



**Telemetry in monkey neurophysiology – Remote monitoring of neuronal brain signals**


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TECHNISCHE UNIVERSITÄT DARMSTADT

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This R&D project is part of  
EUPRIM - Joint Research Activity 3

**Telemetry for distance monitoring and minimal invasive investigation in primate research**


Coordinator: Alexander Gail (DPZ)



Biomedical Primate Research Centre  
Rijswijk, NL



German Primate Center  
Göttingen, GE



Defence Science and Technology Laboratory  
Porton Down, GB

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**JRA3 – Objective**

- Miniaturized, minimal-invasive telemetry systems for primates in research
- Relevant fields of research
  - Behavioral & Cognitive Ethology, Neuroethology, Sociobiology
  - Biomedicine, Toxicology
  - Cognitive Neuroscience
  - Neuroprosthetics



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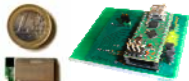
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## JRA3 - Telemetry subsystems

### System A

- remote intra-cortical neurophysiological recordings
- multi-channel neuronal activity (single units, field potentials)
- very high data rates, optional pre-processing
- one (or few) animal(s)
- short range (cage based)
- several hours



### System B

- remote physiological monitoring
- core temperature, heart-rate, actimetry
- low data rates, optional data-logging
- all animals in a defined area
- short or long range
- days, weeks, month...



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## Outline

- Why do we need invasive neurophysiology in monkeys?
- Neurophysiology in monkeys – Examples from Cognitive Neuroscience
- How could neurophysiology benefit from telemetry?
- Why don't we use telemetry as the standard technique?



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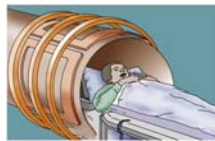
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Why do we need *invasive* neurophysiology in monkeys?

What about alternative, non-invasive, functional brain imaging methods, like ...

- fMRI
- EEG
- MEG
- PET etc.

... applicable in humans?



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### Understanding brain function – spatial scales

Structure	Size Order of magnitude	Number Order of magnitude	Methods
Brain	~10 cm	1	fMRI, PET, EEG, MEG
Lobe	1-10 cm	1-10	fMRI, PET, ECoG
Area	~1-10 mm	10-100	fMRI, ECoG, opt. imaging (surf.)
Layer	~100 $\mu$ m	1-10	microelectrode (FP-CSD)
Column	~100 $\mu$ m – 1 mm	specific for area and species	microelectrode (FP), opt. imaging
Neuron	~10 $\mu$ m	~100 billion ( $10^{11}$ )	microelectrode, fluoresc. imaging
Synapse	~1 $\mu$ m	>100 trillion ( $10^{14}$ )	patch-clamp

↑ Invasiveness ↓

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### Understanding brain function – behavioral time scales

Behavior	Duration/Frequency/Speed Order of magnitude
Auditory localization (inter-aural time differences)	~1 ms
saccadic eye movements	~10-100 ms, 1-10 per sec.
visual categorization	~10-100 ms presentation time
visually instructed motor response	Eye: ~200 ms Hand: ~500 ms
reading and speech comprehension	~100-500 words/minute
typing	~50 (up to 120) words/minute
drawing a gun 	The faster, the better.

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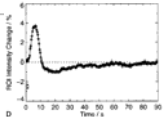
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### Understanding brain function – neuronal time scales

Event/Signal	Duration Order of magnitude	Methods
Spike, rate / synchro.	~1 ms ~10 ms	Microelectrode
Post-synaptic potential	~10 ms	microelectrode, fluorescence-imaging
Cortical/epidural/ scalp field potentials	~10-100 ms (5-100 Hz)	microelectrode, ECoG, EEG, MEG
Hemodynamic response	~10 s	fMRI-BOLD, PET

↑ Invasiveness ↓

➤ Information transfer in the brain via axonal spikes, synaptic transmission, and post-synaptic potentials



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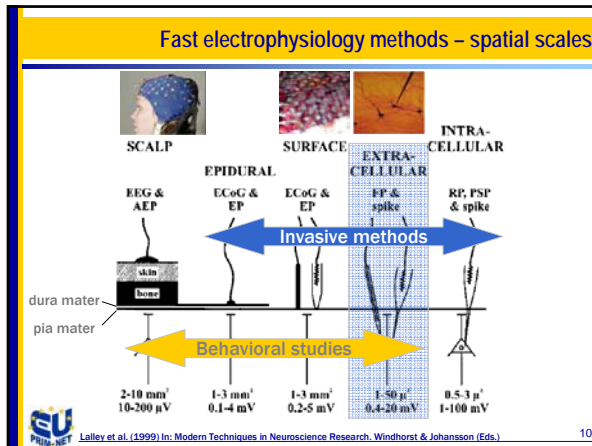
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- ### Invasive neurophysiology in monkeys
- For systemic cognitive neuroscience we need ...
    - subjects who solve cognitive tasks
      - awake, behaving subjects
      - performance compatible to human behavior
    - signals that are relevant for neural processing
      - neuronal spiking activity
      - field potentials
      - synaptic activity
    - high temporal precision of the recorded signal
    - precise localization of the recorded signal

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- ### Invasive neurophysiology in monkeys
- The sum of these requirements is only fulfilled in awake monkey electrophysiology based on intra-cortical microelectrode recordings
  - A combined methodology will help bridge the gap between human and animal research
  - To reduce the gap, new methodological developments can be helpful, e.g., like telemetric neurophysiological recordings in unrestrained animals

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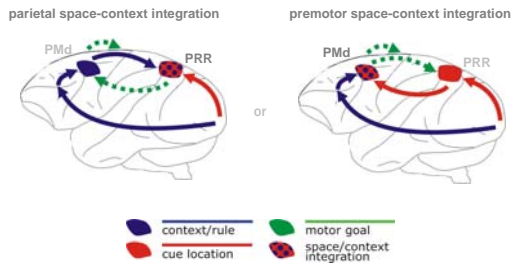
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## Motor-goal encoding in the frontoparietal sensorimotor loop



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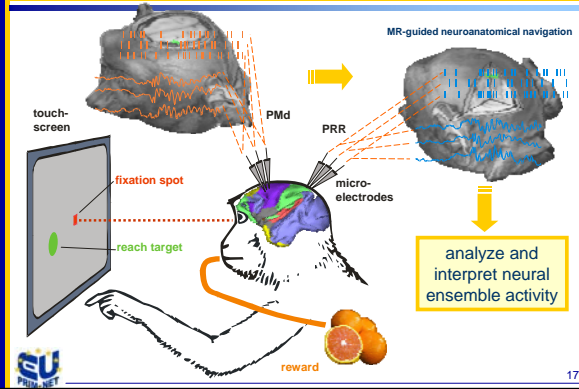
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## Intracortical recordings in behaving monkeys



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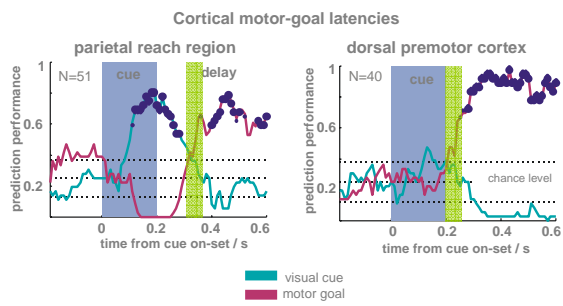
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## Motor-goal encoding in the frontoparietal sensorimotor loop



Gaïl & Andersen 2006 J Neurosci, Brozovic, Gaïl & Andersen 2007 J Neurosci, Gaïl et al. 2007 SFN 18

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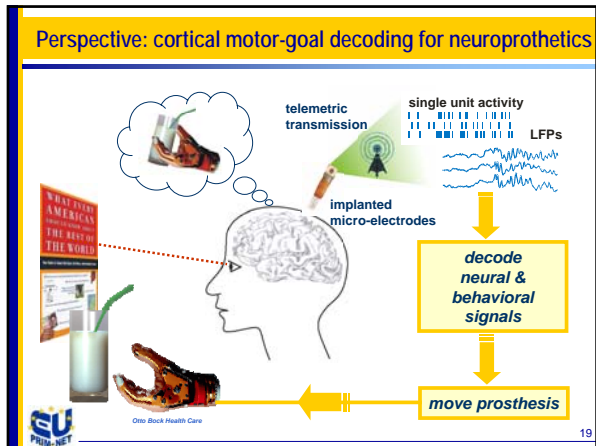
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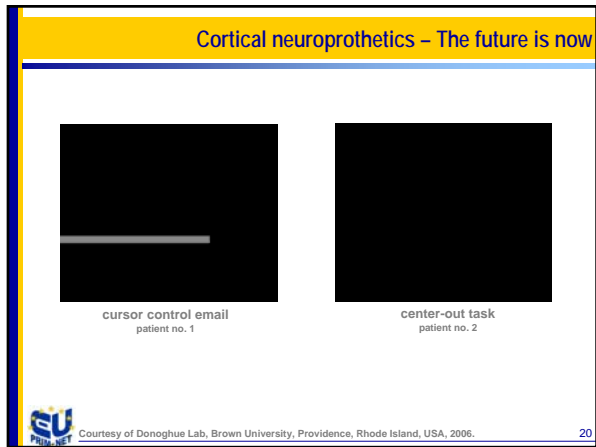
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How can neurophysiology benefit from telemetry?

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## Benefits of telemetry in primate neurophysiology

### ➤ Novel neurophysiological research questions addressable

- sensory & motor processing during unrestrained movements or even under natural conditions (Lei et al. 2004)
- neuronal basis of behavior occurring only during social interaction, like vocalization (Grohrock et al. 1997, Hage & Jürgens 2006, 2007)



### ➤ Novel medical applications feasible

- long-term monitoring of seizure activity (Bastlund et al. 2004, rats)
- brain-machine interfaces & neuroprosthetics



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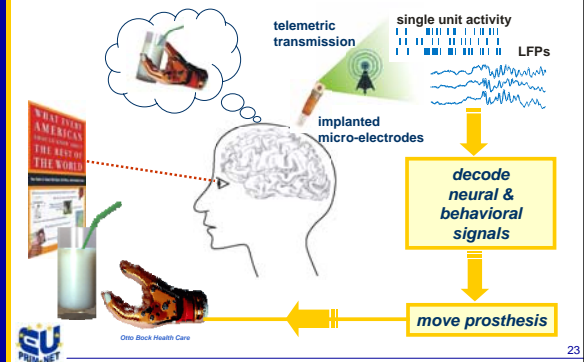
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## Perspective: cortical neuroprosthetics



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## Telemetry in neuroprosthetics

### ➤ Advantages of telemetric data transfer in neuroprosthetics

- sealed recording system
  - less infectious risk
- no wires on/below scalp
  - more comfort
  - aesthetically more appealing
- remote control of technical devices, other than prosthesis
  - wheel chair
  - computer, micro-wave, TV, etc.



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## Reduced invasiveness with telemetry

- Telemetric techniques are still invasive
  - the micro-probes need to be implanted
  - the transmitter/transceiver needs to be implanted
  - the implants need maintenance (batteries, etc.)
- But telemetric techniques are less invasive:
  - less frequent capturing
  - no movement restraining for data collection



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## Benefits of telemetry in neurophysiology research – 3Rs

- Contribution to the **3R-concept**:
  - **Refinement** and improvements in animal welfare
    - no repeated capturing
    - less risk by fewer invasive interventions or treatments
    - shorter experiments through continuous monitoring
  - **Reduction** of the number of animals needed for a given scientific project
    - less stress for individual animal → longer use ethical
    - improved data collection → less animals necessary
      - reduced stress, less confounds
      - long-term, around-the-clock sampling
  - **Replacement**
    - partial transition to experiments with unrestrained animals



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Why don't we use telemetry as a standard technique?



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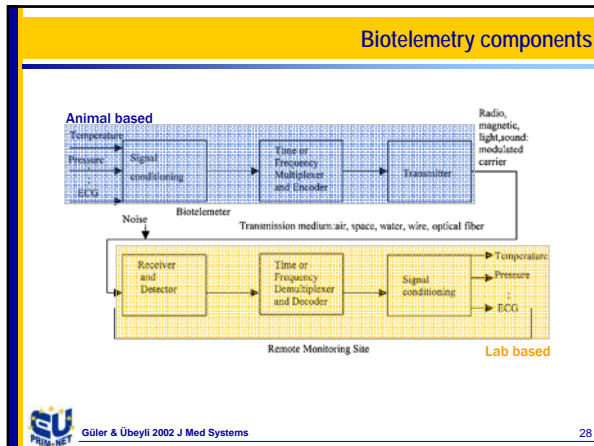
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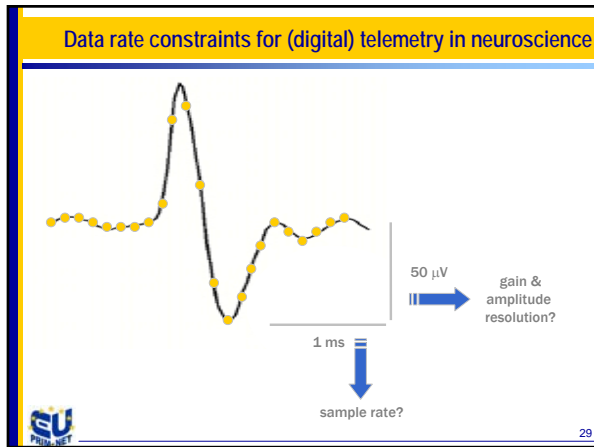
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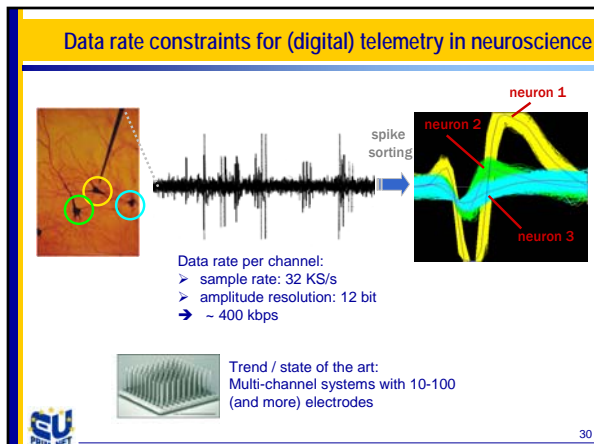
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## Technological constraints for telemetry in neuroscience

- sufficient data rate
  - ~400 kbps per channel
- bi-directionality
  - gain control
  - electrode positioning
- working range
  - 5-10 m for cage based recordings
- size and weight of transceiver
  - max. 5% body weight, less for head-mounted devices
- energy consumption
  - trade-off between running time (min. 1-10 hours) and size/weight
  - heat production



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## Digital wireless technologies

Non-standardized	≤ 1 Mbit/s (remote control)
ZigBee	≤ 250 kbit/s (sensor networks)
Bluetooth	≤ 3 Mbit/s (multimedia)
WLAN	≤ 54 Mbit/s (networks, internet)
WirelessUSB / UWB	≤ 110 Mbit/s („wireless cable“)



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## Telemetry in animal research

Thank you for your attention!



"A southern elephant seal (*Mirounga leonina*) retains its dignity, despite having the latest in multi-parameter recording sensors stuck to its head."  
(Source: [www.nature.com](http://www.nature.com))



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