

The validity of the static charge sensitive bed in detecting obstructive sleep apnoeas

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ABSTRACT: The demand for polysomnographic recordings associated with respiratory control exceeds the capacity of the few existing sleep disorder centres and therefore a simple and inexpensive method is needed for screening and diagnosing sleep-related breathing disorders. The static charge sensitive bed (SCSB) permits long-term recordings of body movements, respiratory movements and the ballistocardiogram (BCG) without electrodes or cables being attached to the subject. The aim of the present study was to test the validity of this particular method in detecting obstructive sleep apnoeas without airflow measurements. Simultaneous SCSB and spirometer recordings were compared in fourteen sleep apnoea patients and six controls. The mean sensitivity of the SCSB method to detect the obstructive apnoeas was 0.92-0.98. The specificity to detect 2 min apnoea epochs was 0.61-0.68 in the apnoea group, while in the control group it was 0.99-1.00. According to this study, the SCSB detects the obstructive events without always distinguishing between severe periodic hypopnoeas and obstructive apnoeas. The sensitivity of the SCSB makes it valuable for screening subjects suspected of having obstructive sleep apnoeas. Further studies will concentrate on a more detailed analysis of the various respiratory, BCG and body movement patterns, which may lead to additional information on the severity of the upper airway obstruction.

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The limited number of sleep disorder centres makes it difficult to perform all-night polysomnographic recordings in all subjects thought to suffer from an obstructive sleep apnoea syndrome (OSAS). Thus there is a need for a more simple screening method. For that purpose the static charge sensitive bed (SCSB) could be of interest.

The SCSB is a sensitive movement sensor. It enables polygraphic recordings of the movements in the head, trunk and extremities, as well as respiratory movements and ballistocardiogram (BCG), reflecting the mechanical activity of the heart. No electrodes, strain gauges or other cumbersome devices need to be attached to the subject [1, 2]. The SCSB has been proposed as a method to investigate different sleep disorders including periodic movements during sleep, sleep-related respiratory abnormalities, sleep-related cardiovascular impairments etc. In a previous study BRISSAUD *et al.* [3] showed that certain SCSB patterns could predict the severity of the arterial oxygen desaturation in obstructive sleep apnoea patients. Because obstructive sleep apnoeas are associated with specific haemodynamic changes [4-6], modifications of respiratory movements [7] and arousal body movements [8], they should be appropriately detected with this method without airflow measurements. To test the validity of the SCSB method in detecting obstructive apnoeas, a comparison was made between

two independent recordings, the SCSB polygraph and a spirometer recording.

Subjects

Fourteen subjects (aged 50 to 74 yr, median 57 yr) with clinical symptoms of a sleep apnoea syndrome (loud snoring, interrupted sleep, nocturnal agitation, daytime somnolence) and six controls (aged 27 to 49 yr, median 35.5 yr) without suspicion of sleep apnoeas, entered the study.

Materials and methods

Instrumentation

The static charge sensitive bed¹ consists of a 2 cm thick movement sensor (registering mattress) lying under a normal foam plastic mattress (fig. 1). The sensor is composed of two bed-sized metal plates separated from each other by a stiff insulating plate. The plates thus form a kind of capacitor which is covered on the other side with static charge producing 'active layers'. Various body movements modify the capacitor charge by shifting the 'active layers' in

¹The static charge sensitive bed (Bio-Matt®) and the preamplifier used in this study are produced and delivered by Biorec, SF-21620 Kuusisto, Finland (price appr. 4 000 dollars).

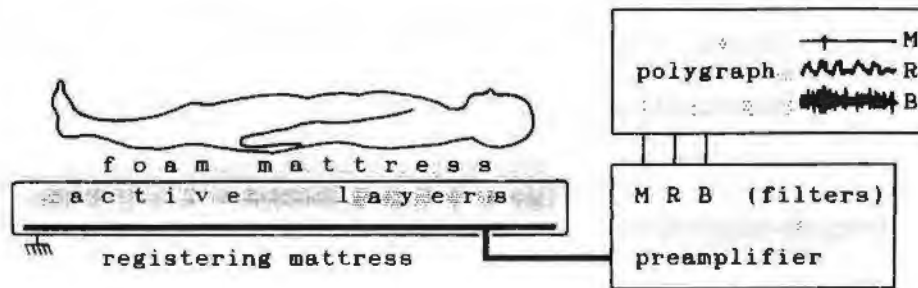


Fig. 1. Principle of the static charge sensitive bed with three channel output (body movement (M), respiratory movement (R) and ballistocardiogram (B)).

relation to the plates. The potential differences consequently induced between the plates are led off to a conventional differential (AC or DC) amplifier.

The body movement channel is derived from the moderately amplified signal in its complete frequency range (0.3–30 cps). For the respiratory movement and the ballistocardiogram the original signal is further amplified and filtered respectively with the frequency limits of 0.3–1.5 cps and 5–30 cps.

According to ALIHANKA [9], obstructive apnoeas are scored on the SCSB if the following criteria are met (fig. 2c): 1) Respiration: increasing amplitude of respiratory movements 2) Ballistocardiogram (BCG): normal or increased respiratory variation of BCG during the apnoeic event 3) Body movement: arousal movement (post apnoea movement) at the end of each apnoeic event.

In this study the SCSB recordings were analysed in 2 min epochs. An apnoea epoch was scored if one or more obstructive apnoeas were counted during the epoch.

The airflow was measured by an ATM Pesty spirometer. The critical part of the spirometer was the thermistor, which was connected to the expiratory line immediately after an inspiratory-expiratory valve attached to a nasobuccal silicone rubber mask. With this device no information about the inspiratory airflow could be obtained. In certain cases a special caulk was needed to insure an airtight fit. To aid the detection of a possible air leak in the mask the arterial oxygen saturation was controlled by a Biox II ear oximeter. A complete cessation of expiratory airflow lasting 12 s (corresponds roughly to the 10 s criterion when the first inspiration after apnoea is included) or more was scored as an apnoea. One or more such cessations of the expiratory airflow during a 2 min epoch indicated a positive apnoea epoch.

Data collection

On-line SCSB (body movement, respiration and BCG channels), spirometer and oximeter signals were recorded on an 8-channel polygraph with a $2.5 \text{ mm}\cdot\text{s}^{-1}$ paper speed. Parallel to this system, a conventional polysomnography (paper speed $10 \text{ mm}\cdot\text{s}^{-1}$) including electroencephalogram (EEG), electro-oculogram (EOG) and electromyogram

(EMG) was used to assess the states of alertness. To enable a comparison of the two recordings with different paper speeds, the tracings were encoded by a binary timer.

Scoring

First, three independent scorers analysed the number of apnoeas and apnoea epochs on the three-channel SCSB recording while masking the spirometer and oximeter channels. The scoring team, then working together, analysed the number of apnoeas and apnoea epochs on the spirometer recording while masking the SCSB channels. For this study, only the first one hour of sleep without prolonged EEG awakening was taken into account.

Data analysis

An analysis of variance for repeated measures design [10] on one factor was used to assess the concordance between the three individual scorers and between the three scorers and the spirometer. An intraclass correlation coefficient of reliability between the three scorers was also determined.

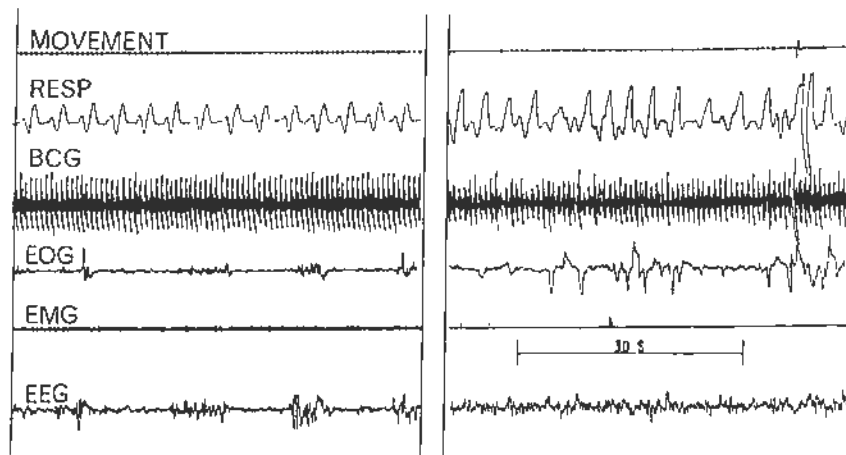
The mean sensitivity and the mean positive predictive value of the method to detect each individual apnoea were determined by comparing the data from the two recordings, apnoea by apnoea. This analysis, however, did not allow evaluation of the specificity.

To assess the specificity and the negative predicted value, the data from the two recordings were analysed in 2 min epochs. The true/false positive/negative apnoea epochs were determined according to the following pattern:

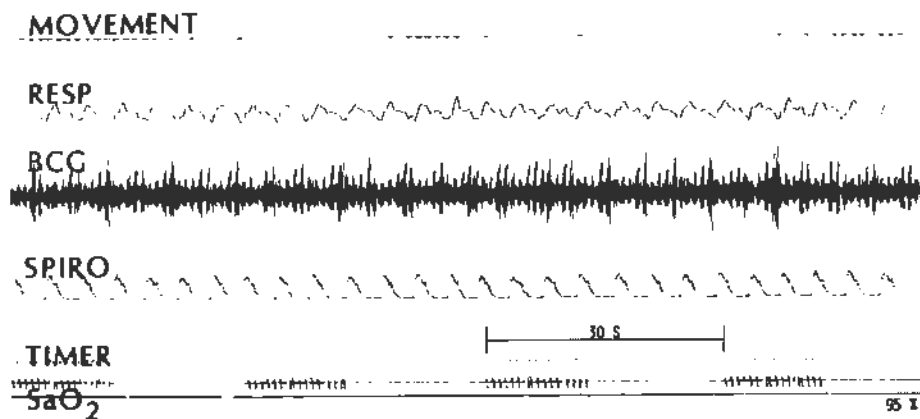
	Spirometer	SCSB
true positive epoch	+	+
false positive epoch	-	+
false negative epoch	+	-
true negative epoch	-	-

+ = one or more obstructive apnoeas detected during the epoch. - = no obstructive apnoeas detected during the epoch.

2a



2b



2c

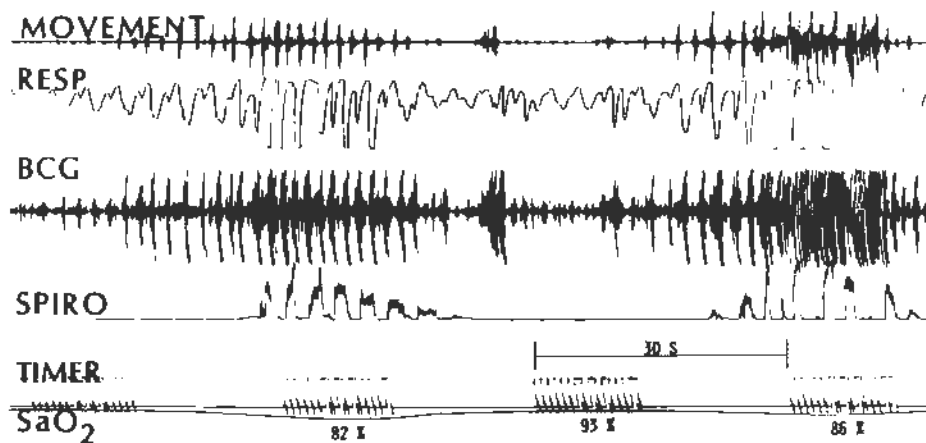


Fig. 2a. A three-channel SCSB recording (body movement, respiratory movement and ballistocardiogram (BCG)) of a control subject without nasobuccal mask and valve in non rapid eye movement (NREM) (left) and rapid eye movement (REM) sleep (right) with a normal respiratory variation of the ballistocardiogram. EOG:electro-oculogram; EMG:electromyogram; EEG:electroencephalogram.

Fig. 2b. A SCSB recording of a control subject with a valve and a nasobuccal mask during a 2 min epoch. The respiratory variation of the ballistocardiogram is slightly increased. No body movements are recorded and the respiration is regular: no apnoeas are counted. The spirometer discloses a constant expiratory volume and the arterial oxygen saturation (SaO_2) is stable.

Fig. 2c. A true positive epoch with two obstructive apnoeas: post-apnoea movements, diamond lace respiratory pattern and increased respiratory variation of the BCG are present. On the spirometer a complete cessation of expiratory airflow is detected.

In the latter analysis, the specificity and the positive predictive value of the method in detecting the 2 min apnoea epochs were also computed.

Results

Table 1 demonstrates the scoring results obtained from the spirometer and by the three SCSB scorers during the first hour of sleep in the fourteen sleep

Table 1. - The number of apnoeas detected by spirometer and SCSB during one hour in fourteen sleep apnoea patients

Patient	Spirometer	SCSB	Scorer	T+	F+	F-	Sensitivity	Positive predictive value
1.	53	65	B.S.	46	19	7	0.87	0.71
		77	L.B.	52	25	1	0.98	0.68
		63	O.P.	47	16	6	0.89	0.75
2.	30	57	B.S.	30	27	0	1	0.53
		40	L.B.	29	11	1	0.97	0.73
		52	O.P.	29	23	1	0.97	0.56
3.	71	73	B.S.	71	2	0	1	0.97
		77	L.B.	71	6	0	1	0.92
		76	O.P.	70	6	1	0.99	0.92
4.	79	79	B.S.	72	7	7	0.91	0.91
		81	L.B.	76	5	3	0.96	0.94
		76	O.P.	74	2	5	0.94	0.97
5.	68	67	B.S.	63	4	5	0.93	0.94
		67	L.B.	64	3	4	0.94	0.96
		68	O.P.	67	1	1	0.99	0.99
6.	49	70	B.S.	45	25	4	0.92	0.64
		77	L.B.	49	28	0	1	0.64
		77	O.P.	46	31	3	0.94	0.60
7.	66	60	B.S.	56	4	10	0.85	0.93
		76	L.B.	66	10	0	1	0.87
		67	O.P.	62	5	4	0.94	0.93
8.	65	65	B.S.	65	0	0	1	1
		65	L.B.	65	0	0	1	1
		65	O.P.	65	0	0	1	1
9.	64	61	B.S.	49	12	15	0.77	0.80
		85	L.B.	64	21	0	1	0.75
		80	O.P.	61	19	3	0.95	0.76
10.	65	65	B.S.	65	0	0	1	1
		66	L.B.	65	1	0	1	0.98
		65	O.P.	65	0	0	1	1
11.	0	5	B.S.	0	5	0	*	0
		4	L.B.	0	4	0	*	0
		2	O.P.	0	2	0	*	0
12.	59	58	B.S.	56	2	3	0.95	0.97
		58	L.B.	55	3	4	0.93	0.95
		54	O.P.	53	1	6	0.90	0.98
13.	10	10	B.S.	6	4	4	0.60	0.60
		22	L.B.	7	15	3	0.70	0.32
		11	O.P.	7	4	3	0.70	0.63
14.	51	90	B.S.	51	39	0	1	0.73
		84	L.B.	51	33	0	1	0.61
		77	O.P.	50	27	1	0.98	0.65
Total	730	825	B.S.	675	150	55	0.92	0.82
		879	L.B.	714	165	16	0.98	0.81
		833	O.P.	696	137	34	0.95	0.84
Mean	52.1	58.9	B.S.	48.2	10.7	3.9		
		62.8	L.B.	51.0	11.8	1.1		
		59.5	O.P.	49.7	9.8	2.4		
SD	23.3	23.5	B.S.	22.3	12.1	4.6		
		24.4	L.B.	23.2	10.9	1.6		
		24.1	O.P.	22.9	11.0	2.2		

T+: true positive findings; F+: false positive findings; F-: false negative findings. ANOVA for repeated measures design on one factor: - at four levels (spirometer, B.S, L.B, and O.P.) $p=0.0034$; - at three levels (B.S, L.B, and O.P.) $p=0.173$; - at two levels (spirometer and the scorers together) $p=0.015$.

apnoea patients. Patient No. 11 did not show any apnoeas meeting the 12 s criterion during the first hour but on the SCSB some false positives were scored by all three scorers. Later on during the night he had a great number of obstructive apnoeas so that an operative treatment was indicated.

The total values show that L.B. tended to score more false positives than the others and thus obtained the best sensitivity but the worst specificity. Analysis of variance (at three levels) showed no significant difference in the mean number of apnoeas counted from the SCSB recordings by the three independent scorers. The intraclass correlation coefficient of reliability between the scorers was 0.94. However, the mean number of apnoeas scored on the SCSB was significantly ($p=0.0034$) higher than the one scored on the spirometer (ANOVA at four levels).

In the control group, one false positive apnoea was scored by L.B.

Sensitivity (apnoea by apnoea)

The individual sensitivity range was 0.60–1. The worst sensitivity was obtained in patient No. 13, who presented a lot of periodic hypopnoeas alternating with obstructive apnoeas. In that case, several false positives were obtained.

For the fourteen patients a mean sensitivity of 0.92–0.98 was obtained.

Sensitivity and specificity (apnoea epoch analysis)

The sensitivity of the SCSB method to detect apnoea epochs was 0.98–0.99 in the apnoea group (table 2). It could not be calculated in the control group because of the absence of any true positive apnoea epochs. The specificity was 0.61–0.68 in the apnoea group, while in the control group it was 0.99–1.00.

Discussion

Cessation of airflow is an early described and the most evident phenomenon of the obstructive sleep apnoea syndrome and therefore its diagnosis has been based on airflow measurements. However, there is no ideal method for monitoring the airflow during sleep. Tracings obtained from thermistors and thermocouples are often obscured by artifacts. The spirometric and pneumotachographic recordings necessitate using a nasobuccal face-mask, which is difficult to tolerate, especially for older subjects and patients with chronic obstructive pulmonary disease (COPD).

Instead of airflow measurements the detection of obstructive sleep apnoeas could be based on other specific pathophysiological events, known to occur during upper airway obstruction. The goal is on the one hand that the diagnosis of the sleep apnoea syndrome would be less complicated and less expensive, and on the other, that the diagnosis would be more accurate in distinguishing different clinical entities and be a guide to proper treatment.

The SCSB is simple and comfortable to use: no electrodes need to be connected to the subject by the laboratory personnel, the subject is free to turn around or to leave the bed when needed. Sleep is little disturbed by the recording procedure itself. The running costs are small: ink and 30–72 meters of polygraph paper (with paper speeds 1 2.5 mm·s⁻¹ respectively) per 8 h of recording. If the data are fed on-line to a microcomputer (software now available) even these costs can be avoided. If the recording is performed in a normal hospital ward, no special personnel are needed for surveillance.

The aim of the present study was to test whether obstructive sleep apnoeas could be appropriately detected according to specific body movement, respiratory movement and ballistocardiographic patterns, registered non-invasively by the SCSB.

The most critical point in the design of this validity study was the choice of reference. A spirometer was chosen because it seemed to give the most reliable data. However, several facts should be pointed out concerning the use of the spirometer. Firstly the respiratory resistance is increased because of the valve, and the dead space of breathing is increased because of the mask. The respiratory variation of the BCG was therefore constantly slightly increased even in the control subjects (figs 2a and b). Furthermore, it is known that rapid eye movement sleep (REM-sleep) latency is lengthened and REM-sleep duration is decreased when a face-mask is used [11]. Only a few of our obstructive sleep apnoea patients entered REM-sleep while wearing a mask, and when they did the stage was short and fragmented. Hence, although our other observations suggest that the SCSB detects the apnoeas during REM-sleep as well, the data obtained during REM-sleep when using the spirometer are incomplete. Because not all the patients tolerated the mask all the night, an equal length of recording (the first one h) was taken into account for the validation study. Thus all the 14 patients were equally represented in the data.

With the SCSB method more false positive than false negative apnoeas were scored. The false positives were found only in the apnoea subject group and they usually consisted of episodes of periodic breathing, corresponding to periodic decreased tidal volume, but not to a total absence of airflow on the spirometer. In some cases false positive findings could be explained by the valve phenomenon [7], where, in spite of complete inspiratory obstruction, some airflow is still detected during expiration. Almost all the false positives were accompanied by an arterial oxygen desaturation and thus seemed to correspond to periodic hypopnoeas.

False negatives were less frequent. To explain their occurrence all the false negative events were examined in further detail. It emerged that none of them exceeded 14 s in duration (the latency between the last and the first expirations).

We conclude that the SCSB detects the obstructive events without always distinguishing between severe

Table 2. - The sensitivity and specificity of the SCSB method to detect obstructive apnoeas in 2 min epochs

Scorers	True positive epochs	True negative epochs	False positive epochs	False negative epochs	Sensitivity		Specificity		Positive predictive value		Negative predictive value	
					T+	T-	F+	F-	(T+)+(F-)	(T-)+(F+)	(T+)+(F+)	(T-)+(F-)
14 subjects suspected of having obstructive sleep apnoeas (420 epochs in total)	B.S.	319	61	34	6	0.98	0.64	0.90	0.91			
	L.B.	322	58	37	3	0.99	0.61	0.90	0.95			
	O.P.	319	65	30	6	0.98	0.68	0.91	0.92			
6 control subjects (180 epochs in total)	B.S.	0	180	0	0	-	1	-	1			
	L.B.	0	179	1	0	-	0.99	-	1			
	O.P.	0	180	0	0	-	1	-	1			

periodic hypopnoeas and obstructive apnoeas. In fact, these two phenomena can be considered as different manifestations of the same clinical entity (the upper airway obstruction disease) with the same pathophysiological consequences (oxygen desaturation, cardiac arrhythmias).

According to our results the sensitivity of the SCSB method is good for screening subjects suspected of having obstructive sleep apnoeas. The specificity was incomplete as far as total cessation of airflow was concerned. Nevertheless, the fact that the false positives were observed only in the apnoea group, and not in the normal controls, suggests that they could still be specific findings for the upper airway obstruction disease. Our further studies will concentrate on a more detailed analysis of the various respiratory, BCG and body movement patterns which, according to our preliminary observations, might lead to additional information on the severity of the upper airway obstruction.

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RÉSUMÉ: Il existe actuellement peu de centres équipés pour effectuer des enregistrements polygraphiques du sommeil couplés à un contrôle de la respiration chez les sujets suspects de syndrome d'apnées au cours du sommeil. Aussi le besoin se fait-il sentir d'une méthode moins lourde permettant l'investigation d'un nombre élevé de sujets. Le matelas électrostatique (static charge sensitive bed) pourrait être la réponse à cette nécessité. Le matelas

électrostatique est un capteur des mouvements. Il permet l'enregistrement polygraphique de différents phénomènes physiologiques: mouvements corporels, mouvements respiratoires, activité mécanique du coeur (ballistocardiogramme), sans aucun capteur attaché au sujet. A ce jour la validité du matelas comme méthode de détection des apnées obstructives n'a pas encore été testée. Le travail présenté correspond à une comparaison des données obtenues par le matelas électrostatique et par la méthode classique utilisant spiromètre et oxymètre. Quatorze sujets suspects de syndrome d'apnées au cours du sommeil et six contrôles ont participé à cette étude. Chaque sujet a bénéficié la même nuit d'un enregistrement conventionnel du sommeil et de la respiration (spiromètre, oxymètre) et d'un enregistrement sur le matelas électrostatique. Les tracés obtenus à partir du matelas électrostatique ont été analysés indépendamment par trois personnes, puis comparés à l'enregistrement spirométrique conventionnel analysé par ces trois personnes travaillant ensemble.

Une analyse de variance a montré l'absence de différence significative entre le nombre d'apnées scorées par chacune des trois personnes sur les tracés obtenus à partir du matelas électrostatique. Mais le nombre d'apnées scorées d'après le matelas électrostatique était significativement ($p=0.0034$) plus élevé que celui obtenu à partir du système d'enregistrement conventionnel. Dans le groupe des sujets apnéiques la sensibilité de la méthode pour détecter les apnées était de 0.92-0.98. Sa spécificité pour détecter les époques avec apnées était de 0.61-0.68. Dans le groupe contrôle la sensibilité n'a pas pu être appréciée vu l'absence de toute apnée. Dans ce même groupe la spécificité était de 0.99-1.00. D'après notre étude la sensibilité de la méthode est bonne et suffisante pour détecter les sujets atteints du syndrome d'apnées obstructives au cours du sommeil. La spécificité dans le groupe des sujets apnéiques est incomplète compte tenu d'une difficulté à distinguer les hypopnées périodiques des apnées complètes.