

PROLONGED SPIKING PERIODS PATTERN DETECTION METHOD BY USING EMFi AND SCSB SIGNALS

Jarmo Alametsä¹, Antti Saastamoinen², Eero Huupponen¹, Alpo Värri¹, Atte Joutsen²,
Joel Hasan², Esa Rauhala³, and Sari-Leena Himanen²

¹Digital Media Institute, Tampere University of Technology, Tampere, Finland

²Department of Clinical Neurophysiology, Tampere University Hospital, Tampere, Finland

³Satakunta Central Hospital, Pori, Finland

jarmo.alametsa@tut.fi, antti.saastamoinen@tut.fi, eero.huupponen@tut.fi,
alpo.varri@tut.fi, atte.joutsen@pshp.fi, joel.hasan@pshp.fi,
esa.rauhala@satshp.fi, sari-leena.himanen@pshp.fi

ABSTRACT

In this work the previously developed spiking detection method [1] was improved in order to compose prolonged spiking periods by post-processing detected spiking events caused by increased respiratory resistance (IRR) from ballistocardiographic (BCG) data, which was recorded with Electromechanical Film (EMFi) sensor and Static Charge Sensitive Bed (SCSB) mattress. In spiking episode, the systolic BCG wave complexes increase in amplitude during IRR.

The SCSB mattress has been used earlier in sleep research for simultaneous recordings of respiration, BCG and movements in order to detect different sleep disorders like apneas and for sleep scoring. Nowadays also the EMFi sheet has shown its usefulness in sleep study.

For this study eleven recordings from different apnea patients were made with SCSB mattress and EMFi sensor in order to detect prolonged spiking episodes of the formerly developed spiking detection method and as a preliminary work to study the amplitude levels from spiking and non-spiking areas of the recorded signals. Adaptable amplitude levels from recorded signals were used for spiking detection and amplitude levels multiplied by 100 times 1.8 were used for artefact rejection. Two variations from formerly presented 10 different variations of the algorithm were chosen and the detected spiking seconds were joined and grouped in order to detect prolonged spiking. In the first step, the allowable time interval between detected spiking seconds is ≤ 4 s making block of groups according to the rule. In the second step these blocks are rearranged to bigger blocks according to the rule, that the allowable time gap between blocks is ≤ 12 s.

Amplitude levels in spiking area grew on average 1.7 times compared to non-spiking area of studied 11 patients making possible to detect spiking seconds and allowing

prolonged spiking episodes to be sorted out from these seconds. On average 17.3% of the visually inspected and visually scored IRR episode duration seconds were detected as prolonged spiking seconds according to the conditions set for detection from studied 11 patients.

KEY WORDS

EMFi, SCSB, BCG, apnea, sleep research, pattern recognition

1 Introduction

A poor sleep quality sleep related breathing disorders can cause a lot of problems in daily cognitive and physical functions by undermining the quality of life. Also in the long run, disturbed and inadequate sleep impairs biological restitution. Patients with respiratory disturbances during sleep have a higher risk of stroke, coronary artery disease, hypertension and myocardial infarction [2,3].

Static charge sensitive bed (SCSB) [4] and Electromechanical Film [5,6] (EMFi) as non-invasive sensors have shown their potential in monitoring different physiological functions in humans. They have been used in recording cardiorespiratory functions, called ballistocardiography [7] together with the respective regulatory mechanics and different motor activities especially in sleep studies. When placed below the mattress of a bed these sensors do not disturb the sleep of a patient.

The EMFi is basically a thin, biaxially oriented plastic film coated with electrically conductive layers, which are permanently polarized. The electret property of EMFi is related to static electric dipoles generated into the voids of thin polypropylene film. Changes in the pressure acting on the film generate a charge (which corresponds with the pressing force) on its electrically

conductive surfaces and this charge can be measured as a current or voltage signal. It can convert mechanical energy to electrical and vice versa. Thus, the EMFit sensor acts as a sensitive movement sensor suitable for BCG recordings.

When EMFit sensor is placed below the mattress cover or SCSB mattress sensor is placed below the bigger mattress of a bed, the mechanical cyclic pumping action of the heart of a sleeping human can be seen with these sensors. Visually spiking can be seen in EMFit sensor or in SCSB mattress signal in the frequency range of 6-16 Hz as sharp spiking episodes of the main systolic complexes of the BCG signal with amplitudes of the systolic complexes much higher than usual. These spiking episodes repeat in synchrony with respiration being the result of increased inspiratory efforts as a response to partial upper airway obstruction [1]. Spiking episodes are related to the increased respiratory resistance (IRR) phenomenon [8]. Spiking can be considered as prolonged spiking, if the amount of spiking in IRR section is at least 10 and the spiking episodes repeat in time at least 2 min, usually 4-5 min. In this paper a pattern recognition method is presented to detect the spiking events automatically.

2 Methods

2.1 Obtained data

In this study, 11 full night recordings (about 8 hours each) from different subjects were made at the Sleep Laboratory of the Department of Clinical Neurophysiology in Pirkanmaa Hospital District in Tampere, Finland. These new 11 recordings were not used in previous [1] study.

The channels evaluated in this study were an EMFit channel and a SCSB channel. Other channels, as nasal pressure and snoring sensor channels were used as a visual conformation for detected spiking episodes and especially for searching non-spiking areas for comparison purposes. In the measurement there was a small EMFit sensor below the mattress cover. A large SCSB mattress was below the EMFit sensor. Using this arrangement, both the sensors measured, in principle, the same measurements from the patient, but the EMFit sensor was closer to the patient. The sampling rate used for EMFit and SCSB data was 200 Hz. All recordings were band pass filtered (6-16 Hz).

2.2 Prolonged spiking detection method

The spiking pattern detection method consists of two main parts: a band-passed amplitude change detection algorithm and a small rule base, which mimics the rules used by the clinicians in determining whether the series of

events detected can be considered as prolonged or not. The amplitude change detection part is a slight modification of our previous method to detect single spikes [1], but rule base to detect the prolonged spiking period is new.

2.2.1 Amplitude change detection algorithm

The amplitude change detection algorithm [1] uses Hanning windowed 1.3s signal segments, which are partly overlapped data segments (length of 0.5s of each). Five properly scaled amplitude spectra are calculated from five sub-windows and maximum and mean values are taken from those values in the frequency range 6-16 Hz. The frequency range 3-16 Hz was tested too, but it gave worse results. After that maximum and minimum are taken from previously calculated maximum and mean values. The maximum values reflect the amplitudes during peaking of the BCG complex and the minimum values reflect the valley between them.

Amplitude levels are extracted from amplitude spectra by using five versions of change feature extraction methods:

$A[k]_A = A_{\text{mean}}[k]$, in submethod A, (1s time resolution).
 $A[k]_{B,C} = A_{\text{max_max}}[k]$, in submethods B,C (0.5s time resolution).
 $A[k]_{D,E} = A_{\text{max_mean}}[k]$, in submethods D, E (0.5s time resolution).
 $A_{\text{max_max}}$ is the maximum of the five consequent maximums and $A_{\text{max_mean}}$ is the mean of the five consequent maximums.

Five versions of moving local base lines, denoted as $B[k]_{A...E}$, are determined based on a 60 s history window:

$B[k]_A = \text{median}(A_{\text{mean}}[k-60:k-1])$,
 $B[k]_B = \text{median}(A_{\text{min_max}}[k-60:k-1])$,
 $B[k]_C = \text{median}(A_{\text{max_max}}[k-60:k-1])$,
 $B[k]_D = \text{median}(A_{\text{min_mean}}[k-60:k-1])$,
 $B[k]_E = \text{median}(A_{\text{max_mean}}[k-60:k-1])$.

In this work, however, the 10 s history window gave better results and was used therefore.

By combining different versions of $B[k]$ and $A[k]$, five variations of change features were extracted as follows:

$A_c[k]_{A...E} = \{(A[k]_{A...E} - B[k]_{A...E}) / B[k]_{A...E}\} * 100\%$.

Thus in the frequency range 6-16 Hz, $Ac[k]_A$ corresponded to method 1, $Ac[k]_B$ method 2, $Ac[k]_C$ method 3, $Ac[k]_D$ method 4 and $Ac[k]_E$ method 5. A BCG spiking event was detected when $Ac[k]$ exceeded the threshold value λ .

2.2.2 Detection threshold selection

In order to study the five versions of different change feature $A_c[k]$ methods in spiking event extraction, the outcome was compared to spiking seconds visually in scored sections of the recordings. The best two methods, methods 3 and 5, which gave good results, also in our previous study [1], were chosen for further study.

Table 1 shows the median values of the amplitude change feature $A_c[k]$ (absolute value and after that median was taken from the chosen section) of methods 3 and 5 in each patient with both the traces from spiking and non-spiking parts of the recording. On the average, the values of $A_c[k]$ of spiking periods were 1.7 times higher than during non-spiking periods. Due to the lack of detailed visual scoring of the spiking events the statistically optimal solution of the spiking event detection threshold λ for $A_c[k]$ was not possible. Therefore λ had to be chosen empirically based on observations of obvious true and false positive event detection. As a result a value of 40 was chosen for λ .

2.2.3 Post processing for detected spiking seconds

In order to detect prolonged spiking episodes, a post-processing method for detected spiking seconds was introduced. In post processing the first rule is, that the longest time gap between spiking seconds can be $\leq 4s$, as the normal variation of the amplitude of the main systolic components caused by respiration can be seen also in scored area. Thus between the spiking seconds due to exhaling there can be seconds, when the amount of air in the lungs is small and no spiking can be seen. Seconds are arranged according to the first rule to groups, and then arranged again to groups, in which the second discriminating rule is, that the gap between groups can be $\leq 12s$. As the main purpose was to detect prolonged spiking episodes, periodical apnea and hypopnea periods have to be cut out in order to achieve these spiking episode seconds.

As artefacts introduced spikes, with much higher amplitudes than normal spiking, the removal of artefacts is done by giving the threshold value λ value 180 (100 multiplied by 1.7 and rounded up, which is an average of amplitude growth value between spiking and non-spiking sections in Table 1). This threshold value for artefacts removal seemed to work well with all studied recordings.

In step 1, the post processing begins by a conditional expression, in which the detected spiking seconds (in this point artefacts are also removed by detecting them by threshold value λ value 180) are stepped second by second basis. If the difference of the current detected second and previous one is $\leq 4s$, current index is stored and equivalent second, when the rule still is valid, is

restored from spiking seconds. In this way, the first valid second according to the rule drops away. Therefore the index-1 value is restored also from spiking seconds. In this way the last valid second drops away from $\leq 4s$ rule. By joining these index and index-1 seconds, the block of seconds, which are $\leq 4s$ can be obtained. After joining, the detected seconds are grouped in the order of magnitude and possible double seconds are removed. This produces blocks of seconds with given $\leq 4s$ criteria and between blocks are seconds beyond the criteria. In the second step the $\leq 12s$ blocks are grouped together in the same manner based on formerly detected $\leq 4s$ blocks. The second rule gives the start and end seconds for the blocks, which can be considered as prolonged spiking episode, if the number of seconds inside the block is at least 10.

3 Results

The measurements turned out to be difficult to perform flawlessly. In only three of the eleven recordings both the sensors (EMFit and SCSB) gave an acceptable signal for the analysis at the same time. EMFit recordings succeeded five times and SCSB recordings nine times.

Fig. 1 depicts an example of EMFit signal with visually scored spiking events and corresponding change features $A_c[k]$ values from different methods. The lower amplitude trace of change feature values in the picture includes methods 1, 3 and 5. Alike in previous paper, method 5 works well when scored and detected spikes are compared.

Moreover, method 3 seems to give some additional value by detecting some extra spikes, which are not so sharp. Method 5 seems to be incomparable in spiking detection and can be considered to be used also alone. Methods 1, 2 and 4 did not perform very well and they are not promising alternatives to further development.

In Table 1 the amplitude growth by 1.7 times on average between spiking and non-spiking area can be seen. In Table 2 the detections have been made with methods 3 and 5 from visually scored spiking sections. For comparison there are also non-spiking seconds from the area of mostly normal respiration, where no snoring traces in the snoring sensor channel and in the nasal pressure channel can be seen. The spiking and the non-spiking areas are the same in Tables 1 and 2. The amount of non-spiking seconds in detected spiking area is much less than the amount of spiking seconds in scored spiking area with $\lambda=40$, which supports the remark of different amplitude levels of change features between spiking and non-spiking areas. With patient 5, the used threshold

value $\lambda=40$ seemed to be too low seen as too many detected spikes in the non-spiking section.

In Table 3 the amount of seconds of visually scored episode duration is compared to the duration of the detected spiking episode block and the prolonged spiking episode block duration. Also the number of the prolonged spiking episode blocks and the median of the length of the blocks are mentioned. On average 32.5% of the visually inspected and scored IRR episode duration seconds were detected as spiking seconds and 17.3% as prolonged spiking seconds of all studied 11 patients.

4 Discussion

As the number of defective recordings, in which EMFi sensor and SCSB mattress signal recordings did not succeed at the same time with the same patient was quite high (7 defective of 11), it was not possible to accomplish the comprehensive comparison between these two sensors. As the main purpose was to find spikes which appear in certain blocks of incidence (prolonged spiking) according to the conditions set for detection, the achieved results are quite satisfactory. The definition of prolonged spiking is somewhat fuzzy at the moment and it can change in the future.

Different threshold values λ from change feature values obtained from different recordings and thus from different people reflect the differences in pumping ability of the heart with different individuals. Due to the lack of second-by-second visual scorings of the spiking it is, unfortunately, not possible to evaluate the performance of the designed pattern recognition method statistically, nor is it possible to set the detection threshold value λ optimally. As seen in the Table 1, differences in the calculated threshold values λ between different sensors reveal slightly different sensitivities between these two sensors. This can be seen also in the differences in the amount of detected seconds between the two sensors with two different methods.

The resolving of the adequate threshold value λ for the spiking section compared to the non-spiking section is sometimes tradeoff between too low and too high threshold value λ . Used threshold value λ of 40 was a good compromise in sorting out between spiking and non-spiking sections seen as a quite low amount of spiking seconds in non-spiking area. Also in the so-called 'normal, quiet respiration' area with no snoring and no spiking, the amplitude of some spikes may reach to the amplitudes in spiking area sections. However, much fewer detections should appear in non-spiking area compared to spiking area with the used threshold value λ .

5 Conclusion

In this work, method 10 was the best in detecting spiking episodes. Also method 8 made some extra value to the detection by introducing some spikes, which can be included into spiking sections. When the number of detected seconds from table 2 is estimated, the method 8 succeeded also very well compared to method 10. Inside the detected spiking seconds there are also the same detection with these two methods, which has to keep in mind (Fig. 2).

Developed post-processing for detected spiking seconds worked also well in grouping detected spiking seconds into certain groups allowing prolonged spiking episodes to be sorted out from detected spiking sections. Prolonged spiking episodes inside the scored area were detected almost with all patients, except with patient 3, where the prolonged spiking episode block candidates did not meet the criteria that the number of seconds inside the block must be at least 10.

References

- [1] Alametsä J, Rauhala E, Huupponen E, Saastamoinen A, Värri A, Joutsen A, Hasan J, Himanen S-L, Automatic detection of spiking events in EMFi sheet during sleep, *Medical Engineering & Physics*. 2006; 28: pp. 267-275.
- [2] Roux F, D'Ambrosio C, Mohsenin V, Sleep-related breathing disorders and cardiovascular disease. *Am J Med* 2000;108:396-402.
- [3] Pittman SD, Tal N, Pillar G, Malhotra A, Hilton MF, Fogel RB, Ayas N, White DP, Automated detection of obstructive sleep-disordered breathing events using peripheral arterial tonometry and oximetry. *Comp Card* 2000;27:485-488.
- [4] Alihanka J, Basic principles for analysing and scoring Bio-Matt (SCSB) recordings (*Medica-Odontologica*, 26, Turun yliopisto, Turku 1987).
- [5] Kirjavainen K, Electromechanical film and procedure for manufacturing same (U.S. Patent no. 4654546, 1987).
- [6] Manufacturer of EMFi: Emfitech Ltd, Vaajakoski, Finland, <http://www.emfitech.fi/>.
- [7] Weissler A.M, *Noninvasive Cardiology; Clinical Cardiology Monographs*, (Grune & Stratton Inc. NY. 1974).
- [8] Kirjavainen T, High-frequency respiratory movements during sleep – physiological determinants and diagnostics usefulness of SCSB spiking. Turun Yliopisto, ISBN 951-29-0942-1, ISSN 0355-9483; 1997.

Table 1: Median value was taken from the absolute value of the change feature values $A_c[K]_{A...E}$ from visually scored spiking area and non-spiking area in order to resolve the suitable threshold value λ from methods 3 and 5 with EMFit sensor and SCSB mattress. The mark na means, that the signal in the recording was defective and thus excluded from this study. In the recording of patient 11, clear non-spiking area meaning quiet sleep and no major snoring sensor activity, was not seen. The amplitudes have grown on average by 1.7 times between spiking and non-spiking areas.

Patient	Spiking area; method 5 (EMFit/SCSB)	Spiking area; method 3 (EMFit/SCSB)	No-spiking area; method 5 (EMFit/SCSB)	No-spiking area; method 3 (EMFit/SCSB)
Patient 1	18.50/na	16.40/na	12.52/na	15.00/na
Patient 2	19.57/na	19.76/na	10.0/na	6.75/na
Patient 3	na/23.18	na/20.83	na/14.67	na/18.10
Patient 4	na/21.16	na/30.89	na/13.10	na/12.32
Patient 5	na/21.85	na/28.05	na/13.80	na/18.50
Patient 6	22.61/37.80	26.90/29.40	14.20/15.90	14.10/13.60
Patient 7	16.80/15.00	18.90/15.40	11.07/14.01	15.33/15.40
Patient 8	na/19.66	na/29.93	na/14.84	na/12.80
Patient 9	31.90/32.72	41.89/39.89	15.88/15.46	32.05/27.0
Patient 10	na/19.26	na/22.79	na/13.69	na/11.76
Patient 11	na/22.92	na/22.24	na/na	na/na

Table 2: Number of detected seconds with threshold value λ of 40 from visually scored spiking and non-spiking areas from methods 3 and 5. The episode duration means the duration of visually inspected and visually scored episode (s). In no-spiking area there is mostly normal respiration with no snoring and no spiking traces. Two different methods, methods 3 and 5, have also detected the same spiking seconds of EMFit or SCSB channels.

Patient	Visually scored episode duration (s)	Detected spiking seconds; methods 3&5 (EMFit/SCSB)	Detected spiking seconds; method 5 (EMFit/SCSB)	Detected spiking seconds; method 3 (EMFit/SCSB)	No-spiking seconds	No-spiking seconds; methods 3&5 (EMFit/SCSB)	Detected no-spiking seconds; method 5 (EMFit/SCSB)	Detected no-spiking seconds; method 3 (EMFit/SCSB)
Patient 1	555	116/na	72/na	96/na	154	3/na	2/na	1/na
Patient 2	946	123/na	67/na	97/na	100	1/na	1/na	0/na
Patient 3	388	na/71	na/59	na/49	248	na/26	na/10	na/20
Patient 4	290	na/72	na/44	na/63	800	na/36	na/32	na/8
Patient 5	443	na/98	na/64	na/92	588	na/63	na/30	na/41
Patient 6	369	114/130	62/114	107/105	310	9/25	7/16	4/13
Patient 7	310	53/42	34/25	46/35	104	11/12	6/8	10/11
Patient 8	1098	na/289	na/123	na/251	128	na/6	na/3	na/3
Patient 9	234	83/73	62/54	77/68	46	10/9	3/3	9/8
Patient 10	315	na/67	na/44	na/58	254	na/26	na/22	na/18
Patient 11	1385	na/272	na/230	na/208	na	na/na	na/na	na/na

Table 3: The total visually scored, visually inspected IRR episode length in seconds are in column two. The following columns show the results of the automatic detection. The sums of spiking episode block duration in seconds (the allowed gap between seconds inside the spiking seconds is $\leq 4s$ and the $\leq 12s$ rule separates different episodes) are in the third column. The detected prolonged spiking episode blocks (PS), in which resembling the previous condition also the amount of the prolonged spiking episode seconds must be at least 10 are in column five. In the columns 7 and 8 the number of the prolonged spiking episode blocks and the median of the length of the blocks are shown.

Patient	Visually scored episode duration (s)	Sum of detected spiking episode block duration (EMFit/SCSB) (s)	Percentage of detected spiking and visually scored episode (EMFit/SCSB) (%)	Sum of detected PS episode block duration (EMFit/SCSB) (s)	Percentage of detected PS and visually scored episode (EMFit/SCSB) (%)	PS EMFit (events/median length(s))	PS SCSB (events/median length(s))
Patient 1	555	193 /na	34.80/na	112/na	20.20/na	7/16	
Patient 2	946	133/na	14.10/na	27/na	2.90/na	2/13.5	
Patient 3	388	na/66	na/17.00	na/na	na/na		na/na
Patient 4	290	na/124	na/42.80	na/95	na/32.80		7/14
Patient 5	443	na/152	na/34.30	na/49	na/11.10		4/12.5
Patient 6	369	109/125	29.54/33.90	36/37	9.76/10.00	3/12	3/12
Patient 7	310	71/62	22.90/20.00	26/29	8.39/9.35	2/13	2/14.5
Patient 8	1098	na/492	na/44.81	na/296	na/27.00		18/14.5
Patient 9	234	134/118	57.27/50.43	98/75	41.90/32.05	6/13.5	4/17.5
Patient 10	315	na/98	na/31.10	na/36	na/11.40		3/12
Patient 11	1385	na/300	na/21.70	na/147	na/10.60		9/14

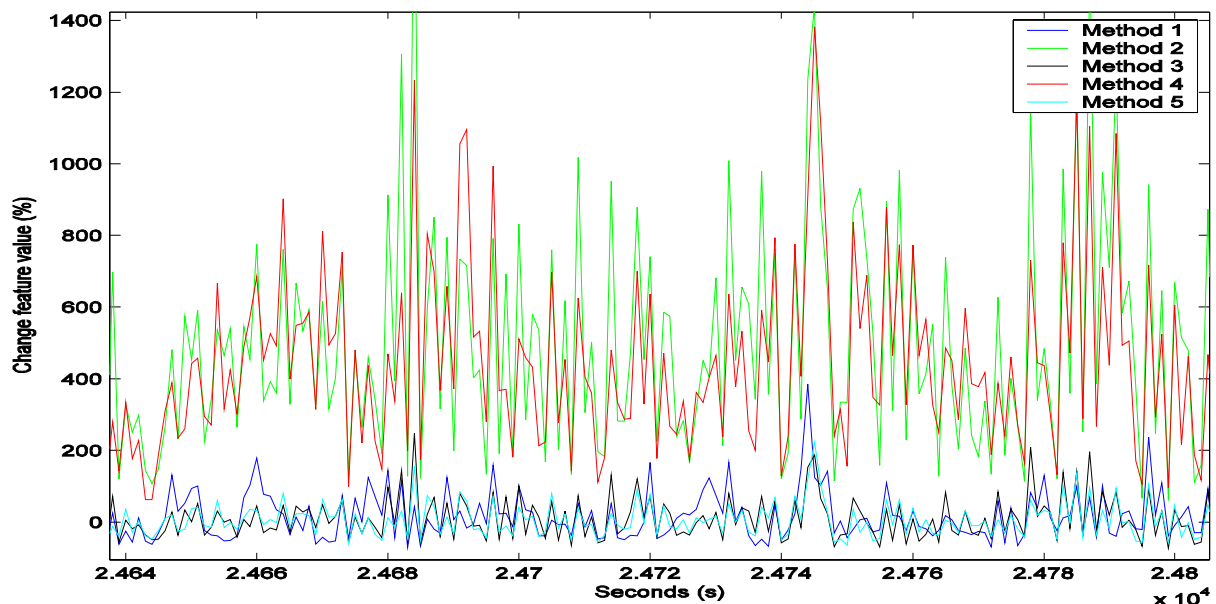


Figure 1: An example of change feature values from EMFit sensor with different methods from patient 9 and from visually scored whole spiking area. The lower amplitude trace of change feature values (0 – 200) includes methods 1, 3 and 5.

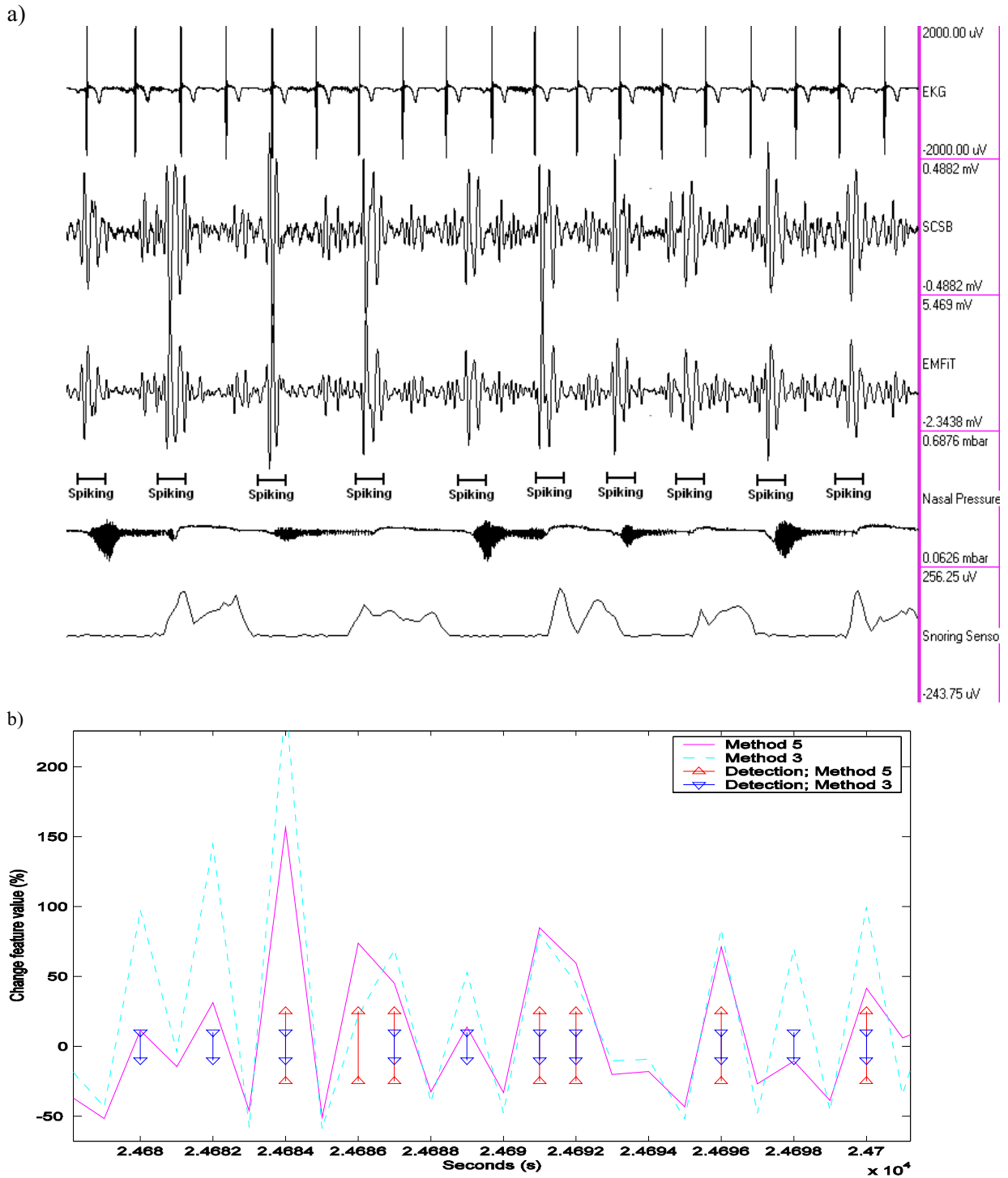


Figure 2: An example of ECG, nasal flow pressure and (6-16 Hz) filtered EMFit and SCSB signal segments of 20s with scored spiking events (a) from patient 9. Corresponding change feature $A_c[k]$ values of methods 3 and 5 and detected spiking events of methods 3 (blue arrows) and methods 5 (red arrows) are seen in (b). This 20s interval belongs to the area of prolonged spiking episode.