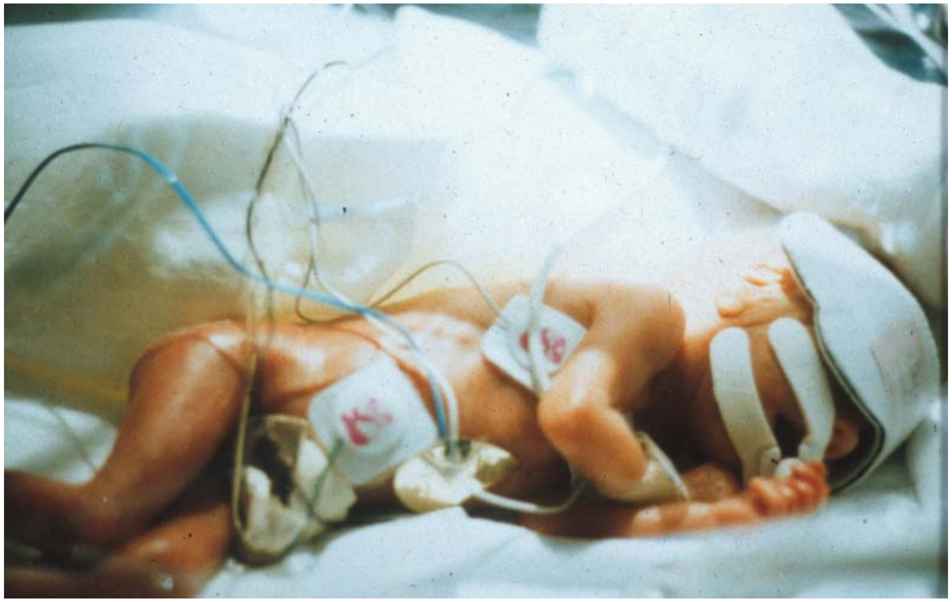
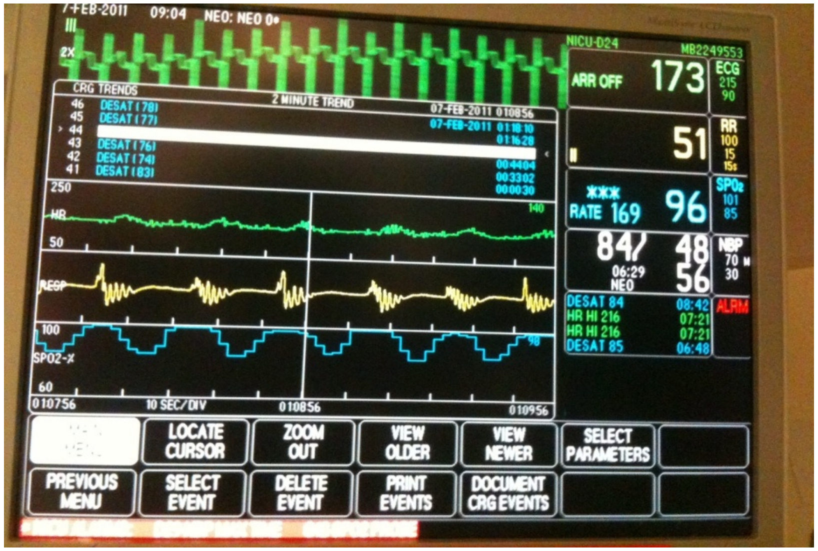
Saving
Infants
in a Heartbeat!

Saving
Infants
by their Heartbeats!

The TV show and movie Star Trek had a fictional Dr. McCoy who used a device called a "medical tricorder" to examine patients in an instant.

Electronic Detection and Diagnosis of Health and Illness of Premature Infants





Big Data

- **The NewBaby Database on SciClone**

- January 2009 – ~Present,

  All waveform and vital sign data from electronic monitors in 45 bed UVa NICU.

  - Waveforms: ECG, Chest Impedance, Pulse Ox (60-240 Hz)
  - Vital signs: Heart & respiration rates, oxygen saturation of hemoglobin (2 sec)
  - ~ 10 TB
  - **Approximately 200 baby-years of data**

  - ~ 2600 admissions, > five years, > 700 VLBW infants.
  - Monitor alarms were stored (e.g. brady, desat, and apnea etc..).
  - Connected clinical database and related info at UVa
  - Respiratory support (room air, CPAP, SiPAP, mechanical ventilation)
  - Administration of medication (e.g. caffeine)
  - Major clinical events (surgery, …)

- **A second database (‘HeRO’)**

  heart rates (times between beats) for ~3×10^9 heartbeats for 3000 infants

  + clinical records of sepsis

Overview

Medical Issues:

Neonatal Sepsis

Apnea of Prematurity

Observations:

Electronic Monitoring of Heart, Respiration

What can we Quants contribute?

Statistical measures

Signal Analysis

Pattern recognition methods

Dynamical theories

Co-Workers

Medical Folks

Randall Moorman
Pamela Griffin
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Alix Paget-Brown
Brooke Vergales
Kelley Zagols
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Quants

Statisticians
Doug Lake
George Stukenborg

Chemical Engineers
John Hudson
Matthew Clark
Craig Rusin
Lauren Guin

Physicists W&M
Abigail Flower
Hoshik Lee
Mary Mohr
Emma Hoggan
Patrick Coleman
Andy Palomo
Tom Lever
John Delos

Supported by NIH.

Sepsis

Presence of bacteria, virus, fungus, or other organism in blood or other tissues and associated toxins.

Of 4 million births each year, 56,000 are VLBW (<1.5 Kg). For them the risk of sepsis is high (25-40%)

Significant mortality and morbidity (doubled risk of death in VLBW infants; increased length of NICU stay; high cost).

The diagnosis of neonatal sepsis is difficult, with a high rate of false negatives

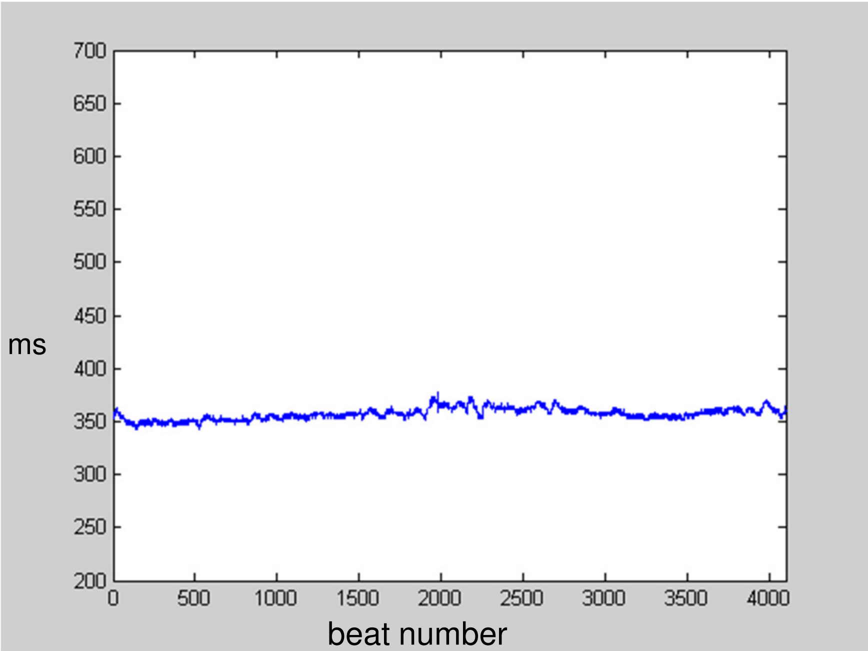
Physicians administer antibiotics early and often.

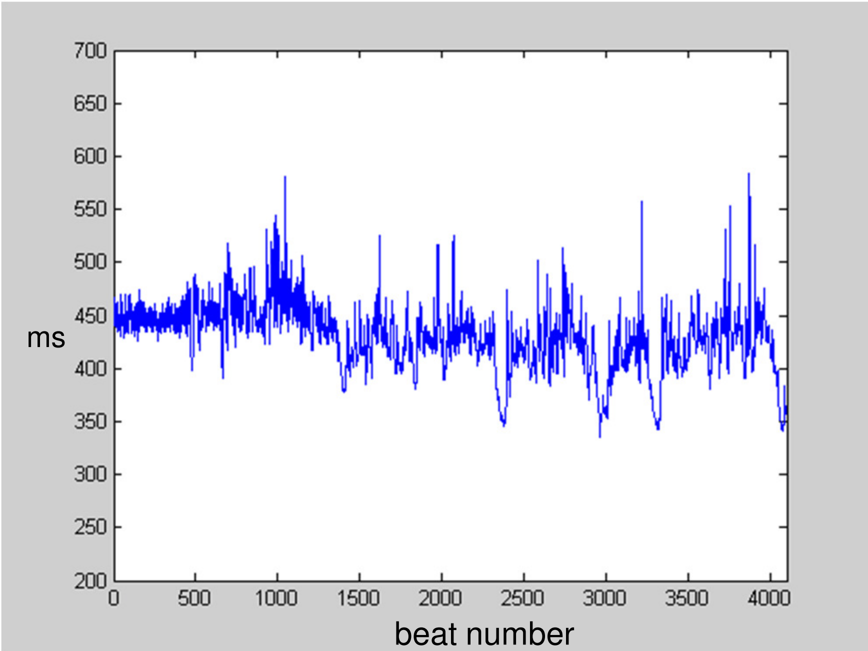
Can heart rate monitoring give early warning of sepsis?

(The invading organisms, or the immune response, may affect the pacemaking system.)
Randall Moorman

Does heart rate give warning of illness?

Plot (Time Between Beats) vs (Beat Number)



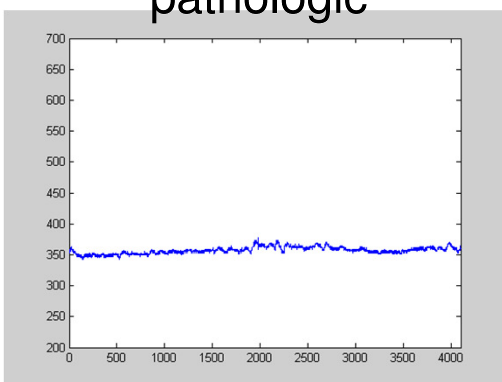


Does heart rate give warning of illness?

Plot (Time Between Beats) vs (Beat Number)

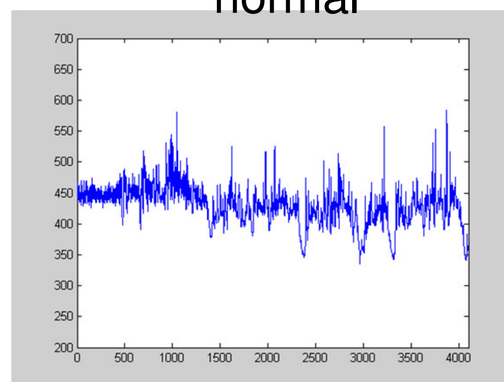
Reduced variability

pathologic



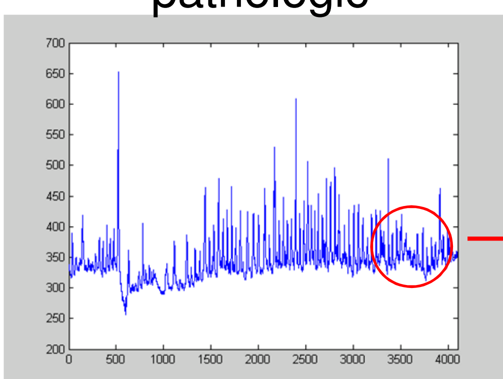
vs.

normal



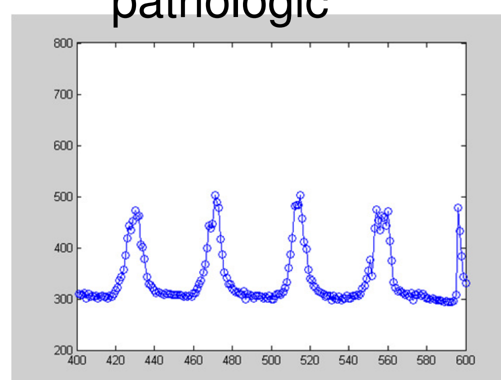
Repeated decelerations

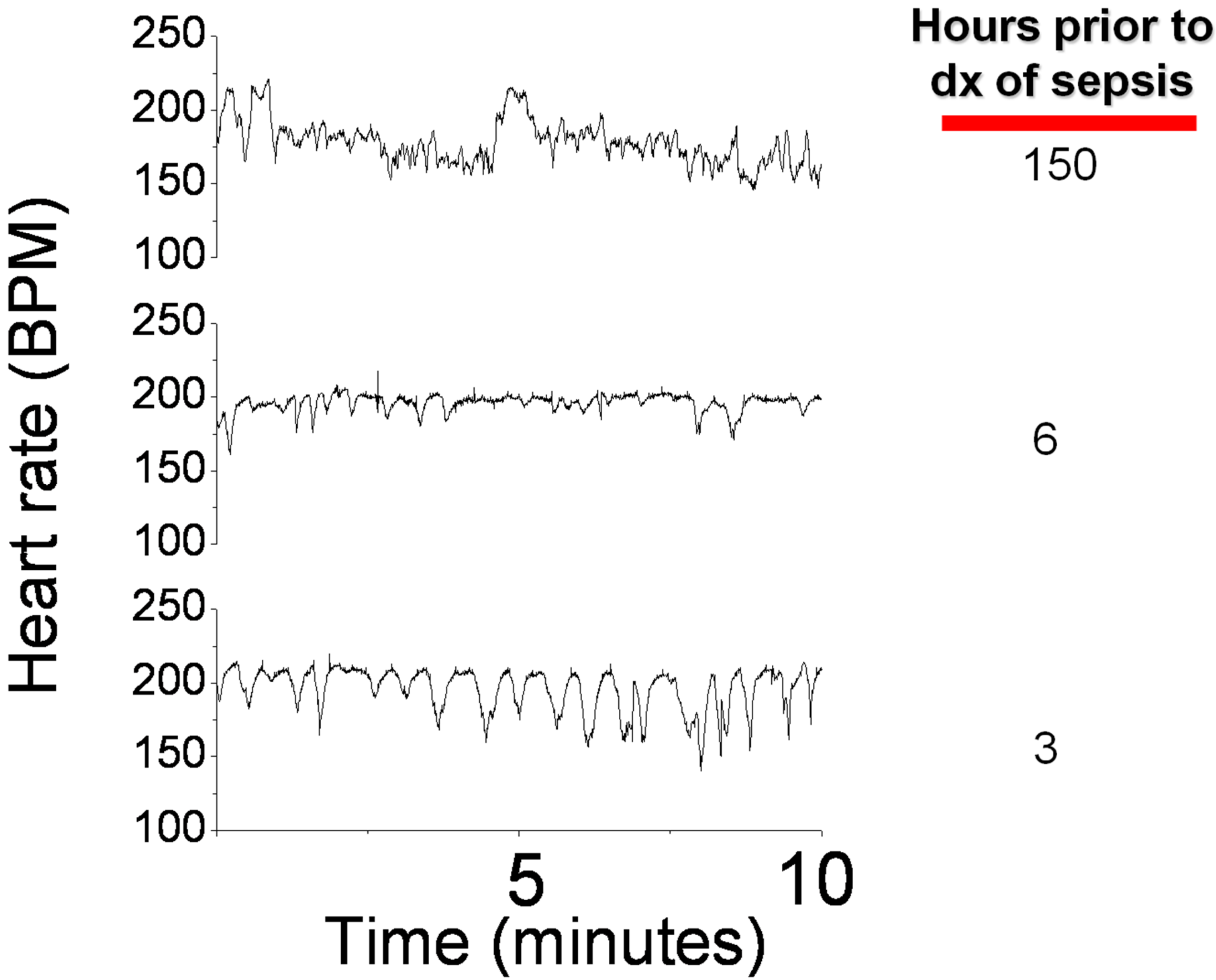
pathologic



expand

pathologic

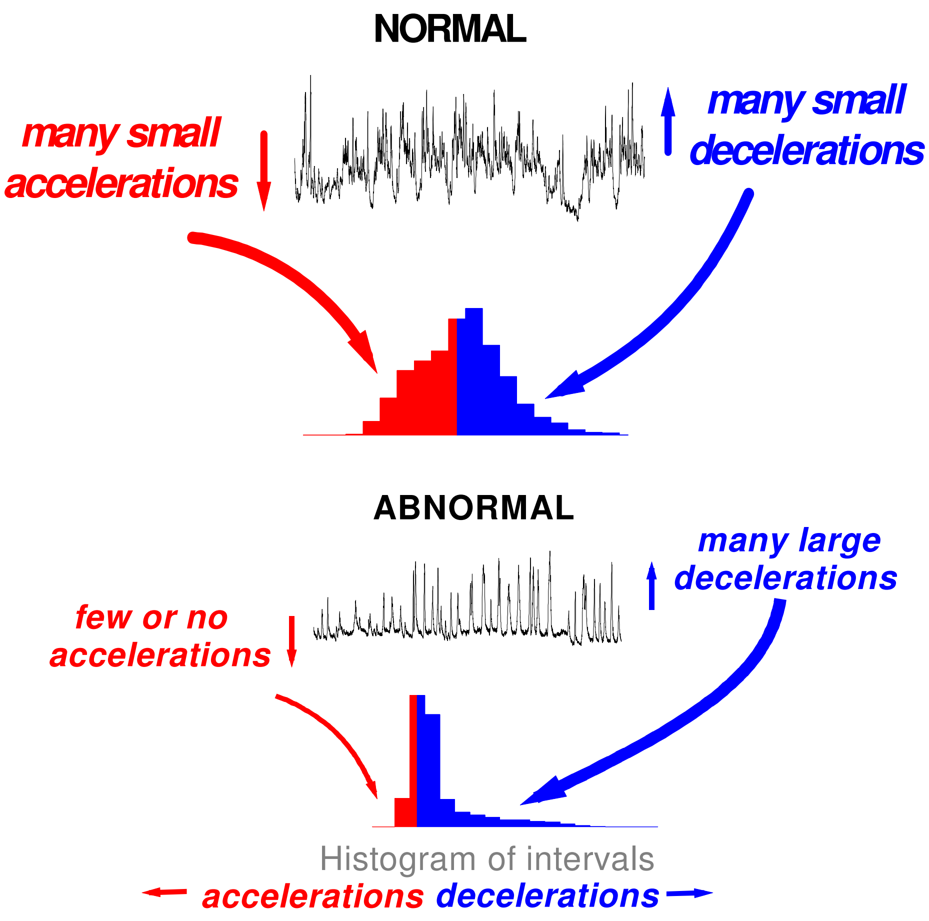



Hours prior to dx of sepsis
150
6
3
Heart rate (BPM)
250
200
150
100
5
10
Time (minutes)

Statistical Measures
of RR Interval Data

- **Standard Deviation and Sample Entropy**: Variability in the signal.

- **Sample Asymmetry**: Prevalence of decelerations over accelerations implies a skew, or asymmetry, in the data which we can detect statistically.



Find correlation of those measures with illness;

report correlation as “fold increase of risk of sepsis”:

Take any random moment.

Examine a window of 24 hours around that moment.

(18 into future, 6 into past)

On average, 1.8% of the infants in the first study

had a sepsis event within that 24 hour window.

Now examine heart rate characteristics in the days before sepsis

Identify how they differ

Convert to a “risk factor”

“Five-fold increase of risk of sepsis” → ~ 10% of infants showing

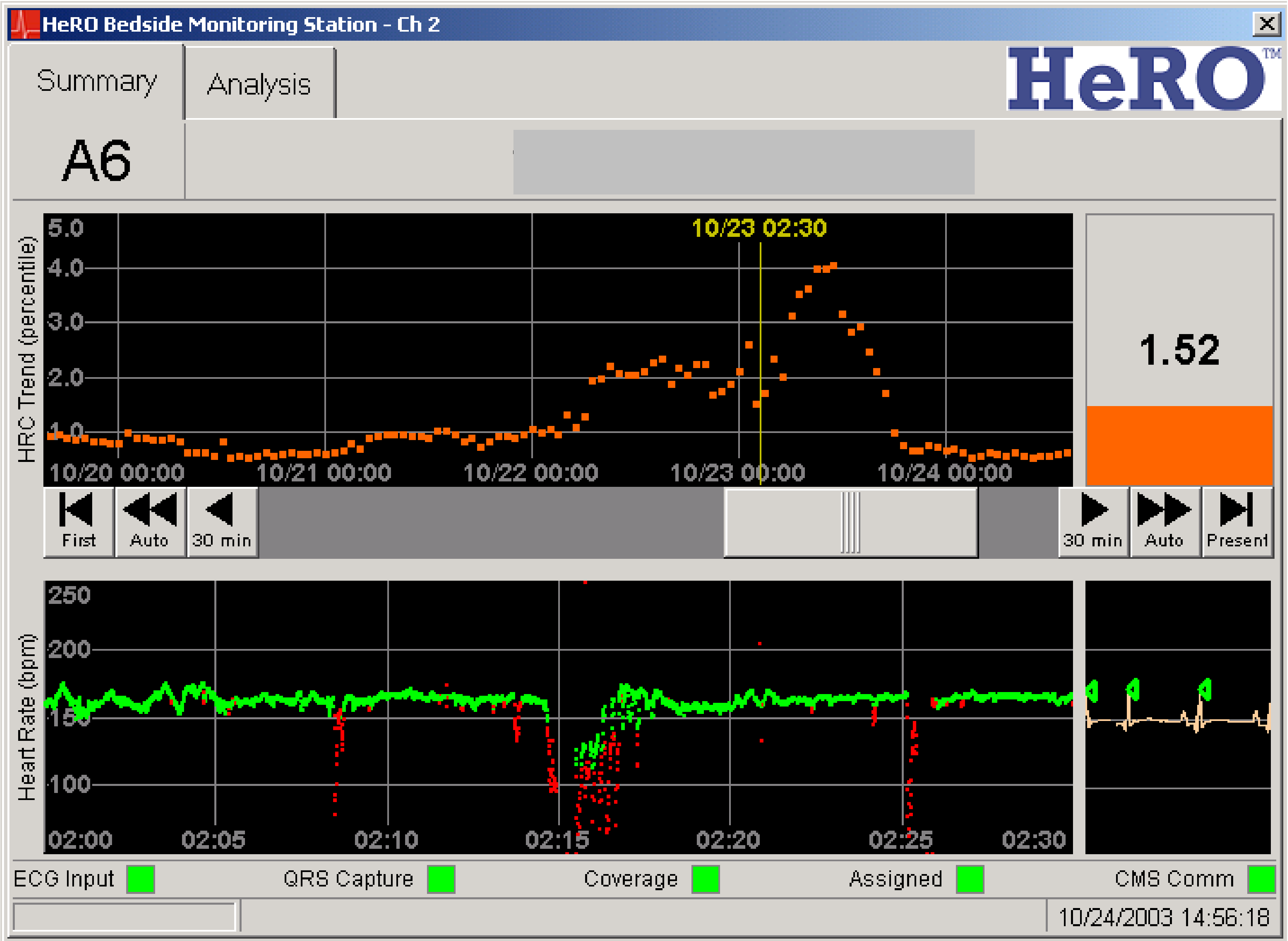
those heart rate characteristics

had a sepsis event in that 24 hour window.

Medical Predictive Science Corporation
has developed and is marketing a system for
Heart Rate Characteristics monitoring in the NICU.

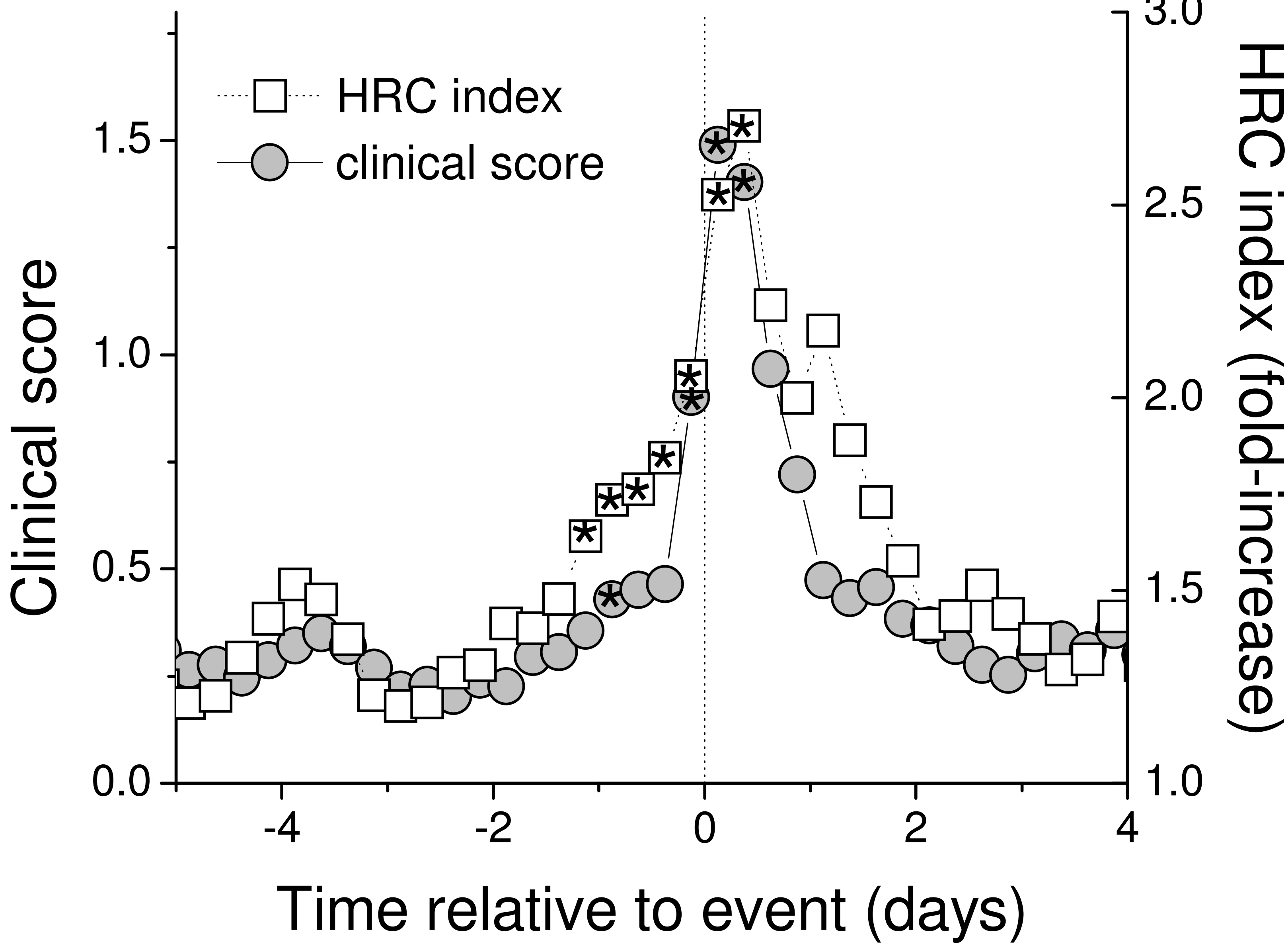
A computer beside each NICU bed continuously collects ECG data, extracts times of R peaks, tracks RR intervals, and provides the following Heart Rate Observation (HeRO).

This system is installed in several NICUs in the US, and a large randomized clinical trial has just been completed.



HeRO Bedside Monitoring Station - Ch 2
Summary
Analysis
HeRO
A6
HRC Trend (percentile)
5.0
4.0
3.0
2.0
1.0
10/23 02:30
10/20 00:00
10/21 00:00
10/22 00:00
10/23 00:00
10/24 00:00
1.52
First
Auto
30 min
30 min
Auto
Present
Heart Rate (bpm)
250
200
150
100
02:00
02:05
02:10
02:15
02:20
02:25
02:30
ECG Input
QRS Capture
Coverage
Assigned
CMS Comm
10/24/2003 14:56:18

HRC rises before illness score



Conclusion 1:

New quantitative analysis of noninvasive, electronically-measured heart rate characteristics – standard deviation, asymmetry, and sample entropy –

provides an early noninvasive warning of sepsis events.

A Randomized Clinical Trial

8 Hospitals

UVa, Wake Forest, UAI (birmingham), Vanderbilt, Umiami, Greenville SC, Palmer (Orlando) Penn State

Control
Save HeRO data
but do not display it

Sample
Display HeRO Score
(but do not tell clinicians
what to do)

2989 VLBW

152 deaths/1489, 10.2%

1513 ELBW

133 deaths/757, 17.6%

A Randomized Clinical Trial

8 Hospitals — UVa, Wake Forest, UAI (Birmingham), Vanderbilt, Umiami, Greenville SC, Palmer (Orlando) Penn State

Control Save HeRO data but do not display it		Sample Display HeRO Score (but do not tell clinicians what to do)
	2989 VLBW	
152 deaths/1489, 10.2%		122 deaths/1500, 8.1%
	1513 ELBW	
133 deaths/757, 17.6%		100 deaths/756, 13.2%

A Randomized Clinical Trial

8 Hospitals — UVa, Wake Forest, UAI (Birmingham), Vanderbilt, Umiami, Greenville SC, Palmer (Orlando) Penn State

Control	Sample
Save HeRO data but do not display it	Display HeRO Score (but do not tell clinicians what to do)

2989 VLBW

Control	Sample
152 deaths/1489, 10.2%	122 deaths/1500, 8.1%

Δ = 2.1% absolute, 22% relative p=0.04

1513 ELBW

Control	Sample
133 deaths/757, 17.6%	100 deaths/756, 13.2%

Δ = 4.4% absolute, 33% relative p=0.02

Conclusion 2:

New quantitative analysis of noninvasive, electronically-measured heart rate characteristics – standard deviation, asymmetry, and sample entropy –

saves lives.

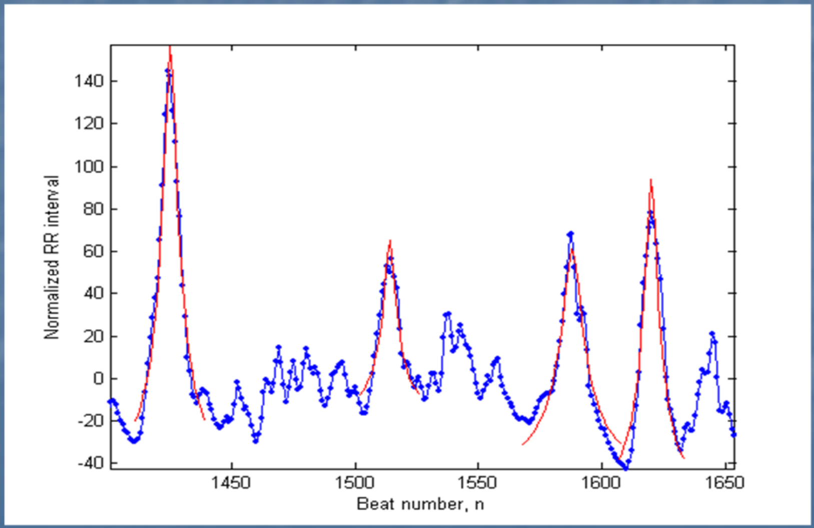
New Question:

Would direct measures of decelerations provide additional information?

Pattern Recognition

for detecting decelerations

Decompose the signal into “decelerations” and “background variability”



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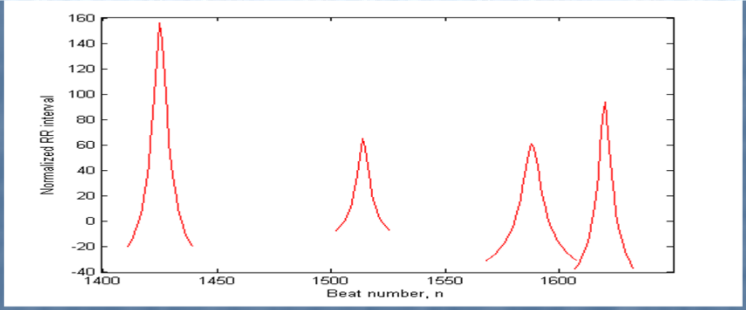

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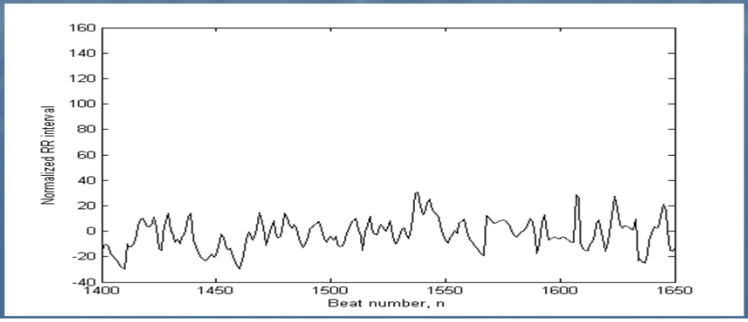
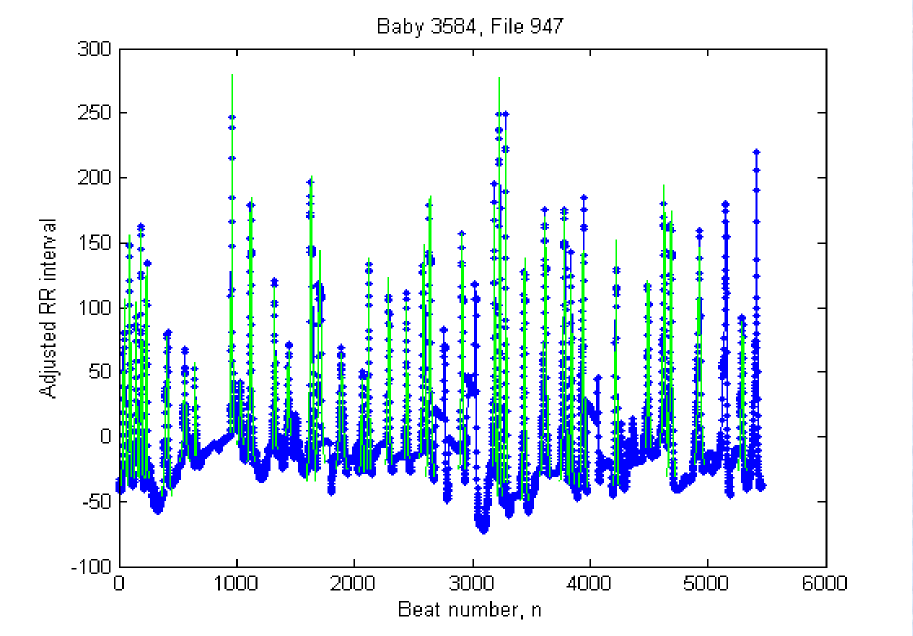


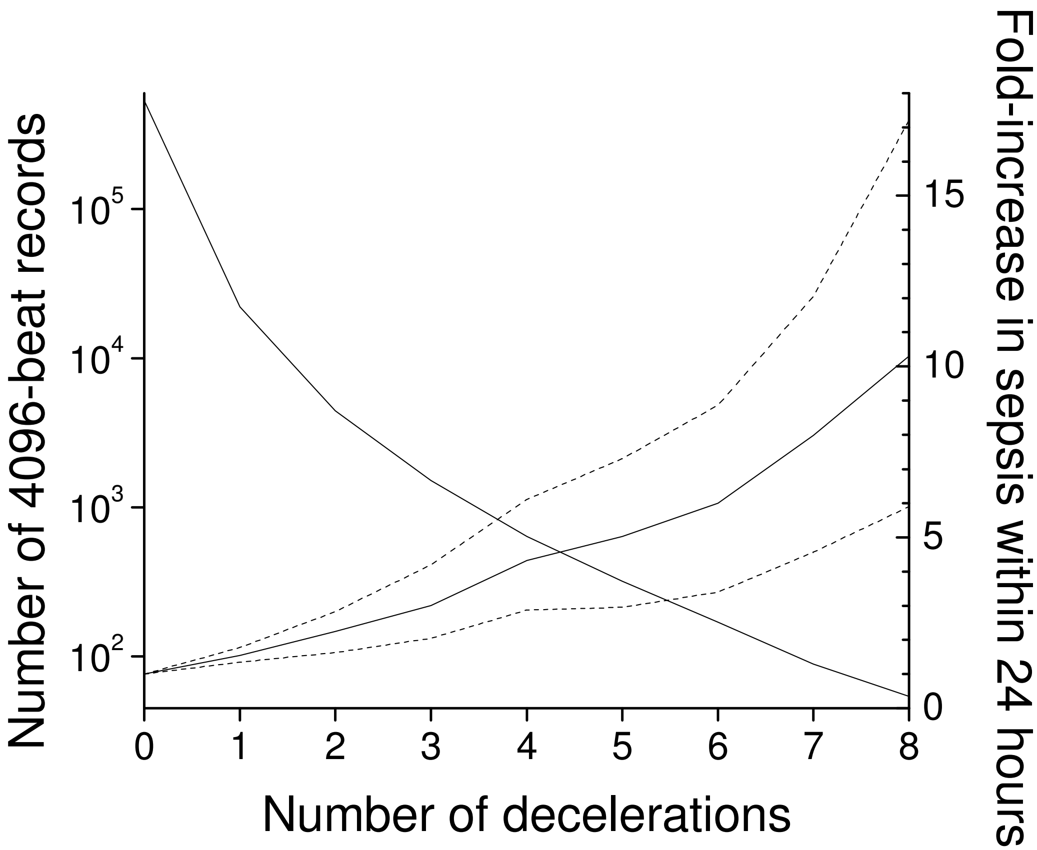
Each 20-minute segment of signal can be characterized by its deceleration information:

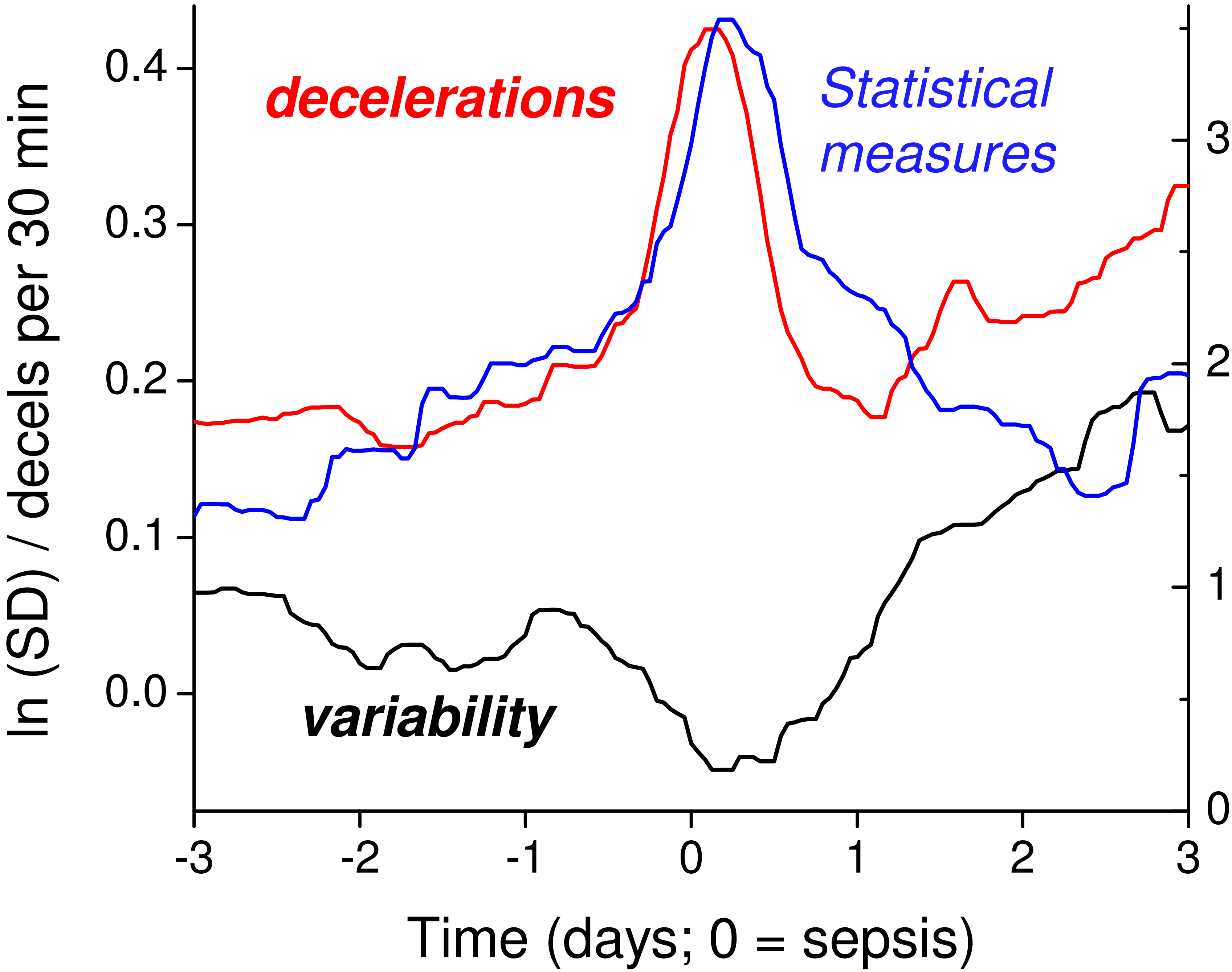
- Number of decelerations
- Location of each deceleration
- Width of each deceleration
- Height of each deceleration
- Fit to model



Find the correlation (if any) of these metrics with illness.

Result:
"Storms" of Decelerations are Highly Predictive of Sepsis





ln (SD) / decels per 30 min
0.4
0.3
0.2
0.1
0.0
decelerations
Statistical
measures
variability
3
2
1
0
-3
-2
-1
0
1
2
3
Time (days; 0 = sepsis)

Conclusion 3

Counting and measuring decelerations gives a second method for early warning of sepsis.

Also an important finding was that HR decelerations are surprisingly similar in infants.

The Future

Electronic diagnosis of infectious disease?
Can we identify invading organisms by HR monitoring?

Preliminary evidence:

Reduced variability ➡ Gram-positive bacteria (e.g. Streptococci, Staphylococci)
➡ vancomycin

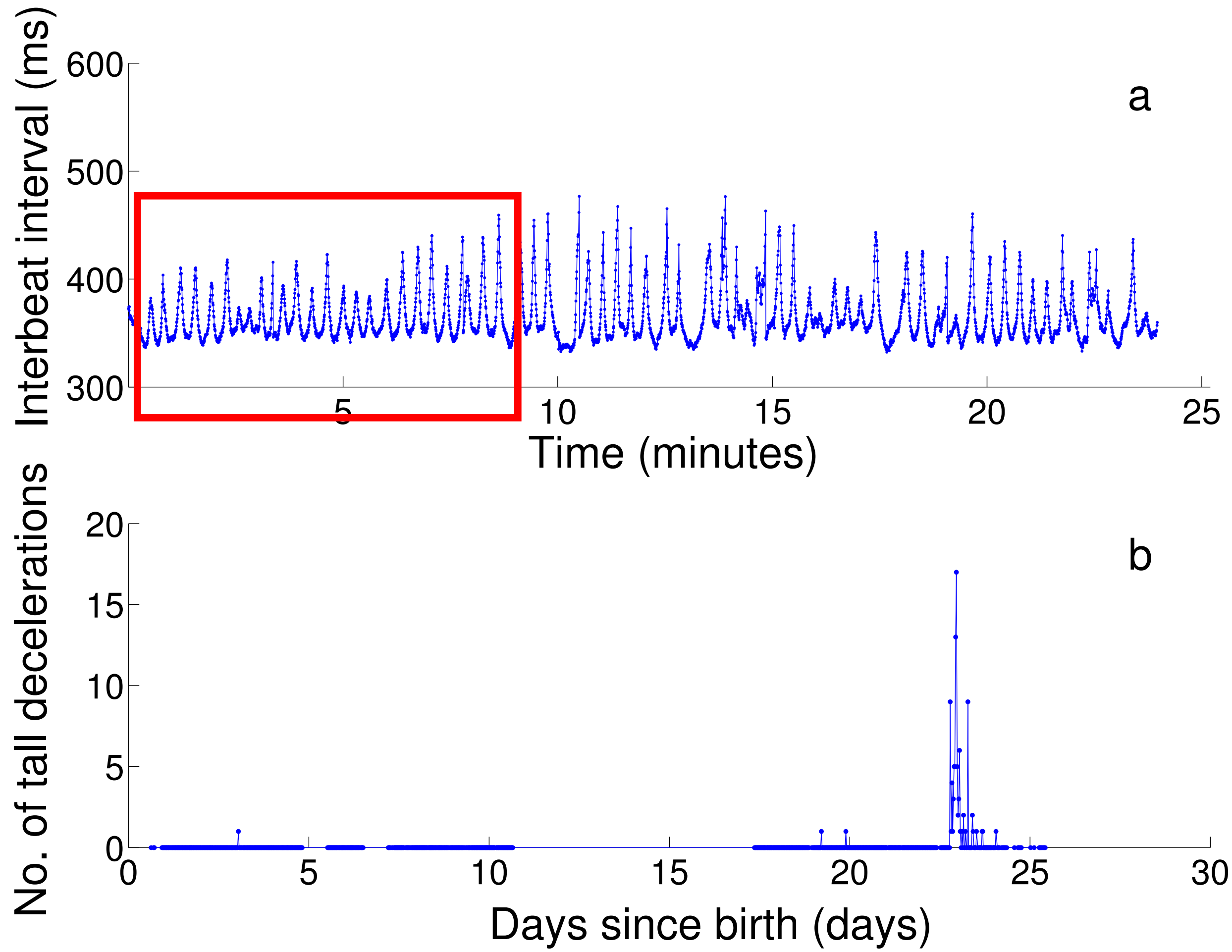
Clusters of decels ➡ Gram-negative bacteria (e.g. E. coli, Pseudomonas)
➡ gentamicin, cefotaxime

If this preliminary result holds up, we have the first example of continuous, noninvasive, purely electronic monitoring that gives early warning of infectious disease and also gives partial diagnosis, thereby identifying the recommended therapy.

(A medical tricorder)

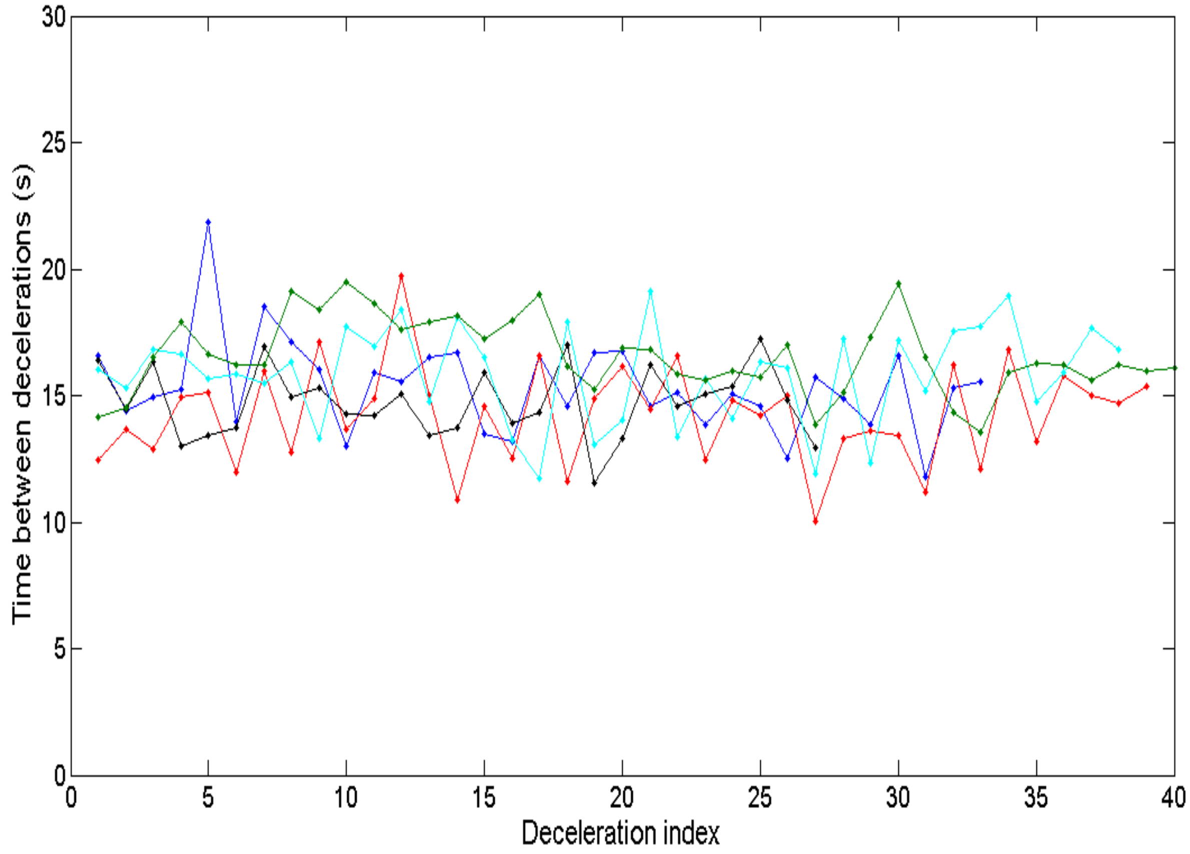
Discovery

We found that, within extended clusters of decelerations, there were sometimes shorter intervals of time, lasting up to several hours, in which the decelerations showed remarkable periodicity.



For **six infants** in our study population we identified deceleration clusters in which periodicity was maintained for at least ten minutes.

In these periodic bursts of decelerations, the time to the next deceleration was about 15 sec.



New Question:

What Causes Periodic Decelerations?

New Question:

What Causes Periodic Decelerations?

periodic apneas

Apnea of Prematurity (AOP)

Apnea (cessation of breathing) is very common for premature infants.

-> 50% of babies whose birth weight < 1500 g (VLBW)

Very Low Birth Weight

-Almost all babies whose birth weight < 1000 g (ELBW)

Extremely Low Birth Weight

Definition of (clinical) AOP

Cessation of breathing > 20s OR

Cessation of breathing > 10s + Bradycardia (Heart Rate < 100 bpm) **and** O_2 Desaturation (SpO_2 < 80%)

Three types common in preemies:

1)Obstructive apnea : blockage of the airway;

2)Central apnea : cessation of respiratory drive;

3)Mixed apneas : obstructive → central.

Central apnea → ***immaturity of control of respiration***

(e.g. discharge from UVa NICU is delayed until apneas have been absent for 8 days).

May be cause or effect or warning of many other clinical illnesses (sepsis, NEC, IVH, abnormal neurologic development).

Serious clinical event → immediate medical attention.

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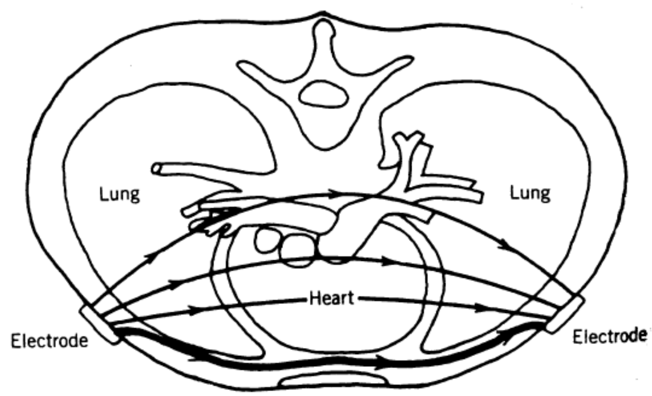
Serious clinical event → immediate medical attention.

The current generation of apnea monitors is unsatisfactory.

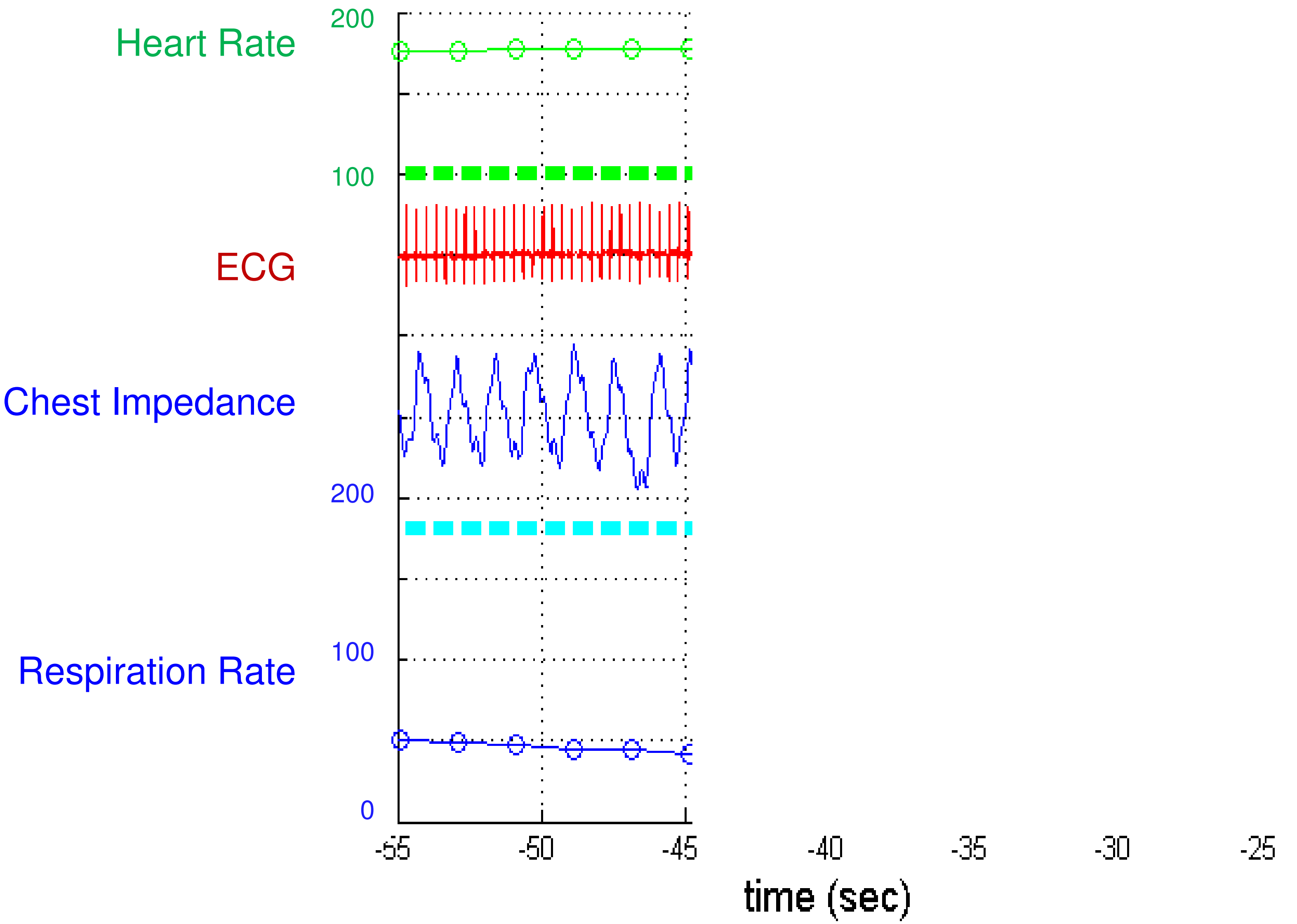
Chest Impedance Measurement



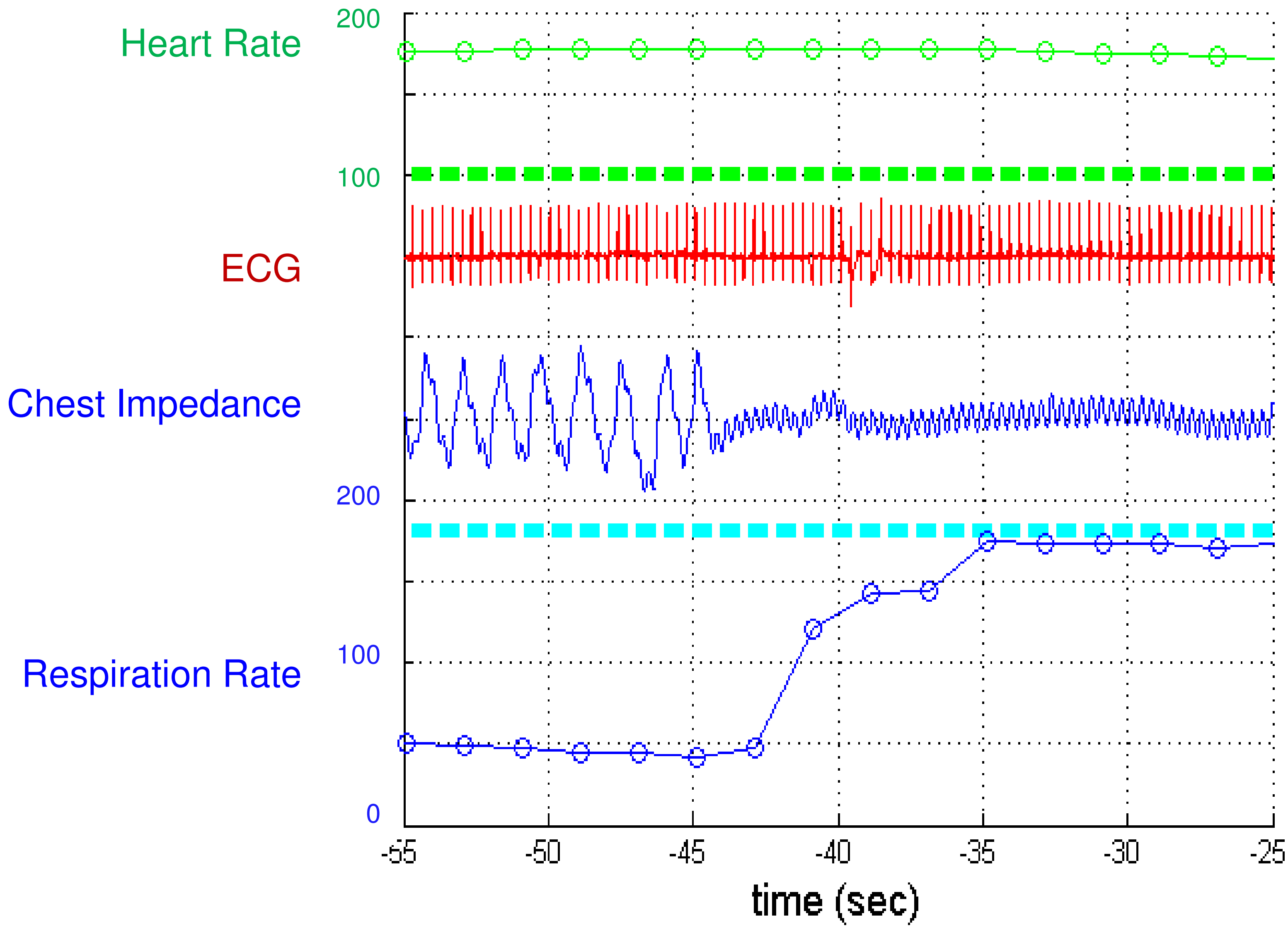
- Easiest way to monitor the respiration of baby
- Impedance between two electrodes placed at the chest.
- Use two electrodes already in use for the measurement of the EKG signal, but use a frequency (52 kHz) far outside the EKG signal.

- Basic impedance (static) : several hundred ohms: muscles, tissue, blood + electrode-skin transitions, and wires.
- Respiration : ~ 2 ohm
  - Air has poor conductivity
  - More air in the lung, higher impedance
- Heart activity : ~ 0.5 ohm
  - Blood is more conductive than air
  - Pumping blood out of thorax, less impedance

ECG & Chest Impedance



ECG & Chest Impedance during Apnea event



How do we remove the cardiac artifact from chest impedance signal? A new algorithm

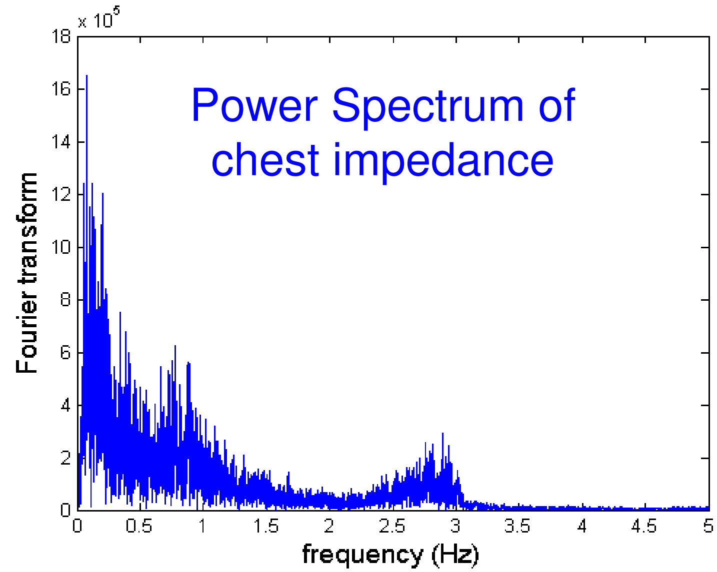
Filtering, signal analysis, pattern recognition

Hoshik Lee

Goal :

Filter the heart signal from chest impedance.

Simple Fourier filter fails. Heart beat band is too broad. Especially, the heart beat slows during apnea.



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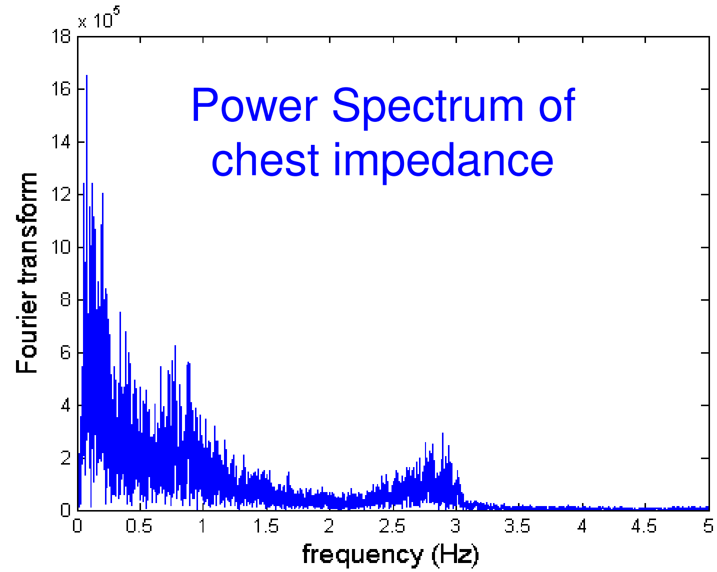

Take an idea from Galileo:

"In 1581 Galileo made his first discovery, which is characteristic of his observant eye. As the story goes, the student of eighteen was one afternoon performing his devotions in the Cathedral of Pisa, and in full view of Maestro Possenti's beautiful bronze lamp which hung (and still hangs) from the roof of the nave. In order to light it more easily the attendant drew it towards him, and then let it swing back. Galileo at first observed this simple incident, as thousands of other worshippers had done before him and have done since, i.e. in a casual way, but quickly his attention became riveted to the swinging lamp. The oscillations, which were at first considerable became gradually less and less, but, notwithstanding, he could see that they were all performed in the same time, as he was able to prove by timing them with … ???

John Joseph Fahie, Galileo, His Life and Work

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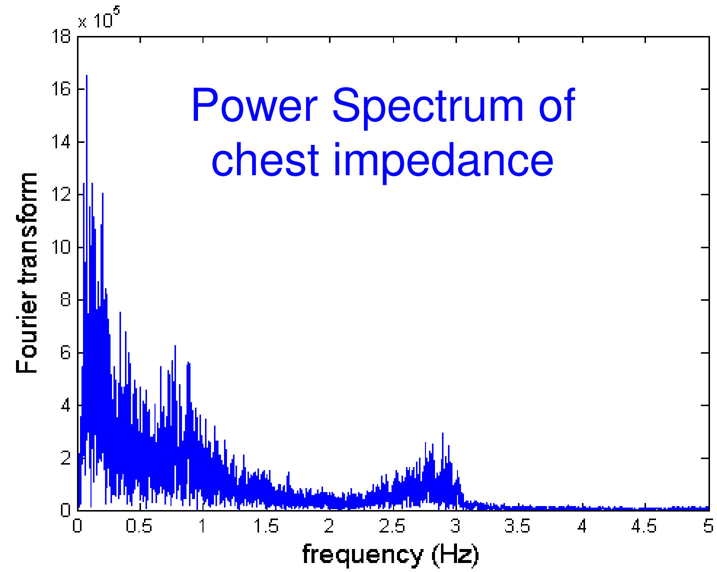

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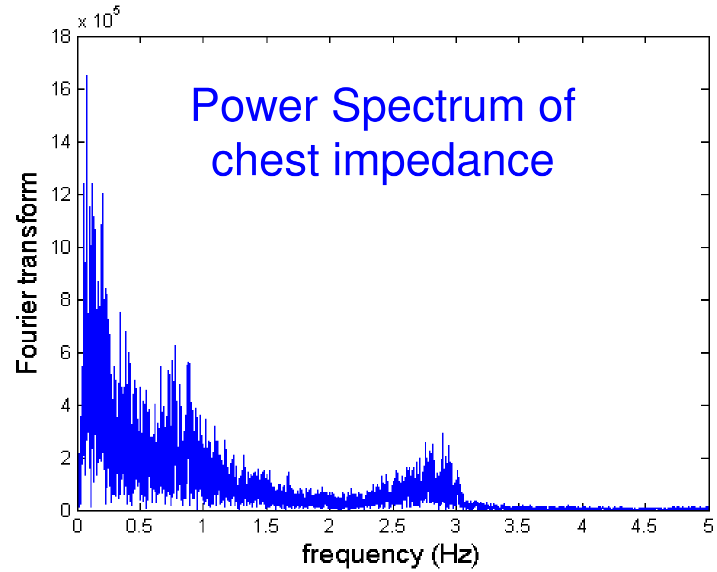
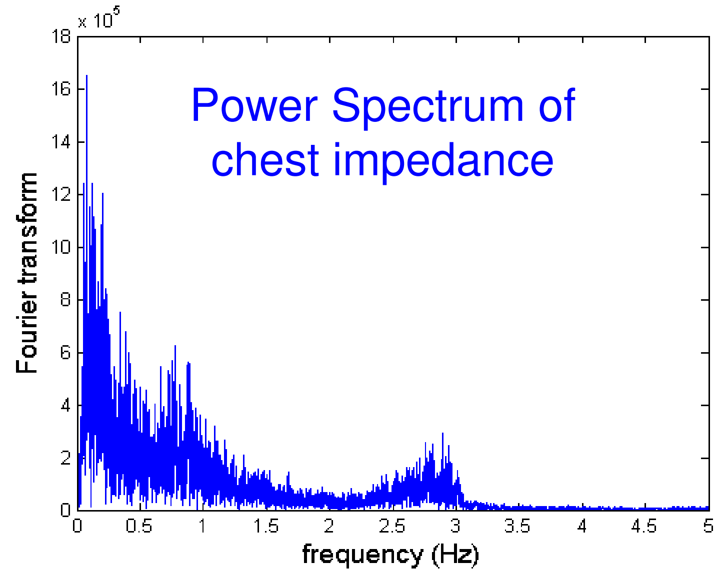


Use the Heart as the Clock !

Goal :

Filter the heart signal from chest impedance.



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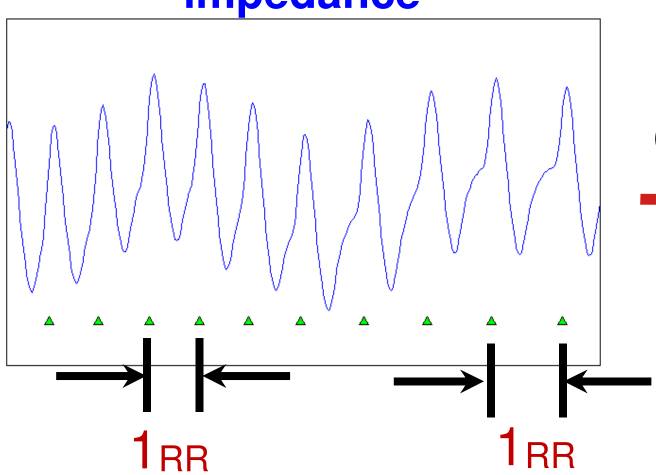
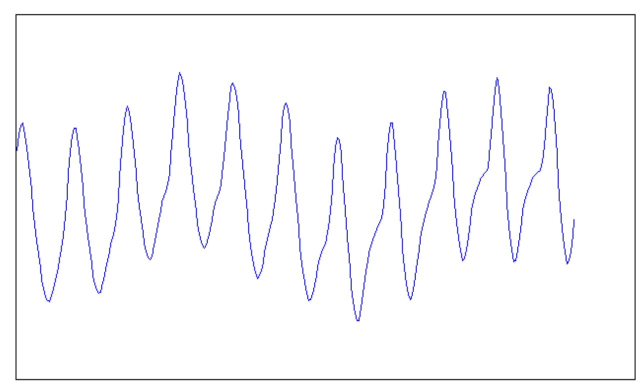
Use the Heart as the Clock !

Cardiac artifact in chest impedance

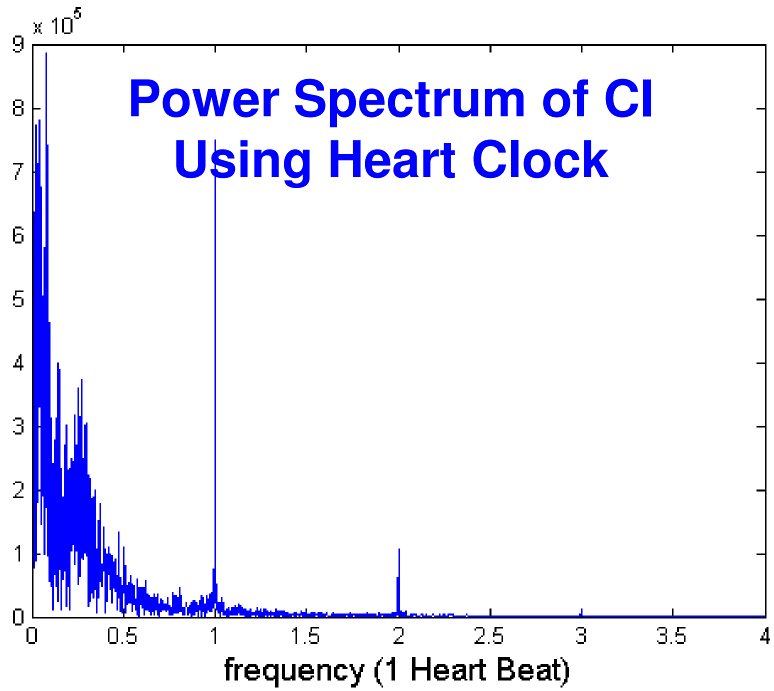


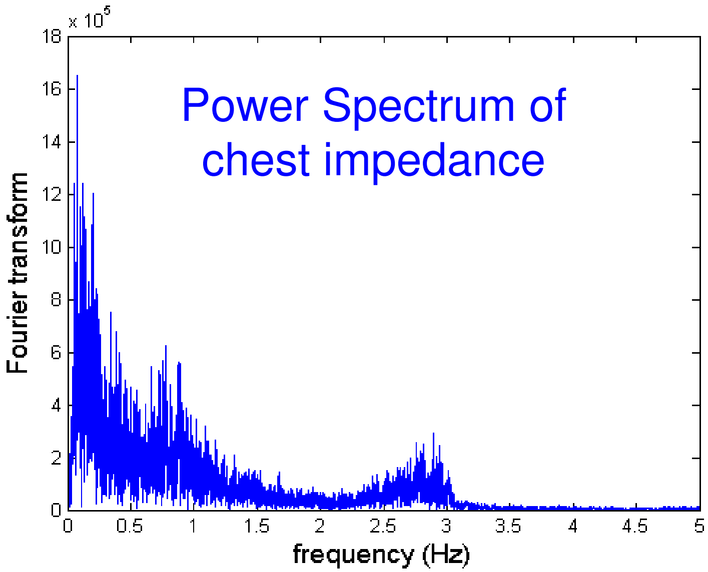
contract/stretch

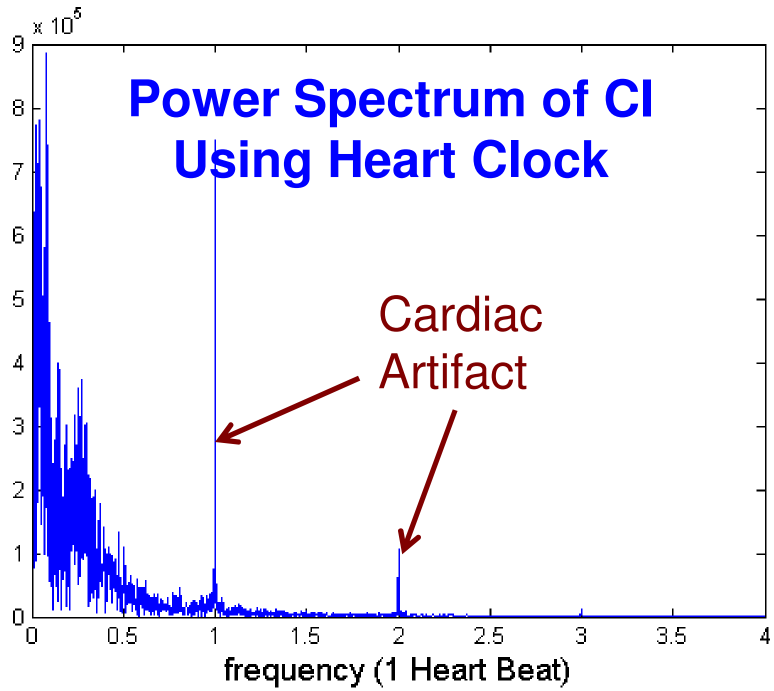
Heart Clock



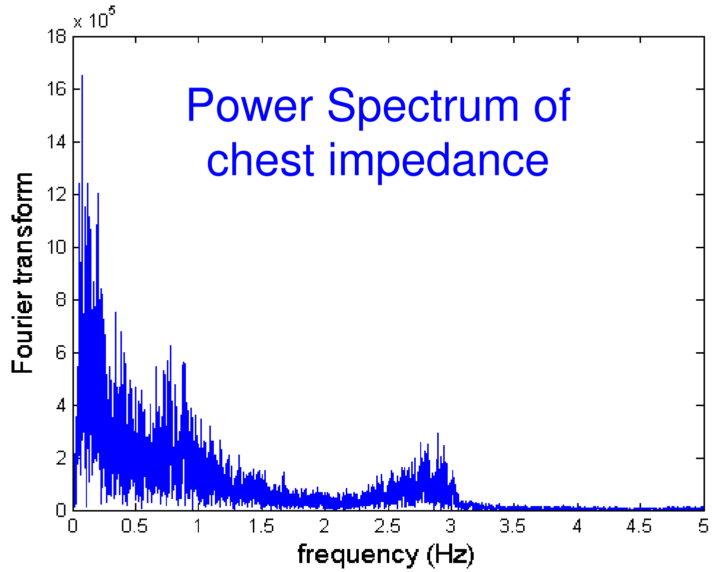
RR intervals are evenly spaced.


Power Spectrum of CI
Using Heart Clock
x 10^5
frequency (1 Heart Beat)

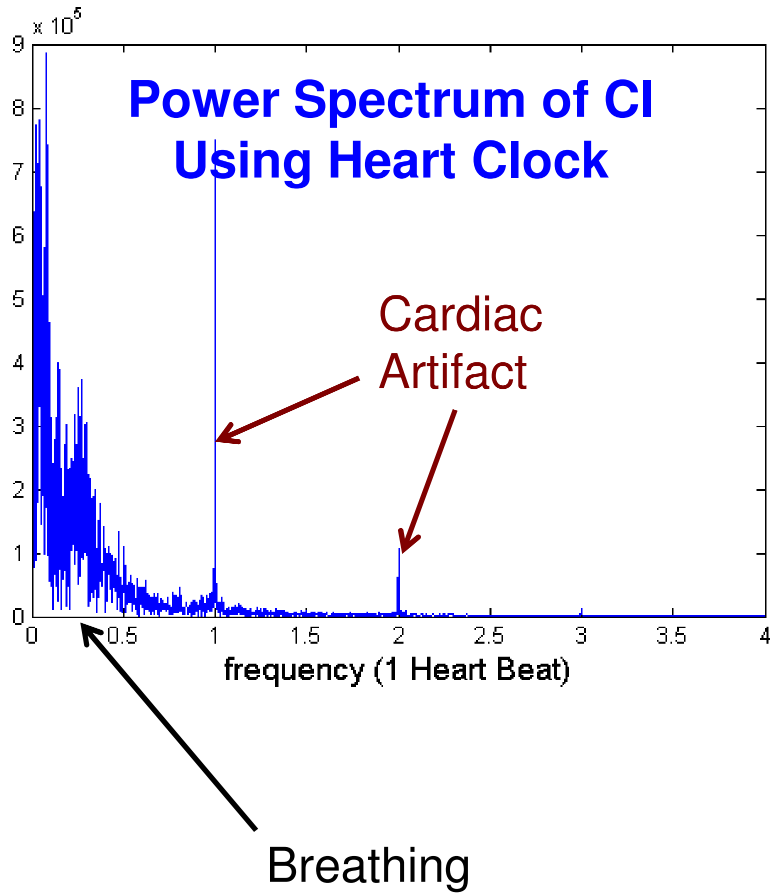

Power Spectrum of
chest impedance
x 10^5
Fourier transform
frequency (Hz)

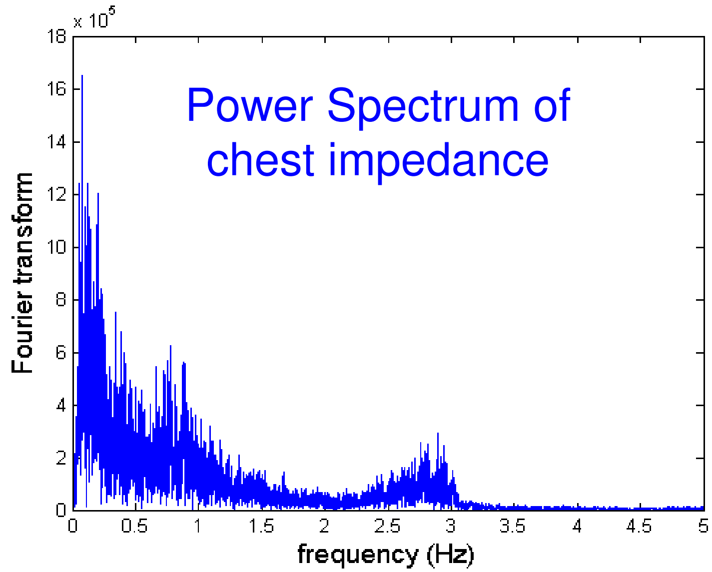


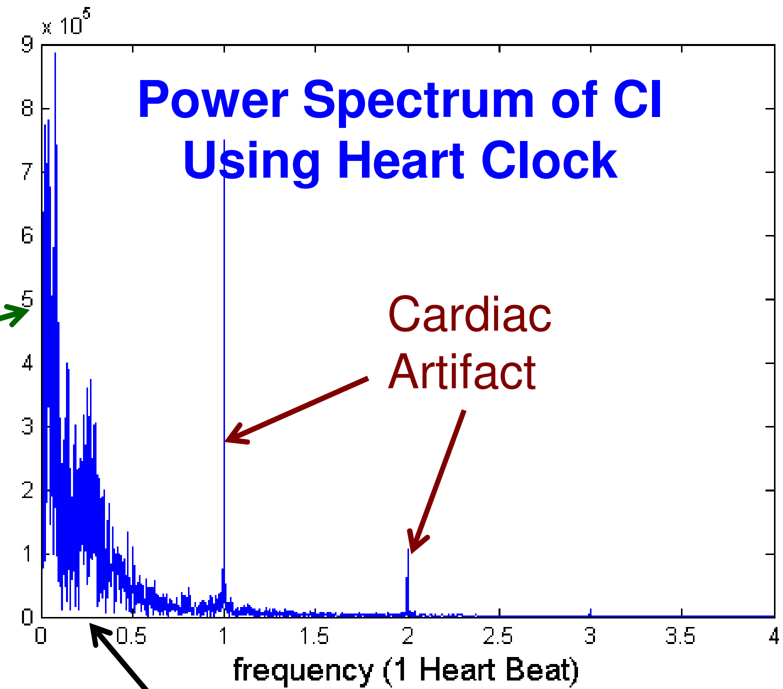
Power Spectrum of CI
Using Heart Clock
Cardiac
Artifact
x 10^5
frequency (1 Heart Beat)



Power Spectrum of
chest impedance
x 10^5
Fourier transform
frequency (Hz)

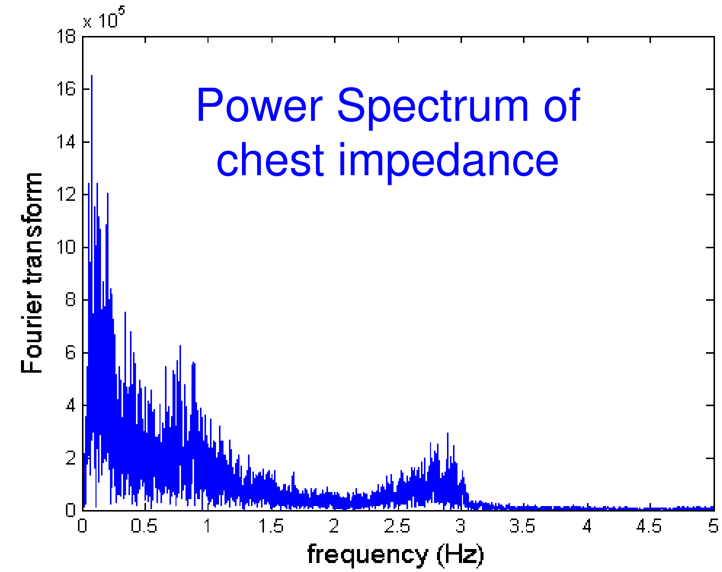

x 10^5
9
8
7
6
5
4
3
2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Power Spectrum of CI
Using Heart Clock
Cardiac
Artifact
frequency (1 Heart Beat)
Breathing

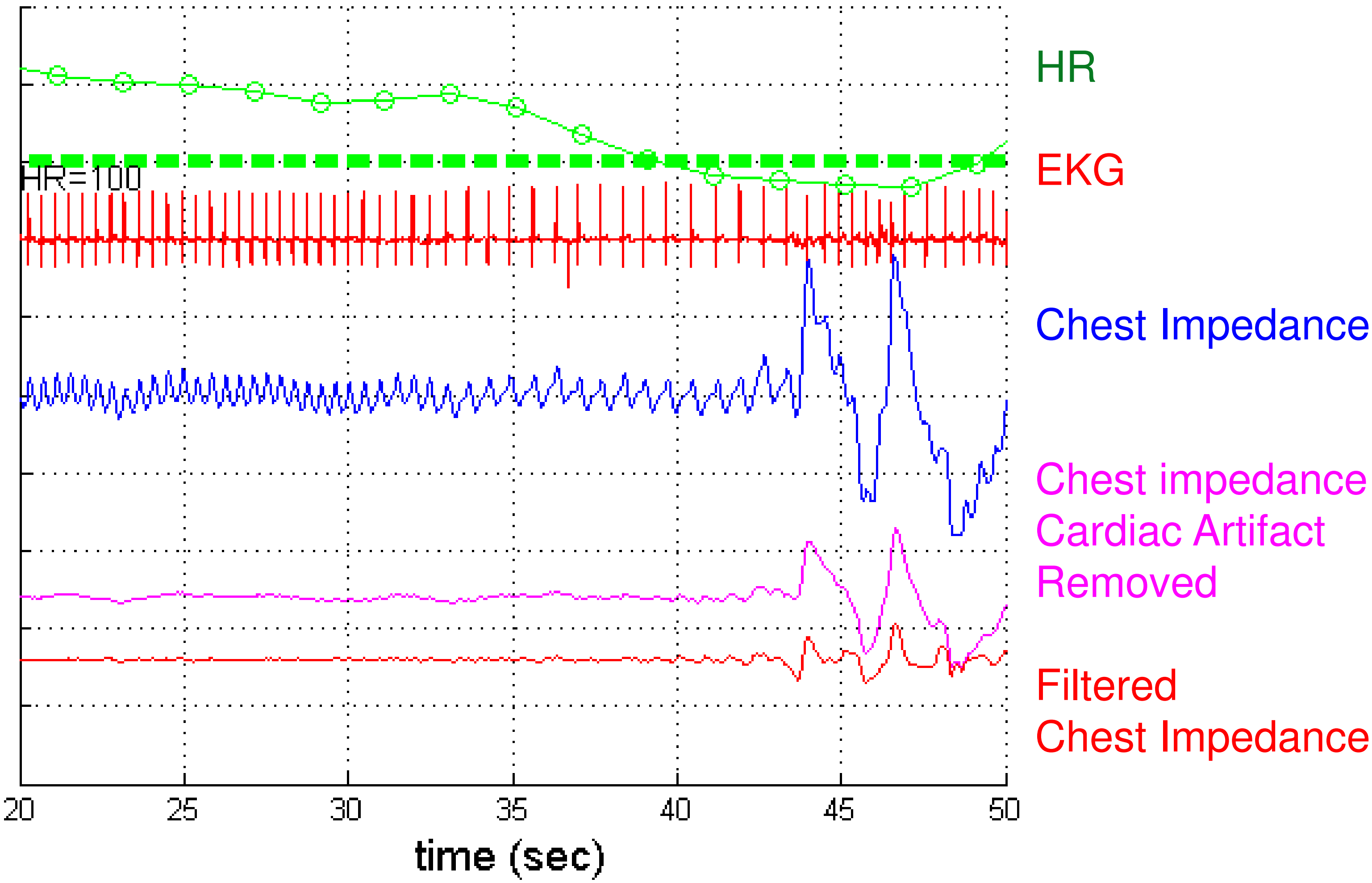

x 10^5
18
16
14
12
10
8
6
4
2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Power Spectrum of
chest impedance
Fourier transform
frequency (Hz)



Breathing

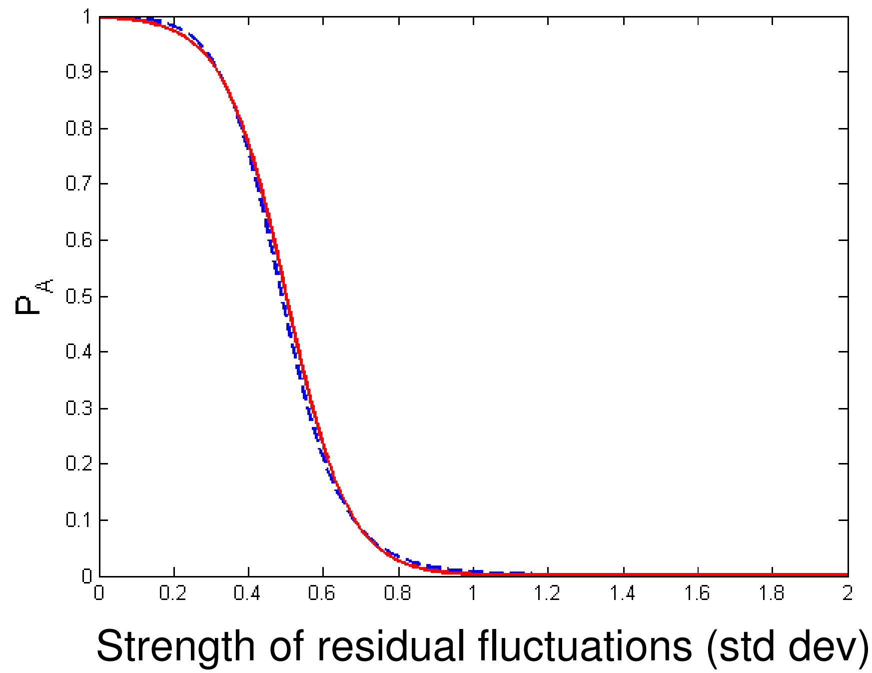
Slow change: movement or
unknown but not breathing





Small fluctuations in filtered CI remain.
Compute standard deviation of fitered signal on 2 sec intervals, spaced by ¼ sec.
Get Probability of Apnea.

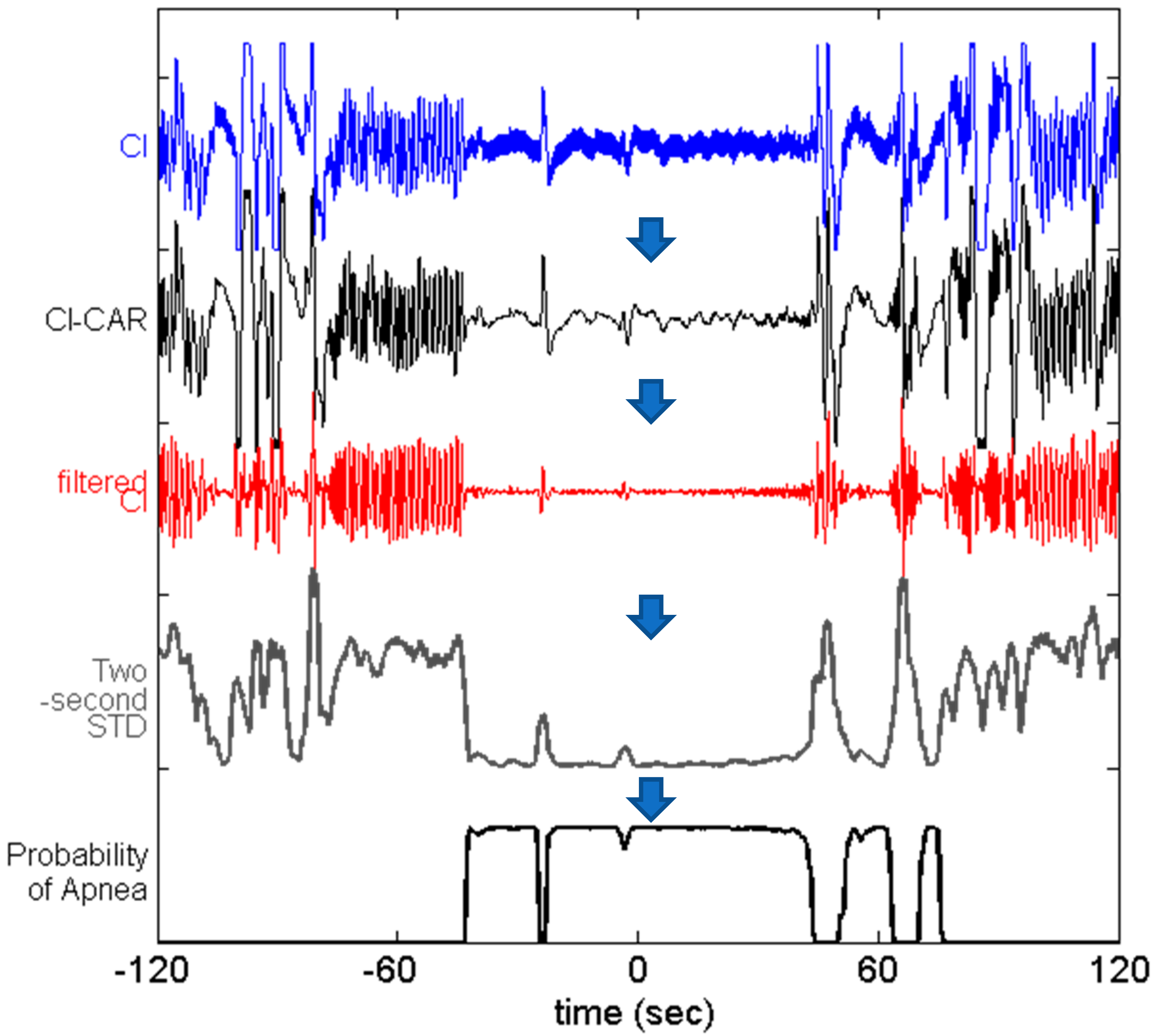
Probability of Apnea



Thresholding function looks like the Fermi distribution function. We obtain fitting function with two parameters.

$$P(E) = \frac{1}{1 + \exp[\beta(E - E_0)]}$$

Summary: from Chest impedance to probability of apnea



CI

Remove cardiac artifact

Remove slow variations and renormalize

Compute 2s std dev

P(apnea)

ABD-N

Apnea	lasting at least N seconds, with	
Bradycardia	(HR below 100)	and
Desaturation	(SpO_2 below 80%)	

$$ABD-10 \supset ABD-20 \supset ABD-30 \supset ABD-60$$

Validating the Algorithm

Algorithm vs. consensus of three expert reviews of hundreds of individual cases

Summary

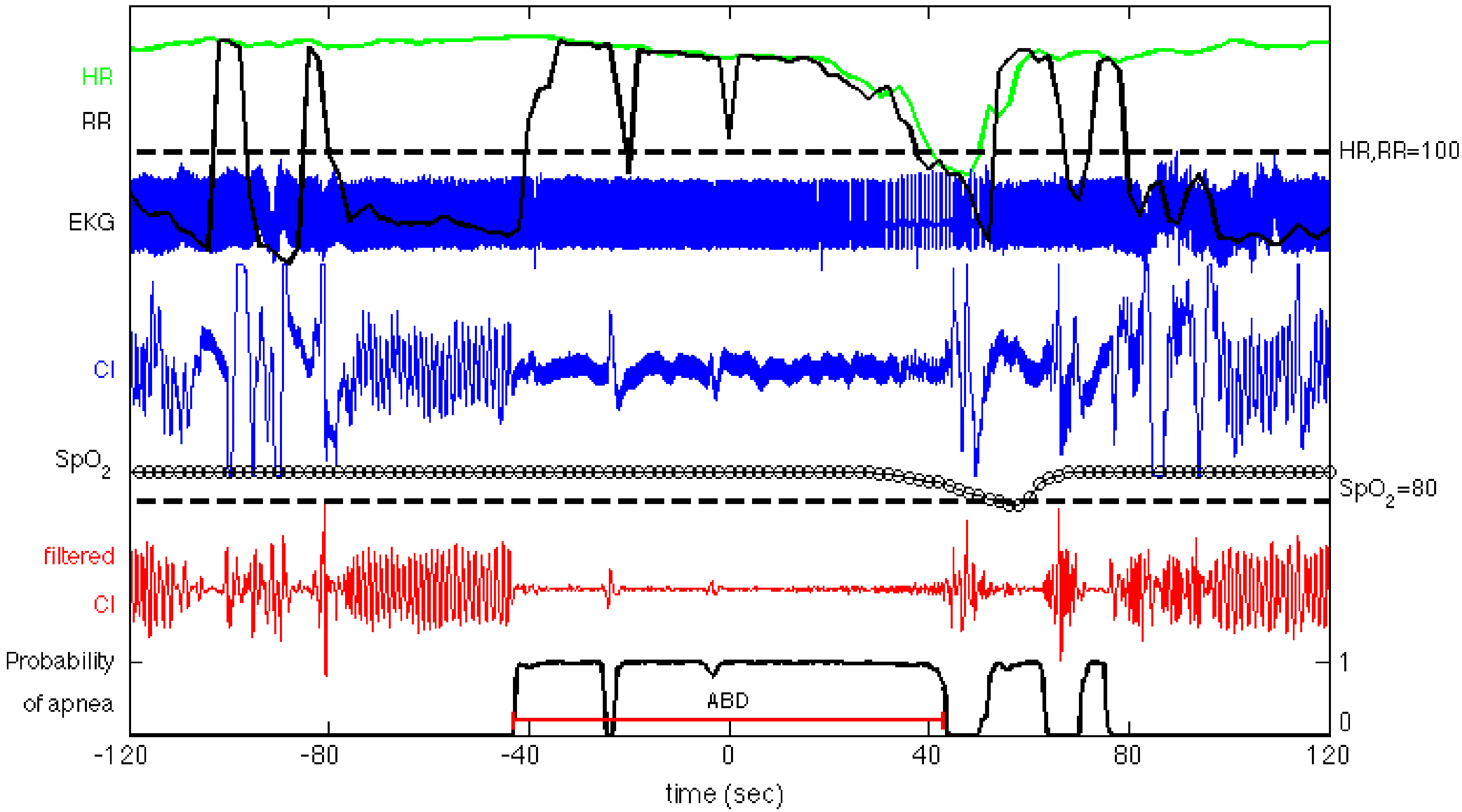
Of events detected by new algorithm, over 90% are validated.

Current generation of monitors completely misses 26% of ABD-30 events, and misses the apnea portion 74% of the time.

Of apnea alarms generated by monitors, ~2/3 are false alarms

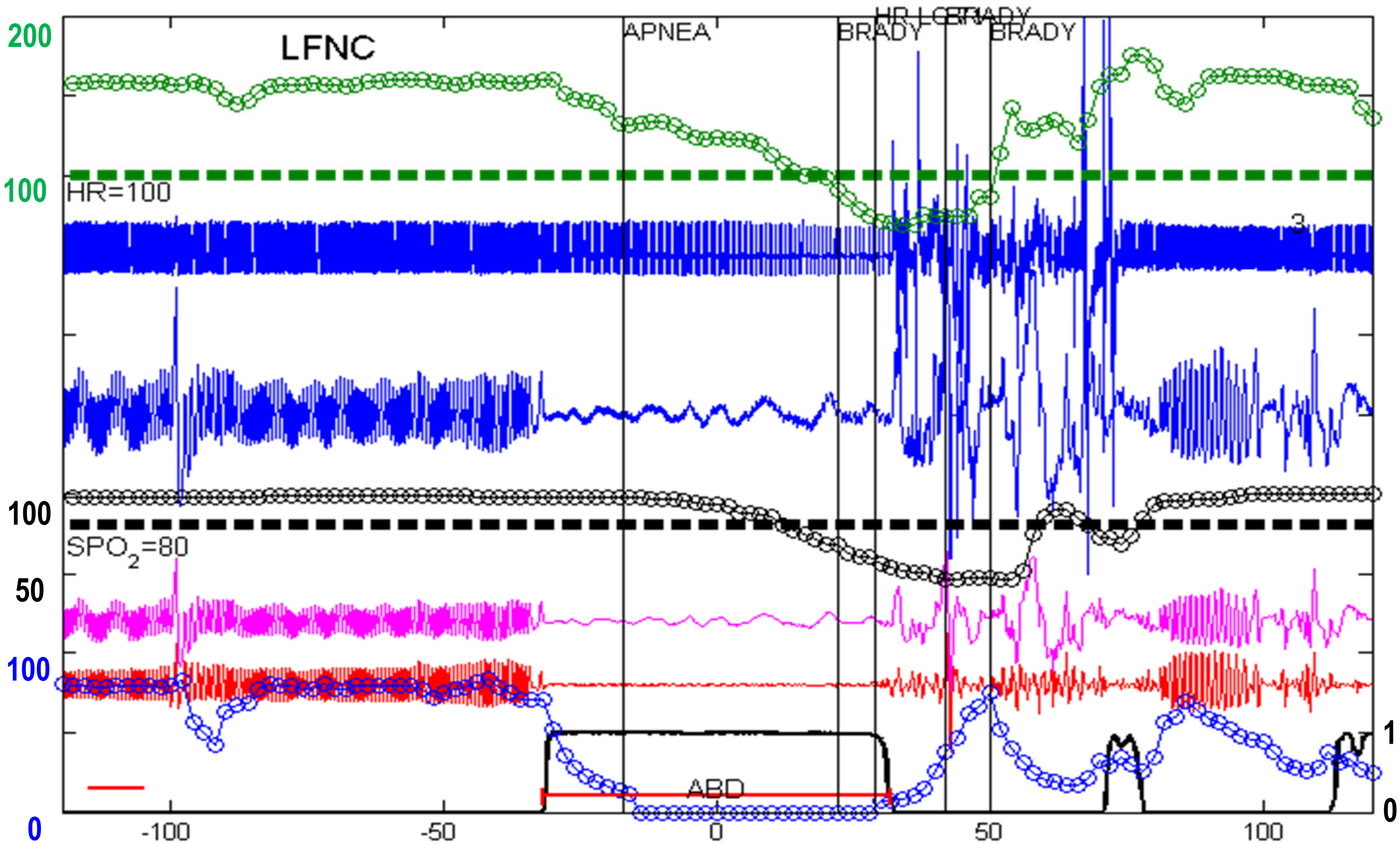
Of those, new algorithm gives about half that rate of false alarms
(hope to reduce that by further refinement.)

Examples



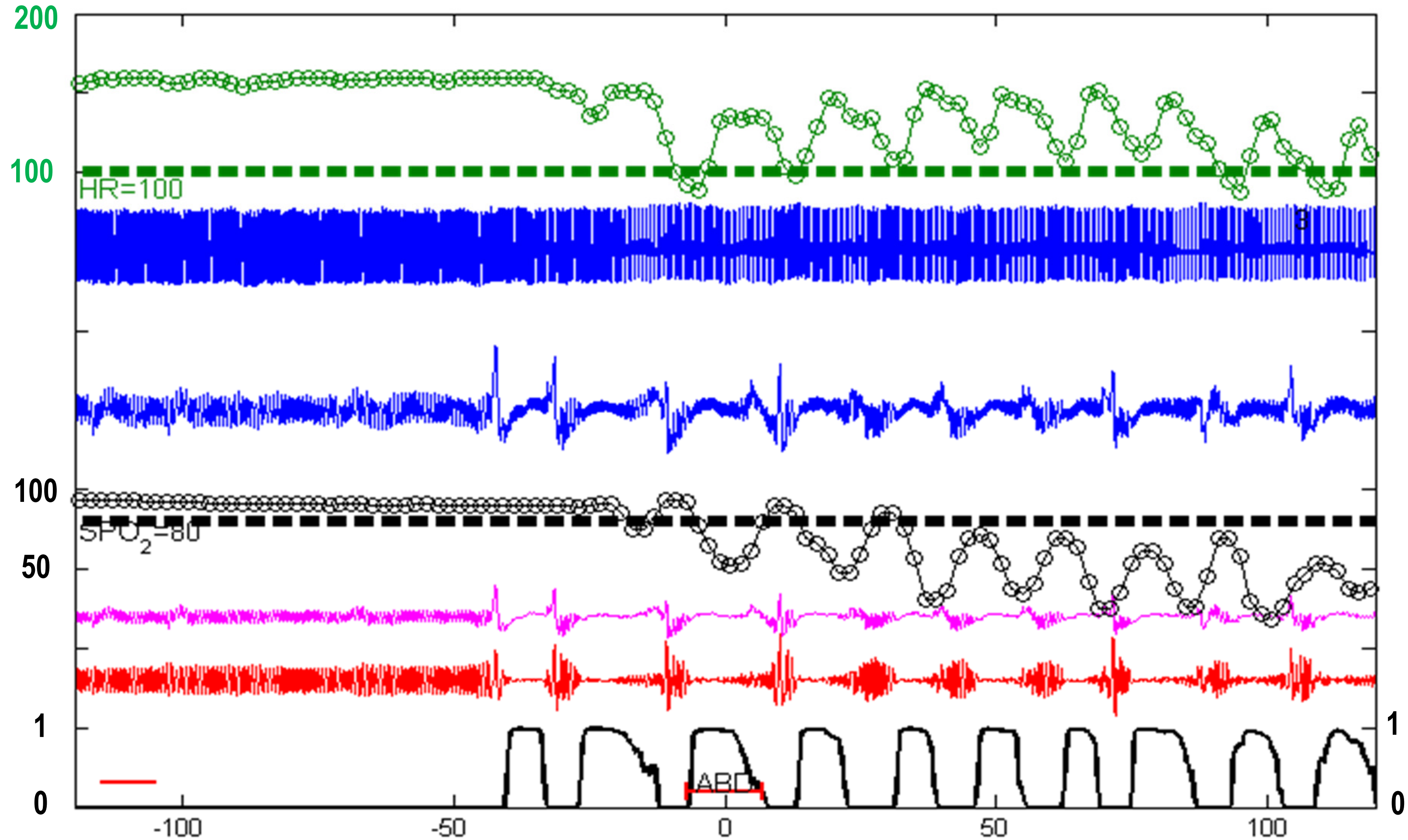
HR
RR
EKG
CI
SpO2
filtered
CI
Probability
of apnea
HR,RR=100
SpO2=80
1
0
ABD
-120
-80
-40
0
40
80
120
time (sec)

Examples



200
100
100
50
100
0
LFNC
APNEA
BRADY
BRADY
HR=100
SPO2=80
ABD
3
1
0
-100
-50
0
50
100

Periodic Apneas = Periodic Breathing



We see periodic decelerations
and periodic desaturations
associated with periodic apneas.

Cycle time ~ 15 sec.

This explains (at least many of) the observed periodic decelerations.

New Question:

What Causes Periodic Apneas?

New Question:

What Causes Periodic Apneas?

respiratory control system goes into oscillation

Mary Mohr

Control Theory
A feedback loop with time delay

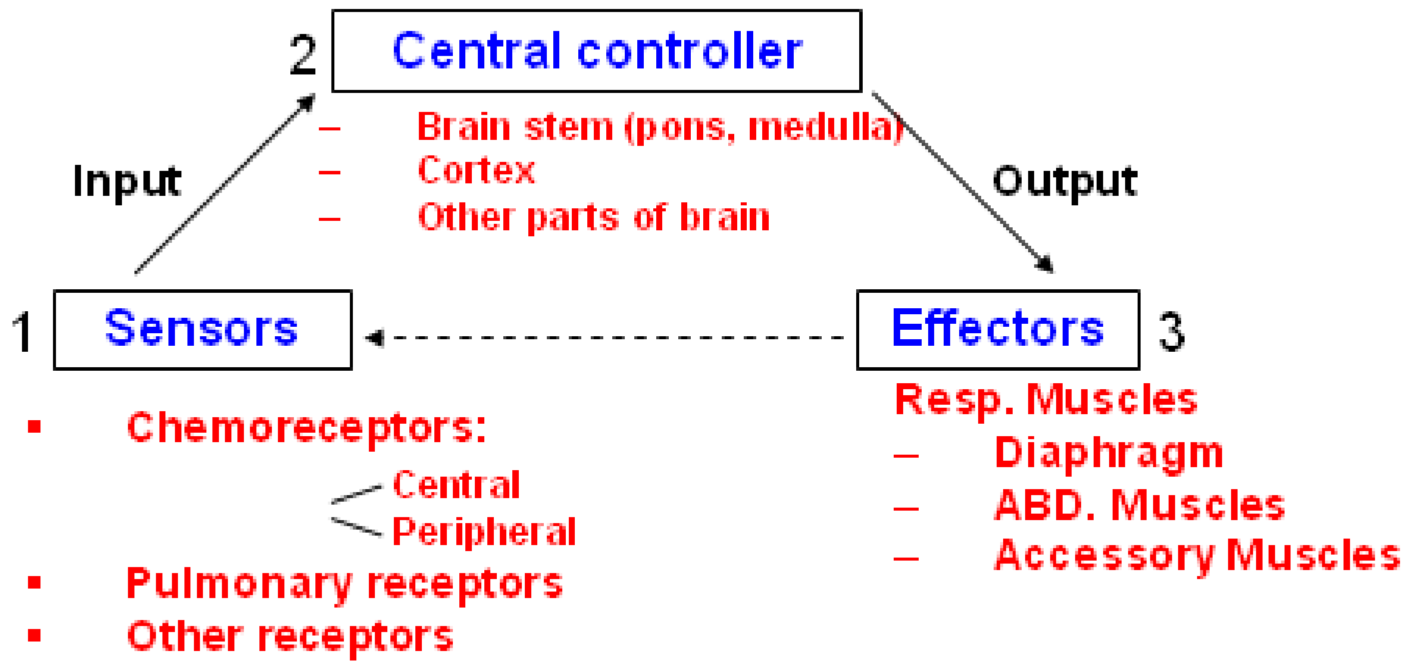
Respiratory system has a stable cycle of steady, regular breathing

such that O_2 and CO_2 in body are "in equilibrium" :
rate of metabolism = rate of transport in or out

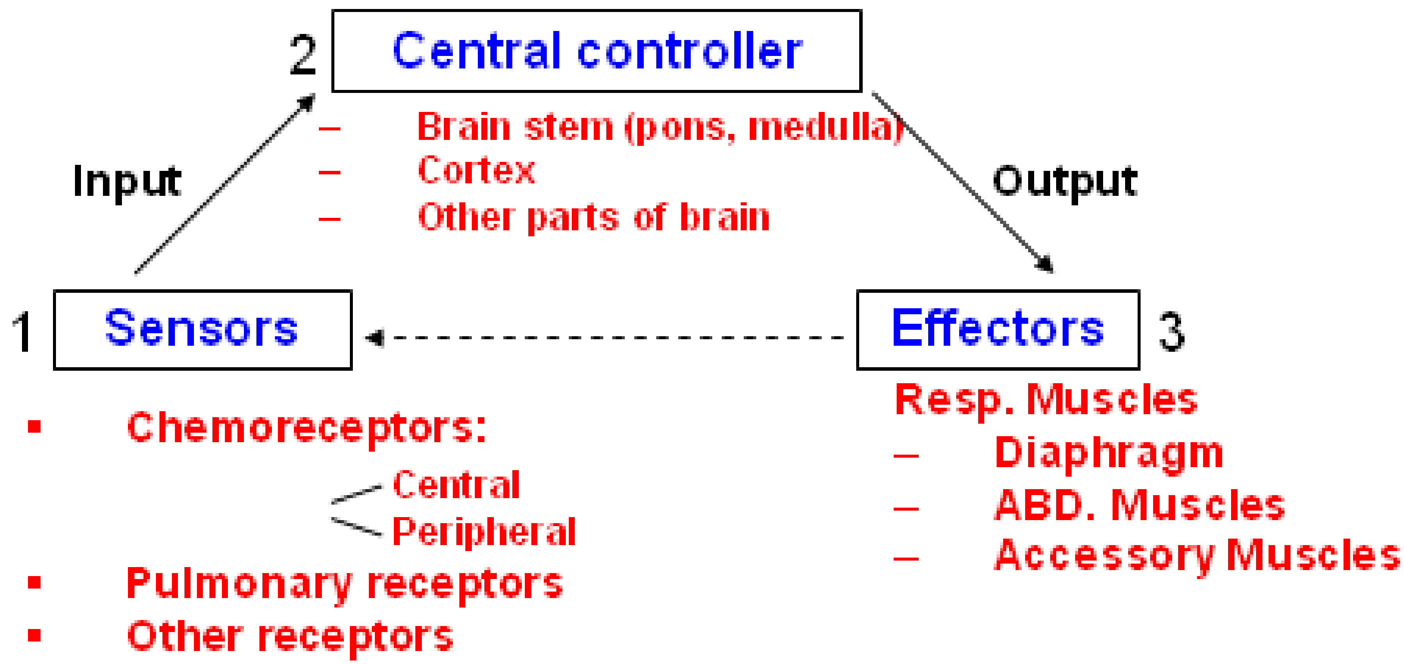
("rest point")

Excess CO_2 or inadequate O_2 stimulate the controller;
it resets the "rest point", adjusting respiration rate.

Control Theory
A feedback loop with time delay



Control Theory
A feedback loop with time delay



Peripheral receptors (sensors) detect O_2 in aortic arch and carotid artery
Send signals to medulla
It processes those and sends signals to diaphragm
Diaphragm responds by increased or reduced ventilation
Oxygenated blood is carried to receptors

Control Theory
A feedback loop with time delay

6 diffeqs + formulas for controllers

Rate of change of O_2 in arteries =

rate of addition from leftover O_2 in veins
(blood flow x concentration of O_2 returning from veins)

– rate of flow out to capillaries, thence to veins
(blood flow x concentration of O_2 in arteries)

+ rate of addition of O_2 in lungs
(ventilation rate x partial pressure dif of O_2 between alveoli and capillaries in lung)

Control Theory
A feedback loop with time delay

Peripheral detectors adjust respiration rate:

$$\dot{V} = G_P \exp(-0.05 P_{aO_2})$$ low O_2 increases resp rate

$$*(P_{aCO_2} - \text{setpoint})$$ linear control of partial pressure of CO_2

BUT

There is a delay τ_P in this loop
(5-6 s in adults)

Khoo et al. J Appl Physiol, Respir Environ Exerc Physiol. 1982 Sep;53(3):644-59.

Simplify to Linear Theory

Controller could make rate of change proportional to displacement from setpoint.

$$dx / dt = -k(x - x_0)$$

$$x(t) - x_0 = \exp(-kt) = \exp(-t / \tau_{decay})$$

Periodic apneas occur when control system goes into oscillation.

Happens if
A. Time delays get large
B. Response of controller is too strong

Controller responds to oxygen deficit *some time ago*

$$dx(t) / dt = -[\mathrm{x}(t - \tau_{delay})] / \tau_{decay} - x_0$$

Behavior depends on

$$(\text{delay time}) / (\text{decay time}) = \tau_{\text{delay}} / \tau_{\text{decay}} = k\tau_{\text{delay}}$$

For delay time << decay time, exponential behavior (with different time-constant):

$$x(t) - x_0 = \exp(-\lambda t)$$

As delay time/decay time increases,
oscillatory decay, then
growing oscillations

Long delay time or strong response (short decay time) leads to oscillations.

$$(\text{delay time})/(\text{decay time}) = \tau_{\text{delay}} / \tau_{\text{decay}} = k\tau_{\text{delay}}$$
$$= \tau_{\text{delay}} / \tau_{\text{response}} = \text{ strength of response } \times \text{ delay time}$$

You have experienced this.

Various theories differ in detailed assumptions about the controller.
Ratio $\tau_{\text{delay}} / \tau_{\text{decay}} = k\tau_{\text{delay}}$ is replaced by a parameter called ‘loop gain’
(compare gain of amplifier caused by feedback loop)

This gives a theory of periodic apneas,
which in turn provides a theory of periodic decelerations of HR.

Furthermore it is known that apneas are associated with sepsis

This may be (part of?) the reason that decels are associated with sepsis

Are periodic apneas and decels significant?

Periodic Apneas: clinical significance?

Two recent deaths:

SIDS

Suspected Sepsis

On retrospective analysis, these infants had extreme time in periodic apneas compared to infants of similar gestational and chronologic ages.

We are collecting statistics on Periodic Apneas,

typical infants spend <10% of time in PA

SID spent ~30-60% of ~3 weeks in NICU in PA

SS spent ~60% of several hours before death in PA

(case reports – ask me later)

Hypothesis:

excessive time in periodic apneas is a warning

Current Studies

What fraction of apneas are recorded by nurses?	(~1/3)
How does the apnea rate change with age?	
Does caffeine reduce apnea?	(?)
Do transfusions reduce apnea?	(Yes)
Can we get early warning of serious apneas?	(Maybe)
What is the significance of very long apneas?	
Are long spells of periodic apneas a warning?	
Do apneas give warning of sepsis? (HeRO monitoring)	

==

Future Work

Develop a good GUI and Indexing System
Convert to real-time monitor (Qun Li & Zhengrui Qin)

Add-on system providing a new way to analyze data that had previously been discarded

Vision for the Future

We are using new analyses of routinely-generated data.

Current generation of monitors based on old technology.

“Disruptive Advances”:

memory	4¢/Gigabyte
speed	some GHz
data input	KHz/patient

Analysis previously done with hardware can now be done with software.

Cheap. Easy to develop. Flexible. Adaptable.
Can be tested and optimized against databases.

Conclusions

1. **Reduced heart-rate-variability and decelerations are correlated with illness, and can be used as a new, noninvasive monitor for illness of premature infants.**

2. **Periodic decelerations are caused by periodic apneas.**

3. **We developed a new state-of-the-art apnea detector.**

4. **With it we are detecting and characterizing very long apneas (>60 sec), and periodic apneas, and we are developing predictive monitoring methods for illness, emergency intubation, success of extubation, effect of transfusions, a Markov model of apneas, cardiovascular coupling, ….**

5. **When we quants work together with physicians, and overcome the knowledge and communication barriers between us, important and unexpected advances in health care can be made.**

Mortality reduction by heart rate characteristic monitoring in very low birth weight neonates: a randomized trial.
Moorman JR, Carlo WA, Kattwinkel J, Schelonka RL, Porcelli PJ, Navarrete CT, Bancalari E, Aschner JL, Whit Walker M, Perez JA, Palmer C, Stukenborg GJ, Lake DE, Michael O'Shea T.
J Pediatr. 2011 Dec;159(6):900-6.e1. doi: 10.1016/j.jpeds.2011.06.044. Epub 2011 Aug 24.

Septicemia mortality reduction in neonates in a heart rate characteristics monitoring trial.
Fairchild KD, Schelonka RL, Kaufman DA, Carlo WA, Kattwinkel J, Porcelli PJ, Navarrete CT, Bancalari E, Aschner JL, Walker MW, Perez JA, Palmer C, Lake DE, O'Shea TM, Moorman JR.
Pediatr Res. 2013 Aug 13. doi: 10.1038/pr.2013.136.

Periodic heart rate decelerations in premature infants.
Flower AA, Moorman JR, Lake DE, Delos JB.
Exp Biol Med (Maywood). 2010 Apr;235(4):531-8. doi: 10.1258/ebm.2010.009336.

A new algorithm for detecting central apnea in neonates.
Lee H, Rusin CG, Lake DE, Clark MT, Guin L, Smoot TJ, Paget-Brown AO, Vergales BD, Kattwinkel J, Moorman JR, Delos JB.
Physiol Meas. 2012 Jan;33(1):1-17. doi: 10.1088/0967-3334/33/1/1. Epub 2011 Dec 7.
http://www.ncbi.nlm.nih.gov/pubmed?linkname=pubmed_pubmed&from_uid=22156193

Accurate Automated Apnea Analysis in Preterm Infants.
Vergales BD, Paget-Brown AO, Lee H, Guin LE, Smoot TJ, Rusin CG, Clark MT, Delos JB, Fairchild KD, Lake DE, Moorman R, Kattwinkel J.
Am J Perinatol. 2013 Apr 16

Predictive monitoring for respiratory decompensation leading to urgent unplanned intubation in the neonatal intensive care unit.
Clark MT, Vergales BD, Paget-Brown AO, Smoot TJ, Lake DE, Hudson JL, Delos JB, Kattwinkel J, Moorman JR.
Pediatr Res. 2013 Jan;73(1):104-10. doi: 10.1038/pr.2012.155. Epub 2012 Nov 8.

Anemia, apnea of prematurity, and blood transfusions.
Zagol K, Lake DE, Vergales B, Moorman ME, Paget-Brown A, Lee H, Rusin CG, Delos JB, Clark MT, Moorman JR, Kattwinkel J.
J Pediatr. 2012 Sep;161(3):417-421.e1. doi: 10.1016/j.jpeds.2012.02.044. Epub 2012 Apr 10.

Breath-by-breath analysis of cardiorespiratory interaction for quantifying developmental maturity in premature infants.
Clark MT, Rusin CG, Hudson JL, Lee H, Delos JB, Guin LE, Vergales BD, Paget-Brown A, Kattwinkel J, Lake DE, Moorman JR.
J Appl Physiol (1985). 2012 Mar;112(5):859-67. doi: 10.1152/japplphysiol.01152.2011. Epub 2011 Dec 15.

Predictive monitoring for early detection of subacute potentially catastrophic illnesses in critical care.
Moorman JR, Rusin CE, Lee H, Guin LE, Clark MT, Delos JB, Kattwinkel J, Lake DE.
Conf Proc IEEE Eng Med Biol Soc. 2011;2011:5515-8. doi: 10.1109/IEMBS.2011.6091407.

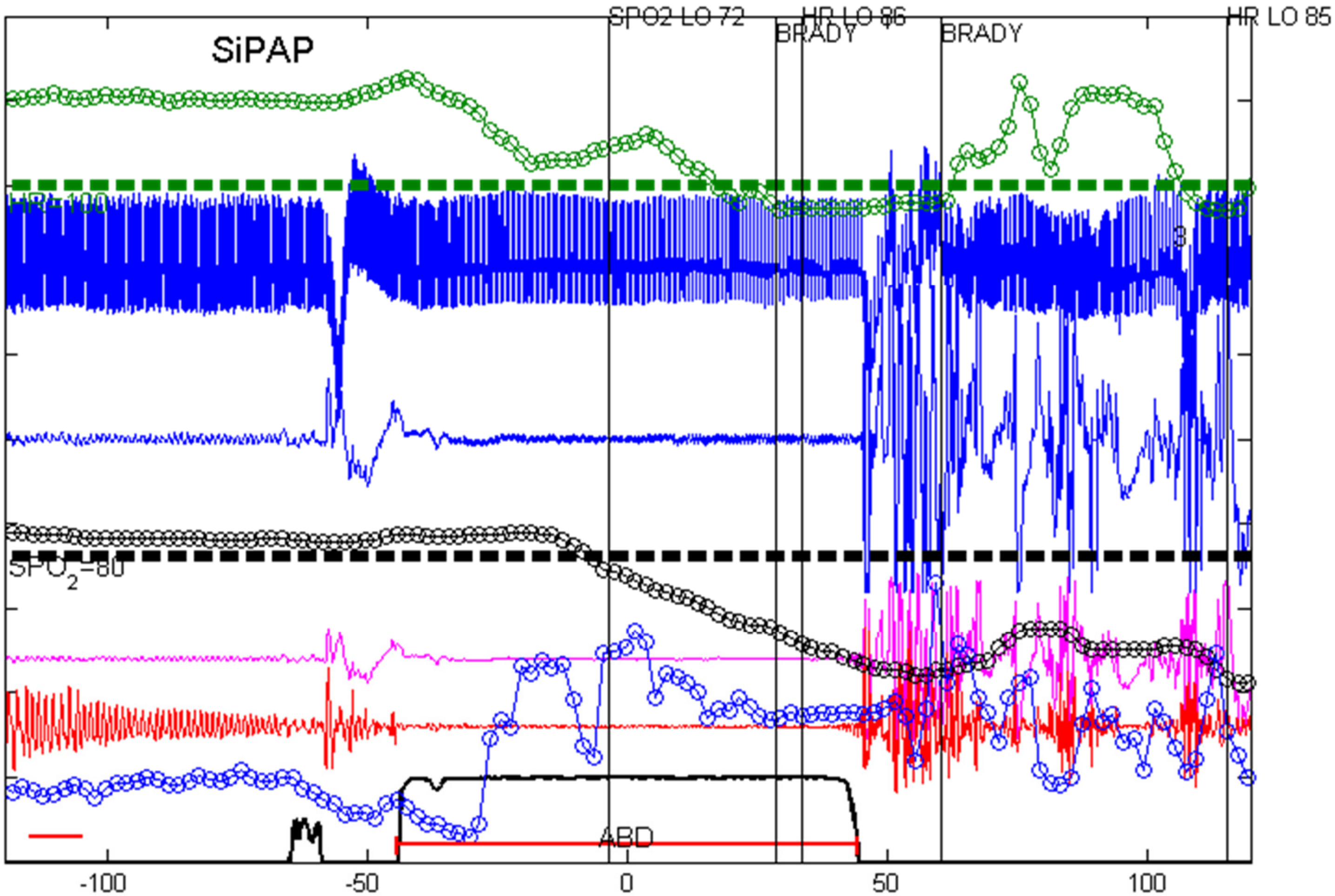
Cardiovascular oscillations at the bedside: early diagnosis of neonatal sepsis using heart rate characteristics monitoring.
Moorman JR, Delos JB, Flower AA, Cao H, Kovatchev BP, Richman JS, Lake DE.
Physiol Meas. 2011 Nov;32(11):1821-32. doi: 10.1088/0967-3334/32/11/S08. Epub 2011 Oct 25.
http://www.ncbi.nlm.nih.gov/pubmed?linkname=pubmed_pubmed&from_uid=22026974

Other applications of the new apnea detection algorithm:

Very Long Apneas

(Mary Mohr)

Very Long Apneas



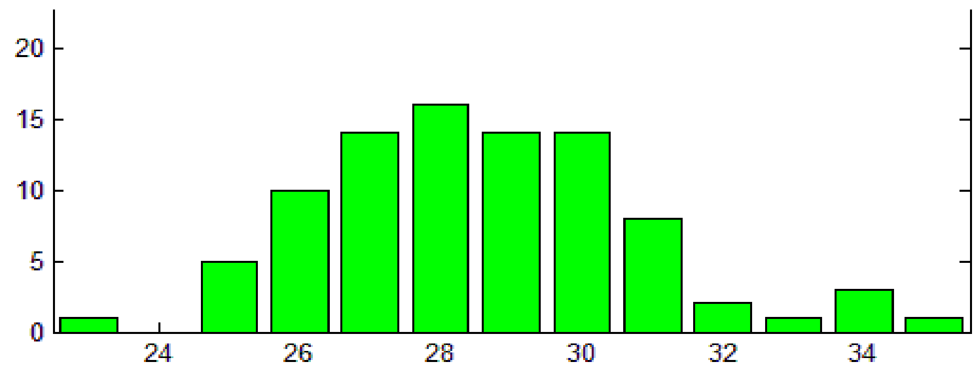
We detected and clinicians conservatively validated 89 apneas > 60 s in 19 infants
> 1 per 200 baby days in UVa NICU

Characteristics of infants:

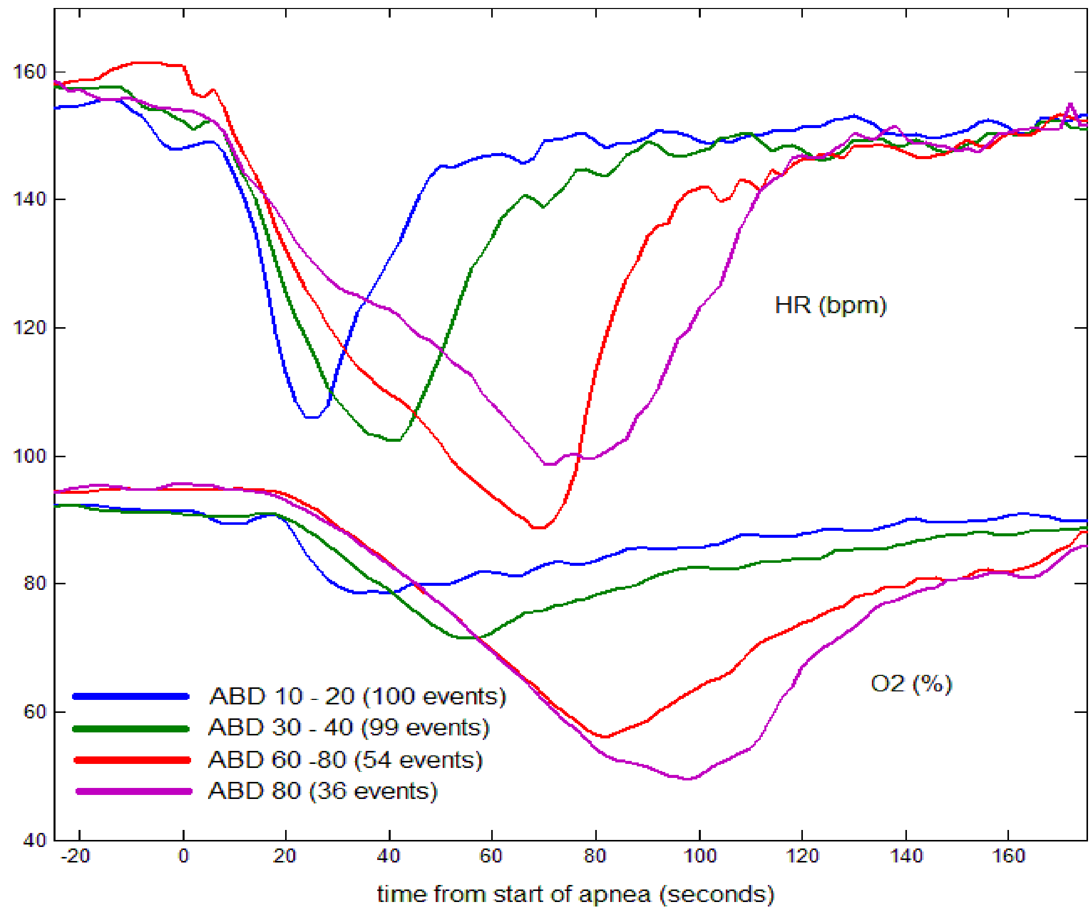
Majority ELBW (< 1 Kg)
Almost all VLBW (<1.5 Kg)

Almost all under 30 weeks gestational age at birth
and under 30 weeks postmenstrual age
and within 3 weeks of birth

One baby had 19 events, 30 had at least one.



Characteristics of events:



In very long events, HR and O2 drop slowly, O2 starts high.
(Has the baby hyperventilated prior to the very long event?)