Noxturnal Snoring – Frequency Evaluation and Reporting package

Customer Support Document

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Nox T3[™], Nox A1[™], and Noxturnal[™] are manufactured by:

Nox Medical ehf Katrinartuni2 IS - 105 Reykjavík Iceland Website: <u>www.noxmedical.com</u>

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This document introduces new viewing and scoring support tools in Noxturnal 5.1 to enhance reporting capabilities around snoring events adding frequency band information. In addition it summarizes content provided for import by Noxturnal software: "Snoring_Noxturnal_5.1_ver2.ndb". The current focus is on Polygraphy studies and does not take Sleep Scoring into account (yet).

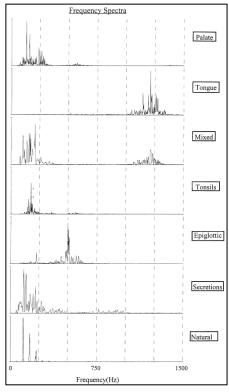
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1. Introduction

Nox Medical System provides state-of-the-art snoring analysis which results in more sensitive and accurate snoring detection based on the use of the build-in audio recording (*E.S. Arnardottir et al.: How to measure Snoring? A comparison of the microphone, cannula and piezoelectric sensor. J Sleep Res. (2015)*). As summarized in this publication "The sensitivity and positive predictive value of scoring snore events from the different sensors was compared to the chest audio: overhead audio (0.78, 0.98), cannula (0.55, 0.67) and piezoelectric sensor (0.78, 0.92), respectively. The chest audio was capable of detecting snore events with lower volume and higher fundamental frequency than the other sensors. The 200 Hz sampling rate of the cannula and piezoelectric sensor was one of their limitations for detecting snore events."

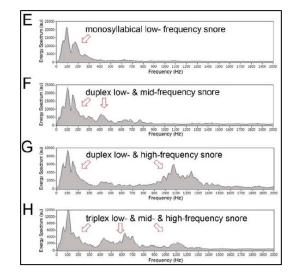
Research ongoing for more than a decade has shown the opportunity of correlating snore frequencies and its origin.



Representative sound frequency spectra of each type of snore recorded.

One of the early publications in this area (S. Agrawal et al.: Sound frequency analysis and the site of snoring in natural and induced sleep. Clin. Otolaryng 27, 162-166, 2002.) characterized some findings in the figure to the left.

Some more recent publications try to cluster snoring sounds in frequency bands and published an approach to a snoring map (L.-A. Lee et al.: Energy Types of Snoring Sounds in Patients with Obstructive Sleep Apnea Syndrome: A Preliminary Observation. PLOS ONE, Vol. 7, Issue 12, e534811, December 2012.). This approach is illustrated by the figure below: "Spectral analyses of full-night snoring sounds ... energy spectrum of an overnight snore map (E–H)".



Increasing demand for individualized treatment and objective outcome control generated a lot of interest to receive additional information about snoring, in particular about its occurrence in different frequency bands, all based on the full audio signal recorded in ambulatory studies with Nox T3 and Nox A1 systems. That prompted new viewing, scoring and reporting tools to be offered.

2. Overview: From recorded signals via Analysis and Scoring to **Enhanced Reporting about Snoring**

2.1. Signal Acquisition

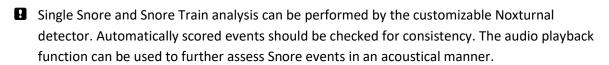
Nox T3 and Nox A1 systems always record an envelope signal of the full audio which is the base for adequate and sensitive snoring detection. The full audio signal (sampled and stored with 8 kHz) however has to be recorded and saved in order to analyze frequency information. This setting is available at the level of Device Profiles for Nox T3 and Nox A1.



Please configure your Device Profiles and used Recording Types based on your own requirements for signals and sensors but enable the full audio acquisition.

2.2 Automatic Snore Event Detection

Noxturnal detects Snore events exclusively based on audio information, in particular on the dBc weighted audio volume in Decibels (stored at 100 Hz). Single Snore events form so called Snore Trains which stand for periods with multiple Single Snores meeting certain time conditions. Single Snore analysis and definition for Snore Trains can be customized.



2.3 Manual Frequency Band Analysis

Noxturnal is able to derive and display bandpass setting depending audio channels. In addition, these channels can also been visualized with their relative Powerbands value. Manual scoring needs to take place depending on the amount of signal content in these frequency bands.

Use the provided views and events to display low / medium and high frequency band and to score prepared events according the Appendix A. Views and events can be customized further but please note that the defined events are used in the suggested report.

2.4 Customized Reporting on Snoring and Snore Frequency Information

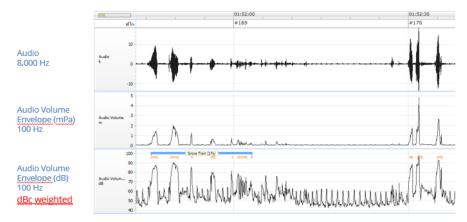
Reporting of Snore events in combination with its frequency information is generated by the association tools in the Noxturnal reporting system. Single Snores will be checked for accordance with the different frequency bands. In addition, these can be reported either as related to respiratory events or independent. Several arbitrary decisions have been taken to define thresholds for time constraints. The setup has been discussed with different clinicians but may not satisfy all users in a similar manner. Please consult for details chapter 5 of this document.



B The current custom report has been defined in cooperation with clinicians interested in the snoring analysis. Criteria can be changed but would also require adjustments in reported variables. Only a reduced number of possible snore event conditions has been selected for reporting. The suggested report is part of the Appendix A.

3. Noxturnal - Automatic Snoring Detection and Frequency Band View

Noxturnal records a full audio signal with 8.000 Hz sampling. An envelope pressure signal of the audio is derived and stored with 100 Hz, followed by a conversion with dBc weighting to receive an audio envelop signal in dB. The automatic snore detection will be performed on this signal by either a fixed or relative dB threshold. A period of multiple Single Snores will be scored as Snore Train.

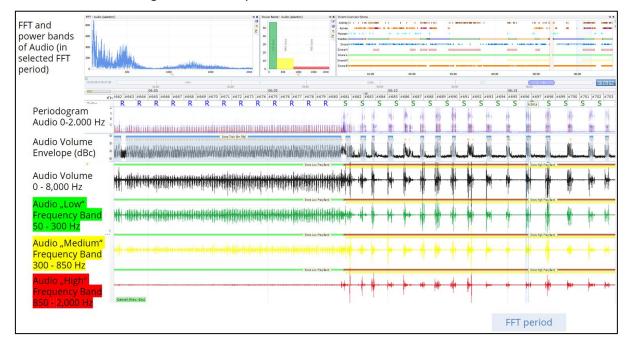


As of today, Noxturnal cannot score automatically (yet) the individual snore events in the different frequency bands but following frequency bands are derived (by FIR band pass filters) and displayed in a signal group with similar scaling properties:

- LFSB (Low Frequency Snoring Band):
- MFSB (Medium Frequency Snoring Band):
- HFSB (High Frequency Snoring Band):



Below figure (example for a 20 minutes window) shows these bands with an audio-periodogram above the audio envelop signal (dBc) with the automatically detected snoring events. A combination of FFT data for the selected period, the distribution into the frequency bands and a selected signal / event overview is configured for the top view area.



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4. Frequency Band Scoring

As Snore events are not automatically scored to the frequencies bands a manual classification (for the snore periods) in the bands must take place. This can be performed in a rather rough manner as the reporting capabilities in Noxturnal will associate the Snore events with frequency information.

The window size can be chosen rather long (below e.g. 4 hours) and as shown in the picture below the information in the Relative Power Band Value (percent) supports a quick manual scoring in the frequency bands.

Audio (1.3 second epoch)		Event Overview-Snore			
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The first three signal are derivations from the full audio to show the power ration of a certain frequency band (LFSB, MFSB, HFSB) to the total of the three. The scales therefore equal percentages: 1 ... to signify 100%; 0,5 to signify 50% and so on. The levels for the axis lines (red dotted lines) are set for easier decision making (NOTE: the 10% are arbitrary chosen for support):

•	LFSB Power Ratio (Low Frequ. Band):	Scale 0 – 100%	Axis Line: 10%
•	MFSB Power Ratio (Medium Frequ. Band):	Scale 0 – 50%	Axis Line: 10%
•	HFSB Power Ratio (High Frequ. Band):	Scale 0 – 50%.	Axis Line: 10%

Three event types have been created to score the snores within these Power Ratio derivations:

- Green \rightarrow Snore with Low Frequency Band contribution
- \rightarrow Snore Low Freq Band

→ Snore High Freq Band

- Yellow \rightarrow Snore with Medium Frequency Band contribution \rightarrow Snore Med Freq Band
- Red \rightarrow Snore with High Frequency Band contribution •

It is recommended to score first the "Snore Low Freq Band" as the red highlighted event for the "Snore High Freq Band" will overlay the green bar. Other more fainted color options are possible but remain for customization by the user.

5. Custom Snoring Reporting including Frequency Band information

The scored information in the signal sheets could be used to create a huge set of parameters. The report information should however still fit a small number of pages and avoid going to extreme detail for all possible conditions. Therefore, the suggested report (see also Appendix A) combines a limited number of numeric and graphical representation for:

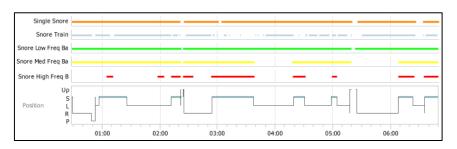
- Single Snores within and outside of Snore Periods
- Snores and coherence for specific frequency bands •
- Snores related or unrelated to Respiratory events (customizable time dependency). •

Following arbitrary decisions got taken:

- 1. Frequency bands are defined to 50 300 Hz, 300 850 Hz and 850 2.000 Hz (this "fits" frequency bands according the two cited publications in the introduction of the document).
- 2. Positional statistics are reported as "All" as well as the split into Supine / Left+Right / Prone.
- 3. Tables for frequency bands take into account Single Snores within Snore Trains only. This means that Snores outside of Snore periods are not analyzed / reported further. However, percentages are given on the base of all Single Snores.

Single Snores within Snore Periods (percentages compare to all S-Snores)									
		All position	S	Sup	vine	Left /	Right	Pro	ne
Reporting all snores which	Count	Total	% of all	Total	% of all	Total	% of all	Total	% of all
contain frequencies of		time[s]	S-Snores	time[s]	S-Snores	time[s]	S-Snores	time[s]	S-Snores
Low Frequ. (50-300 Hz)	2259	2837,8	86,6%	462,3	18,4%	2366,6	67,9%	8,9	0,3%
Medium Freq. (300-850 Hz)	1608	1987,9	61,7%	461,9	18,4%	1517,2	42,9%	8,9	0,3%
High Frequ. (800-2.000Hz)	313	307,8	12%	196,6	8,1%	111,3	3,9%	0	0%

- 4. A relation of snore to respiratory events is defined as given for any Single Snore within a Snore Train which follows within 20 seconds after a respiratory (OSA) event. In contrast, it requires a minimum of 5 minutes to define Snore events as unrelated (outside of) to OSA events. Any Snore events not meeting one of these conditions will not get reported further.
- 5. The combination of different frequencies is presented independent from OSA relation (only).
- 6. For quick view the snores and frequency content is represented against the body position.



The suggested report uses Noxturnals high flexibility and reporting capabilities for variables structured with several conditions. The resulting report represents an advanced level, but, can be used directly without experience in Noxturnal report setup. Using the feature to hover with the mouse over a displayed derived variable with the mouse will show the Number of Single Snore events in Sleep

conditions for the variable. \rightarrow Example:

that overlap Snore Train events that overlap Snore Low Freq Band events that are near Apnea or Hypopnea events which start 0 seconds before and up to 20 seconds after

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6. Appendix A: The "Snoring_Noxturnal_5.1_ver2.ndb" content – Required layouts, events and report

Views

Sheet Layouts (these include the derived signals):

- 20min Snore L,M,H and Periodogram
- Snore Score Bands Distribution
- Overview L,M,H Snore plus Period

Workspace Layout:

• Snore Bands L,M,H for PG

Snore Analysis, Events and Event Groups

Customized Snore Detector

• Snore Modified ver0

Analysis Event Types:

- Snore Low Freq Band (in Group "Snore LoF")
- Snore High Freq Band (in Group "Snore MeF")
- Snore High Freq Band (in Group "Snore HiF")

Event Group (use in Overview sheet):

• Snore Summary Freq (Label "Snore")

Report Variables

• Library of required specific variables for the report (no need to be imported but made available for possible further reference, adjustments)

Report parts (Report Part Section "Snore Special ver1")

- Short Trend Summary Snore and Pos Graphics
- Single Snore Distribution to Resp Events Graphics
- Single Snore Freq Band distribution Graphics
- Single Snores in SP no OSA Table
- Single Snores in SP Table
- Single Snores in SP with OSA Table
- Snore Indices General Table

Report

• Snore Special L,M,H ver1 (3 pages)

Custom Fields for Recording library use

• Snore Frequency Band (\rightarrow see figure right)

Label	Identifier
Snore Frequency Band	SnoreFreqBand
ype	
Field Type	Unit Label
Multiple Choice	•
lacement	
Tab Label	Divider Label
Patient	▼
	Values with same label are grouped
Option Values	

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Power Bands:

- LFB Snore
- MFB Snore
- HFB Snore

7. Appendix B: Examples and information about derived traces, events and views

Snoring Detector Settings for "Snore Modified"

Snore Detection			Snore Train	
Shortest Snore Duration:	0,2	seconds	Minimum Number of Snores: 3	
Longest Snore Duration:	2,5	seconds		
Absolute Threshold:	65	dB	Validation	
Relative Threshold:	5	• 14,0dB	Test for inhalation overlap	
* Times the average back	round activ	rity	Test center frequency	
		-	Exclude during movement	

Example signal derivation for frequency bands – LFSB (derived from full audio)

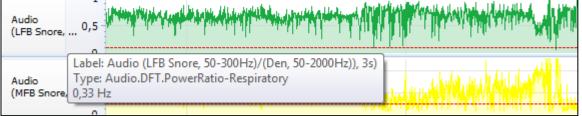
New Derived Signal	
Select derived signal type	
Filtering	Properties
FIR Filter	Filter Design
Moving Average	O Low Pass
Powerline Filter	High Pass
General	Band Pass
Integral	Band Stop 0-4000 Hz
Inverted	U Danu Stop
Spectral =	Pass frequency 50 to 300 Hz
AR Spectrum	Filter Size: 1000 taps
DFT Power Band	Signal Window: Hamming -
Periodogram	

Custom Power Bands and properties for Power Band Views

Power Bands Create or edit defa spectal power band		oands are used f	or analysis and various views showing	ower Band	ls - Audio (1	3 second epoch)	+ ×	Powerband Properti	ies 8-13 Hz
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MFB Snore	300-850 Hz			6 Uous g	B Snor	B Shor		HFB Snore LFB Snore	850-2000 Hz 50-300 Hz
HFB Snore	850-2000 Hz	-		4	W	노		MFB Snore	300-850 Hz 4-8 Hz
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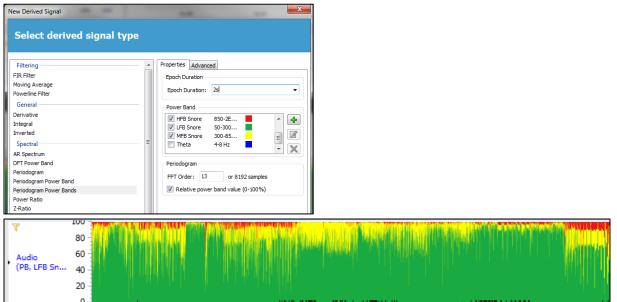
Relative Frequency Band Power Ratio View (derived from full audio)

lew Derived Signal	The second s		
Select derived signal type			
Filtering Filter	Properties		
Noving Average	Epoch Duration		
Powerline Filter	Epoch Duration: 3s		
General	Power Ratio		
Derivative	Numerator: LFB Snore		
Integral			
Inverted			
Spectral	E Denominator: Den	v	
AR Spectrum DFT Power Band	Band Range: 50 to 2000 Hz		
Periodogram	-DFT Spectrum		
Periodogram Power Band	Signal Window: Hamming	▼	
Periodogram Power Bands			
Power Ratio			
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Median			
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Relative Power Band View (derived from full audio)



Frequency Band Events - example "Snore High Freq Band"

Event Types & Groups						
Event Type	es Event Groups					
Event Type	Event Type					
General Behi	avior Display Location Properties					
Name:	Snore Special SNH-Snore High Freq Band					
Label:	Snore High Freq Band					
Short label:	Short label: SHFB					
	Is scoring event					
	Is period event					

Event		Туре			Default Duration	Shortcut Key
Snore HiF						
Snore High Freq Band snore special snh-sn			re high f	freq band	10 s	
Snore LoF						
Snore Low Freq Band snore special snl-sno			e low fr	eq band	10 s	
Snore MeF						
Snore Med Fre	q Band	Snore Special SNM-Sn	ore_Me	d_Freq_Band	10 s	
General Behavior	Display Location Proper	ties	Γ			
Display as:				General Behavior	Display Location Prope	erties
Display as:	Show background			General Behavior Suggested location		erties
Display as:	Show background					rties
Display as:	Show background			Suggested location		rties
	Show background Show label Show bar Show duration	erage 🔄 Median 📄 Minimum		Suggested location		rties
Display as: Show signal value:	Show background Show label Show bar Show duration	srage 📄 Median 📄 Minimum		Suggested location		rties
	Show background Show label Show bar Show duration Peak to peak	erage 📄 Median 📄 Minimum		Suggested location		rties

Custom Audio Periodogram (derived from full audio)

New Derived Signal	×
Select derived signal type	e
Derivative Integral Inverted AR Spectral AR Spectrum DFT Power Band Periodogram Power Band Periodogram Power Band Periodogram Power Bands Power Ratio 2:Ratio Statistical Max Max Synchronize to scoring epochs	Properties Epoch Duration Epoch Duration Epoch Duration Periodogram FFT Order: 9 or 512 samples Overlap: 50 % Signal Window: 35mming Normalized, divided by the number of samples in spectrum
	Restore Defaults OK Cancel

The 3-D resolution and color saturation in below periodogram can even manually changes quickly by the "magic hands".

Properties Axis Signal 30 Derived Signals 4 P Axis High: 250 M Axis Axis High: 250 M Axis Low: 0 M Ø Auto Magnitude Values Ø Axis High: 250 M Magnitude Mega Ø Auto Decimals Ø Auto Decimals Ø Auto Decimals Decimal Places: 1 Ø Draw Axis Grid Ø Draw Axis Grid Ø Draw Axis Grid Axis Height: 82 pixels Ø Draw Axis Grid Ø Draw Axis Grid	Ludio 0-2000 (Periodogra 1- 0-250 Mega] Audio 0-2000 Hz (Periodogram, 0,1s) [0-2000 Hz] [0-250 Mega]	
Axis High: 250 M		
Apply OK Cancel Apply OK Cancel	Axis High: 250 M Axis Low: 0 M Magnitude Mega V Decimal Places: 1 V Axis Height: 82 pixels	Axis High: 250 M Axis Low: 0 M ✓ Auto Magnitude Values Magnitude Mega ✓ Auto Decimals Decimal Places: 1 ✓ Draw Axis Grid Axis Height: 82 pixels

Event Group	X			
Group Name: Group Label:	Snore Summary Freq Snore			
Description:				
Events:	Select Order	Snore Single	Apn - CA - MA - I OA - IOI CH - CH -	
	OK Cancel		SMFB - SHFB -	
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Rudio Volum 80 70 60 50				
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kion uoto ooo-eso He)			dining and the second	þ
ludio 850-2000 Hz)	·····		·····	

Complete Night Study Overview (incl. custom event group)

For questions or further information please contact support@noxmedical.com.