Activity Measurement and Monitoring Technologies

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- Basis for activity monitoring
- Review of existing methods
- IST Vivago activity measurement - measurement principles
- Comparison of IST Vivago activity signal with other methods in sleep/wake detection

Basics

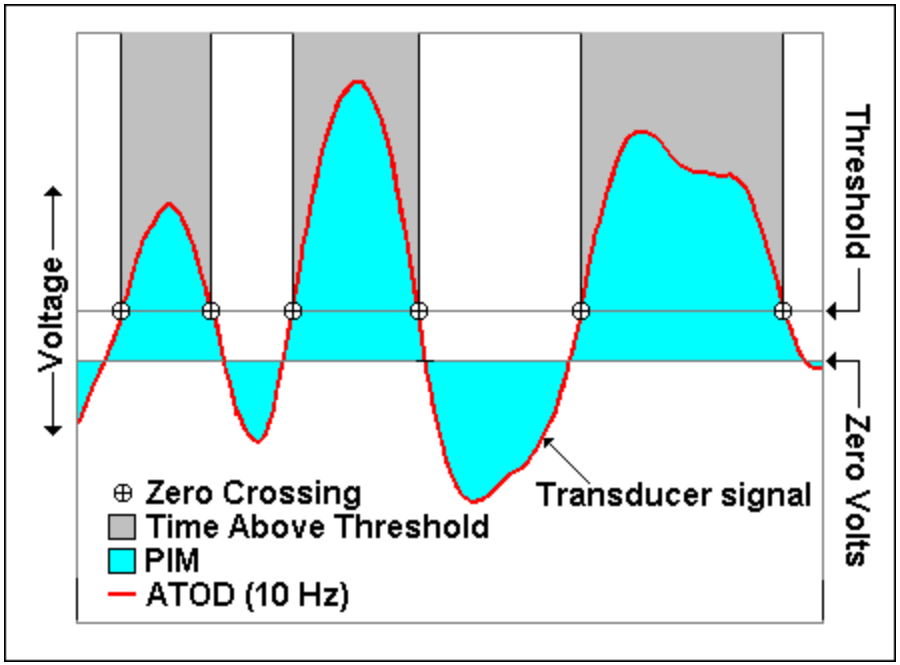
- Measurement of the activity of an ambulatory subject is based on measurement of **accelerations** or **forces** caused by the movements
  - Measurement site
  - Measurement technology
- **Actigraph** = small, wrist-worn device that measures movement
  - (Wrist) actigraphy
  - May also be worn in other sites e.g. ankle (PLMS)
- Application: recording of long-term (days-weeks) body movements with minimal disturbance in free moving subjects
  - sleep quantity and quality
  - other movement-related disorders and fatigue
  - evaluation of drug effects
  - circadian rhythm

Actigraphy: measurement technology

- Standard actigraphs use accelerometers for detection of movement
- One-axial actigraphs: measurement in one direction
  - More simple and cheaper
  - Most commonly used devices e.g. ActiWatch, Mini-Motionlogger
- Tri-axial actigraphs: measurement in 3D
  - More expensive
  - e.g. Tritrac-R3D, Tracmor

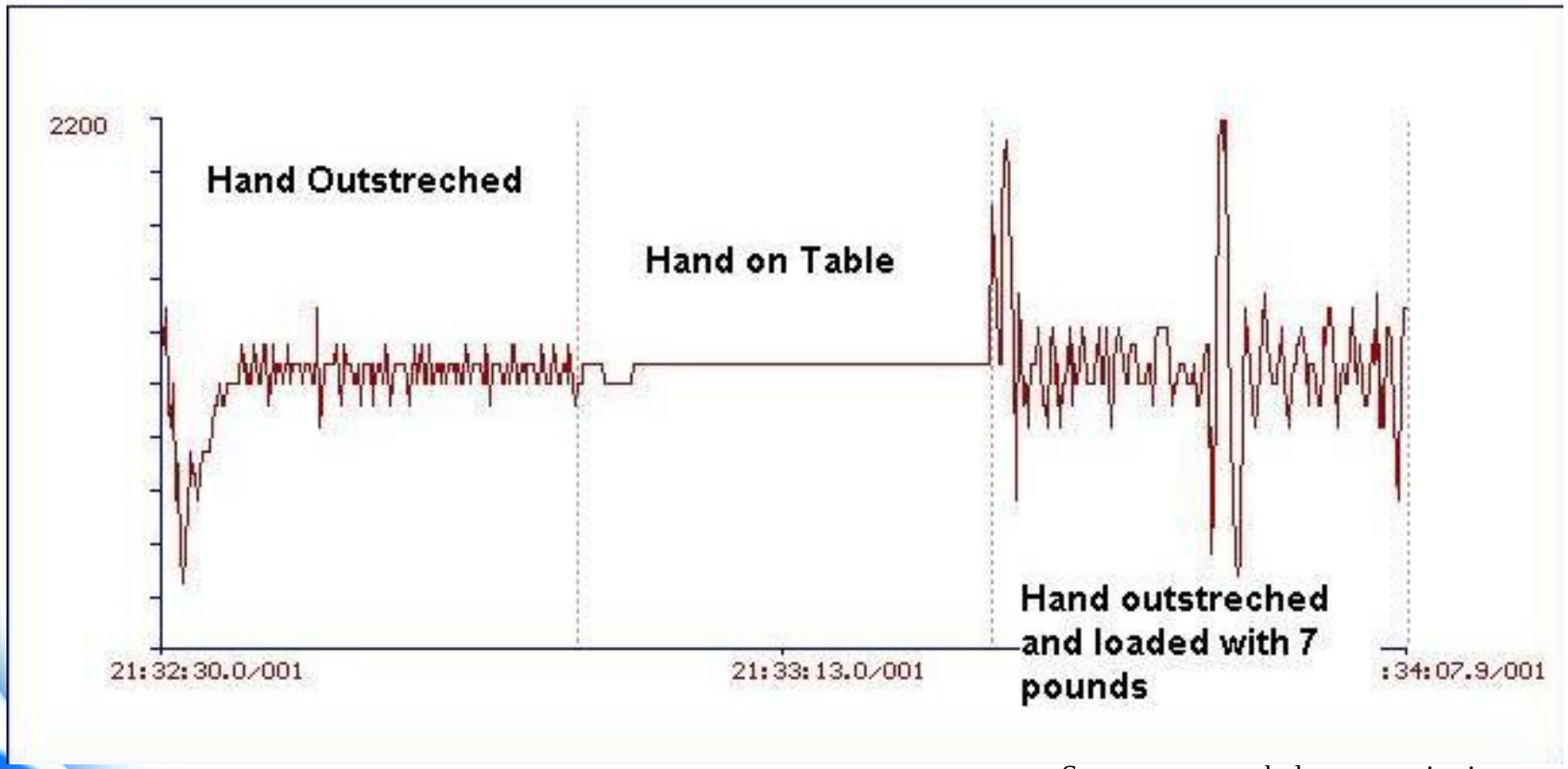
Actigraphy: composition of the activity signal

- Actigraph quantifies the acceleration signal into digits and constructs an *activity signal*
- Most common approach: *Count* of activities exceeding a certain threshold (typically 0.1g) within a fixed period of time (typically 30sec or 1min)
- Also area under curve (integral), time above threshold, zero crossing rate, ...
- Data from different systems difficult to compare
  - However, from applicability point of view, results are usually comparable with different systems



Source: www.ambulatory-monitoring.com

Acceleration signal



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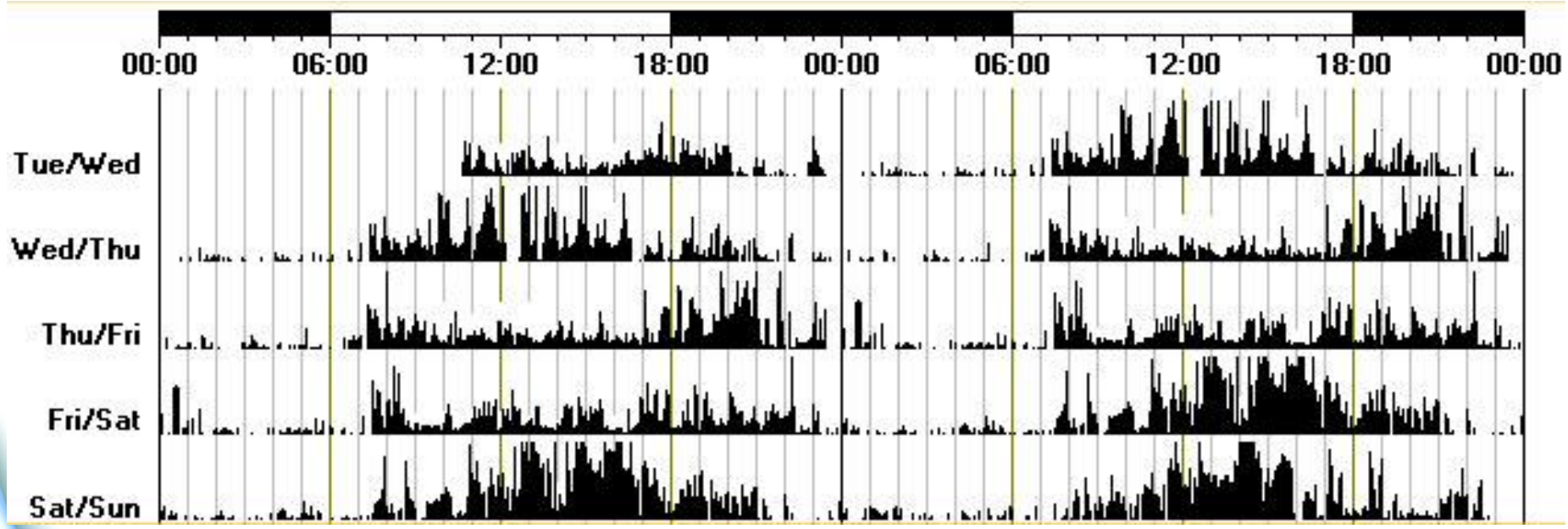
Actigram signal



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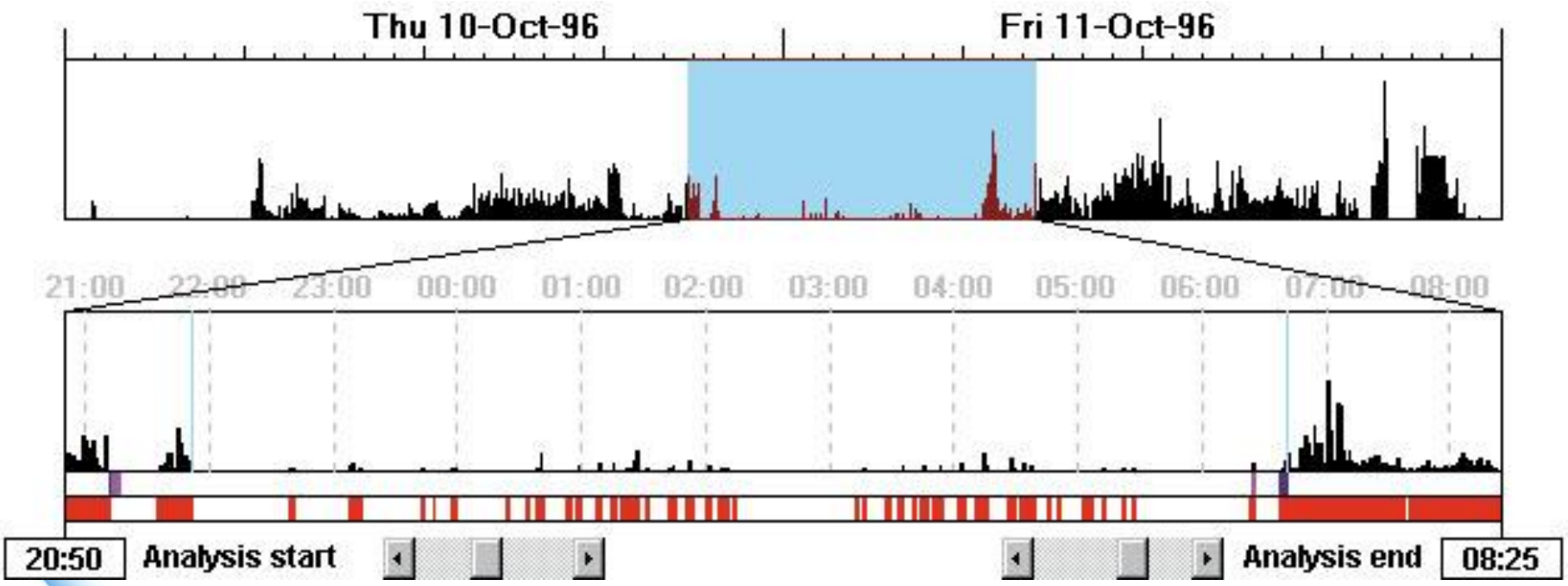
Sleep/wake scoring by actigram



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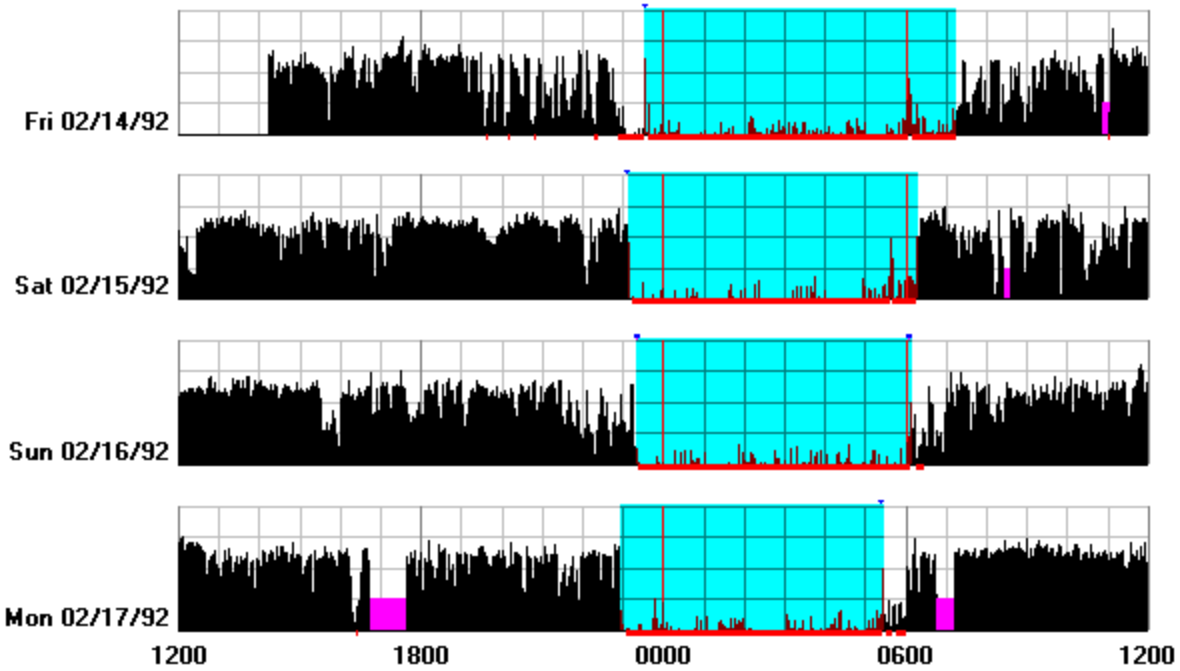
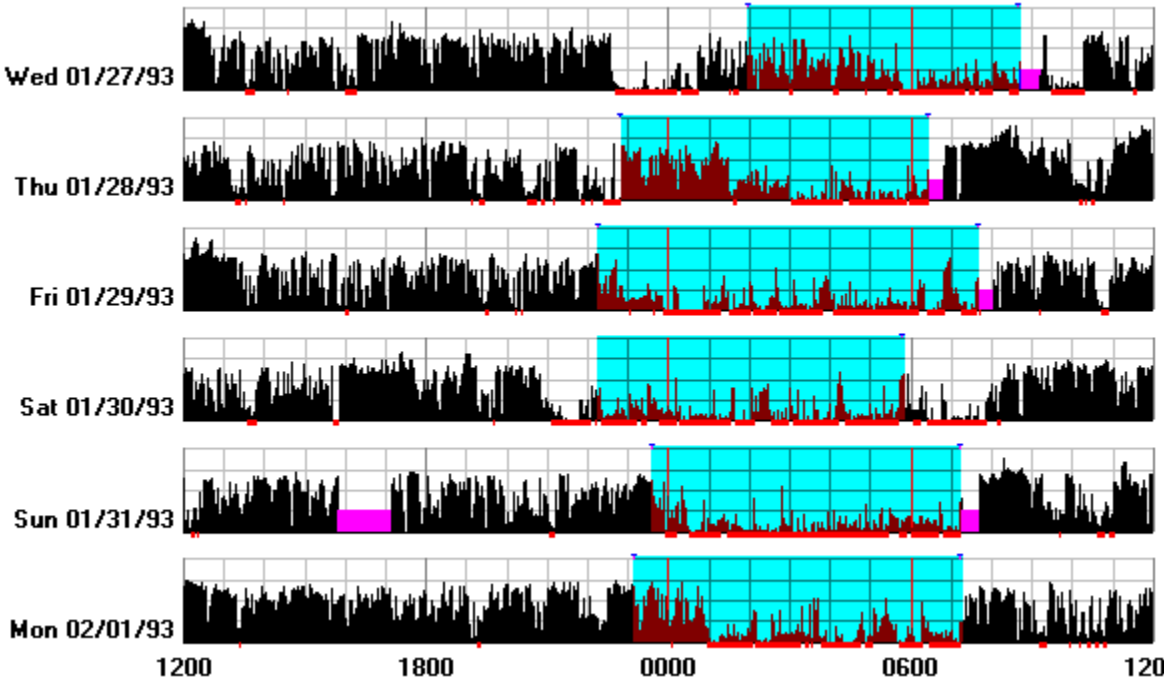


Normal actigram

Source: www.ambulatory-monitoring.com



Chronic pain actigram

Measurement guidelines

- Site: nondominant hand (wrist) recommended e.g. for sleep studies
- Analysis resolution: 30sec or 1min
- For reliable results min. 3 consecutive 24h periods
- Limiting factors:
  - Identification of "unit off" periods difficult in standard systems
  - Length of the allowable collection period depends on sampling rate; typically max. order of a week or two
  - Artifacts
    - Breathing artifact
    - Co-sleeping
    - Sleep disorders
    - Periodic leg movement syndrome (PLMS) or other movement disorders, incl. Parkinson's disease

Performance of actigraphy in sleep/wake detection

- Golden standard: polysomniography (PSG)
- Actigraphy used as a diagnostic tool
  - long-term measurements
  - normal environment
- Minute-by-minute agreement rates with PSG in normal subjects ~90%
- Total sleep time (TST) estimation with average error ~15min have been reported
  - However, error may be much higher in individual cases!
- Lower agreement if
  - Sleep disorders
  - Movement disorders
  - Artifacts

BASIC Mini-Motionlogger® Actigraph

Cambridge Neurotechnology Actiwatch®

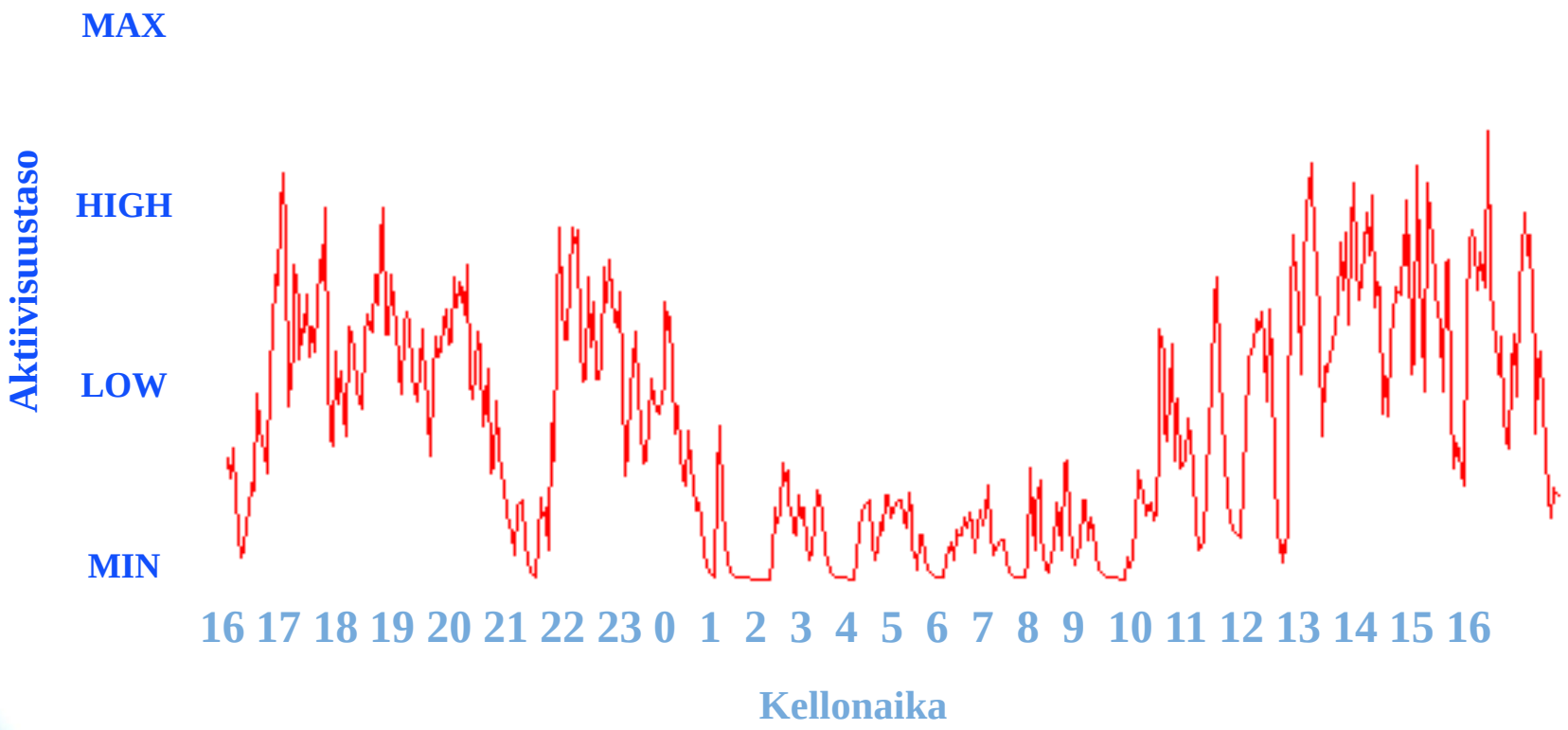
Source: www.ambulatory-monitoring.com

Activity signal from Vivago®

1. Wrist unit measures forces between the wrist unit and the wrist
2. Force signal is transformed into messages, which are transmitted to the base station
3. *IST Vista* software (in institutional system) transforms messages into an activity signal
    - both *force level* and *intermessage timing* are used in the transformation

- The resulting activity signal has a time resolution in the order of ~2min

Vivago activity signal in a normal subject



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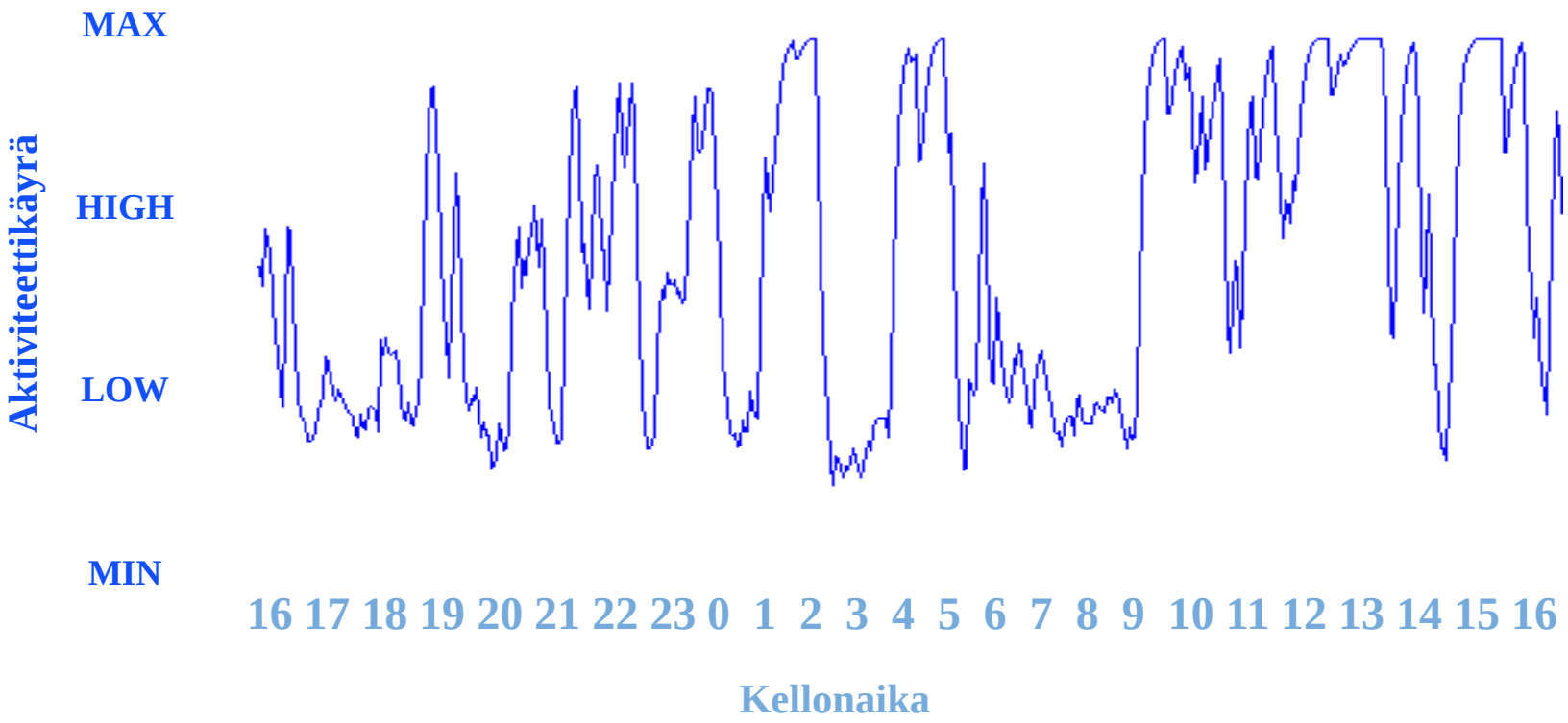
VIvago activity signal in a demented 81-year old subject



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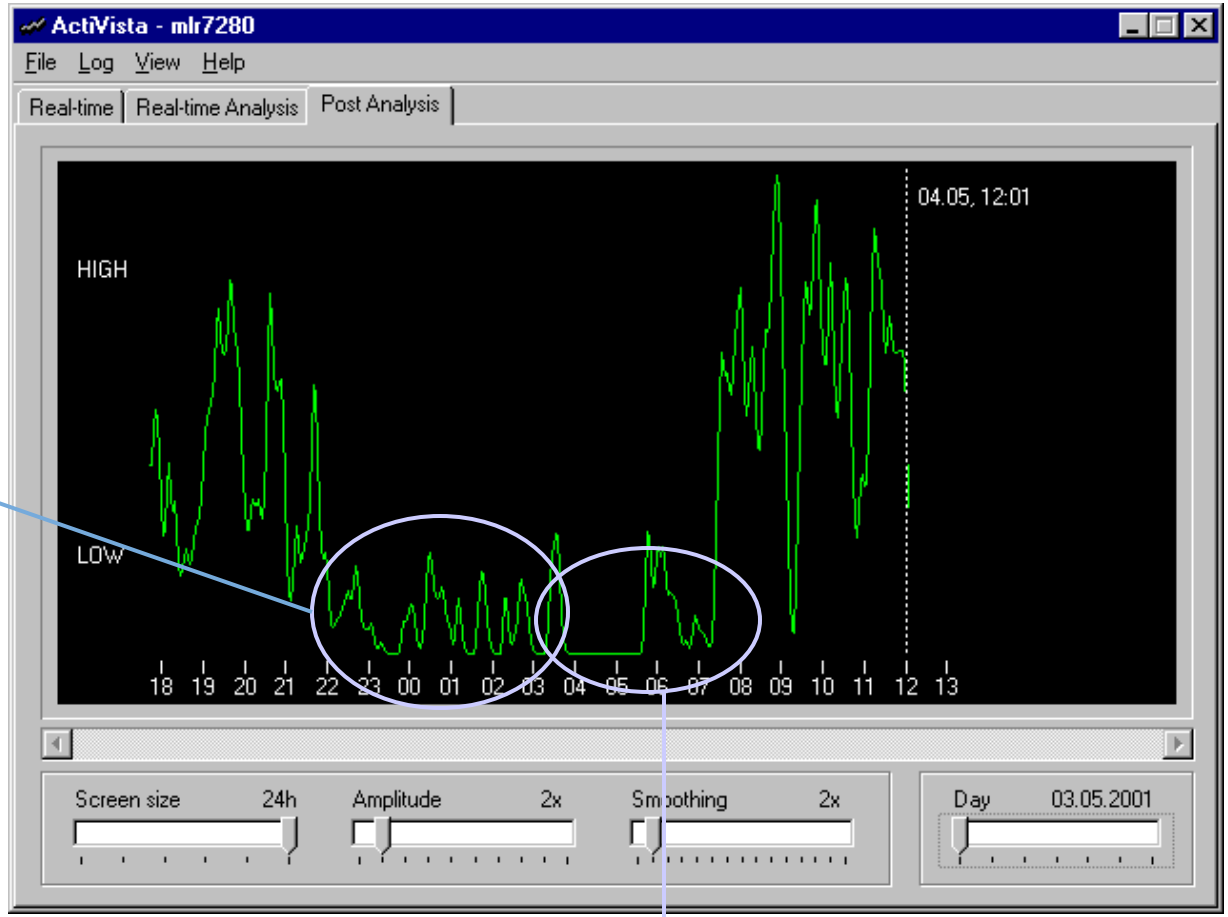
Activity signal and automatic alarms

- Originally, Vivago has been designed for automatic alarms, which are based on the activity signal generated.
  - Improved sensitivity in low levels of activity for discrimination of sleep and unconsciousness
- Detection based on unusually low levels of activity or no activity at all
  - Alarm delays adaptive and depend on the normal activity cycle of the subject
  - Different function during day and night

- (A short validation study to test the alarms against specifications for a home unit; passed; VTT 2002)

Example of an automatic alarm based on activity

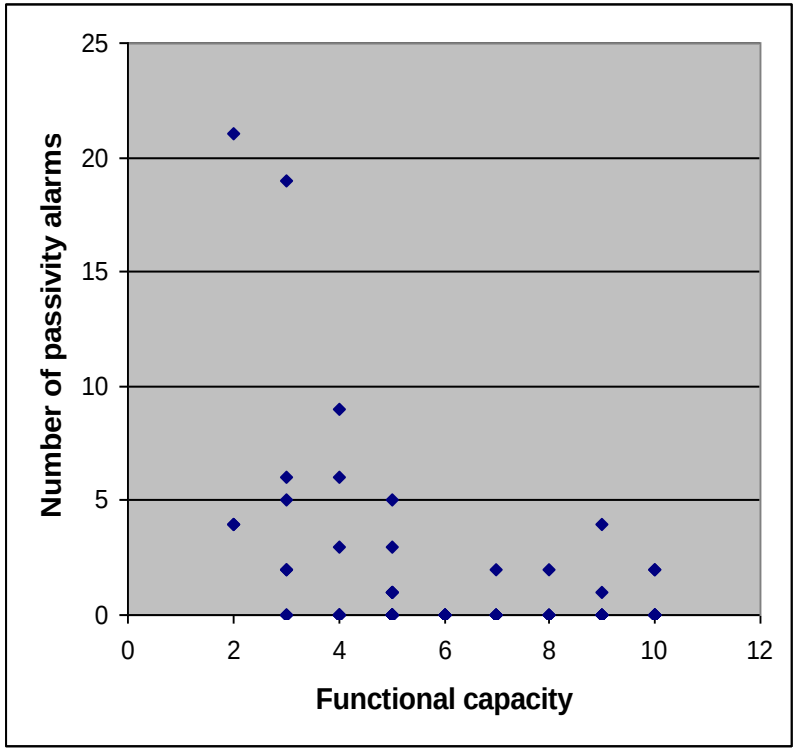


Sleeping

Woke up 3:50, fell and stayed unconscious;
deterioration alarm at 5:00, help arrived 5:30

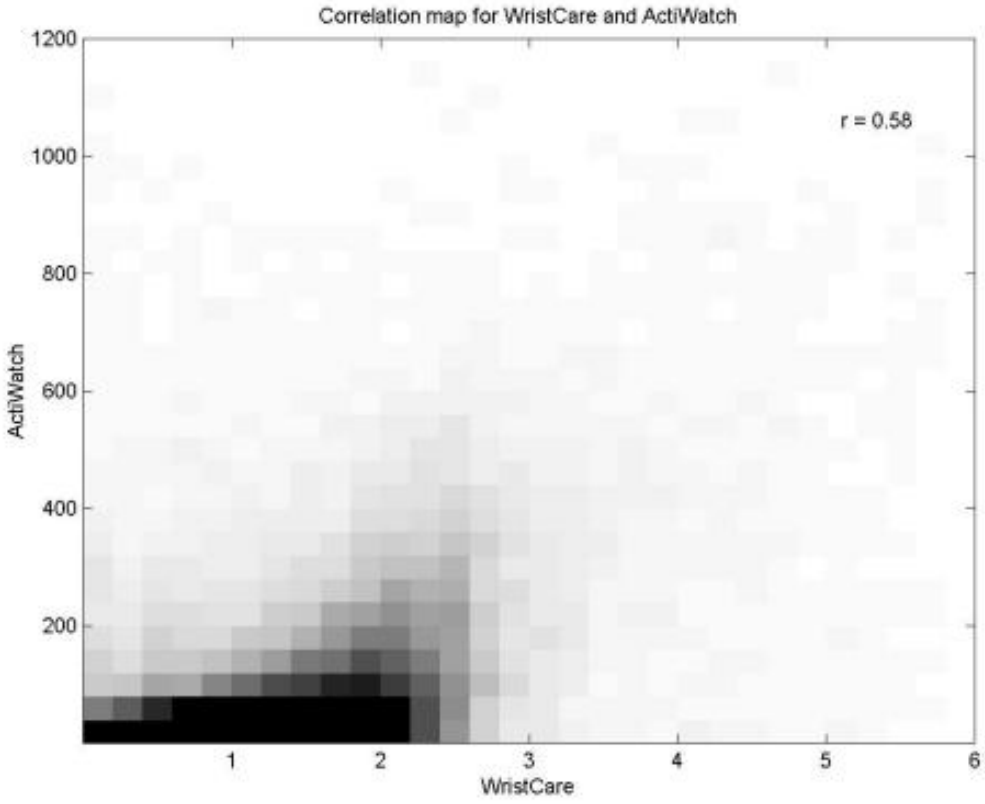
Other technical features of the Vivago®

- Features designed primarily for alarm usage are also useful for activity monitoring
  - "Off wrist" detection → monitoring of real usage (minimisation of artifacts in interpretation)
  - Online monitoring → no need to separately transfer data to computer
    - True long-term monitoring, unobstrusiveness
- Field trial in Savitaipale (2001), 83 elderly users
  - Utilisation rate ("on wrist") 94%
  - Number of passivity and deterioration alarms correlates to functional capacity
  - Out of 6 falls during the trial, 5 caused an alarm



IST Vivago® vs. actigraphy

- Vivago signal has been optimised for alarms, hence:
  - At low levels of activity Vivago is more sensitive (detects smaller movements)
  - At high levels of activity actigraphy has larger dynamics



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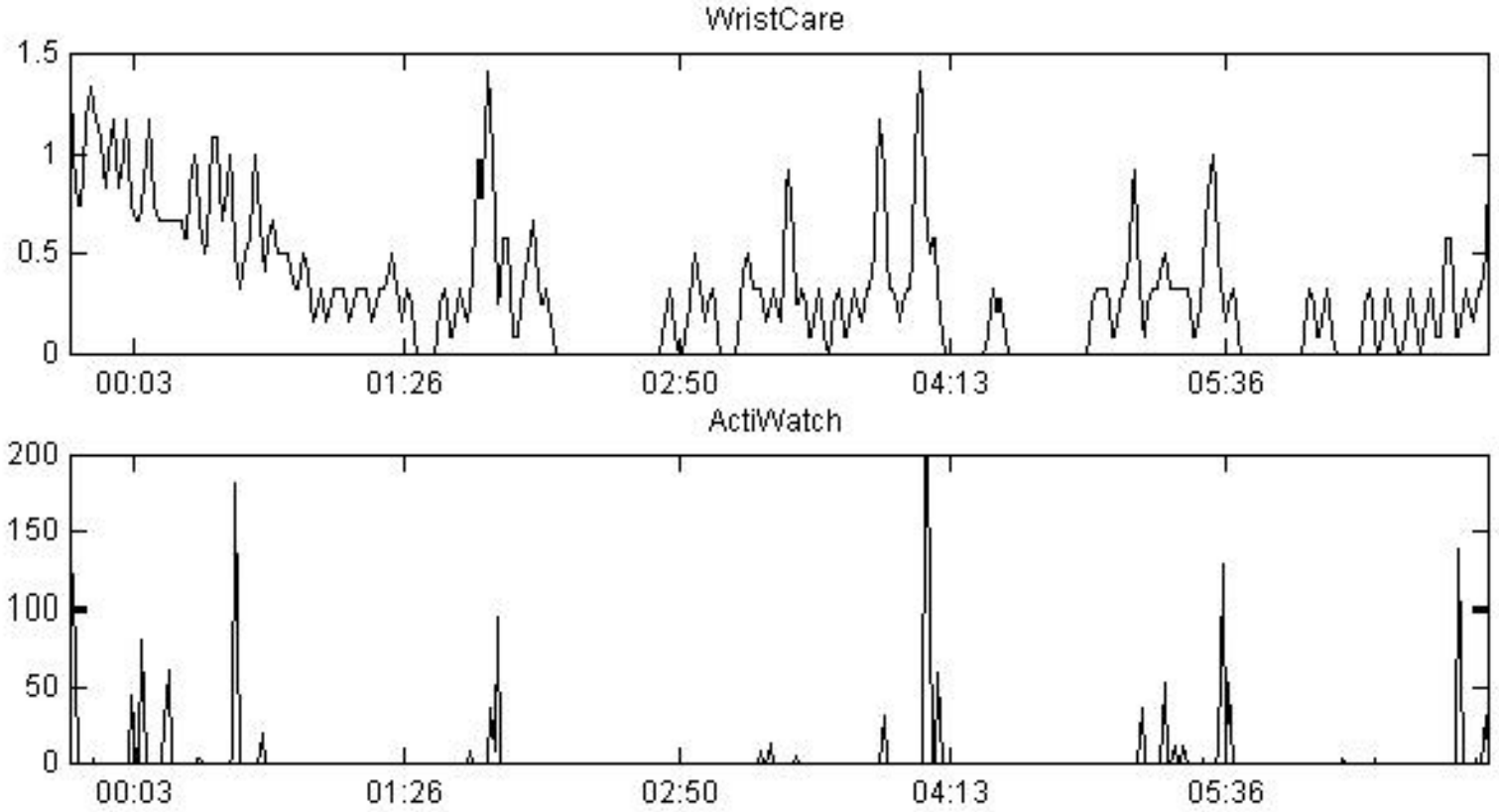


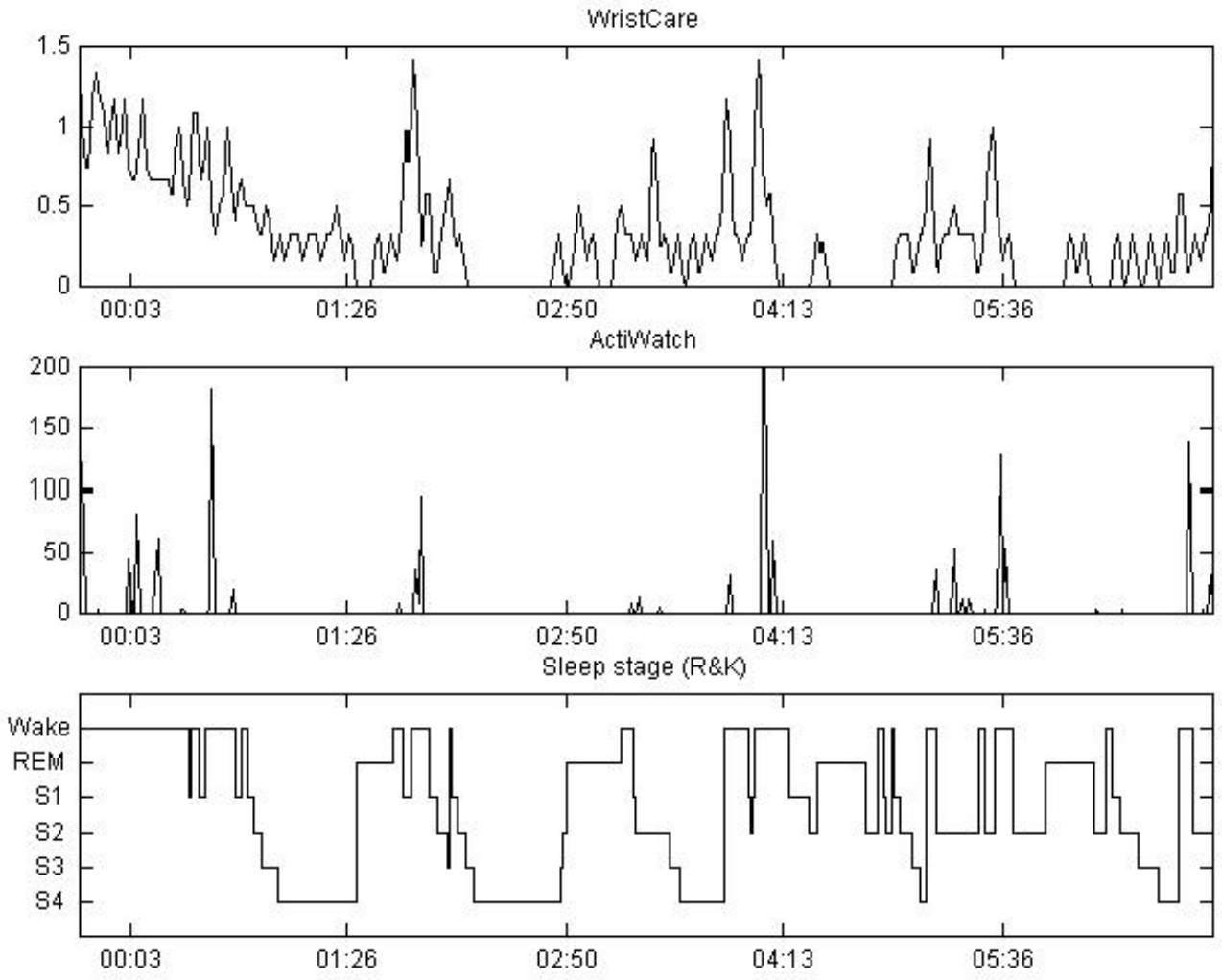
Validation study for Vivago in sleep/wake detection

- Goal: to define how well Vivago performs in sleep/wake detection as compared to standard actigraphyGolden standard
- Study design:
  - 28 subjects (age<65 N=13 normal; age>65 N=15)
  - 1 night in sleep laboratory (PSG, golden standard)
    - Haaga Neurological Research Center, Helsinki, Finland
  - 1 week of actigraphy (nap analysis)
  - Comparison in terms of
    - Night-time minute-by-minute agreement-% with PSG
    - Nap analysis (ref. diary)

Methods for sleep/wake detection

- Actigraphy by ActiWatch (Cambridge Neurotechnology); in large clinical use
- Standard sleep laboratory PSG scored by sleep specialist for reference; golden standard
- Sleep/wake scoring
  - Methods for automatic detection were optimised on the basis of agreement-%
  - Identical methods were applied both for actigraphy and Vivago
    - Minimisation of the effect of scoring algorithm
  - Sample bias was minimised by leave-one-out optimisation

Example of signals in sleep laboratory



Results: agreement with PSG

AGREEMENT (%)		
All subjects (N=28)	WristCare	Actigraphy
Thresholding	77/13	78/10
Logistic regression	78/12	81/11
Senior subjects (N=15)		
Thresholding	77/7	75/7
Logistic regression	77/7	78/9
Middle-aged subjects (N=13)		
Thresholding	84/11	85/10
Logistic regression	85/10	86/11

Results: nap analysis

- Agreement-% between Vivago and actigraphy was 87%
  - Naps <10min were ignored
- Vivago and actigraphy provided equal detection of naps in terms of duration and number of naps
- Naps reported in sleep diaries (N=13);
  - Actigraphy correctly detected 11 of them
  - Vivago correctly detected 12 of them

Conclusions

- The performance of the Vivago activity signal can be assumed to be well comparable to actigraphy in sleep/wake studies.
- The study suggests that the device may be used in long-term monitoring of sleep/wake patterns with similar performance to actigraphy.
- Advantages of Vivago: inexpensive, true long-term online monitoring, available in daily normal environment, "off wrist" detection
    - Screening, follow up, ...
- Cautions: validation study based on relatively small sample - longer and larger studies are needed to confirm the results and to extrapolate to other applications.