



Predicting Technical Success in Home Sleep Apnea Test

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Abstract

Background: Home sleep apnea tests are economical but their technical failure rate is higher than with in-lab studies. We aimed to predict factors related to failures.

Methods: Altogether, 1,055 consecutive respiratory polygraphy recordings for subjects aged 16-90 years (38% female) were included. The sleep nurses were asked to predict the success of the upcoming recording according to their experienced perception. The recording was considered successful if the main recorded parameters (nasal flow, thoracic and abdominal movements, blood oxygen saturation, snoring, and posture) were intelligible during $\geq 80\%$ of the night.

Results: Defects due to a recording device caused a failure rate of 4.4%, and those recordings were excluded from further analyses. Subject-related reasons caused a failure rate of 10.4% (i.e. 70% of all failures). There were no statistically significant differences in the failure rate regarding gender, age, education level, ESS, smoking habits, BMI, comorbidities, sharing a bed with someone, having small children or pets, being outside of working life, or working irregular hours. Nurse's prediction of reliability sorted out successful and unsuccessful recordings statistically significantly ($P=0.035$). The technical success was not statistically significantly different between first-time and repeated recordings.

Conclusions: Background characteristics of the subject or conditions during the recording did not predict the failure of home sleep apnea test. An experienced nurse could still predict the technical success of the recording based on her perception. Even if the first test failed, it is still worthwhile to retest at home, as the failure rate in repeated recordings stayed low.

Keywords

Obstructive sleep apnea; Home sleep apnea test; Reliability; Failure; Recording; Retest

Abbreviations: AASM: American Academy of Sleep Medicine; AHI: Apnea-hypopnea Index; BMI: Body Mass Index; CCI: Charlson Comorbidity Index; CPAP: Continuous Positive Airway Pressure; ESS: Epworth Sleepiness Scale; HSAT: Home Sleep Apnea Test; ODI3: Oxygen Desaturation Index Of Three Percentage Units; OSA: Obstructive Sleep Apnea; PSG: Polysomnography; REI: Respiratory Event Index (corresponding to AHI in PSG)

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Introduction

Obstructive sleep apnea (OSA) is characterized by recurrent upper airway collapse during sleep associated with frequent oxygen desaturations and arousals. OSA is the most common sleep disorder leading to an increased risk of cardiovascular and neurologic comorbidities. The reference standard for diagnosing OSA is an attended overnight polysomnography (PSG) [1]. However, this Level 1 sleep testing is expensive and laborious both for patients and staff. Level 3 testing uses portable monitors which record at least three channels of data (e.g., oximetry, airflow, respiratory effort). This home sleep apnea testing (HSAT) allows diagnostic sleep studies to be done at the patient's home or elsewhere outside a sleep laboratory, like in a hospital ward. For subjects without suspicion of other sleep disorders than OSA, a multi-channel HSAT, respiratory polygraphy, is equally reliable compared to PSG [2,3]. As for the results of HSAT, American Academy of Sleep Medicine (AASM) recommends the use of respiratory event index (REI) instead of apnea-hypopnea index (AHI) because the actual sleep time cannot be determined [1].

Unattended sleep studies have inevitably higher risk of technical failures than attended ones. Previously, the proportion of technically unsuccessful recordings with Level 3 portable monitors has ranged from 3 to 27% [4-11]. Subject-related factors associated with failure rate have not often been addressed. Domingo and Vigil reported that correct performance of HSAT was not affected by gender, smoking habits, education, or type of health insurance [7]. In another study among patients with chronic kidney disease, HSAT was more often failed, if the patient also had comorbid diabetes [10].

Most subjects sleep better at home than in the sleep laboratory [12]. Sometimes children creeping to the same bed during the night, snoring sounds of a bed partner, noise from restless pets or other environmental sources may disturb sleep during the test night, however. Both sleep laboratory personnel and subjects themselves may have doubts about whether a non-professional can manage to hook up the necessary sensors at home before going to bed.

We aimed to look more closely at factors eventually leading to unreliable HSAT, including background characteristics of the subjects but also conditions during the preparations and the actual process of overnight recording in the home environment. Our hypotheses were that subjects with old age, low education level, high body mass index (BMI), or who smoke, have small children or pets at home, suffer from comorbidities in addition to OSA, work irregular hours or are outside of working life, sleep poorly, share a bed with someone, or have findings of a severe OSA in the recording, have higher failure rate in HSAT than subjects without these attributes.

Methods

The Helsinki and Uusimaa Ethics Committee approved the study (38/2013), and because the study is based only on documents completed during normally scheduled outpatient visits and diagnostic procedures, no written informed consent was required.

All consecutive home sleep apnea tests made during the year 2014, altogether 1,055 recordings, were included in this retrospective study. Subjects were referred to our laboratories for suspicion of OSA.

A referral was accepted if the subject had two or more of the following symptoms: excessive daytime sleepiness, loud snoring, pauses in breathing during sleep observed by someone else, headache in the morning, shortness of breath during sleep, cognitive impairment, or depression with a suspicion of association with sleep apnea. Most of the subjects were snorers and suffered from a variable degree of daytime somnolence.

This study was conducted in two separate laboratories: Center A: Department of Clinical Neurophysiology and Center B: Sleep Unit at the Heart and Lung center.

Center A

Subjects were referred by general practitioners (65%) and specialists (35%, mostly otorhinolaryngologists and neurologists), and 947 HSATs were conducted during the single year. Nineteen qualified female nurses with a mean age of 43 years and with an experience of eight years on average, and two female nursing students participated. Of note, there are very few sleep technicians in our country, and therefore qualified nurses prepare the recordings and instruct the subjects.

Center B

Subjects were referred mainly from pulmonary or other departments in the university hospital. Sleep Unit is focused on performing in-lab PSG and starting continuous positive airway pressure (CPAP) treatment. During the single year, 108 HSATs were conducted by eight qualified female nurses with a mean age of 35 years and with an experience of four years on average.

On both locations, qualified nurses instructed the subjects in the preceding afternoon before HSAT. The guiding session usually lasted about 30 minutes. Afterwards, the nurse predicted the technical success of the upcoming recording by marking a vertical line on a 10 cm long line segment, the ends being total success (100%) and total failure (0%). She was asked to explain which factors she based her prediction on, the options being the subject's fine motor, memory, or language skills, other diseases, aberrations in sleep cycle, motivation, being in a hurry, and understanding the instructions. It was possible to pick more than one predictive factor.

In addition, between the guiding session in the afternoon and going to bed in the evening, the subject was asked to predict the technical success of the upcoming recording, similarly to a nurse. The subject was also asked to estimate his or her motivation to the study and whether he or she felt that the amount of information about how to proceed at home in the evening, during the night, and in the morning was sufficient. These two estimates were asked with the help of the 10-cm long line segment, as well. The subjects also filled in a questionnaire based on Basic Nordic Sleep Questionnaire [13] with some new questions about the household arrangements, e.g., ages of children living with the subject. Age-adjusted Charlson comorbidity index (CCI) was measured, as well [14,15].

All cardiorespiratory polygraphs included in this study were performed at home. Subjects used either a NOX T3 Sleep Monitor (Nox Medical, Reykjavik, Iceland) or an Embletta Gold device (Embla, Denver, CO, USA) to perform HSAT. Respiratory parameters were scored manually according to AASM criteria [16].

Every morning, when an HSAT device was returned to the center, the recording was downloaded to a computer and all the signals were inspected. Had there been faults lasting for more than a

couple of minutes, the function of the particular sensor was checked thoroughly, usually so that the nurse wore the sensor herself for a while. Thus, defective sensors and devices were detected before they were given to the next subject. This procedure allowed us to classify failures to device-related and subject-related, as well. If no defect was found during the check, we assumed that the failure in the recorded signal was caused by the subject, who perhaps totally forgot to put on an oximeter or did not fasten it tightly to a finger etc.

Two authors (AA, AB) went through all the signals in all the recordings and assessed if they were good enough to be interpreted. First, a proportion of recording time with a technically reliable signal was assessed for each signal. Then, the recording was considered *technically successful*, if the recording time was ≥ 4 hours and all the important recorded signals (nasal cannula or thermistor, either thoracic or abdominal respiratory belt, pulse oximetry, snoring sensor, and position sensor) were intelligible during at least 80% of the night [7].

However, not all those recordings which failed to fulfill the criteria presented in the literature were actually repeated. If the initial results showed a diagnosis of severe OSA (i.e., REI was $>30/h$), a retest was not carried out despite moderate technical problems in order to avoid further delays in starting the treatment. A total failure in the oximeter signal was always an indication for retest, however. In addition, it was considered possible to give a reasonably reliable answer from the recording in a case when a subject slept only 3 h 50 min or there were problems with snoring sensor or respiratory belts, but the remaining available data showed a moderate or severe OSA. These recordings were considered *clinically reliable* and this assessment was agreed by all the authors. In other words, *clinically reliable* recording refers to the processes in everyday clinical practice.

Statistics

Results were generated with a computerized statistical package (IBM SPSS® Statistics 22.0, Armonk, NY, USA). We used the Student's *t* test for continuous variables and Chi Square test for categorical variables. Some of the measured parameters had slight abnormalities with their distributions, but our material is so large that parametric tests can be used in any case. All *P* values are two-sided, and the significance level is set at 0.05 throughout. For descriptive purposes, we report values as means and standard deviation.

Results

Altogether, 1,055 successive HSATs were included in this material. They were done to 997 different subjects, aged 16-90 years. Additionally, 58 recordings were repetitions. Sixty-two percent of tests were performed to male subjects, who were, on average, younger than female subjects (Table 1).

Of these 1,055 recordings, 900 were *technically successful* (see methods for the definition). That is to say, *technical success* rate in the whole material was 85.2%. When separate signals are considered, thermistor was by far the most vulnerable signal, while the position detector had the highest quality (Figure 1). Recording time was less than four hours in only four recordings, if they were otherwise technically successful. Female subjects' recordings had better quality in all different signals, particularly the air flow measured by nasal cannula (Table 1).

Failure of the recording was due to a technical defect in the function of a measuring device in 30% of the *technically unsuccessful* cases. In

Table 1: All home sleep apnea tests.

	All	Female	Male	P
n	1055	402	653	
Age (y)	53.8 (15.0)	56.2 (15.0)	52.4 (14.8)	<0.001
Quality of air flow, nasal cannula	95.2 (16.5)	97.4 (11.2)	93.9 (19.0)	<0.001
Quality of air flow, thermistor (n=111)	87.2 (29.9)	91.7 (25.1)	84.7 (32.1)	0.205
Quality of oximeter	94.2 (20.2)	95.7 (16.8)	93.3 (21.9)	0.045
Quality of respiratory movements, thorax	95.5 (19.1)	96.0 (17.4)	95.2 (20.1)	0.466
Quality of respiratory movements, abdomen	95.6 (18.8)	97.1 (15.0)	94.8 (20.8)	0.038
Quality of snoring with microphone (n=629)	95.4 (13.1)	96.1 (9.4)	95.0 (14.9)	0.222
Quality of position data	97.8 (12.7)	98.9 (6.4)	97.2 (15.2)	0.014
Technically successful (%)	85.2	87.6	83.8	0.092†
Technically unsuccessful (%)	14.8	12.4	16.2	0.092†
Failure due to device (%)	4.4	3	5.2	0.086†
Failure due to subject (%)	10.4	9.4	11	0.086†
Clinically unreliable (%)	7.6	6.5	8.3	0.283†

Note: Quality of the main recorded signals and success rate as a whole in female and male subjects. Data expressed as mean (standard deviation) or percentages. Statistically significant gender differences written in bold. †Chi Square test (for categorical variables), other rows: Student's t test (for continuous variables).

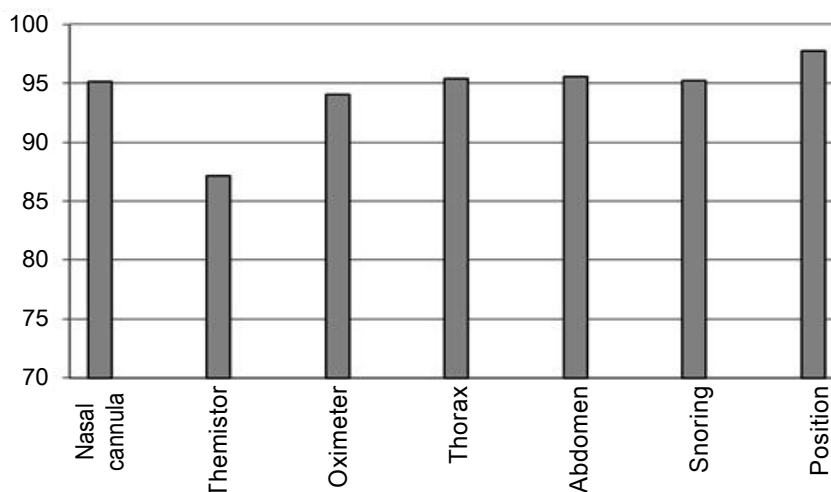


Figure 1: Success rate of first-time and retested recordings with no statistically significant differences (P=0.435).

other words, defects due to a recording device caused a failure rate of 4.4%, and those recordings were excluded from further analyses. The most common reasons comprised defects in an oximeter contact or a missing data from the whole night. There were differences between the separate laboratories. The smaller Sleep Unit conducted 8.3% of all recordings but 21.2% of *technically unsuccessful* recordings.

Of all recordings, 10.4% were *technically unsuccessful* due to the subject and not device. Subject-related reasons caused 70% of all failures. The classification to device-related and subject-related failures was made after the check in the following morning by the sleep nurse (see methods for further details). In order to find out what kind of subjects are more prone to failures, we analyzed further only those 1,009 recordings, where the device itself had functioned properly. The *technical success* rate without device-related failures was 89.1%.

All the background characteristics of the subjects with *technically successful* and *unsuccessful* recordings without device-related failures are compared in Table 2. Surprisingly, there were no statistically

significant differences in regard to gender, age, education level, Epworth sleepiness scale (ESS), smoking habits, BMI, having comorbidities, sharing a bed with someone, having small children or pets at home, being outside of working life, or working irregular hours. REI, oxygen desaturation index of three percentage units (ODI3), recording time, and subjective sleep quality during the recording were also similar. The used device or the laboratory did not make a difference here.

Nevertheless, the nurse could still predict the *technical success* of the upcoming recording statistically significantly, as the prediction for success in recordings that turned out to be *technically successful* was 86.9%, while the prediction was 83.2% in recordings that failed in the following night (Table 2). Furthermore, in a gender-specific analysis, it was noticed that the nurse could very well predict the *technical success* of the recordings of male subjects: the nurse's prediction for success was 88.0% (SD 14.3%) in *technically successful* recordings vs 82.0% (SD 18.9%), P = 0.014, in *technically unsuccessful* recordings. On the contrary, the nurse could not at all predict the *technical success* of the upcoming recording of female subjects: the

Table 2: HSAT without device-related failures.

	Technically successful	Technically unsuccessful	P
n	899	110	
Females (%)	39.2	34.5	0.349†
Age (y)	53.8 (14.7)	54.3 (17.2)	0.768
BMI	29.5 (6.4)	29.4 (7.0)	0.926
ESS	8.2 (4.4)	8.4 (4.6)	0.751
Age-adjusted CCI	0.61 (1.3)	0.76 (1.5)	0.298
Smoker (%)	19.5	20.2	0.860†
Ex-smoker (%)	35.2	40.4	0.297†
Sleeps usually alone (%)	51.9	44.3	0.142†
Underage children (%)	22.4	21.9	0.918†
Pets (%)	25.2	19.6	0.213†
Working (not unemployed, sick, or retired) (%)	49.8	41.2	0.102†
Shift work (%)	7.3	8.8	0.589†
High education level (%)	33	29.1	0.429†
Nurse's prediction of success (0-100%)	86.9 (15.0)	83.2 (17.1)	0.035
Subject's prediction of success (0-100%)	81.5 (17.6)	78.6 (18.5)	0.141
Subject's motivation (0-100%)	93.3 (10.6)	93.5 (7.8)	0.8
Subject's view of adequate information (0-100%)	94.3 (9.4)	94.0 (8.8)	0.761
Embletta Gold device (vs. NOX T3) (%)	39.5	39.8	0.948†
Sleep Unit (vs. Dep. of Clin. Neurophysiol.) (%)	8.3	12.7	0.126†
REI (/h)	20.7 (21.5)	17.7 (18.5)	0.151
ODI3 (/h)	21.2 (21.4)	19.7 (21.3)	0.533
Recording time (min)	435 (71)	419 (99)	0.128
Subjective sleep quality (0-100%)	44.3 (25.1)	44.5 (28.0)	0.929

Note: Background characteristics, estimates of the reliability by nurses and subjects themselves prior to the recordings, and recording details of *technically successful* and *unsuccessful* HSAT. Data expressed as mean (standard deviation) or percentages. Statistically significant differences written in bold. †Chi Square test (for categorical variables), other rows: Student's t test (for continuous variables). HSAT: Home Sleep Apnea Test; BMI: Body Mass Index; ESS: Epworth Sleepiness Scale; CCI: Charlson Comorbidity Index; REI: Respiratory Event Index; ODI3: Oxygen Desaturation Index of Three Percentage Units.

nurse's prediction for success was 85.1% (SD 16.0%) in *technically successful* recordings vs 85.3% (SD 12.9%), P = 0.943, in *technically unsuccessful* recordings.

Understanding the instructions during the guiding session was the most significant predictive factor (P = 0.047). By contrast, the subject himself/herself was not able to predict the *technical success* of the upcoming recording. His or her motivation or the impression of having adequate amount of information about the recording did not differ at all between *technically successful* and *unsuccessful* recordings (Table 2).

However, not all those recordings which failed to fulfill the criteria for *technically successful* recording presented in the literature were repeated. Of the total amount of 1,055 home sleep apnea studies, 80 (7.6%) recordings were *clinically unreliable* (see methods for the definition), i.e. it was necessary to repeat them. In Table 3, background characteristics of the subjects are compared between those *clinically reliable* and *unreliable* HSAT where the device had functioned properly. If the subject usually sleeps alone, the recording was more prone to be *clinically reliable*. Other background characteristics of the subjects were similar in *clinically reliable* and *unreliable* recordings. REI was statistically significantly higher in *clinically reliable* recordings.

The nurse could predict the *clinical reliability* of the upcoming recording even better than the *technical success* described above, particularly of male subjects: the nurse's prediction for success was 87.9% (SD 14.4%) in *clinically reliable* recordings vs 76.9% (SD 21.1%), P<0.001, in *clinically unreliable* recordings, but not of female subjects. Understanding the instructions during the guiding session

was statistically very significant predictive factor (P = 0.001). In addition, a memory deficit was a significant predictive factor for a *clinically unreliable* recording, although it appeared quite rarely.

In repeated HSAT, the *technical success* rate without device-related failures was 86.0% (Figure 2). It was not statistically significantly different from first-time recordings (P = 0.435). Repeated recordings did not differ from the first-time recordings in any of background characteristics or recording details, either (not shown).

Discussion

To the best of our knowledge, this is the largest study aiming to predict factors causing *technically unsuccessful* HSAT. We studied all recordings during one year conducted to subjects with moderate or high susceptibility for obstructive sleep apnea. We found that age, education level, ESS, smoking habits, BMI, comorbidities, sharing a bed with someone, having small children or pets at home, being outside of working life, or working irregular hours did not predict the failure. Had there been significant predictive factors for *technically unsuccessful* recordings, they would certainly have emerged in this very large material.

Many colleagues working in the sleep medicine field presume that elderly subjects or subjects with numerous pets or many small children cannot be reliably studied in the home environment. Our present data did not support this presumption. There were no statistically significant differences in the *technical success* rate with respect to age or any other background characteristics or conditions during the recording. Surprisingly, if a subject had a teenager or a dog at home, a recording was actually slightly more prone to be technically successful in our study. Probably these factors are not

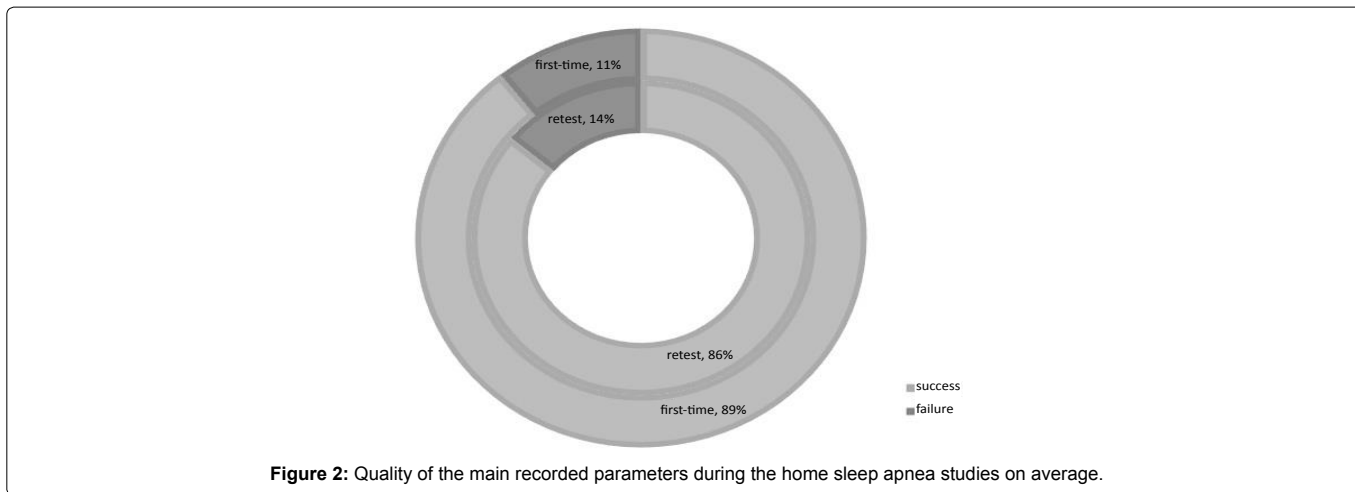


Figure 2: Quality of the main recorded parameters during the home sleep apnea studies on average.

Table 3: HSAT without device-related failures.

	Clinically reliable	Clinically unreliable	P
n	959	50	
Females (%)	38.7	38	0.923†
Age (y)	53.9 (14.9)	53.4 (17.3)	0.84
BMI	29.5 (6.4)	29.7 (7.2)	0.792
ESS	8.2 (4.4)	8.6 (4.3)	0.579
Age-adjusted CCI	0.61 (1.3)	0.90 (1.6)	0.218
Smoker (%)	19.7	15.6	0.490†
Ex-smoker (%)	35.3	44.4	0.213†
Sleeps usually alone (%)	51.9	35.4	0.026†
Underage children (%)	22.3	21.7	0.925†
Pets (%)	24.9	20	0.460†
Working (not unemployed, sick, or retired) (%)	49.2	40.9	0.282†
Shift work (%)	7.5	6.8	0.861†
High education level (%)	32.7	31.1	0.830†
Nurse's prediction of success (0-100%)	86.8 (15.0)	79.5 (19.3)	0.018
Subject's prediction of success (0-100%)	81.3 (17.7)	80.6 (16.8)	0.81
Subject's motivation (0-100%)	93.3 (10.5)	93.2 (8.2)	0.907
Subject's view of adequate information (0-100%)	94.2 (9.4)	94.6 (6.6)	0.692
Embletta Gold device (vs. NOX T3) (%)	39.2	45.8	0.360†
Sleep Unit (vs. Dep. of Clin. Neurophysiol.) (%)	8.9	8	0.834†
REI (/h)	20.6 (21.3)	12.9 (17.8)	0.029
ODI3 (/h)	21.2 (21.2)	17.6 (27.8)	0.532
Recording time (min)	435 (72)	402 (115)	0.096
Subjective sleep quality (0-100%)	44.5 (25.2)	40.7 (28.4)	0.339

Note: Background characteristics, estimates of the reliability by nurses and subjects themselves prior to the recordings, and recording details of *clinically reliable* and *unreliable* HSAT. Data expressed as mean (standard deviation) or percentages. Statistically significant differences written in bold. †Chi Square test (for categorical variables), other rows: Student's t test (for continuous variables). HSAT: Home Sleep Apnea Test; BMI: Body Mass Index; ESS: Epworth Sleepiness Scale; CCI: Charlson Comorbidity Index; REI: Respiratory Event Index; ODI3: Oxygen Desaturation Index of Three Percentage Units.

protective as such but they associate with a subject having “a life in order” with an interest in health.

Even if strong predictive factors could not be detected, experienced nurses could still predict *technical success* rate and *clinical reliability* very well in this large material. Our nurses managed to predict the failure of the recording remarkably well in men, but not in women. One reason behind this gender difference might be women's older age which, in the conditions of using technical equipment, sometimes rises concerns among younger personnel. Another explanation could be that, during the guiding session, women expressed their worries about the recording while men often hid their expressions.

The fact that home sleep apnea tests collected in this study were conducted in two separate sleep laboratories revealed some differences between centers. Center A, Department of Clinical Neurophysiology, was larger than Center B, Sleep Unit. It is specialized in various recordings and tests, also outside the sleep medicine field. Center A performed eight times more HSAT than center B, yielding in better team and personal experience. Center A had a detailed and systematic check of the recorded signals which probably prevented some device-related technical failures that emerged in Center B where a shorter device check was done. As a consequence, the device-related *technical success* rate was slightly lower in center B. The practice

of routinely testing the quality of the main recorded signals can be warmly recommended to every sleep laboratory conducting HSAT. The number of the recording devices should be large enough in order to enable a proper check and also maintenance, if needed, between the recordings. When only subject-related *technical success* rate is considered, there was no statistically significant difference between the centers. This leads to a conclusion that both centers had sufficiently qualified nurses. The nurses evaluated the ability of the subject in assimilating instructions and adjusted their instructions to obtain the best results. Sometimes a 30-minute instruction time proved insufficient but the nurses had to cope with their daily schedule.

The overall proportion of *technically unsuccessful* and *clinically unreliable* recordings was comparable to earlier research. Previously, results have ranged from 3 to 27%, depending on the definition of failure and on the characteristics of the patient group, like devastating comorbidities [4-11]. Our failure rate was relatively low, as only 7.6% needed another test. What is more, repeated HSAT also had an equally low failure rate. Hence, there is no need to send the subject to much more expensive in-lab sleep study.

Limitations

Our study has certain limitations to address. All subjects in the study had the same national insurance system covering about 90% of the total HSAT costs; therefore, we cannot generalize our conclusions to other health insurance systems. Moreover, 99% of subjects were of Caucasian origin, and the failure rate may be different in other groups. Both participating centers were part of the university hospital, and results cannot be generalized to other types of sleep centers. We cannot draw conclusions about other types of HSAT devices than the two used in this study. The precise time spent in the individual guiding session prior to the recording and its correlation to the success rate is unknown.

Conclusions

Gender, age, education, comorbidities, or other background characteristics did not predict the failure of HSAT. Even if there was a failure, it is cost-effective to retest at home, as the failure rate in repeated recordings stayed low.

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