

SMART

Scalable Medical Alert Response Technology

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Disaster Management

- Motivation
- SMART
 - Project overview
 - System
 - Results
 - Lessons learned



Emergency Medical Response

Locate

Rescue

Assess/Triage

Care

Identify

Transport

Resource allocation needs
to change according to
evolving conditions



How Can We Provide Best Care?

- Monitor patients
 - How are they?
 - Where are they?
 - Who is the primary responder?
- Monitor caregivers
 - Locate nearest available provider
 - Avoid broadcast alerts
- Track
 - Equipment
 - Providers
 - Transport units
- Make decisions
 - Resource allocation



Current Care



- Assessment
- Triage
 - Emergency Severity Index (ESI)
- Prioritization

Paper tags

Vital signs recorded periodically

ESI indicated by detaching colored part

Continuous Remote Monitoring



e-tags

Vital signs analyzed continuously

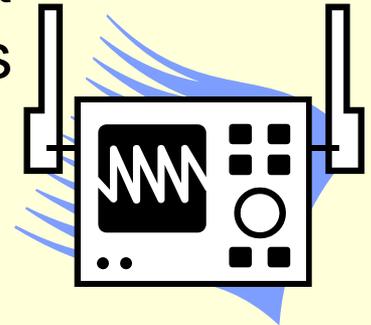
Updatable Emergency Severity Index

Remote transmission



Rationale

- Monitor patients' vital signs and location in non-traditional contexts:
 - Mass casualty situations
 - While waiting for medical attention
 - In an ambulance
 - At home
- Make technology part of standard of care so it does not have to change in disaster situations



SMART Testbed: Emergency Department at BWH

- Excessive time spent waiting
 - 3 hour wait for medical care
- Difficulty finding patients, personnel and equipment
 - over 50 beds in three different units
 - units expand and contract
- Triage Priority System cannot account for changes
 - Medical conditions can worsen in waiting room
- Uncoordinated alarms
 - sensory overload





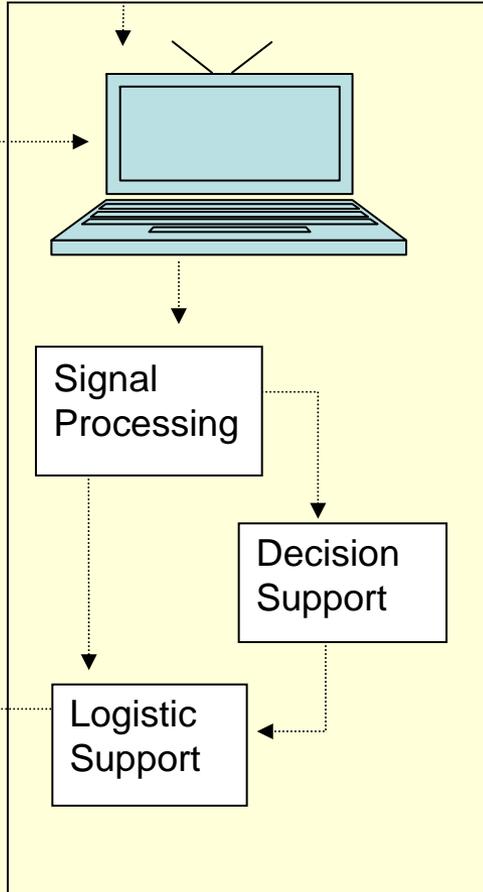
Patient PDA
Sensors
Location tag

SpO₂
ECG
Location



Equipment
Defibrillator

Location



Location



Caregiver PDA
Location tag

Location System

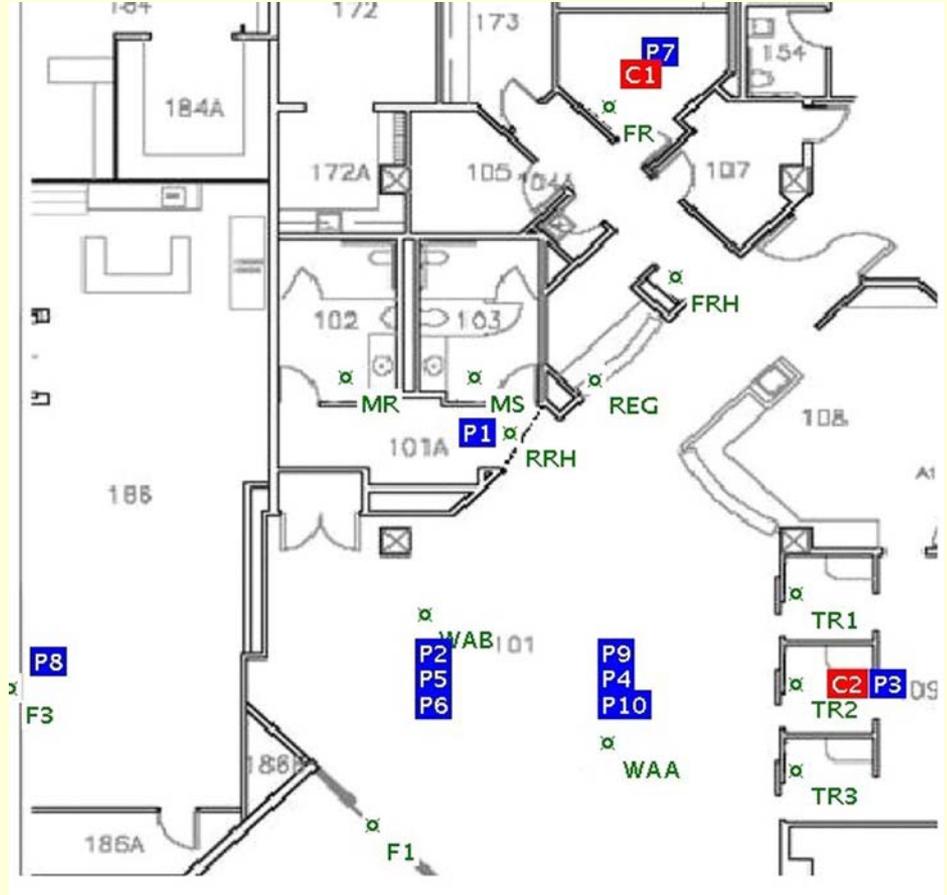
- Patients, Providers, Vehicles

Indoor

- Ultrasound-based (Sonitor Technology)
- Room and zone-level location

Outdoor

- Commercial GPS

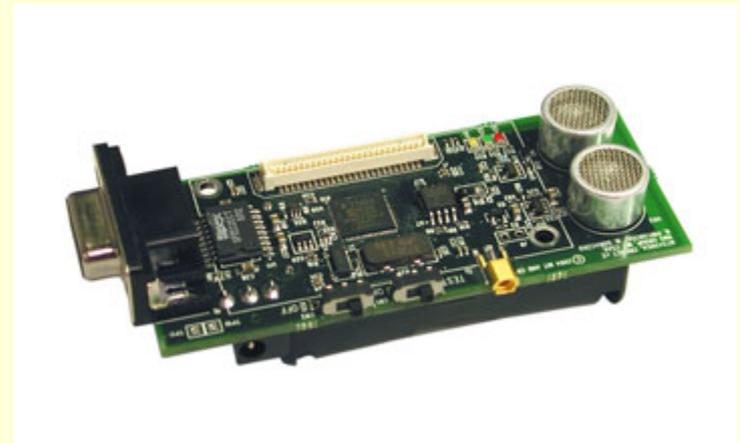


Sonitor Indoor Location: Tags and Detectors

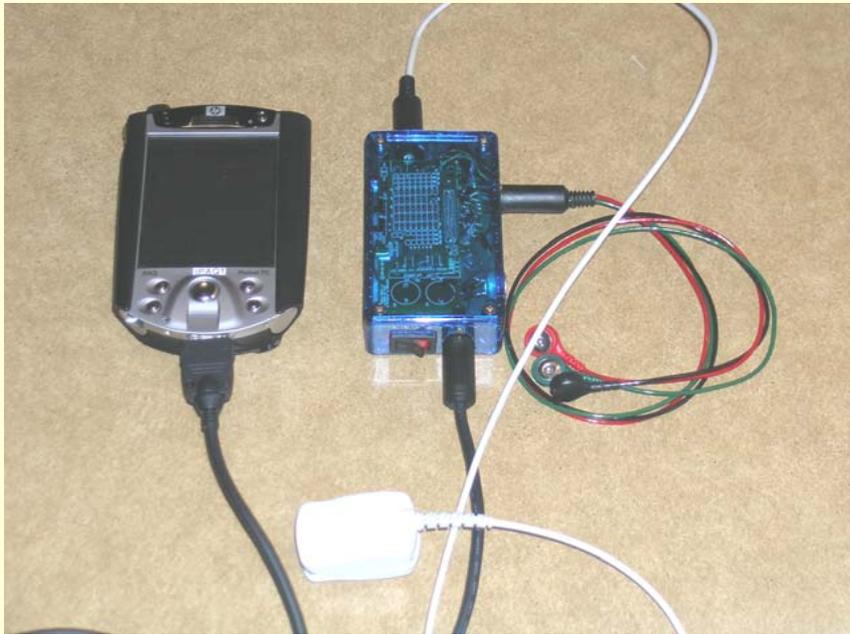


Other Indoor Positioning Systems

- RFID (passive and active)
- Cricket (ultrasound and RF)
- 802.11-based tracking
- ...



Patient Monitoring System



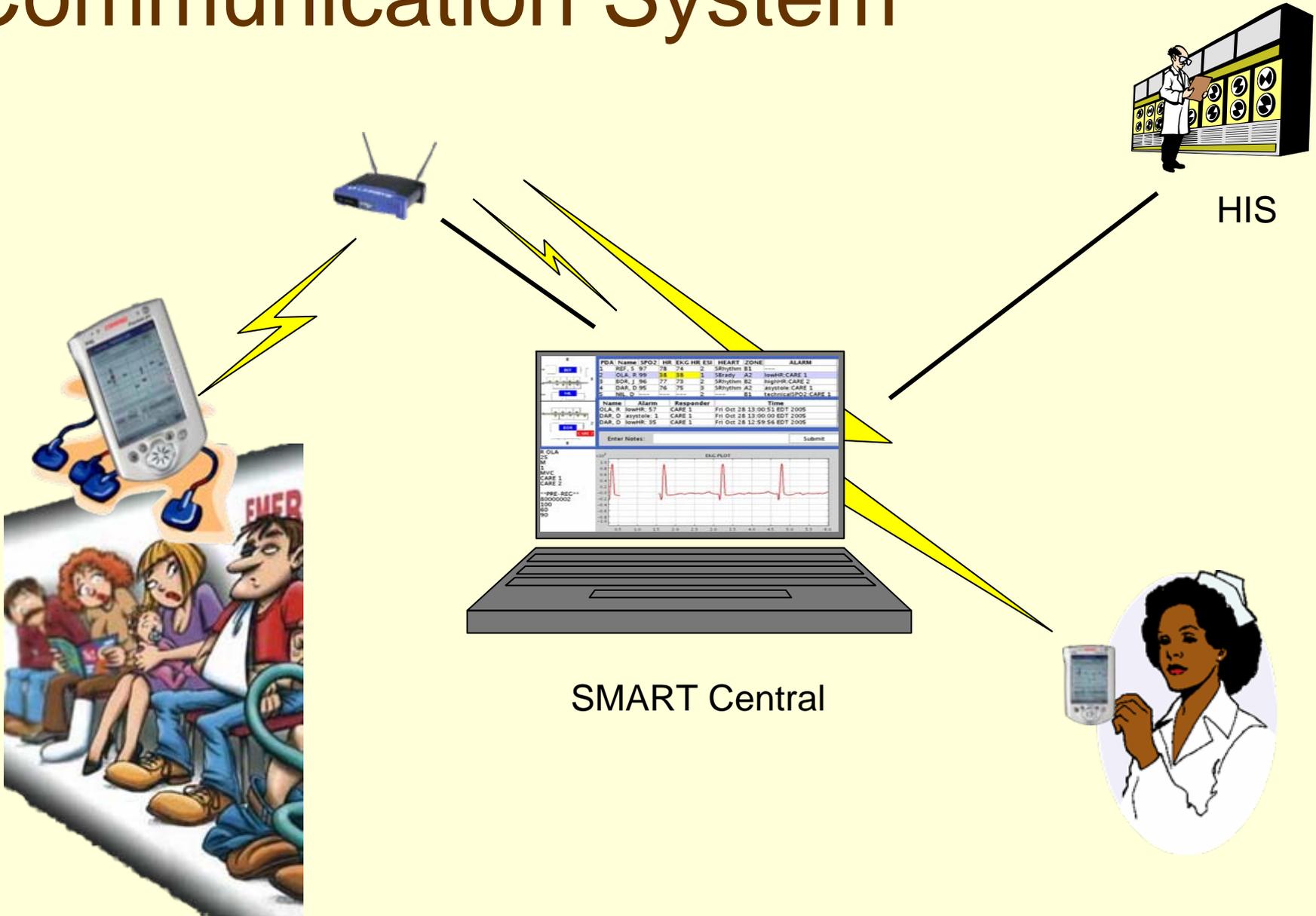
One lead EKG

Oximeter

Patient Monitoring



Communication System

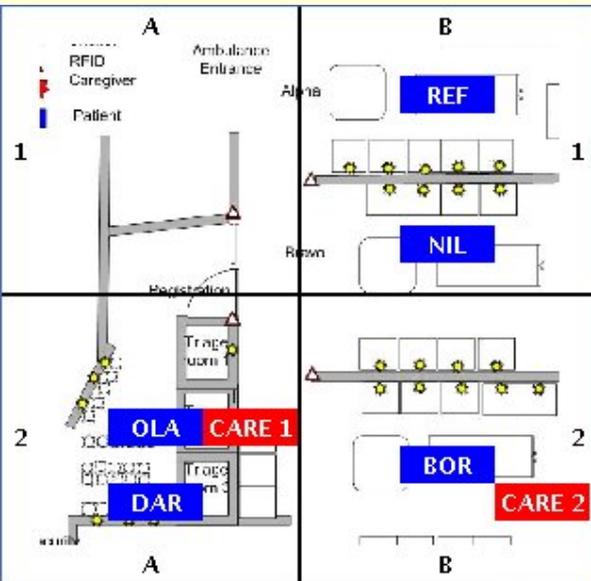


SMART Central



IRB requirement: ACLS-trained professional to monitor the central station (the “SMART Operator”)

SMART Central



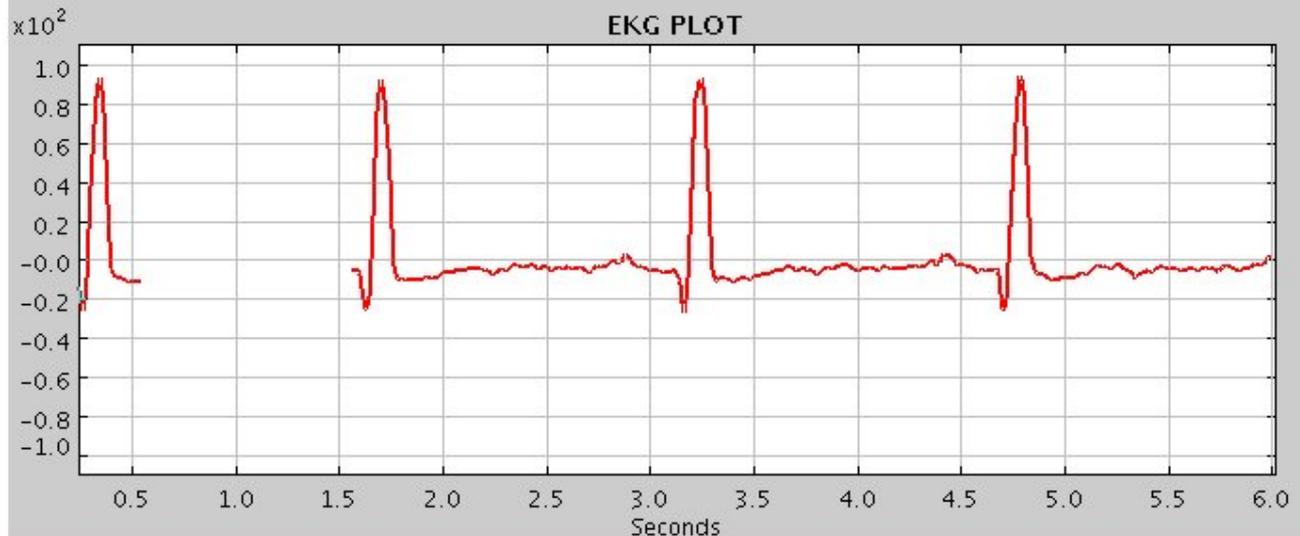
PDA	Name	SPO2	HR	EKG HR	ESI	HEART	ZONE	ALARM
1	REF, S	97	78	74	2	SRhythm	B1	---
2	OLA, R	99	38	38	1	SBrady	A2	lowHR:CARE 1
3	BOR, J	96	77	73	2	SRhythm	B2	highHR:CARE 2
4	DAR, D	95	76	75	3	SRhythm	A2	asystole:CARE 1
5	NIL, D	---	---	---	2	---	B1	technicalSPO2:CARE 1

Name	Alarm	Responder	Time
OLA, R	lowHR: 57	CARE 1	Fri Oct 28 13:00:51 EDT 2005
DAR, D	asystole: 1	CARE 1	Fri Oct 28 13:00:00 EDT 2005
DAR, D	lowHR: 35	CARE 1	Fri Oct 28 12:59:56 EDT 2005

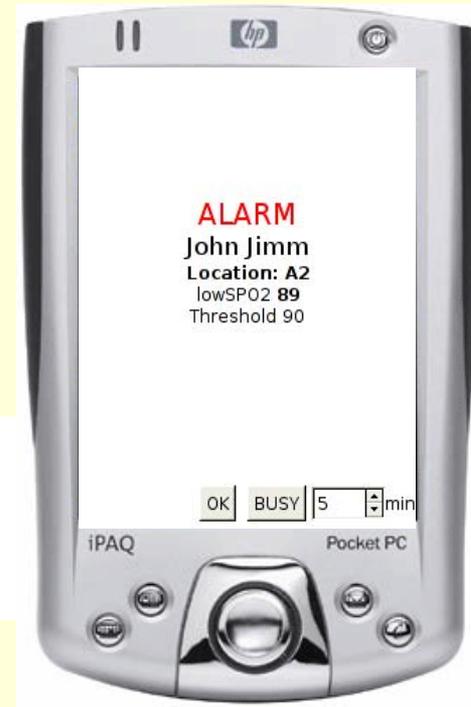
Enter Notes:

Submit

Name: R OLA
 Age: 25
 Gender: M
 ESI: 1
 Complaint: MVC
 ED RN: CARE 1
 ED Dr: CARE 2
 Allergies:
 Precautions: **PRE-REG**
 MRN: 80000002
 THR: High HR 100
 THR: Low HR 60
 THR: Low SPO2 90



Caregiver PDA



Ambulance Bridge



SMART Central with GPS Location





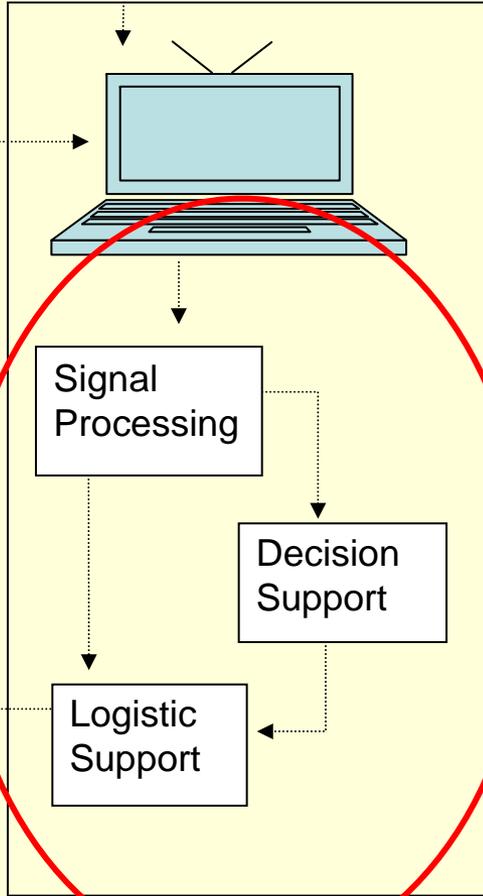
Patient PDA
Sensors
Location tag

SpO₂
ECG
Location



Equipment
Defibrillator

Location



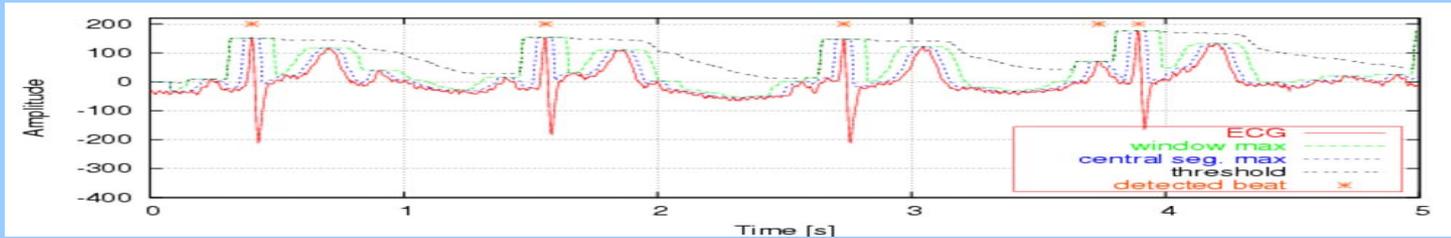
Location



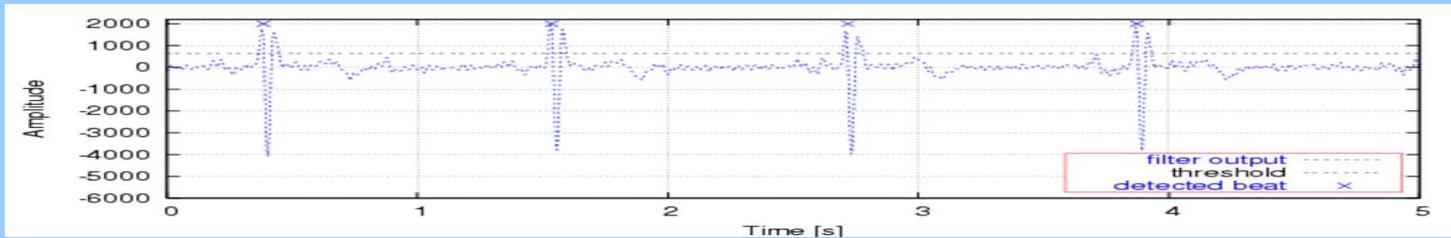
Caregiver PDA
Location tag

Beat Detection Algorithms

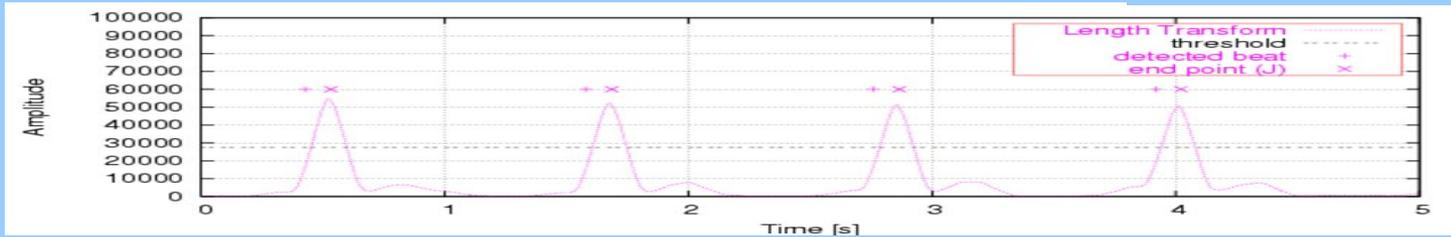
Peak Alg.



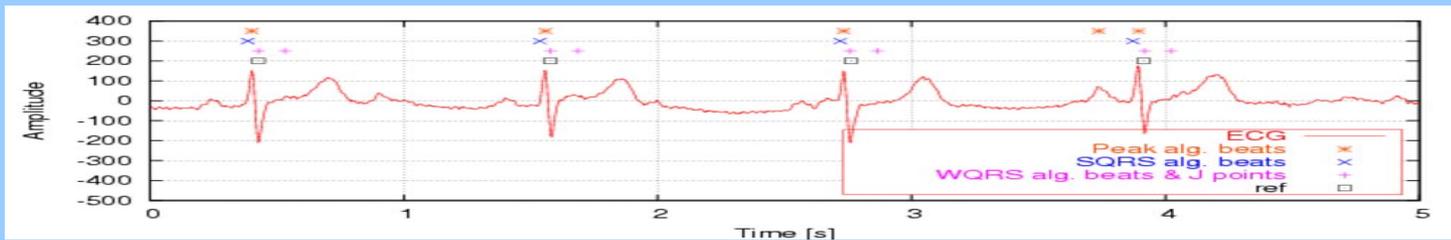
SQRS Alg. (FIR filter)



WQRS Alg. (Length transf.)

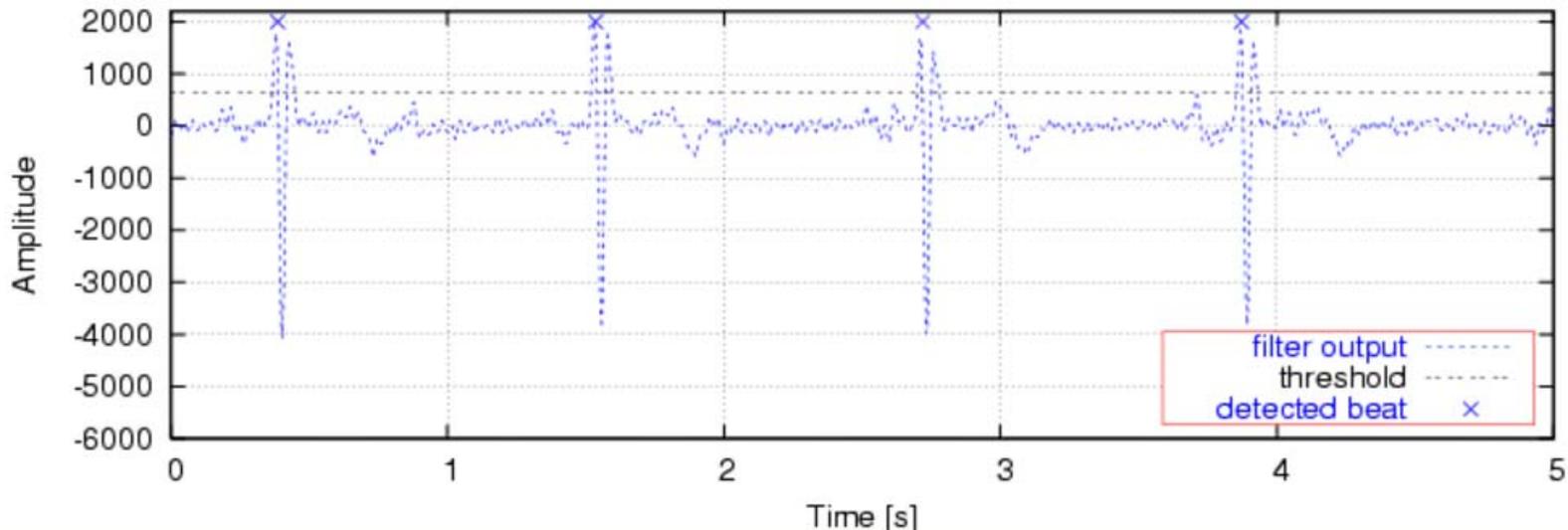


Comparison



Signal Processing

- Several algorithms were implemented
- Simple SQRS algorithm was selected
- Comparisons with QRS detection from oximeter showed some discrepancies



Decision Support System

- Integration of data from multiple sensors
- Recognition of potentially dangerous conditions
 - Arrhythmia diagnoses

Logistics

- Alerts to specific providers
 - Avoid broadcast alerts
 - Minimize false alarms
 - Escalation strategy



Oximeter Medical Alarms

- High HR
 - Heart rate from oximeter sensor above patient-specific threshold (default threshold is 100bpm)
- Low HR
 - Heart rate from oximeter sensor below patient-specific threshold (default threshold is 60bpm)
- Low SpO₂
 - Oxygen saturation below patient-specific threshold (default threshold is 90%)

ECG Medical Alarms

- Tachycardia, Bradycardia
- Irregular
 - ECG QRS complexes are irregularly spaced
- Asystole
 - No beat detected in 3 seconds
- Ventricular Fibrillation
 - ECG shows artifacts, abnormal skewness, wide waves or no waves, lacks QRS complexes, and the SpO2 heart rate is missing, below 20bpm, or above 150bpm
- Ventricular Tachycardia
 - ECG has wide QRS complexes and heart rate > 100 bpm

Technical Alarms

- Leads Off
 - ECG lead is off (signal is saturated)
- No signal
 - No ECG data received
- Technical SpO₂
 - Oximeter sensor removed from finger
- AWOL (away without leave)
 - No communication between PDA and SMART Central
- Battery
 - Low battery (below 20%)

Poseidon Disaster Drill

- 50 federal, state, local agencies
- \$750,000
- 150 injured, 25 dead
- threat at LNG (liquid natural gas) facility
- Cambridge Galleria (mall) with a dirty bomb
- (Volunteer) patients processed as usual and delivered to a variety of hospitals
- at BWH, SMART monitored the arrivals (after decontamination)
- system set up quickly ~5 minutes: one laptop, one wireless hub
- 8 patients monitored

Formative Evaluation

- Feasibility of devices
 - Will patients wear the monitor?
- Reliability of devices
 - Are there benefits in dual monitoring?
 - How well do indoor positioning systems work?



Feasibility

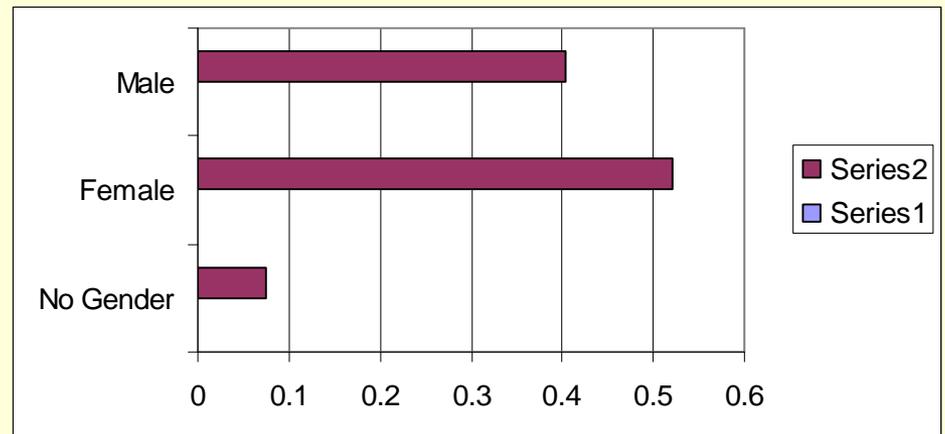
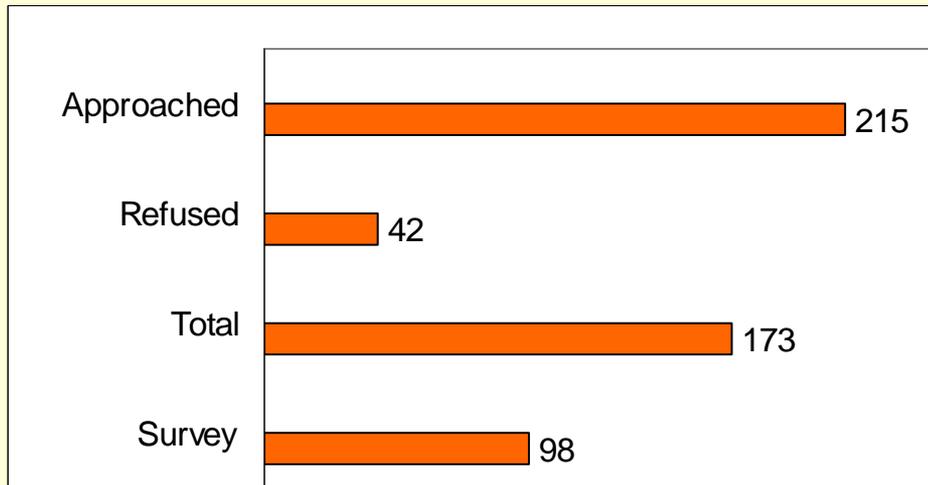
- Of first 42 eligible patients approached, 33 signed consent form
 - 1 changed his mind before starting
 - 2 were admitted before having chance to start
- No patient returned the device before end of study
- Duration varied from 26 seconds to 2:24h
- 20 patients answered surveys



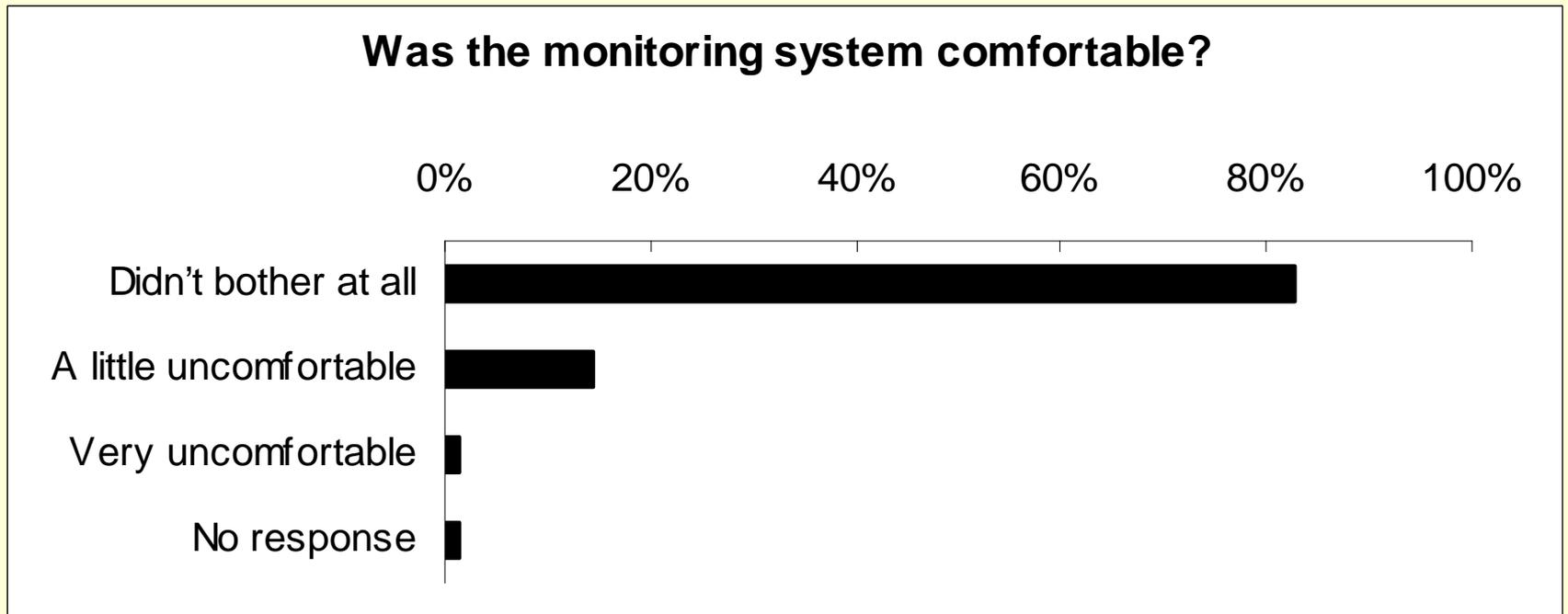
Data

- Eligibility: cardiovascular complaint, not too severe, during hours covered by the SMART operator
- Signed informed consent
- Survey languages:
 - English, Spanish, Portuguese
- We collected 129hr 59min of data

Subjects

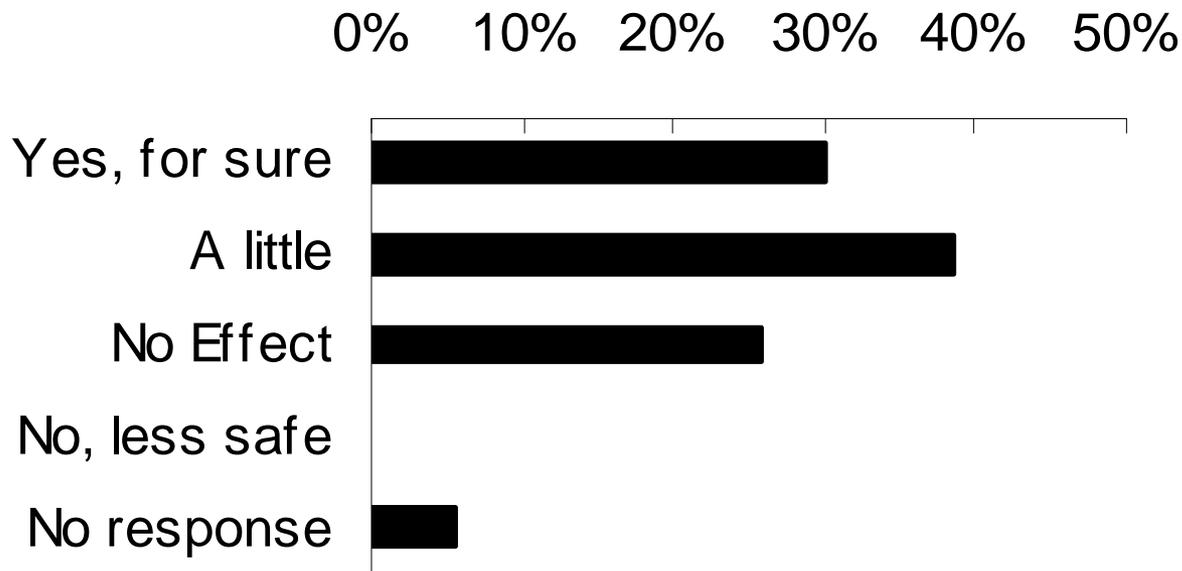


Patient Survey: Comfort



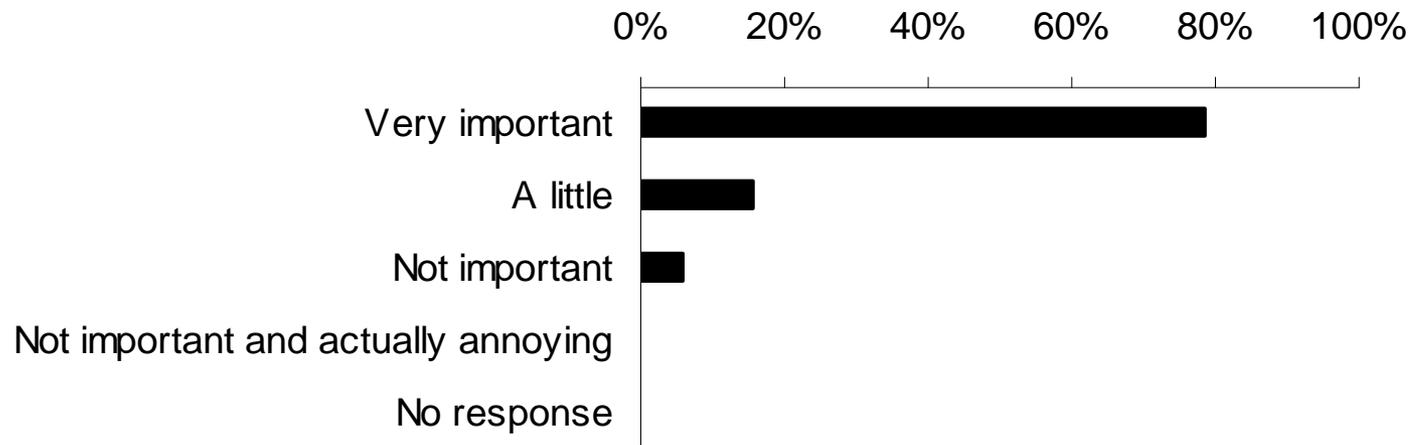
Patient Survey: Safety

Did the monitoring system make you feel safer?



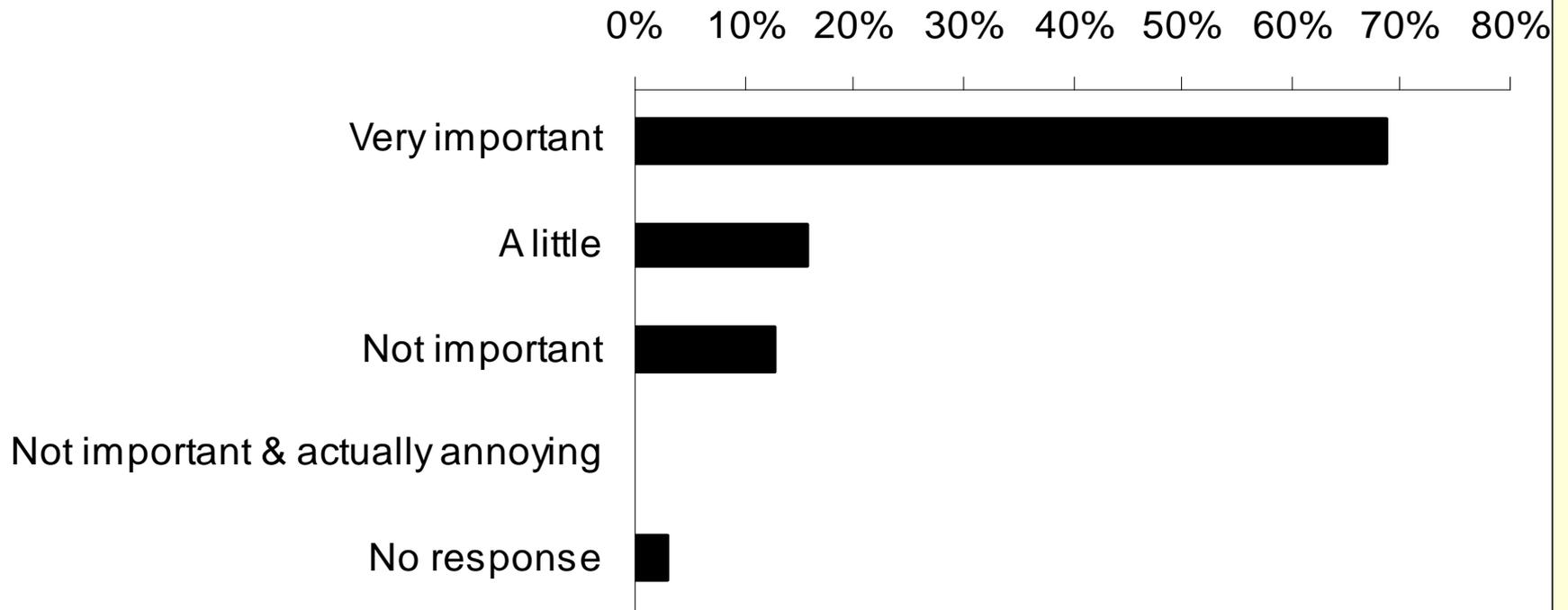
Patient Survey: Value of Monitoring Vital Signs

Value of vital signs monitoring



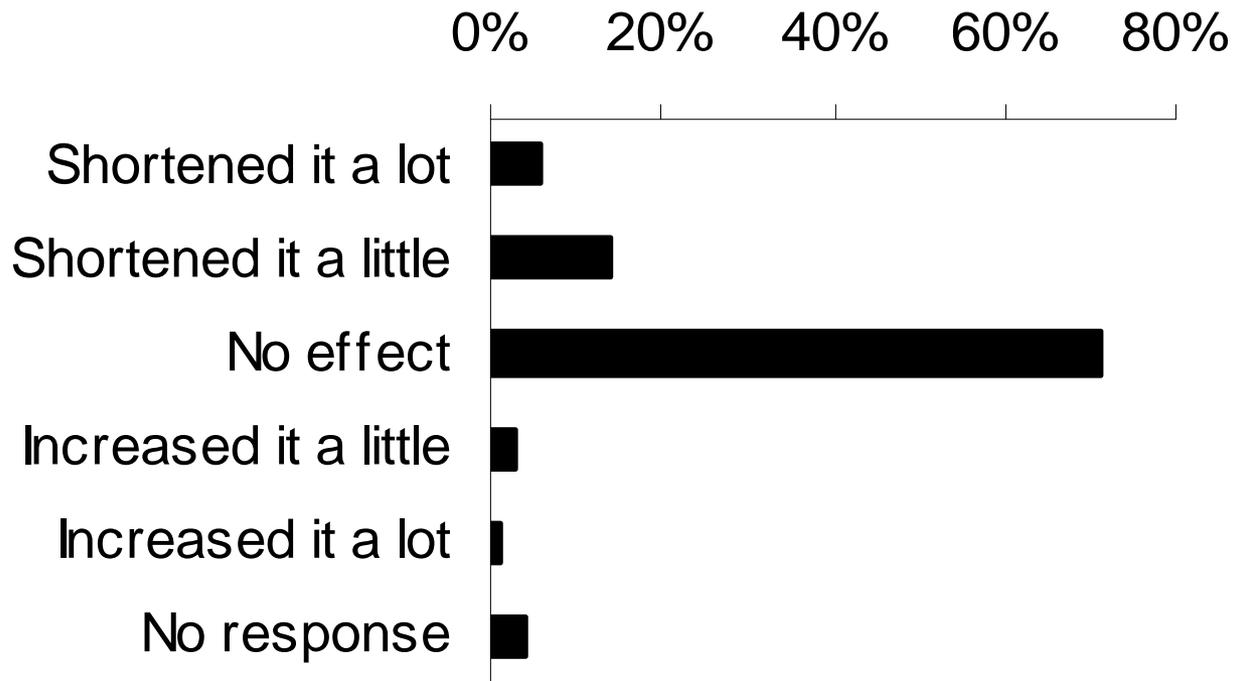
Patient Survey: Value of Location Monitoring

Value of having location known



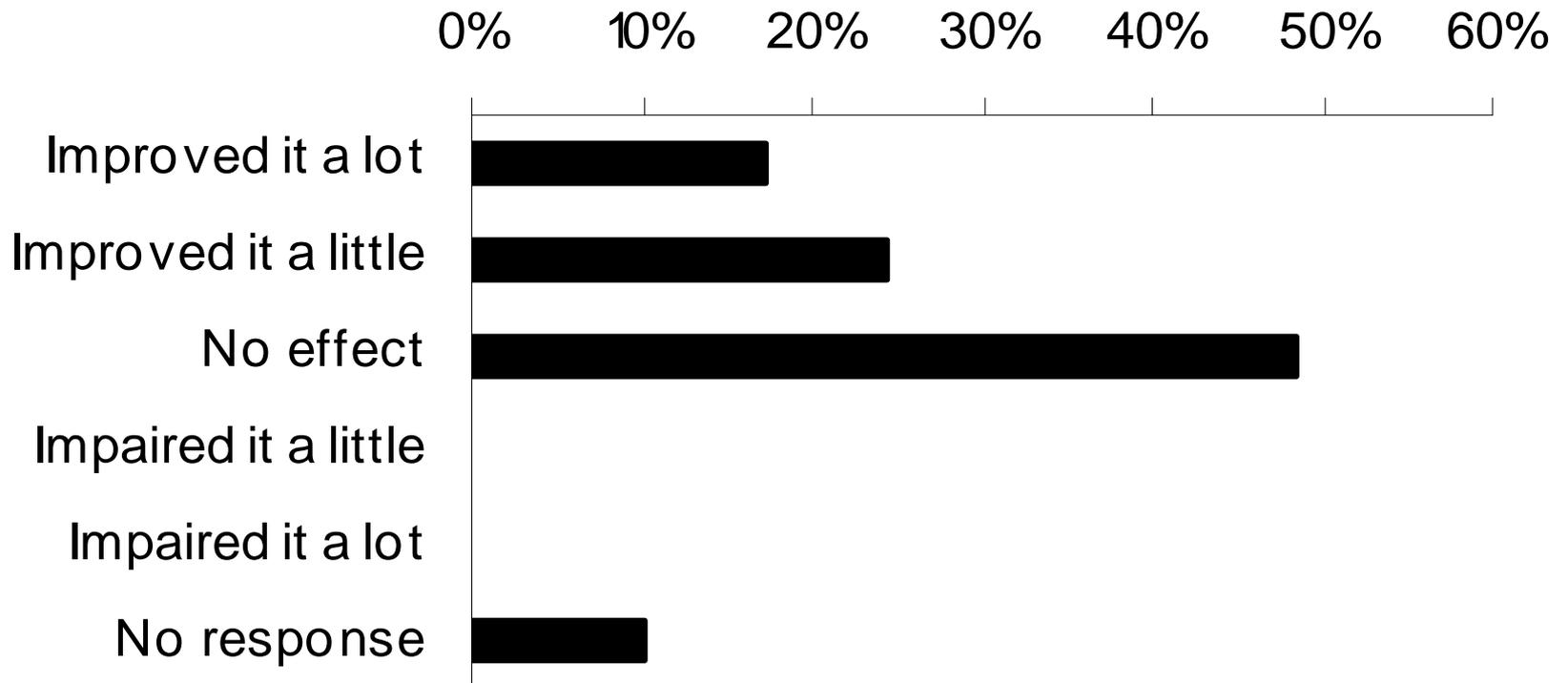
Patient Survey: Effect on Wait

Effect of SMART on length of wait



Patient Survey: Effect on Care

Effect of SMART Monitoring on Care



Patient Survey: Wear Again?

Would you wear a SMART pouch again?

0% 10% 20% 30% 40% 50% 60%

Yes, for sure

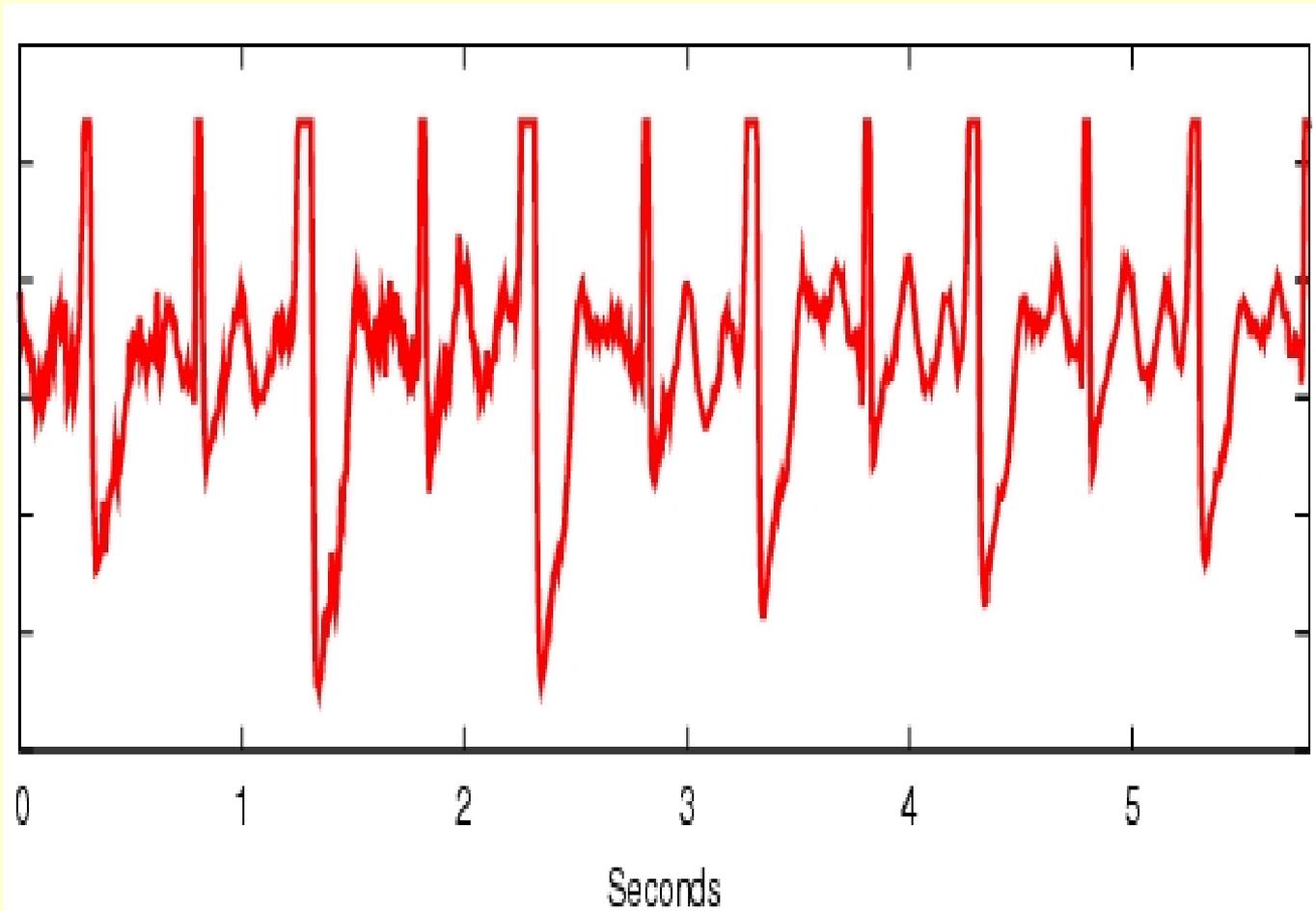
Probably

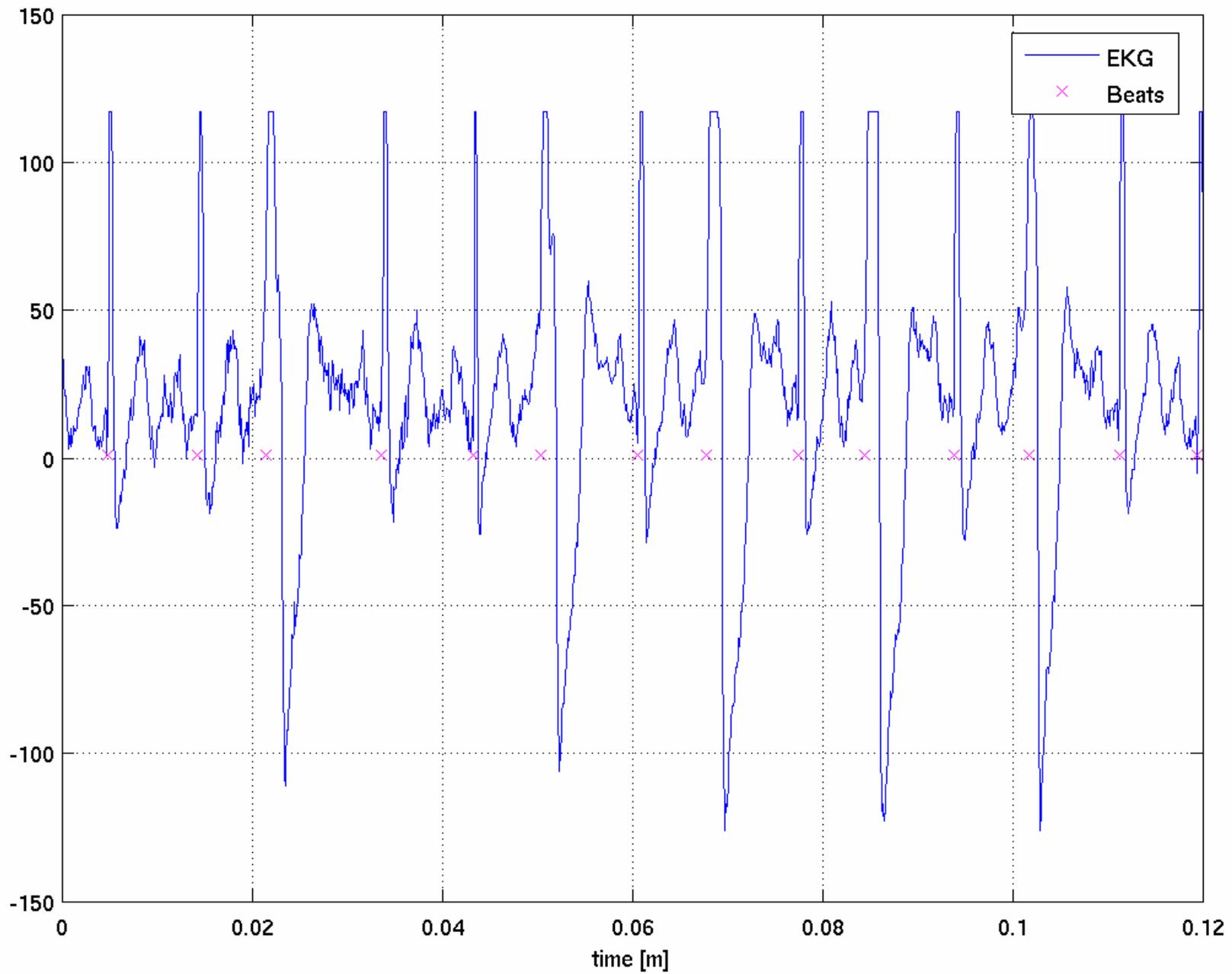
No

No response

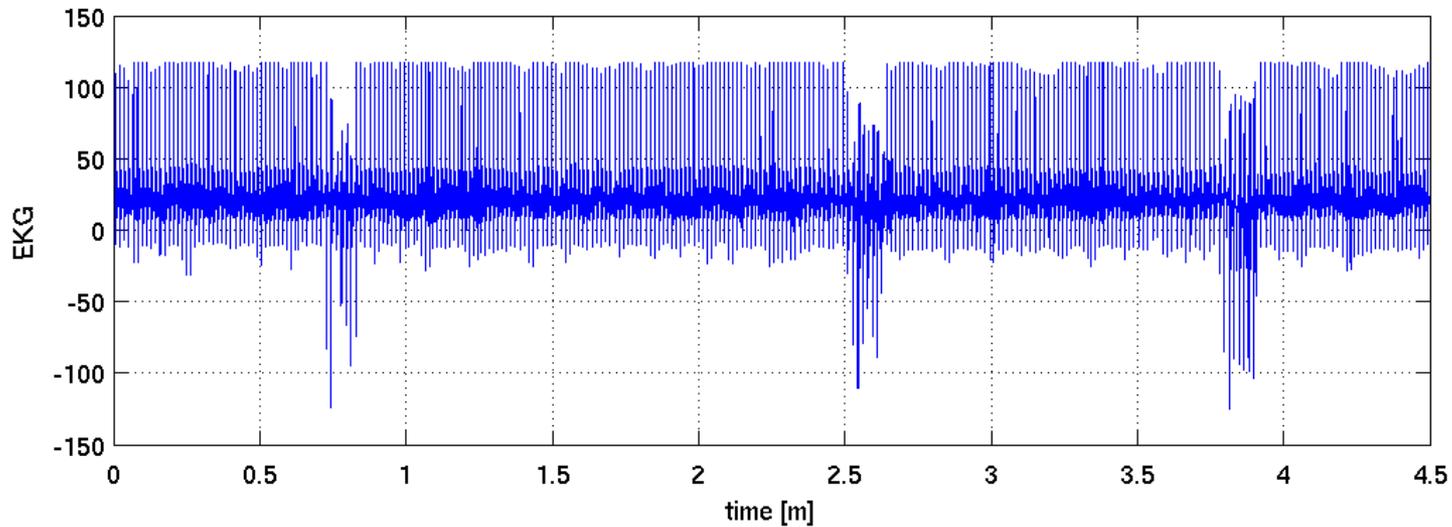
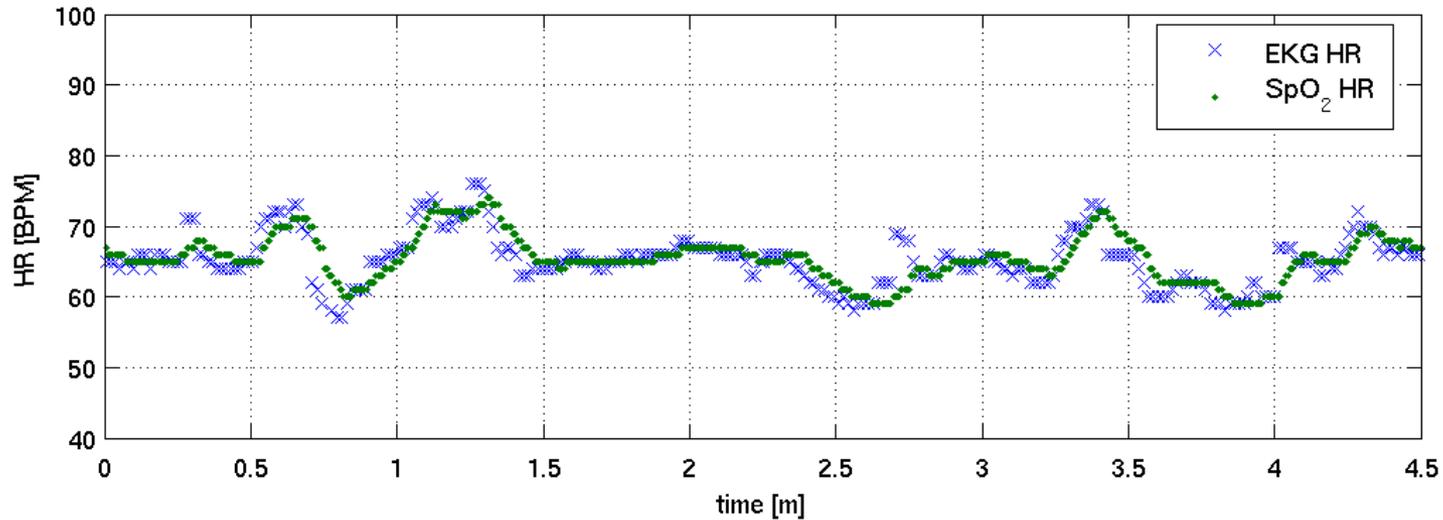


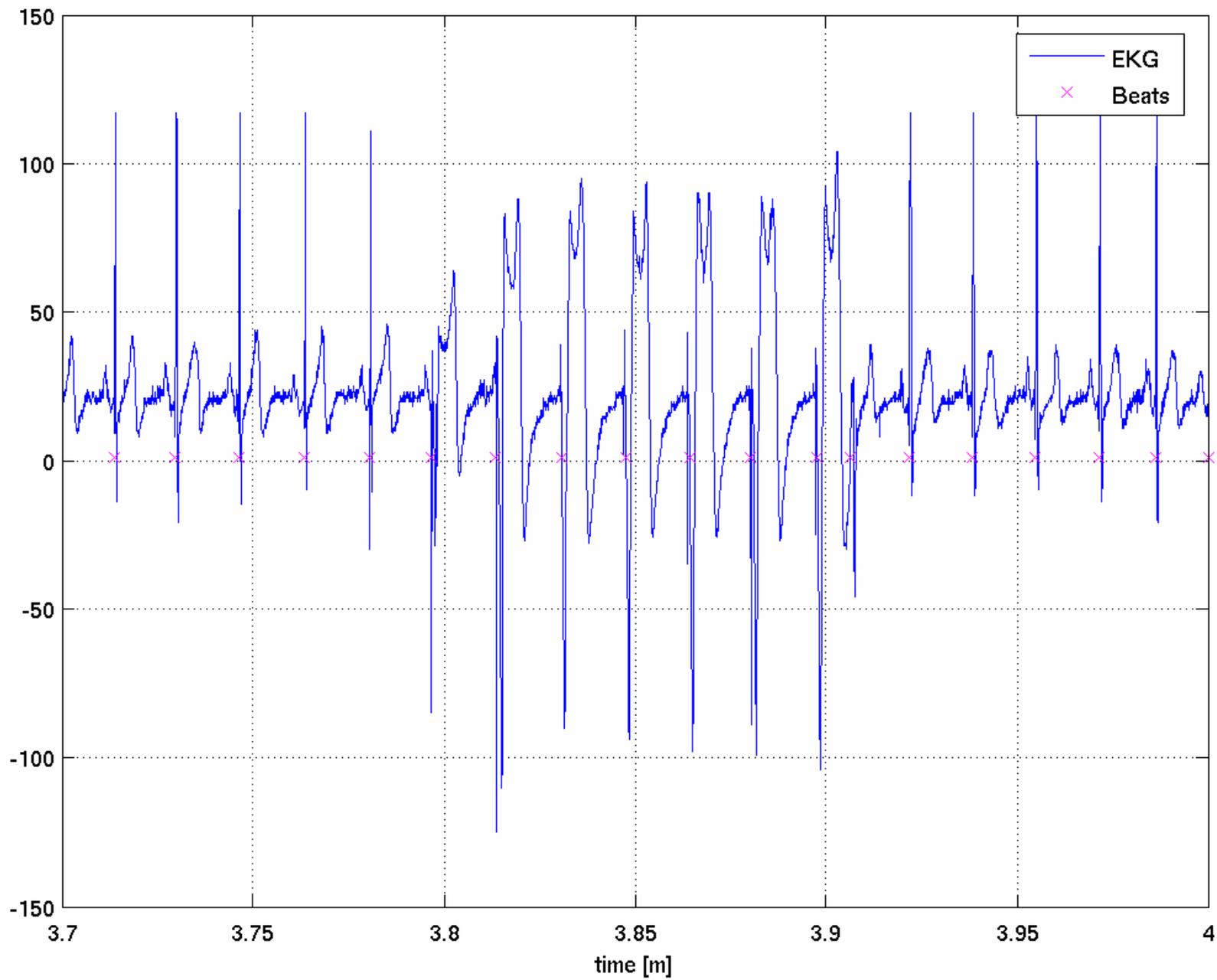
Reprioritization Due to Bigeminy





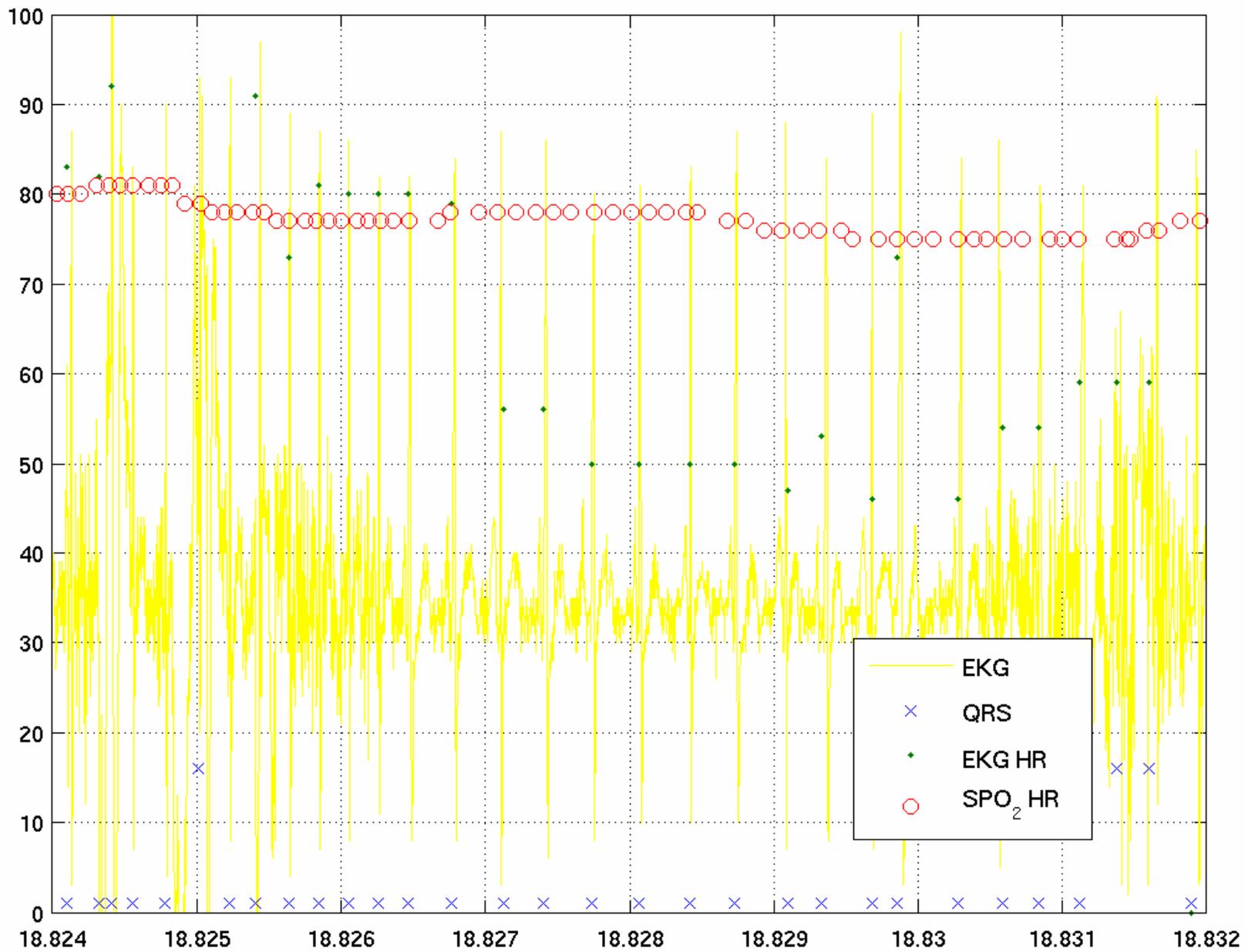
Is the Pace Maker Working?





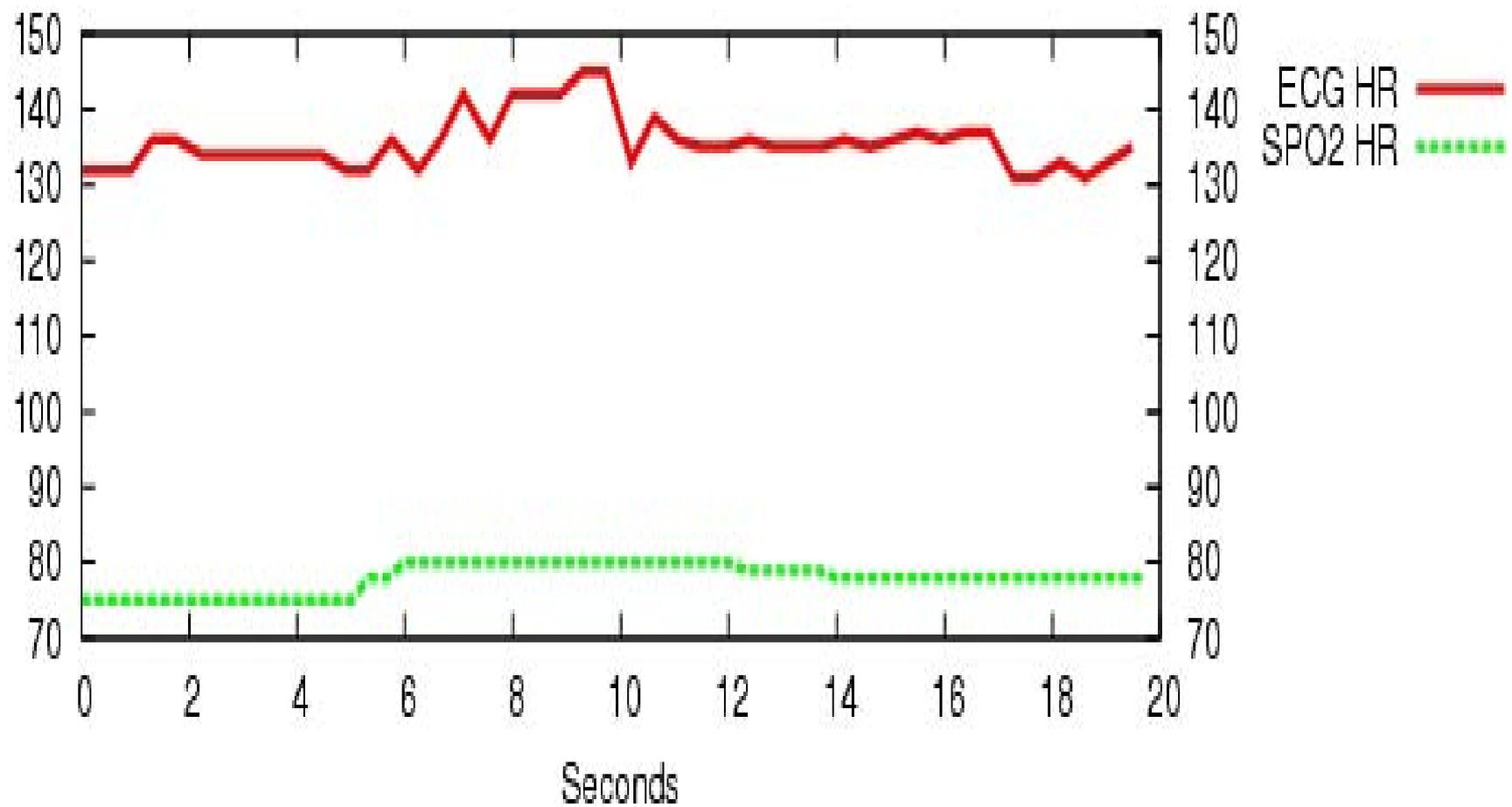
Mismatch

- ECG diagnosis inconsistent with SpO2 heart rate:
 - (a) if ECG indicates asystole and oximeter heart rate is between 20bpm and 150 bpm, or
 - (b) if ECG indicates ventricular fibrillation and oximeter heart rate is between 20bpm and 150 bpm with noisy artifacts and acceptable skewness in ECG signal



Possible Atrial Fibrillation

Database = sensor_data_20061030 PDA = #6
Date = 20061030 Start time = 12:59:45 Duration = 20 seconds



SpO2 Alarm Results

Alarm	Total	True Positive	False Positive	Unclear
High HR (SpO2 sensor)	79	75	1	3
Low HR (SpO2 sensor)	21	15	3	3
Low SpO₂	44	35	5	4

ECG Alarm Results

Alarm	Total	True Positive	False Positive	Unclear	Comments
Tachycardia (ECG)	124	61	31	32	Noise often mistaken for tachycardia
Bradycardia (ECG)	18	12	5	1	
Irregular rhythm	116	43	34	39	Noise often mistaken for irregular

More ECG Alarm Results

Alarm	Total	True Positive	False Positive	Unclear	Comments
Asystole	79	0	79	0	No SpO2 sensor present + noise or no signal
Ventricular Fibrillation	46	0	46	0	No SpO2 sensor present + noise
Ventricular Tachycardia	0	0	0	0	

More ECG Alarm Results

Alarm	Total	True Positive	False Positive	Unclear	Comments
Irregular rhythm	116	43	34	39	Noise often mistaken for irregular
Mismatch	59	59	0	0	
Noisy	59	47	12	0	
Leads Off	56	49	2	5	Noise sometimes mistaken for leads off
No Signal	0	0	0	0	

Technical Alarms

Alarm	Total	True Positive	False Positive	Unclear
SpO2 Sensor Off	86	85	1	0
AWOL	329	309	16	4
Battery	16	15	1	0

Lessons Learned (1)

- Acceptance of device by patients was high
- Institutional requirements for ACLS trained individual made testing of provider response not feasible
- ED doctors liked it, nurses accepted it, but wanted improvements:
documentation of abnormalities in paper form was requested



Lessons Learned (2)

- The number of false positive alerts was still relatively high, but manageable for the SMART operator
- Location system was somewhat underutilized because of the low volume and limited space that needed coverage
- Technical solution to disaster management is even more feasible now than when this pilot started: a cost-effective system can be developed from off-the-shelf components

SMART Collaborators

Decision Systems Group

BWH

- Rosa Figueroa, MS
- Staal Vinterbo, PhD
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- Omolola Ogunyemi, PhD
- Michael Blechner, MD
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- Ediza Heraldez, MD
- Jennifer Morrissey, RN



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