THE UNIVERSITY OF MEMPHIS

IPSN 2011
The 10th International Conference on Information Processing in Sensor Networks

Continuous Inference of Psychological Stress from Sensory Measurements Collected in the Natural Environment



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Outline

- **Motivation and Background**
- **Stress model development (lab data)**
  - Physiological stress model
  - Perceived stress model
- **Model evaluation on field data**
- **Conclusions and Future Work**

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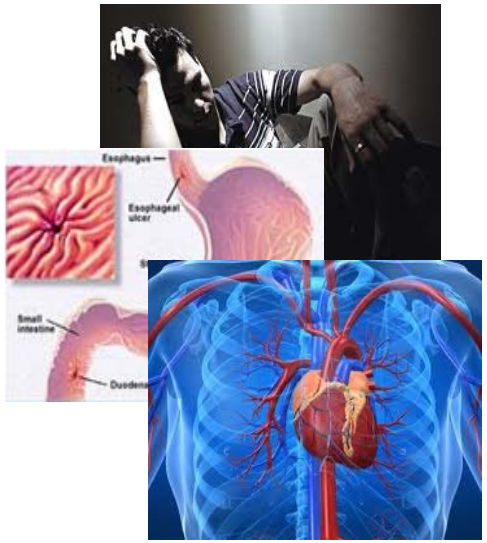
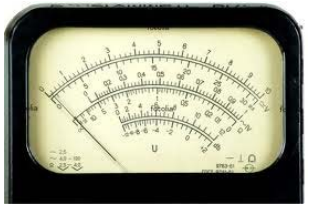
Negative Effects of Stress on Health

- **Excessive stress adversely affects**
  - Body
  - Mind
- **Over long time it increases risk of**
  - Physical illness: cancer, cardiovascular health
  - Mental illness: depression, anxiety disorder
- **Strong motivation to study stress**
  - Measure continuously, in natural environment
- **Need robust methods for measuring stress**





Measuring Stress in the Field

- **Self-reports have been used for a long time**
  - Questionnaires or surveys
  - Measure perceived stress

- **Strengths and limitations**
  - Capture detailed information
  - Discrete sampling
  - Burden to participant

- **Need an automated approach for continuous stress measurement in the field**

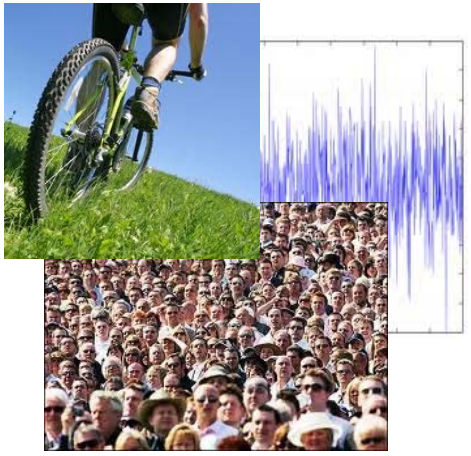
The Quest for Automated Stress Measure

- **Predicting psychological state from physiology**
  - William James – pioneering work (1880)
  - John Cacioppo and others – revitalized interest (1990)
- **Many emotion and stress prediction studies**
  - Identified stress and emotion markers (Heart rate, skin conductance)
  - Mostly in controlled settings
- **Few studies in uncontrolled environments**
  - M. Myrtek (1996), J. Healey (2005), J. Healey (2010), Shi (2010)
  - Either no validated stressors, no lab session to train models, not able to account for confounders, or tried to match self-reports directly

Challenges of Stress Study in Field

1. **Need an unobtrusively wearable sensor system**
   - Collect multiple sensor modalities
   - Provide scientifically valid data

2. **Control for confounding factors**
   - Activity, change in posture, food, all affect physiological measurements

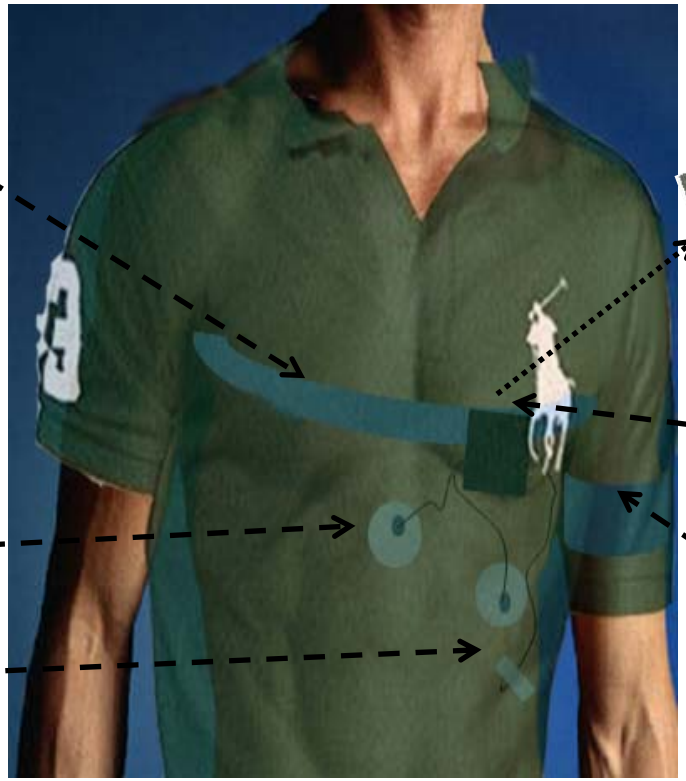


3. **Account for between-person differences**
4. **Unavailability of ground truth in the field**
   - Self-reports are one source of ground truth

In the AutoSense Project

- **We developed a new wearable sensor suite**
- **Conducted scientific user study with validated stress protocol**
  - **21 participants, 2 hour lab study, 2 day field study**
    - Protocol designed by behavioral scientists
    - Stressors used are validated and known to produce stress
    - Self-reports designed by expert behavioral scientist
    - Participants wore AutoSense for in lab and for two days in field
- **Developed new stress models to measure**
  - **Physiological response to stress**
    - To measure adverse physiological effects of stress
  - **Perception of stress in mind**
    - To derive a continuous rating of perceived stress

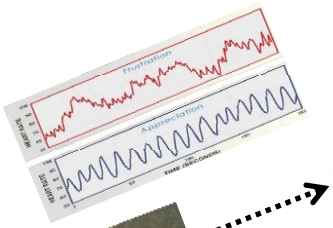
AutoSense Wearable Sensor Suite

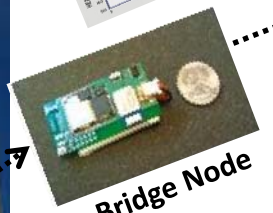


Respiration Band

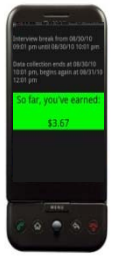
ECG Electrodes

Temperature Probe





Bridge Node



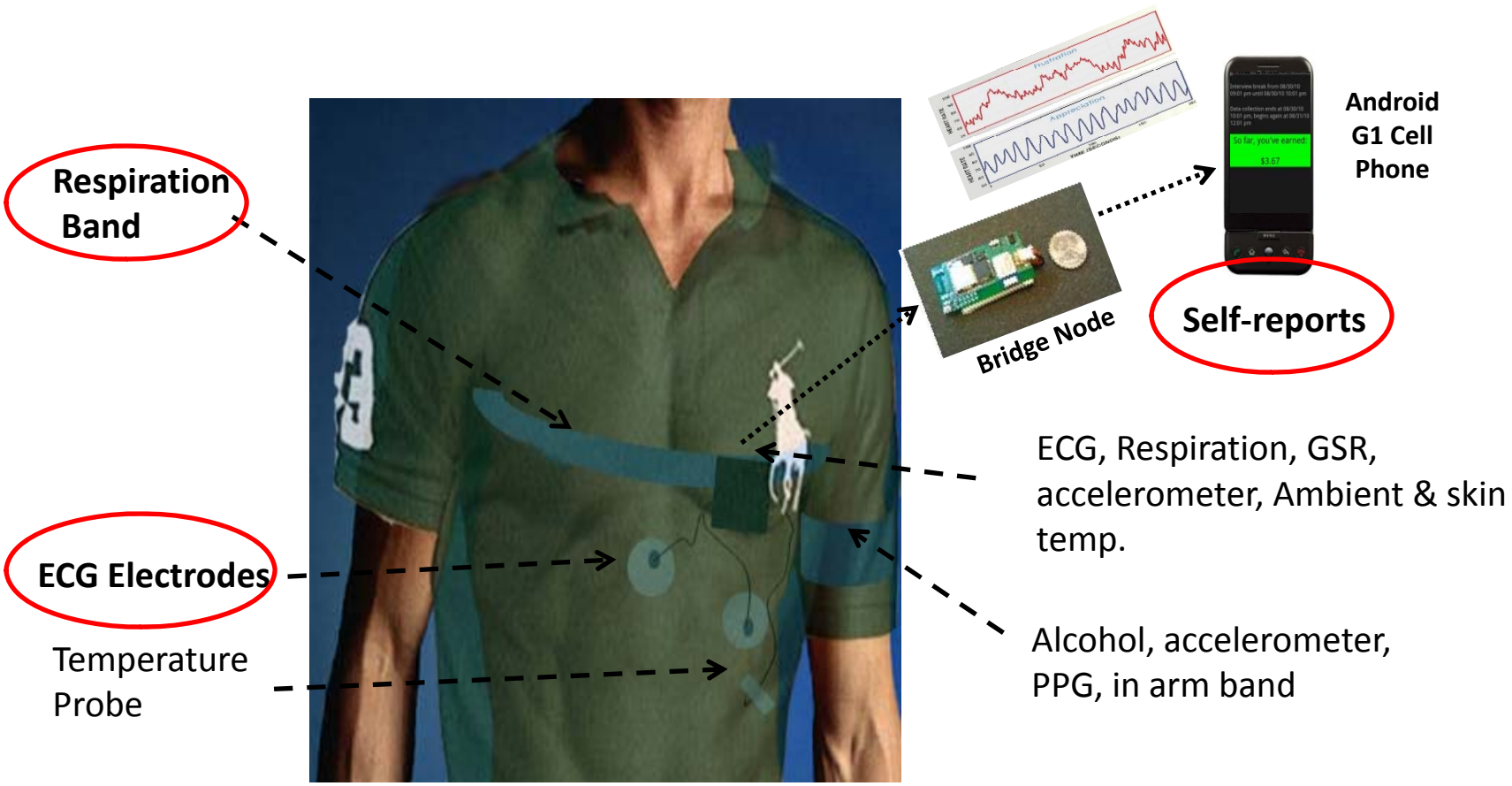
Android G1 Cell Phone

Self-reports

ECG, Respiration, GSR, accelerometer, Ambient & skin temp.

Alcohol, accelerometer, PPG, in arm band

AutoSense Wearable Sensor Suite



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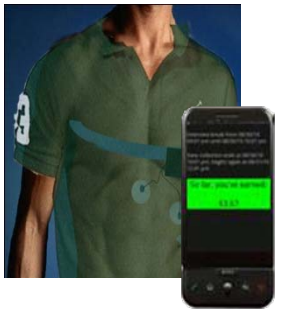
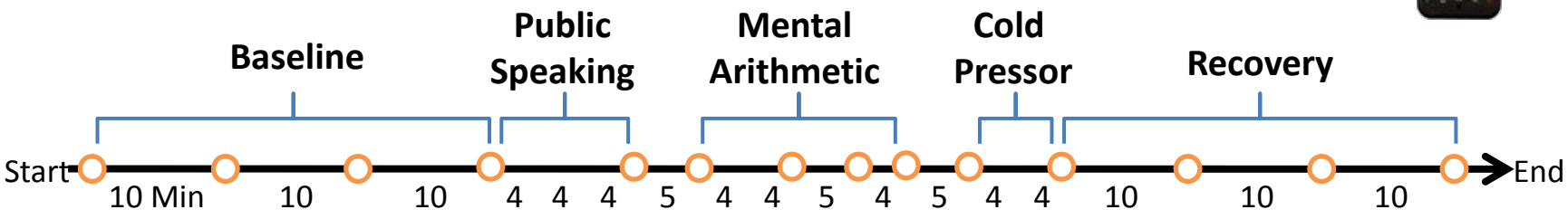
Lab Study – Stress Protocol

- **2 hour lab session**
  - **Subjects exposed to three types of stressors**
    - Public speaking – psychosocial stress
    - Mental arithmetic – mental load
    - Cold pressor – physical stress

- **Physiological signals recorded at all times**
  - Using AutoSense
  - **Also, collected self-reported stress rating 14 times**

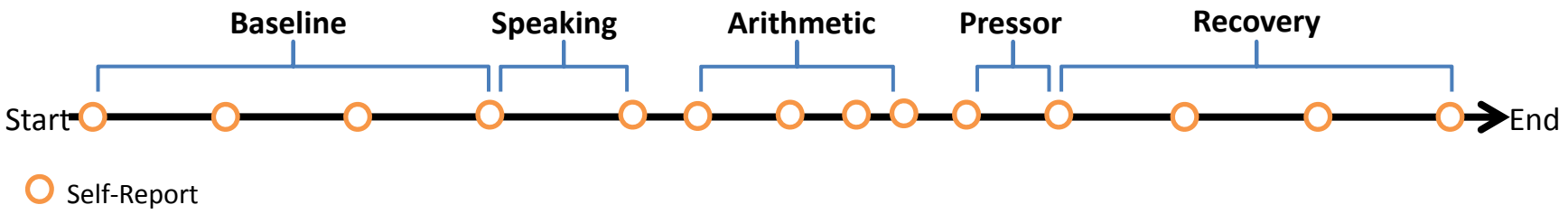




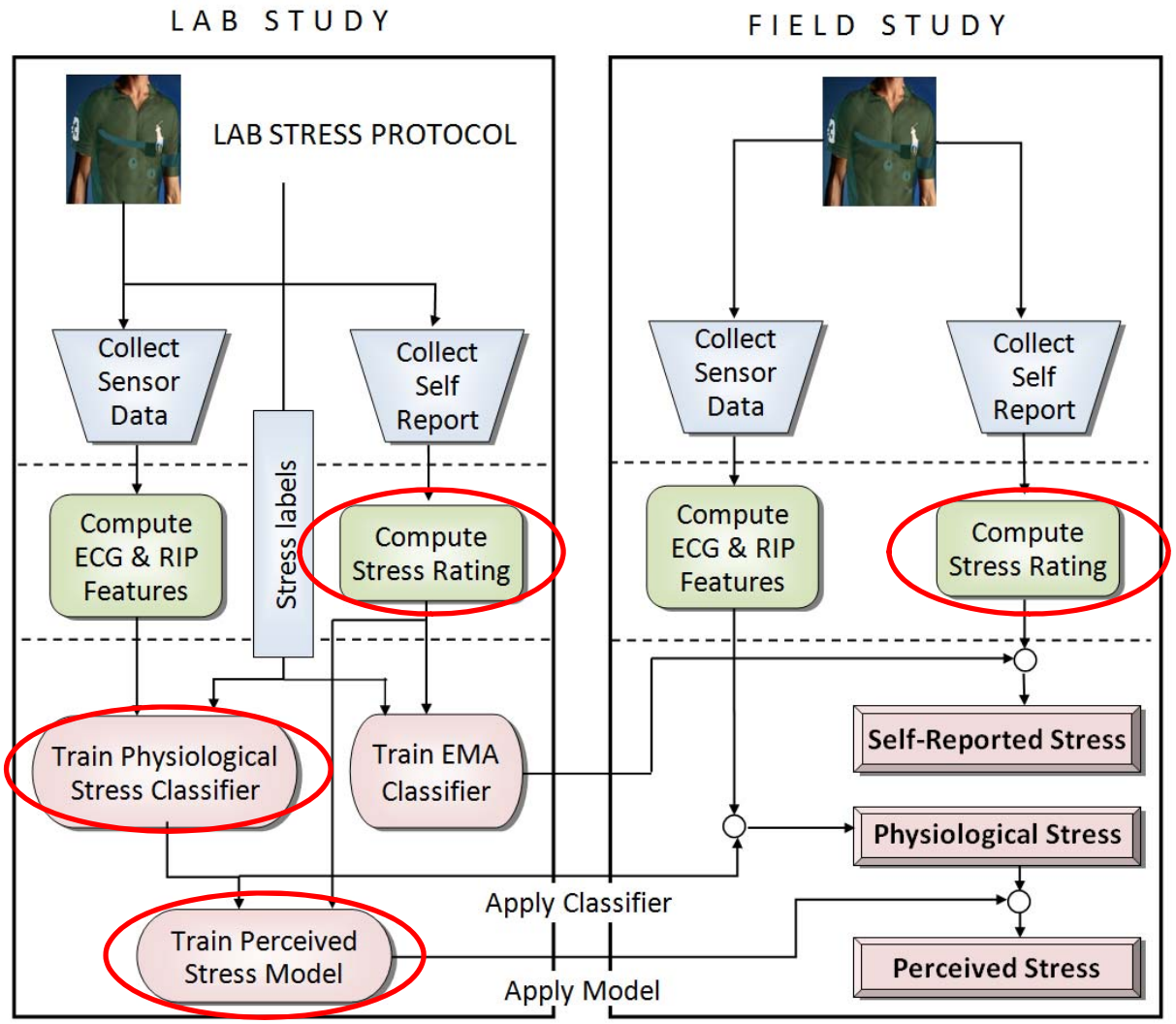
Self-Report Measures of Stress

- **Self-report questions related to affective state**

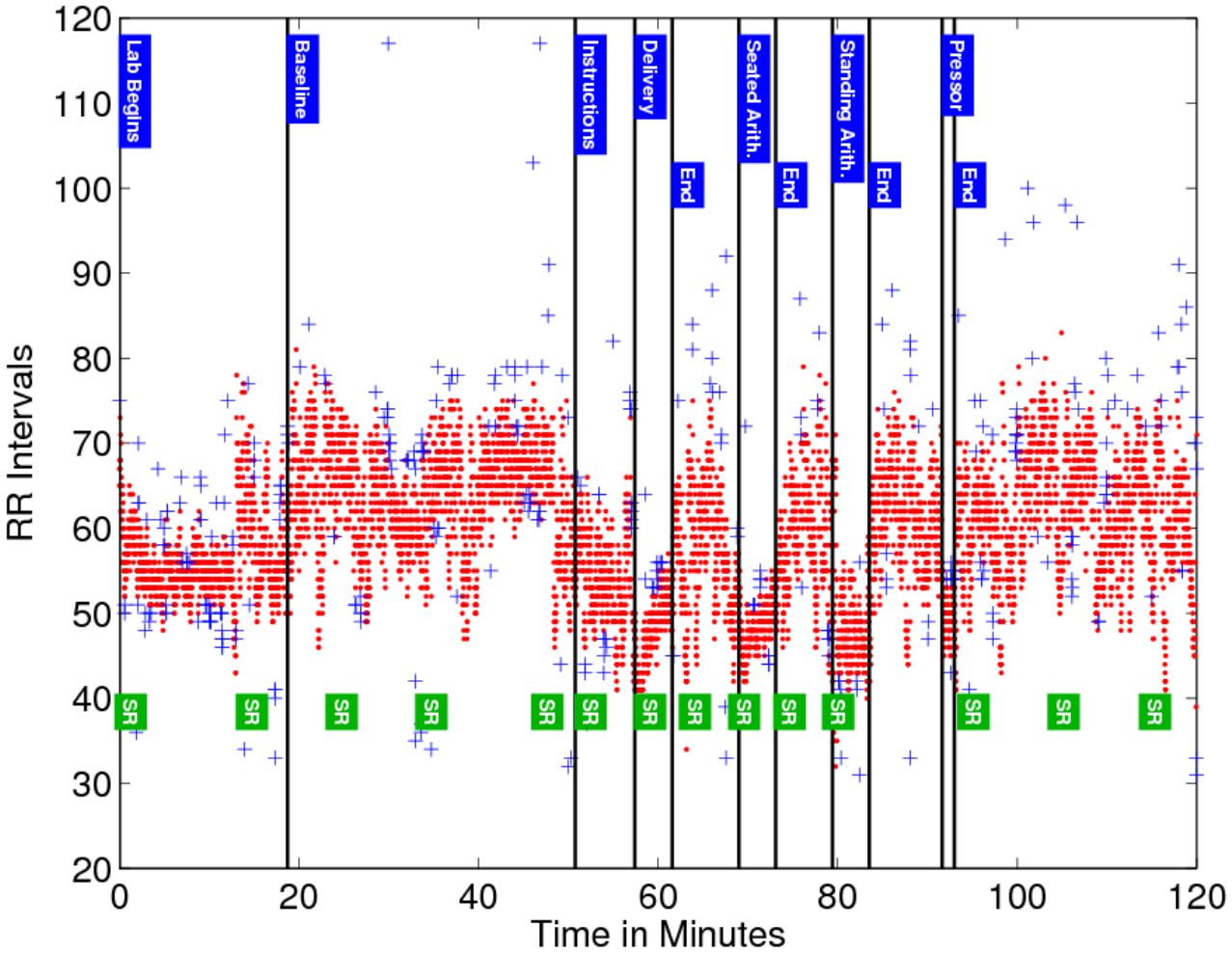
Question	Possible Answer	Code
Cheerful?	YES yes no NO	3 2 1 0
Happy?	YES yes no NO	3 2 1 0
Frustrated/Angry?	YES yes no NO	0 1 2 3
Nervous/Stressed?	YES yes no NO	0 1 2 3
Sad?	YES yes no NO	0 1 2 3



Overview of Model Development



Impact of lab stressors on ECG measure



- **Selected 1 minute intervals from each period**
- **Removed outliers from RR intervals**
- **Computed 35 features**
  - Normalized features

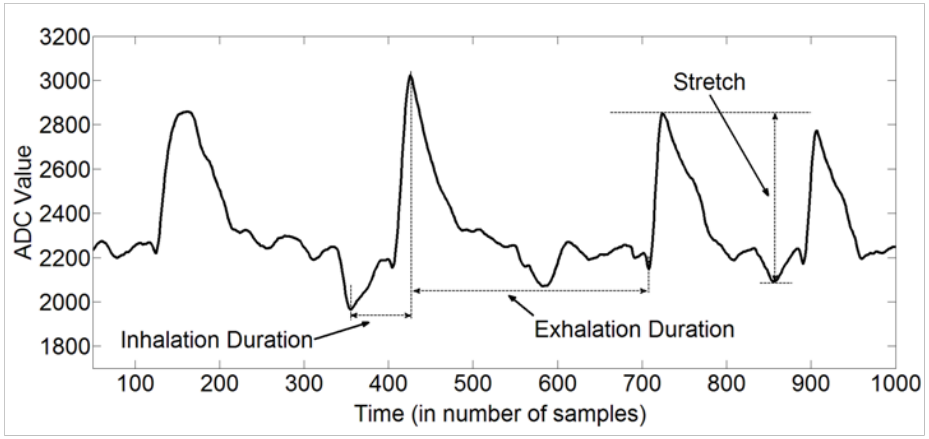
Identified 22 Features from Respiration

Basic Features

- Inhalation Duration
- Exhalation Duration
- Respiration Duration
- Insp./Exp. Ratio
- Stretch
- Breathing Rate
- Minute Ventilation

Statistical Features

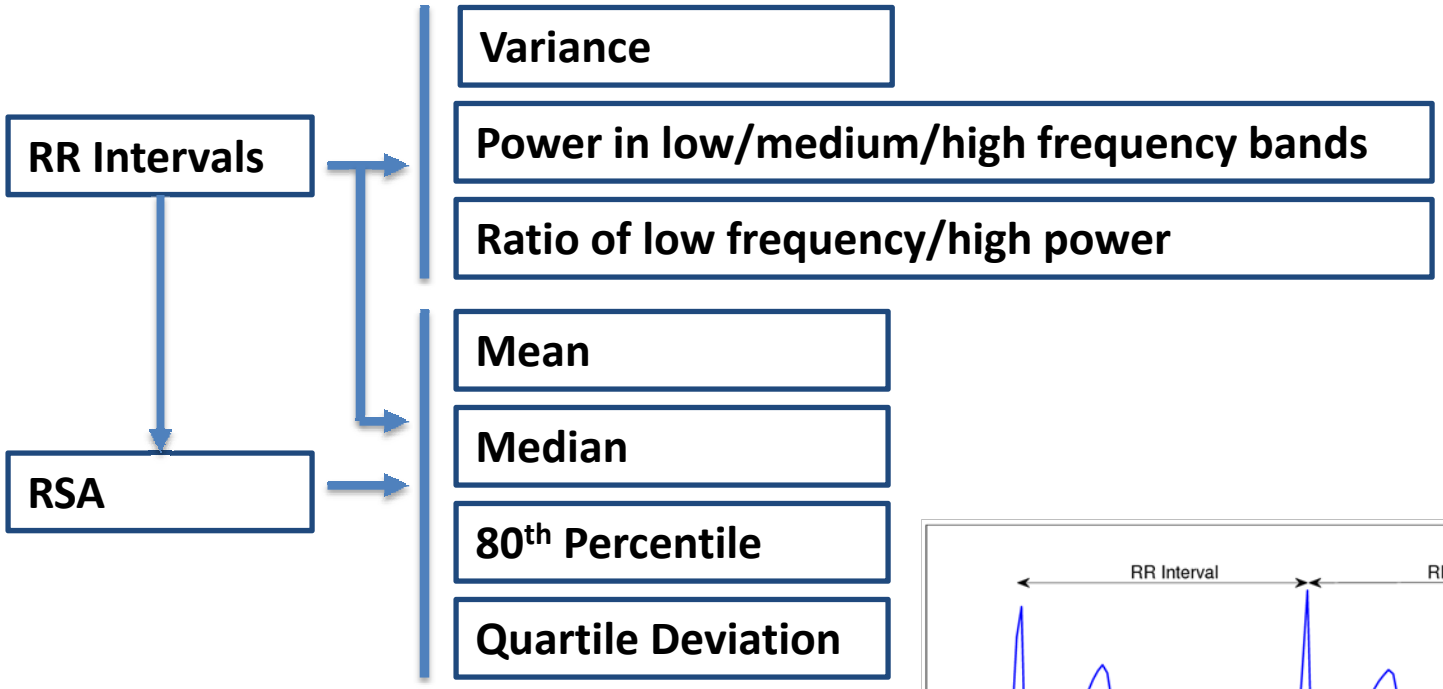
- Mean
- Median
- 80th Percentile
- Quartile Deviation

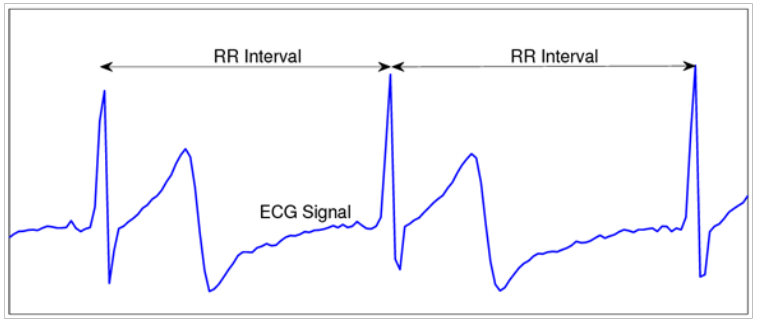


Computed 13 Features from ECG

Basic Features

Statistical Features





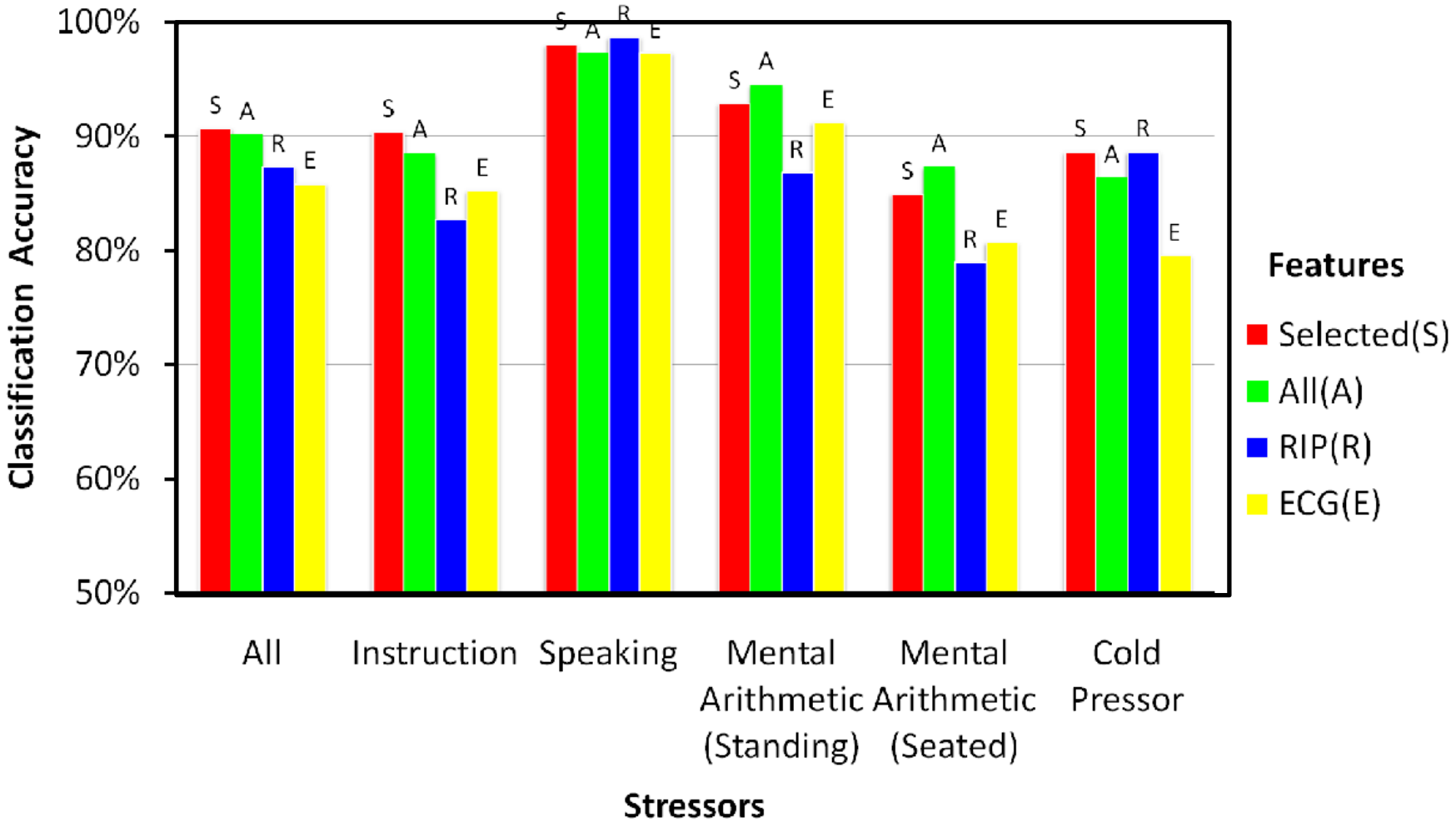
Feature and Classifier Selection

- **Used Weka for Training**
  - Evaluated Decision Tree, DT with Adaboost, and Support Vector Machine
  - Using 10-fold cross validation, and training/test data
- **Classification results using 35 features**

J48 Decision Tree	J48 with Adaboost	SVM
87.67%	**90.17%**	**89.17%**

- **After feature selection, 13 features**
  - 8 Respiration, 5 ECG

Classification Accuracy on Lab Data



Perceived Stress Model

- **Want to relate physiological classifier to self-report**
  - Predict what the person would have responded

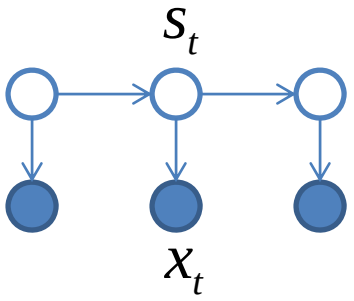
- **Self-report rating**
  - Five answers mapped to real value
  - Average of 5 numerical codes

Answer	Value (-)	Value (+)
NO	0	3
no	1	2
yes	2	1
YES	3	0

Using a Hidden Markov Model

- **Use a binary Hidden Markov Model**

$s_t \in \{0,1\}$ is perceived stress



$$\pi_t = \mathrm{P}[s_t = 1 \mid x_1, \ldots, x_t] \text{ is perceived stress value}$$

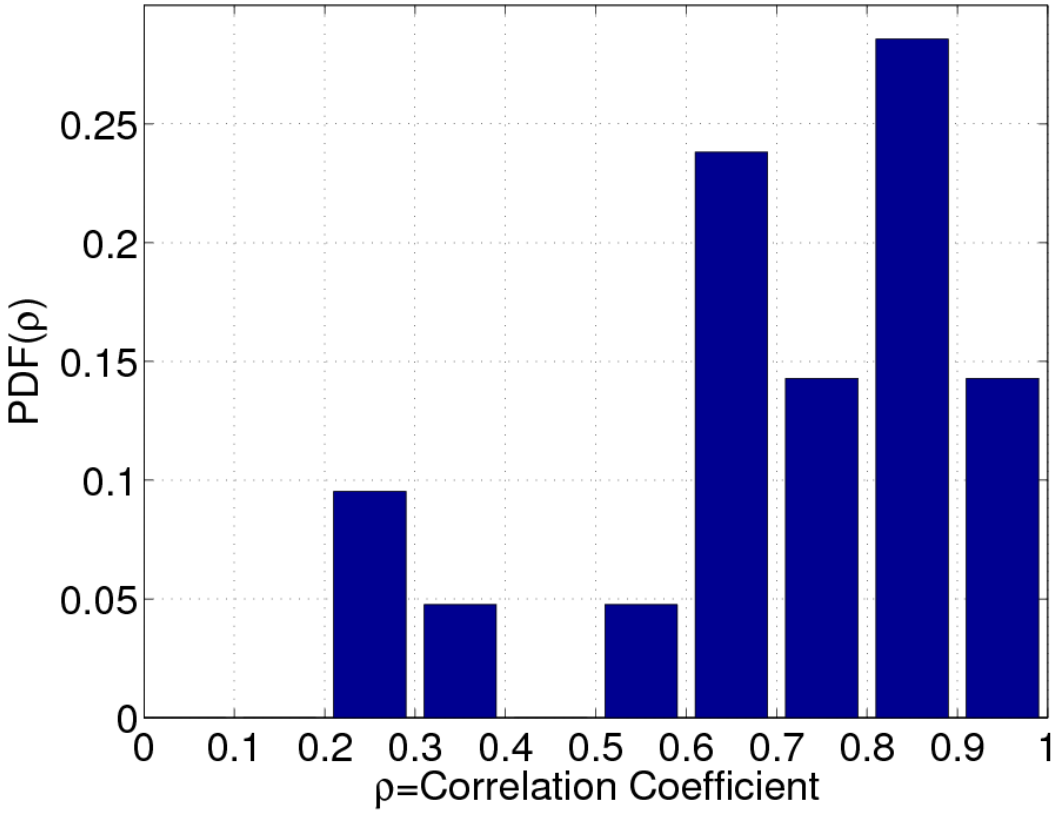
- **To reduce number of parameters we approximate π_t by**

$$\hat{\pi}_t = \alpha \hat{\pi}_{t-1} + \beta x_t$$

α, β person-dependent parameters

Evaluation of the Model (on Lab Data)

- **Correlation of accumulation model and self-report rating**
- **21 Participants**
- **Median correlation**
  - 0.72
- **Values of ρ<0.5**
  - Not significant



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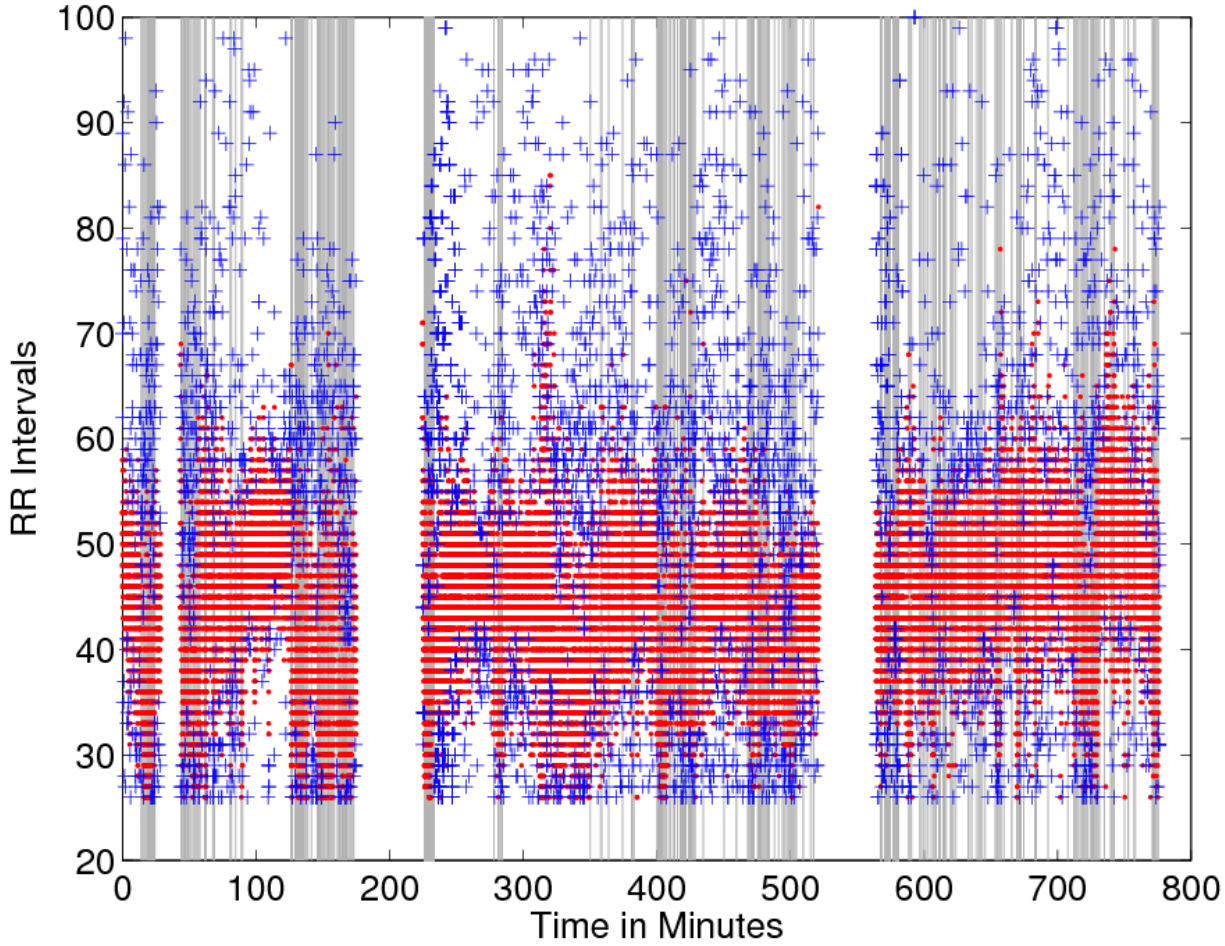
Field Study Protocol

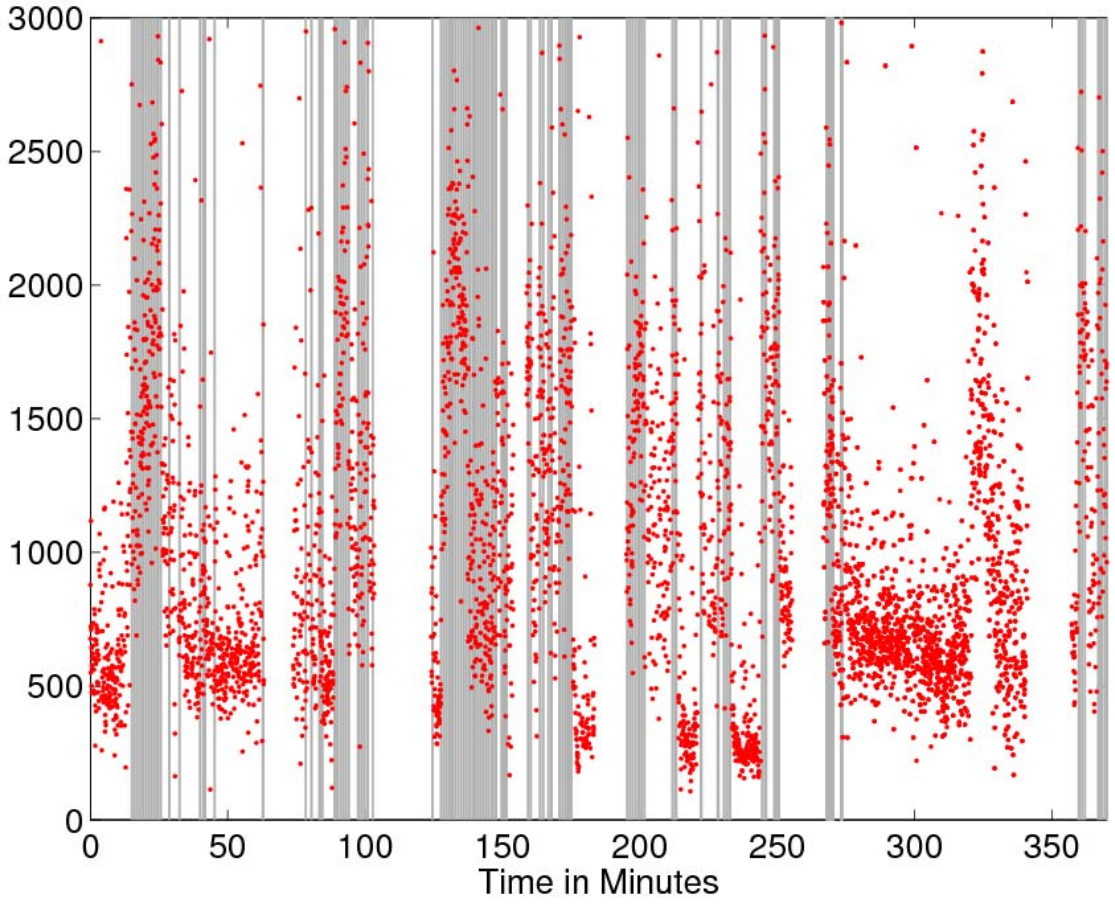
- **Participants wore AutoSense continuously, for 2 days**
  - Going about their life (home, school, etc.)
  - Except at night
- **Field self-reports**
  - Participants responded to self-reports 20+ times each day
  - Same questions about affect state as in the lab
    - Additional context information
- **Additional behaviors automatically collected**
  - Speaking, from respiration patterns
  - Physical activity, from accelerometer

Realities of Natural Environment



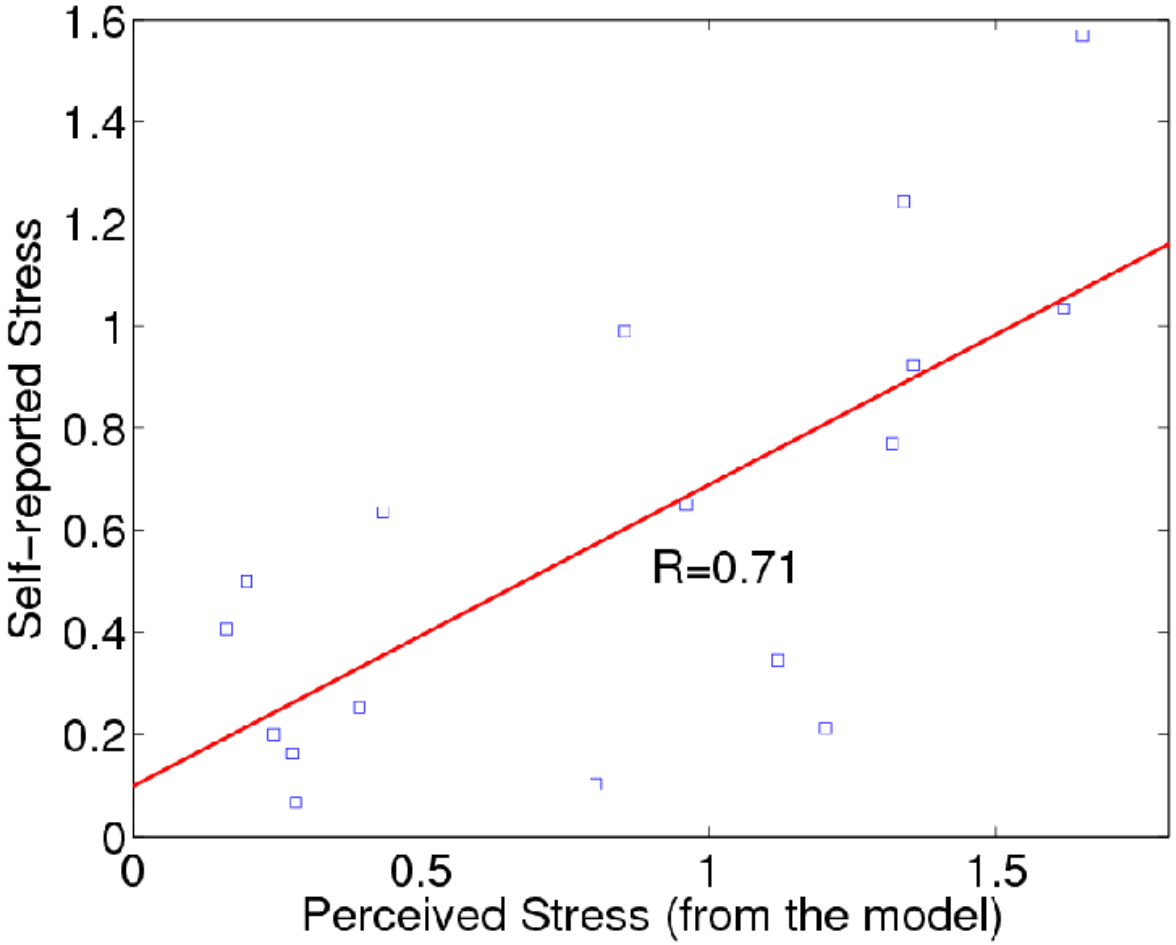
- **Data eliminated**
  - 37% affected by activity
  - 30% poor quality
- **Less than 4 min consecutive data**
- **4 subjects missing data or self-report**

Realities of Natural Environment



- **Evaluation is on average stress level over both days**

Evaluation of the Model (Field)



- Compared average stress ratings over both days
- Accumulation model versus self-report
- Linear interpolation

Conclusions and Future Work

- **The long-standing question on whether stress can be measured automatically in the field has now been answered**
  - The focus can now shift from “Whether” to “How Well?”
  - Three additional user studies (with 50+ subjects) in progress for additional refinement and validation of stress model
- **New apps can now be developed for monitoring of stress and to help reduce stress in daily life**
  - For example, to select a less stressful route for driving
- **Mediators of stress can now be investigated in the field**
  - For example, relationship between stress, smoking, drinking, physical activity, entertainment, etc.