volume change during the breathing.

Breathing is one of the few bodily functions which, within limits, can be controlled both consciously and unconsciously. Sleep breathing is totally different from the waking state breathing, and for this investigation the patient must be asleep.

3 Solution

The experimental configuration we used is a wall mounted ToF camera connected to a portable PC. The ToF camera has its own illumination source in infra red light, invisible for the human eye, so it also works in complete darkness. The recorded movie is processed in real time and the results are transmitted to another room by a wireless network.

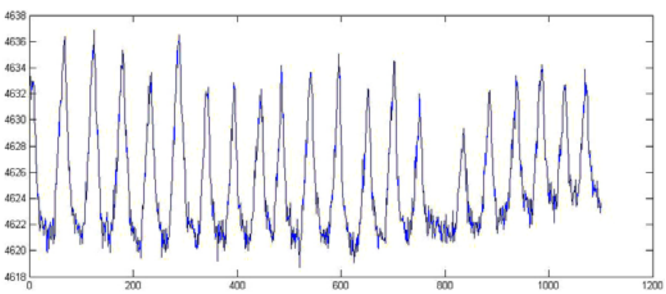

Fig. 6. The breathing effort record. The distance to the patient is represented on the ordinate [mm] and the picture number on abscissa. The recording was made at 14.5[frames/second].

If we recorded the breathing effort of the thorax or abdomen is sufficient to put in evidence a central apnea because in this case is no breathing effort. If there is no breathing effort (the brain stopped the breathing and the respiratory movements cease) as in Fig. 9 this is a case of central apnea. If the patient has an obstructive sleep apnea then the breathing effort exists, but we don't have any air flow, to diagnose this is necessary to record the air flow. The breathing effort during the obstructive sleep apnea is different and we can put in evidence this recording both the thorax and abdomen movements. When the airflows wais are obstructed the contractions of diaphragm muscle determines an anti phase movements of the thorax and abdomen. For the first evaluation of a patient this simple method is benefic.

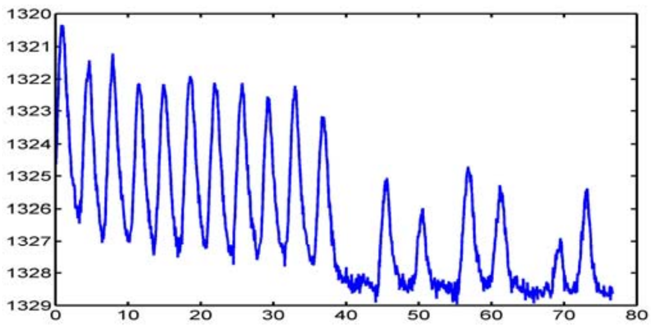

Fig. 7. Normal breathing.

In Fig. 7 shows a recording of a normal breathing, the time in seconds is plotted on the abscissa and the distance to the chest in mm on the ordinate. In the beginning the respiratory frequency of the patient was higher, at 16 breaths per minute. The blood CO_2 changed and the brain commanded the decrease of the breathing frequency to the value of 10-12 breaths/min. The change in the breathing frequency is not always provoked by physiological causes, but also by psychological dreaming, and these changes cannot last for long because the blood parameters are determinant. The above recordings allow us to compute the breathing frequency for each breathing period.

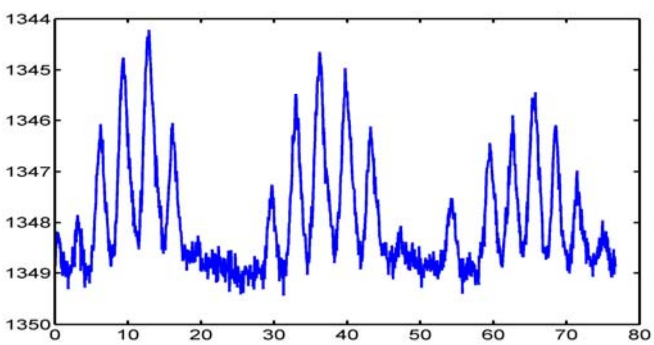

Fig. 8. Snoring breath.

Fig. 8 represents the recording of the thorax movement in the case of a snoring breath. In all these recordings the distance resolution of the thorax movements is less than 1 mm.

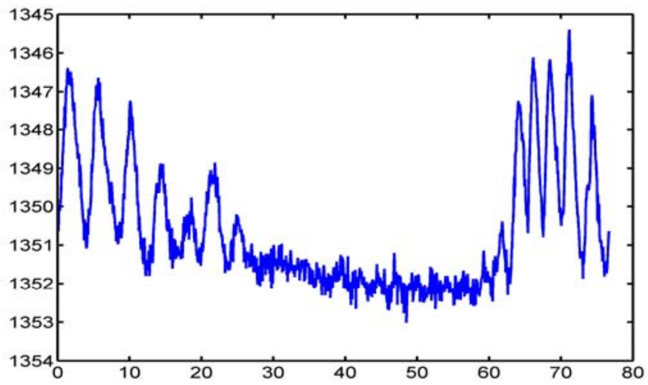

Fig. 9. The thorax movements recording.

The recording of the chest movements in Fig. 9 represents a case of apnea. From this recording it isn't clear whether this is a central or a combined central plus obstructive apnea. The breathing frequency before the apnea was 13 breaths/min and after this it becomes 26 breaths/min. This increase of the breathing frequency is the organism's reaction to the 40 seconds obstruction period.

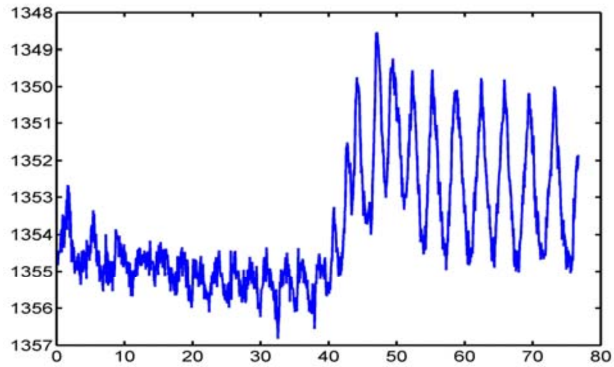

Fig. 10. The thorax movement record.

In the following recordings we encountered a tipic situation which happened during an obstructive apnea. In Fig. 10 and 11 the thorax and abdomen movements have been recorded and in Fig. 12 the movements of the thorax and abdomen have been recorded together.
Because during the apnea period the thorax and abdomen moves in anti phase we observe in Fig. 12 that, during this period, the breathing force is absent, but in the other two recordings it is present. In Fig. 10 the thorax moves during the apnea period and the abdomen also (Fig. 11).

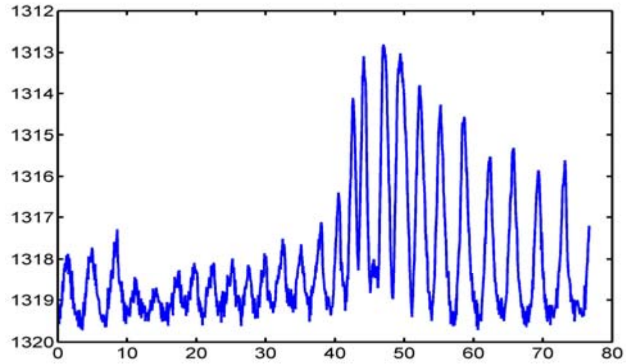

Fig. 11. The abdomen movement record.

We normalized the thorax and abdomen's recordings to the mean distance; these normalized recordings are plotted together in Fig. 13. We observe on this plot that, during the apnea stroke, the respiratory effort has opposite phases for the thorax and abdomen movements. This is the result of the diaphragm muscle action and of the obstruction of the airflow ways.

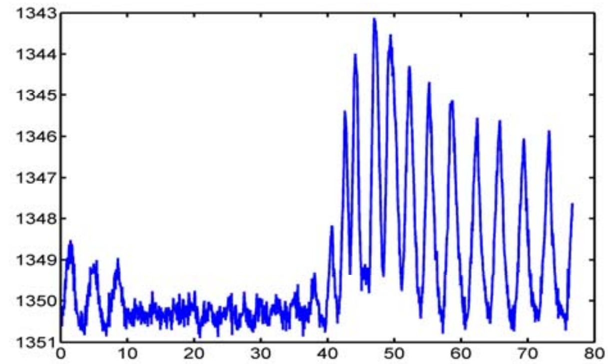

Fig. 12. The sum of the thorax and abdomen movements record.

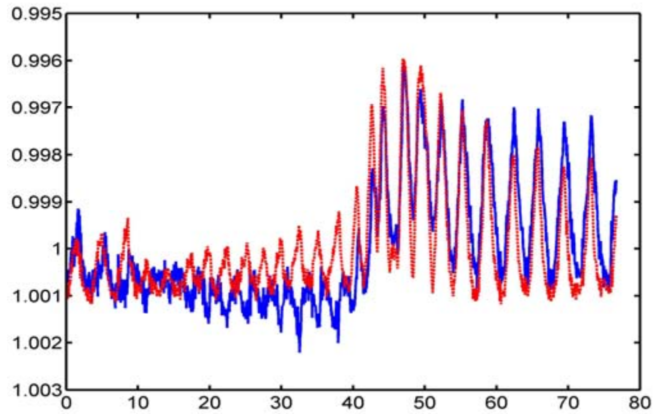

Fig. 13. The thorax (blue) and abdomen (red) normalized movement record.

In Fig. 14 is recorded a mixed apnea with a central component (no airflow or respiratory effort) followed by an obstructive component (no airflow with continued

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respiratory effort) from the Level III portable monitoring system used unattended in the patient's home. The patient was instructed in the outpatient area of the medical center; he took home the system, attached it to himself just before retiring for the night and brought the system back the next day for analysis. The epoch is 60 seconds in duration. Note that the start of arterial oxygen desaturation occurs at about 20 seconds after the start of the apnea. This time delay is due to a combination of arterial circulation lag time from lungs to finger and the oximetry machine electronic lag time from time of sensing to display. Abbreviations: SpO2, pulse oximetry; HR, heart rate; FLOW from a nasal/oral pressure cannula; EFFOR(T) from the movement of a chest wall belt; Pos(ition) is supine (S).[6]

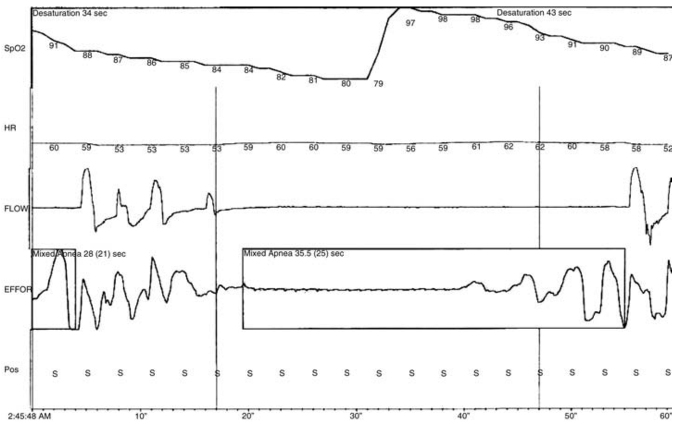

Fig. 14. A mixed apnea with a central component (no airflow or respiratory effort) followed by an obstructive component (no airflow with continued respiratory effort), [6].

4 Conclusion

We developed a non-invasive method of the respiratory effort record and applications of this method to sleep apnea diagnosis.

This new monitoring technique is extremely cheap, efficient and it can be extensively used in hospitals.

The advantages of this method also recommend its use at home to monitor the sleep and the respiratory effort if someone likes to know if he/she has breathing problems and how severe the problems are.

This simple diagnosis method can be used for testing drivers [7], pilots … to prevent human errors because people suffering of sleep apnea have an increase chance of work-related or driving accidents.

Sleep apnea usually is a chronic (ongoing) condition that disrupts sleep 3 or more nights each week; a single negative test in a hospital is not relevant.

Similarly, in any person who has some form of sleep apnea (including obstructive sleep apnea), breathing irregularities during sleep can be dangerously aggravated by taking some drugs as compared to a person with no history of sleep apnea, because apnea is likely to occur with even low levels of the drugs in their system.

Premature infants with immature brains and reflex systems are at high risk for central sleep apnea syndrome, even if these babies are otherwise healthy.

Sudden infant death syndrome is sometimes theorized to be attributable to sleep apnea.

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