Online Supplement for:

DIAGNOSIS OF SLEEP APNEA BY AUTOMATIC ANALYSIS OF NASAL PRESSURE AND FORCED OSCILLATION IMPEDANCE

APPENDIX A

Weighted Kappa Statistic

The weighted kappa statistic provides a measure of agreement κ_w (*scorer1*, *scorer2*) between two scorers (*scorer1* and *scorer2*) who classify observations into one of several groups or categories. The following description is adapted from reference (E1).

Two scorers (*scorer1* and *scorer2*) analyze a set of N observations by classifying each observation into one of g groups. This leads to a $g \times g$-matrix n, the table of occurrences. A cell n_{ij} represents the number of observations that have been classified as belonging to category i by *scorer1* and to category j by *scorer2*.

Depending on the particular situation to be investigated, a weight w_{ij} between zero and 1 is given to each cell n_{ij}. The weight w_{ij} quantifies the degree of discrepancy between the two categories i and j. Cells on the diagonal of the table of occurrences n, corresponding to equal classification by both scorers, are given weights of 1; whereas cells n_{ij} with highly different categories i and j receive weights w_{ij} close to or equal to zero. The weights w_{ij} given to the different cells n_{ij} of this second-by-second table of occurrences are displayed in Table E1. Whereas weights w_{ij} close to 1 indicate that the respective classes i and j are close, weights close to zero correspond to classes that are very different. On the one hand, the choice of this particular set of weights is motivated by the intention to penalize a missed apnea (weight zero) more severely than a missed hypopnea (weight 0.5) or than a respiratory event detected by both

scorers but classified as an apnea by one of them and as a hypopnea by the other (weight 0.5). On the other hand, this set of weights specifically disfavors episodes classified as central apneas by one scorer and as obstructive apneas by the other (weight 0.25).

The weighted observed proportional agreement between the two scorers is obtained as

$$p_{o(w)} = \frac{1}{N}\sum_{i=1}^{g}\sum_{j=1}^{g} w_{ij} n_{ij}.$$

Abbreviating the row and column totals of the table of frequencies for the *i*th category by $r_i = \sum_{j=1}^{g} n_{ij}$ and $c_j = \sum_{i=1}^{g} n_{ij}$, the weighted proportional agreement expected just by chance is estimated by

$$p_{e(w)} = \frac{1}{N^2}\sum_{i=1}^{g}\sum_{j=1}^{g} w_{ij} r_i c_j .$$

Then, weighted kappa, which may be interpreted as the chance-corrected weighted proportional agreement, is given by

$$\kappa_w = \frac{p_{o(w)} - p_{e(w)}}{1 - p_{e(w)}}.$$

It has a maximum of 1 when agreement between the two scorers is perfect; whereas a value of zero indicates no agreement better than chance, and negative values show worse than chance agreement.

APPENDIX B

Algorithm for Automatic Detection and Classification of Respiratory Events

As a first step, segmentation of the mask pressure recording into breathing cycles is carried out by identifying local pressure maxima with a time distance of at least the threshold T_{max} from the closest higher pressure value. Mask pressure amplitudes are extracted for each breathing cycle of a recording. If the current amplitude falls below the product of the threshold $c_{p,ev}$ with the 10^{th} highest amplitude of the preceding 2 minutes and remains low for at least 10 seconds and for at most 240 seconds, beginning and end point of the corresponding episode are stored as onset and termination of a respiratory event.

For each detected event, the minimum pressure standard deviation σ_p during a time interval of 10 seconds is computed. Furthermore, the minimum standard deviations σ_{FOT1} and σ_{FOT2} of the forced oscillation technique (FOT) signal during a time interval of 5 seconds within the first and second half of the event are calculated. In a similar manner, the minimum standard deviations σ_{FOTb} and σ_{FOTa} during periods of the same length immediately before and after the event are extracted. Moreover, the medians of the FOT signal during the respective time intervals (Med_{FOT1}, Med_{FOT2}, Med_{FOTb} and Med_{FOTa}) are computed.

Cardiogenic oscillations in the FOT signal are detected by investigating the properties of the autocorrelation function of the normalized FOT signal during the event. $T_{FOT,co}$ denotes the time during which cardiogenic oscillations are considered to be present within the respiratory event.

Classification of a respiratory event is based on the values of σ_p, of the ratios $\sigma_{FOT1}/\sigma_{FOTb}$, $\sigma_{FOT2}/\sigma_{FOTa}$, Med_{FOT1}/Med_{FOTb} and Med_{FOT2}/Med_{FOTa}, and of $T_{FOT,co}$.

Depending on the magnitude of these features, compared with thresholds $c_{p,ah}$ for pressure variability, $c_{FOT,ah}$ for variability ratios of the FOT signal, $c_{FOT,oc}$ for FOT median ratios, and T_{co} for presence of cardiogenic oscillations in the FOT signal, the event is classified as either obstructive apnea, mixed apnea, central apnea, or hypopnea with central or obstructive origin.

Reference

E1. Altman DG. Practical Statistics for Medical Research. Boca Raton, FL: Chapman & Hall; 1991. p. 403-409

TABLE E1. WEIGHTS USED FOR WEIGHTED KAPPA STATISTIC TO EVALUATE SECOND-BY-SECOND AGREEMENT BETWEEN TWO SCORERS OF A PSG RECORDING

	Scorer2					
Scorer1		N	H	OA	MA	CA
	N	1	0.5	0	0	0
	H	0.5	1	0.5	0.5	0.5
	OA	0	0.5	1	0.5	0.25
	MA	0	0.5	0.5	1	0.5
	CA	0	0.5	0.25	0.5	1

Definition of abbreviations: CA = central apnea; H = hypopnea; MA = mixed apnea; N = normal breathing; PSG = polysomnography; OA = obstructive apnea.

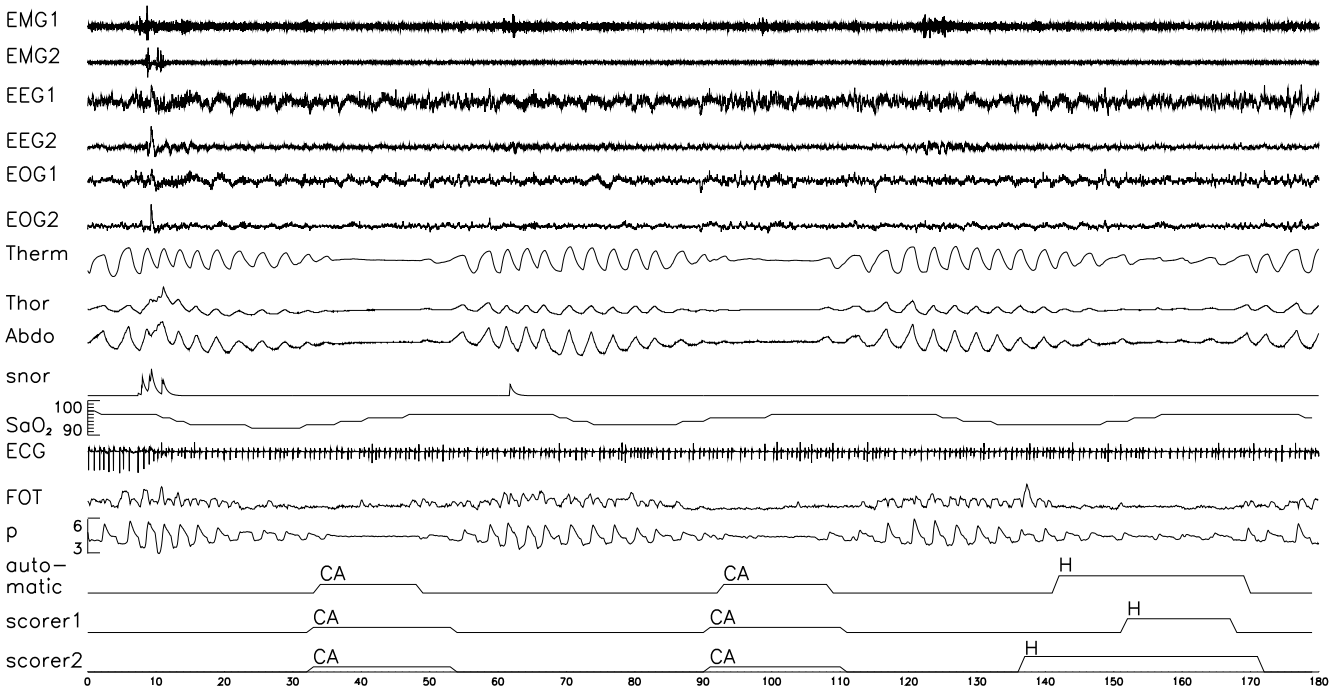
EMG1
EMG2
EEG1
EEG2
EOG1
EOG2
Therm
Thor
Abdo
snor
100
SaO₂ 90
ECG
FOT
p
6
3
auto–
matic
scorer1
scorer2
CA
H
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180

Figure E1

Figure E1. Examples of central apneas (CA) with low forced oscillation technique (FOT) signal, suggesting open airways. Three minutes extracted from a polysomnographic (PSG) recording with submental (EMG1) and tibial electromyogram (EMG2), two EEG channels, left and right electrooculogram (EOG1, EOG2), oronasal thermistor (Therm), thoracic (Thor) and abdominal (Abdo) inductance plethysmography, snoring sounds (snor), oxyhemoglobin saturation (Sa_{O2}) in %, electrocardiogram (ECG), estimated modulus of respiratory input impedance measured by FOT and nasal mask pressure (p) in cm H_2O. The three bottom tracings show onset, end, and class of respiratory events as detected by automatic analysis of FOT and mask pressure as well as by visual analysis of full PSG except FOT signal performed by two scorers. H = hypopnea.

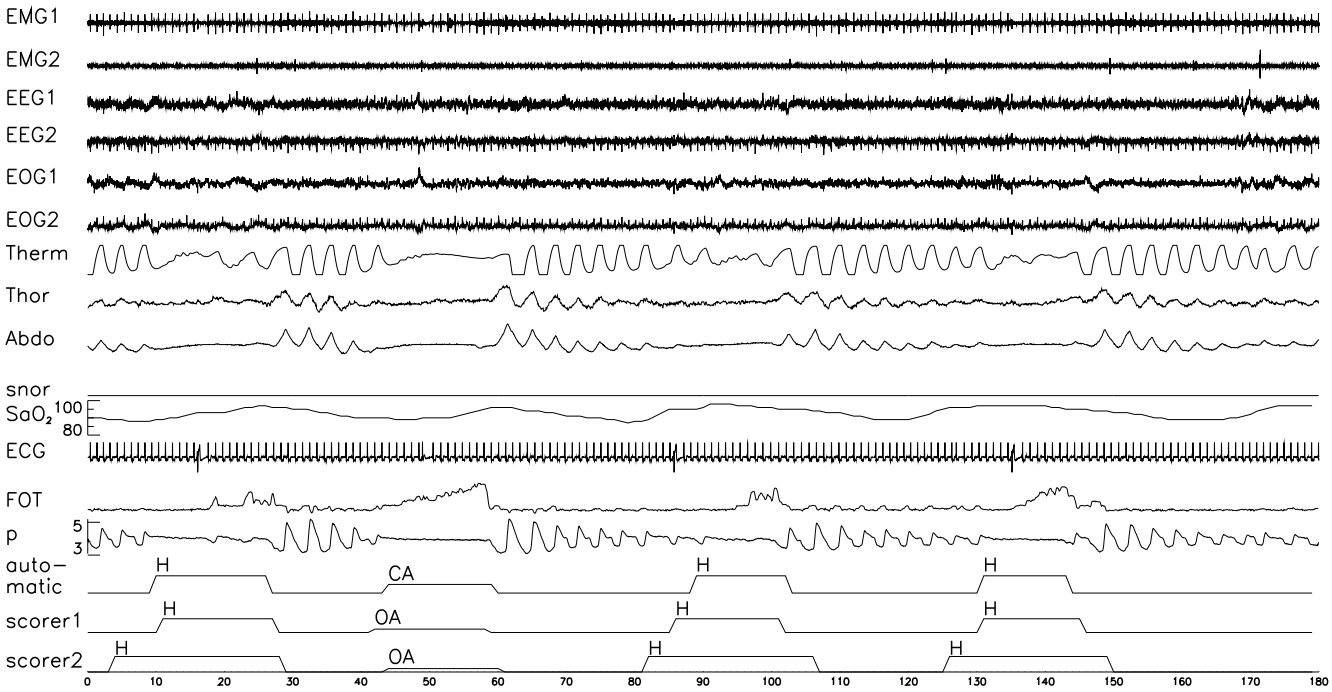
EMG1
EMG2
EEG1
EEG2
EOG1
EOG2
Therm
Thor
Abdo
snor
SaO2
100
80
ECG
FOT
p
5
3
auto–
matic
scorer1
scorer2
H
CA
OA
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180

Figure E2

Figure E2. Example of an event classified as central apnea (CA) by automatic analysis due to cardiogenic oscillations detected in the forced oscillation technique (FOT) signal between the 50^{th} and 60^{th} second of the displayed time interval. Both scorers classified the same event as an obstructive apnea (OA) due to noise in the thorax signal interpreted as breathing effort. This example originates from a patient with more OA than CA, which may have mislead the two scorers. However, cardiogenic oscillations in thermistor signal, mask pressure, and FOT signal during the apnea as well as during the adjacent hypopneas (H) suggest a central origin of this event. Annotations of signals as in Figure E1.