

Biosignal-Adaptive Systems for Better Work & Life

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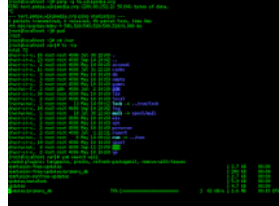
Keynote Lecture at CHIRA 2025
Marbella, October 20th 2025



Interaction technologies develop rapidly ...



Batch



Command Line



Graphical UI



Mobile UI



NL UI



Wearable UI



30 years

20 years

15 years

7 years

...

But: Interaction technologies still know little about the human body, its activities and psychological states. This can trigger negative outcomes at work & life!

Some Examples of Negative Outcomes and a Potential Solution



Limited attention at desktop work



Reduced flow due to interruptions



High load and fatigue in online meetings



Back-firing due to incorrect state detection and interventions

**Biosignal-
adaptive systems**
that quantify the
**human body and
its activities** with
biosignals for
recognizing
**psychological
states** to deliver
**personalized
interactions**

The Human Body and its Activities

The human body is a complex, interconnected system with the **nervous system** acting as its control center. It receives information from senses, processes it, and generates responses to both internal and external stimuli.

Human activities can be roughly assigned to the different building blocks of the nervous system along **three major dimensions**:



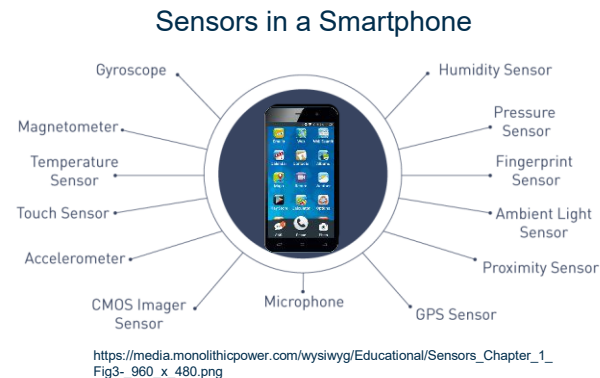
Source: <https://dbuweb.dbu.edu/dbu/psyc1301/softchalk/s2lecture1/nervoussystem.jpg>

Central Nervous System - Neurological Activities	Peripheral Nervous System	
	Autonomic Nervous System - Physiological Activities	Somatic Nervous System - Physical Activities
Sensory processing, Motor control, Cognitive functions, etc.	Heart Beat, Pupil Dilation, Sweating, Digestion, etc.	Writing, Sitting, Smile, Picking up objects, etc.

Quantifying Human Activities with Sensors and Biosignals

Signals convey **information about a phenomenon** varying over time or space. **Sensors** are devices that convert a physical quantity into a measurable signal.

⇒ Sensors are crucial for **bridging the physical and digital world!** They enable advancing human-computer interaction.



Biosignals quantify human activities using a broad spectrum of rapidly evolving sensors integrated into (mainstream) devices, e.g.:



Laptops and MR Devices with Eye-tracking

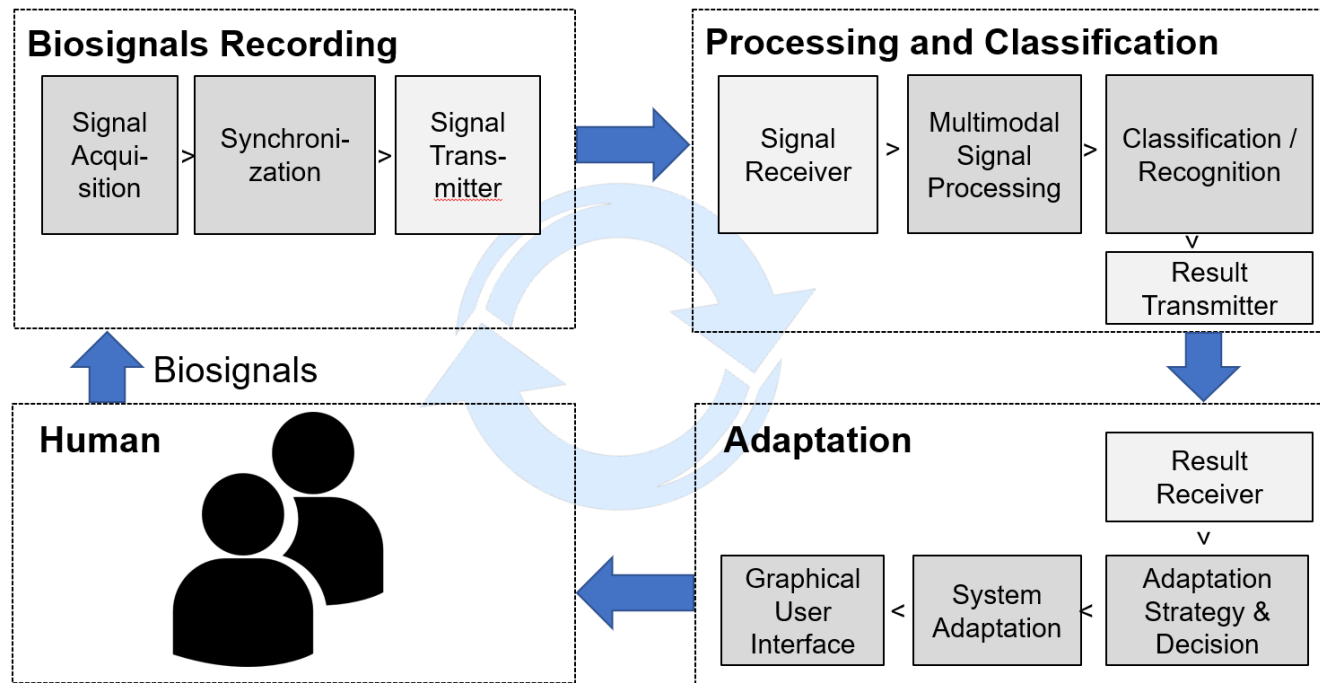


Smartwatches & Earables with Photoplethysmogram (PPG) and chest straps with electrocardiography (ECG)



Headbands with Functional Near-Infrared Spectroscopy (fNIRS) and Electroencephalography (EEG)

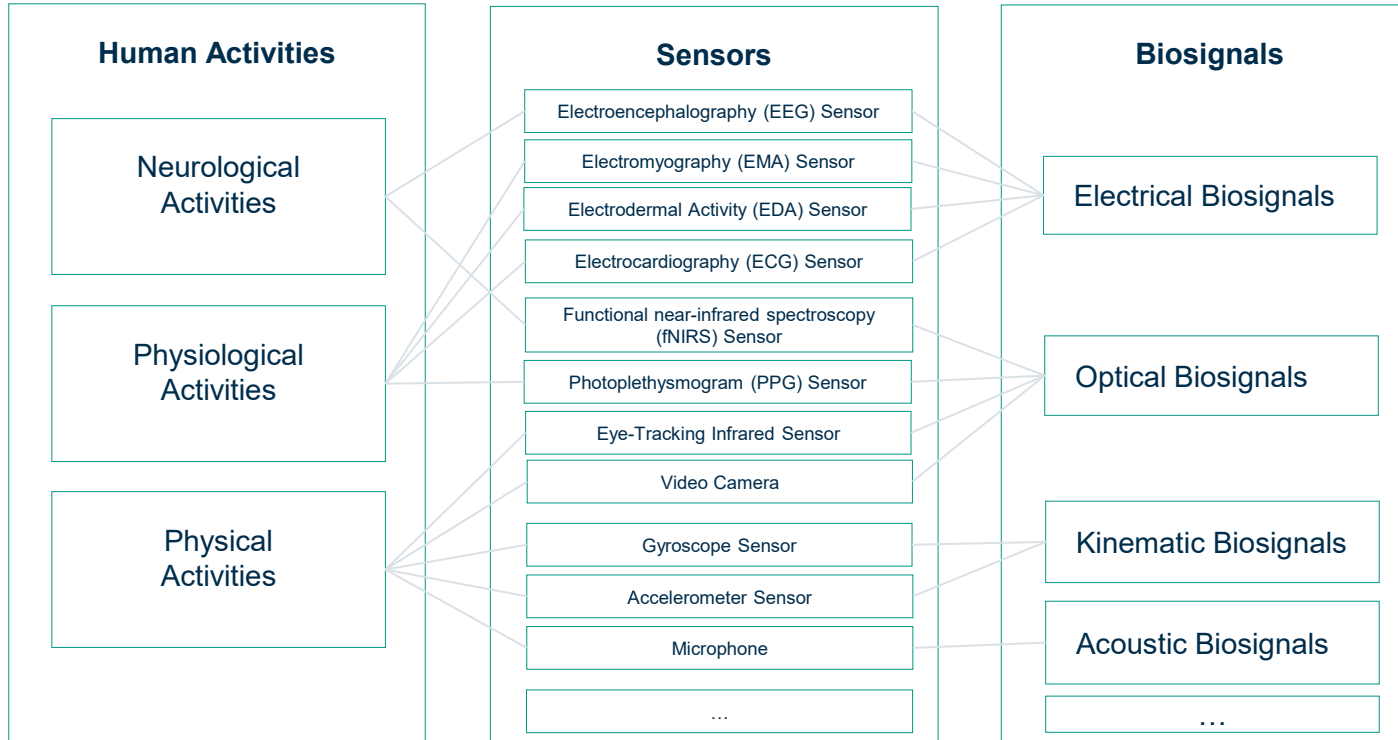
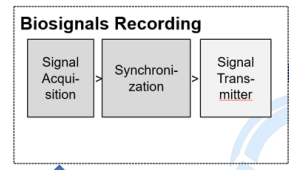
Biosignal-Adaptive Systems: A Continuous Loop Approach



- **Biosignal-Adaptive information technology** records, processes, and classifies biosignals and finally delivers personalized interactions
- **Biosignal-adaptive systems** are **socio-technical systems**, humans and information technology co-adapt **continuously**.

Schultz, T. & Maedche, A. (2023) Biosignals meet Adaptive Systems. SN Appl. Sci. 5, 234. <https://doi.org/10.1007/s42452-023-05412-w>

Capturing Human Activities with Sensors in Biosignals



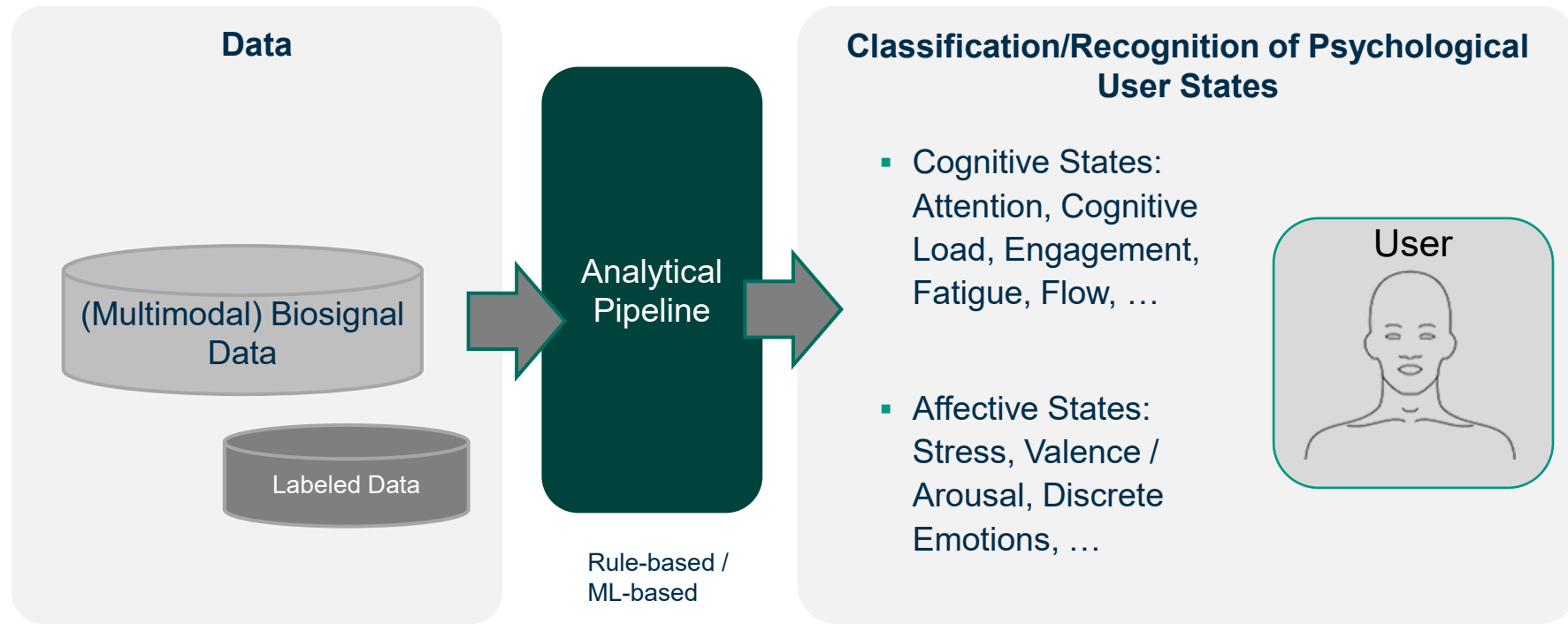
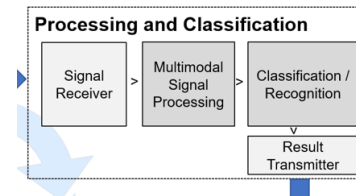
One can further distinguish **primary (direct)** biosignals and **derived (indirect)** biosignals.

Example: Physiological activity of the heart captured by ECG sensor:

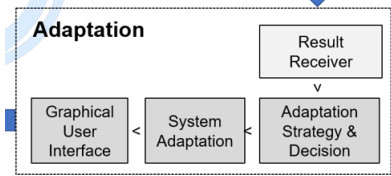
- Primary: Raw ECG Signal
- Derived: Heart rate (HR); Heart Rate Variability (HRV)

And: **Multimodal** approaches combine several biosignal!

Classifying and Recognizing Psychological User States using (Multimodal) Biosignals



Delivering the Adaptation: The “Personalization Process”



Personalization is defined as a process that changes the content, interface, channel, functionality [...] of a system to increase its personal relevance to an individual [...]. Fan & Poole (2006)

Adaptation Elements (What?):

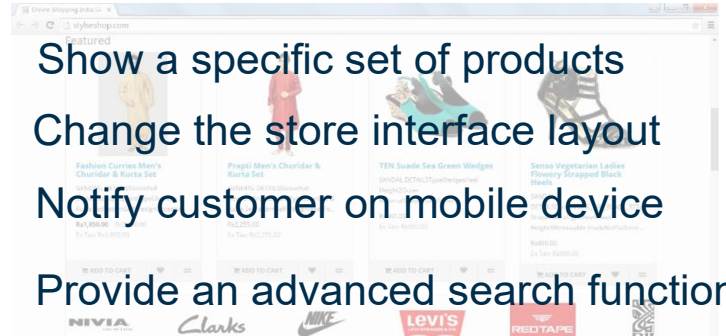
Content (the information itself)

Interface (how is the information presented)

Channel (how is the information delivered)

Functionality (what users can do with the system)

Example: E-Commerce Store

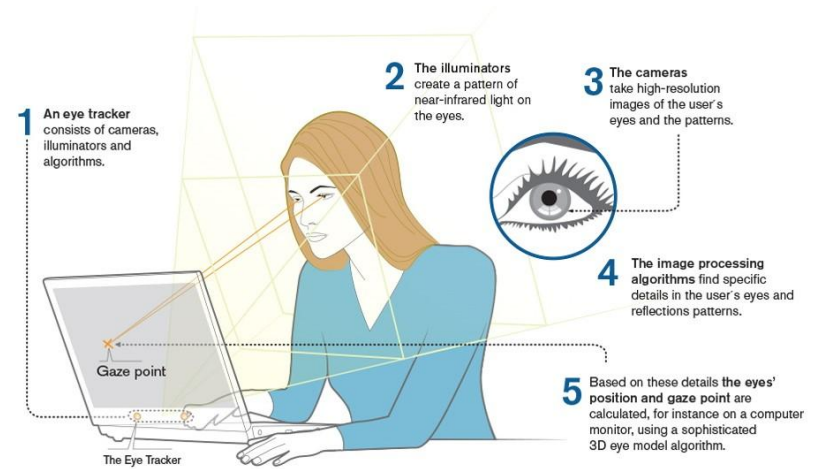


In addition to what question (adaptation elements), one needs to answer the how (user-/system-/mixed-initiative trigger) and the when question (timing)!

Biosignal-Adaptive Systems using Eye-Tracking Sensor Technology

Eye-Tracking Technology: Measuring the Activities of the Human Eye

- The eye tracker sends out near infrared light. The light is reflected in the eyes.
- Those reflections are picked up by the eye tracker's cameras. Through filtering and calculations, the eye tracker can capture where one is looking.



ref: [Tobii Website 1 / 2](#)

- What can we do with this?
 - The eye-mind hypothesis (Just & Carpenter, 1980) argues that there is a link between eye-movements and cognitive processes
 - By quantifying eye movements we can determine different psychological states

Attentive Information Dashboards

Challenge: Human attention is a scarce commodity in today's information-rich world. However, attention is critical when performing data exploration tasks.

Approach:

- Capture gaze behavior of users when performing data exploration tasks on information dashboards.
- Provide individualized attention feedback to users based on the gaze behavior

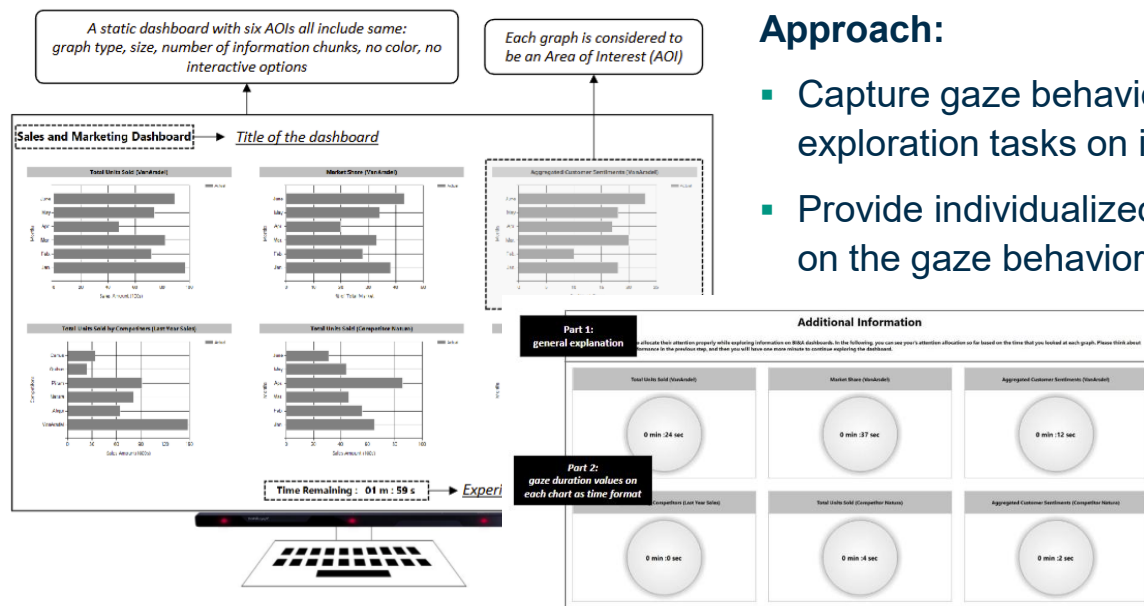


Figure 7. Instantiation of Design Principle 2: Individualized Visual Attention Feedback

- **Key Results** from Controlled Experimental Lab Study (n= 92) shows positive effects on users' attentional resource allocation, attention shiftrate, and attentional resource management.

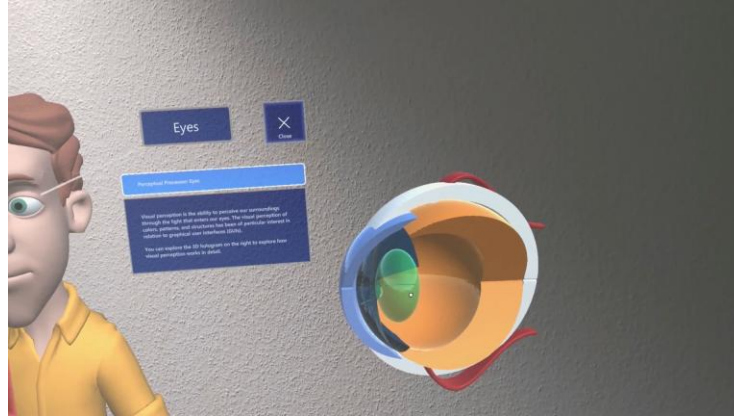
Toreini, P. et al. (2022). [Designing Attentive Information Dashboards](#). Journal of the Association for Information Systems, 23 (2), 521–552. [doi:10.17705/1jais.00732](#)

AF-Mix: A Gaze-Aware Mixed Reality Learning System with Attention Feedback

Challenge: Sophisticated visualizations in MR learning environments may result in potential visual overload, posing a challenge for users in efficiently allocating their attention

AF-Mix

The AF-Mix System provides an immersive self-directed learning experience for the Human Information Processing Model.



- Approach: Capture gaze in mixed reality learning session using eye-tracker in Hololens.



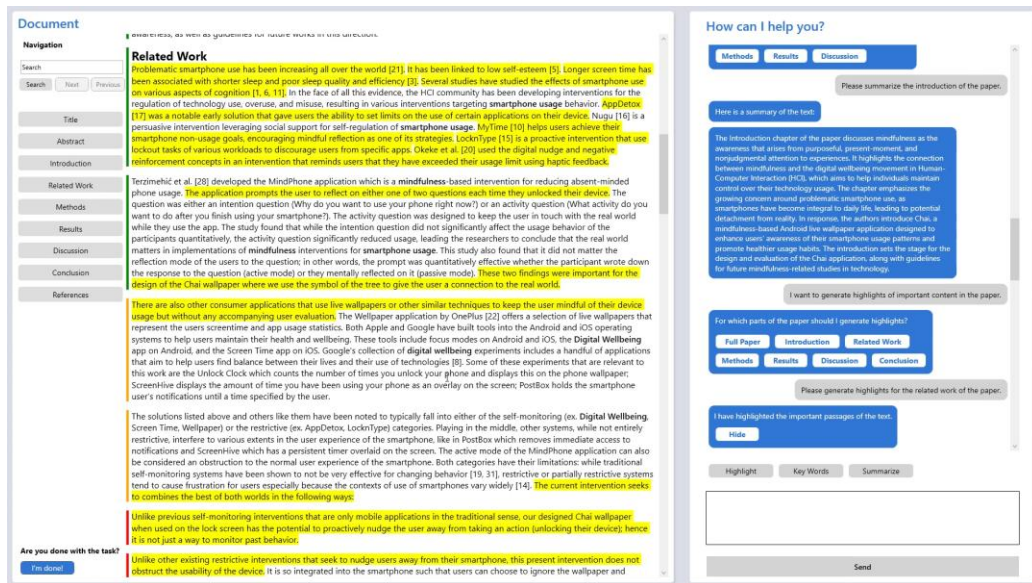
- Provide attention feedback based on attention allocated to learning content

=> Evaluation study (n=22) shows that providing attention feedback supports students in attention management and self-reflection.

Liu, S. et al. (2025). AF-Mix: A gaze-aware learning system with attention feedback in mixed reality, International Journal of Human-Computer Studies, Volume 198, 2025, 103467, <https://doi.org/10.1016/j.ijhcs.2025.103467>.

GIRA: A Gaze-Aware LLM-based Reading Assistant

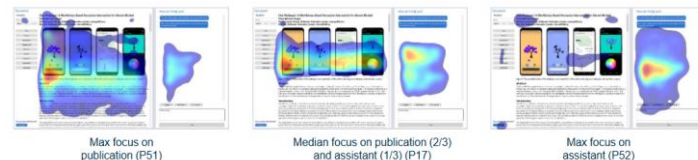
Challenge: Using Large Language Models (LLMs) for document reading and summarization is prone for overreliance and lower comprehension



Approach:

- Leverage eye-tracking to capture gaze activity.
- Provide attention feedback and feed gaze activity into large language model to generate comprehension questions for unread paragraphs.

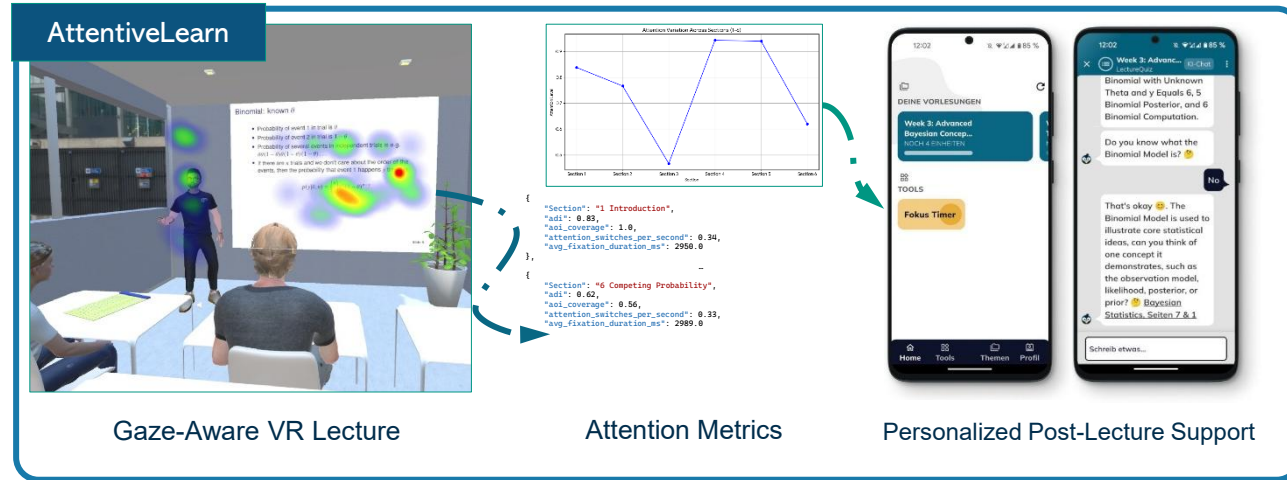
Results from Lab Study (n=44):



=> Various strategies followed by participants; higher focus on document leads to higher comprehension, engagement with assistant reduces workload

AttentiveLearn: A Multi-Device Gaze-Aware Learning System combining a VR Classroom & LLM-powered Mobile Assistant

Challenge: Provide personalized post-lecture support for individuals based on their visual attention allocation in the VR classroom.



- Approach: Capture gaze in virtual reality classroom using eye-tracker Meta Quest Pro



- Compute attention metrics and feed them into an LLM to provide personalized post-lecture support using a mobile learning app.

Results: 4 week field study (n=36) shows higher perceived usefulness and engagement as well as improved intermediate learning outcomes with personalized mobile app. However, no significant differences found for final exam scores.

Liu, S. et al.. (2025). [GazeClass: Towards Gaze-Adaptive Cross-Device Learning Support for Virtual Classrooms](#). CHI EA '25: Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems. Ed.: N. Yamashita, Article No.: 299, Association for Computing Machinery (ACM). [doi:10.1145/3706599.3720232](#)

Cognitive Load & Fatigue in Remote Meetings: The Need for an Adaptive Self-view

Experimental lab study using eye-tracking with 57 participants to understand the impact of the self-view feature on cognitive load as antecedent of fatigue. Seitz et al. (2024)



Identified different groups of self-view users:

1. Benefitting Users,
2. Cognitively Challenged Users,
3. Control Losing Users

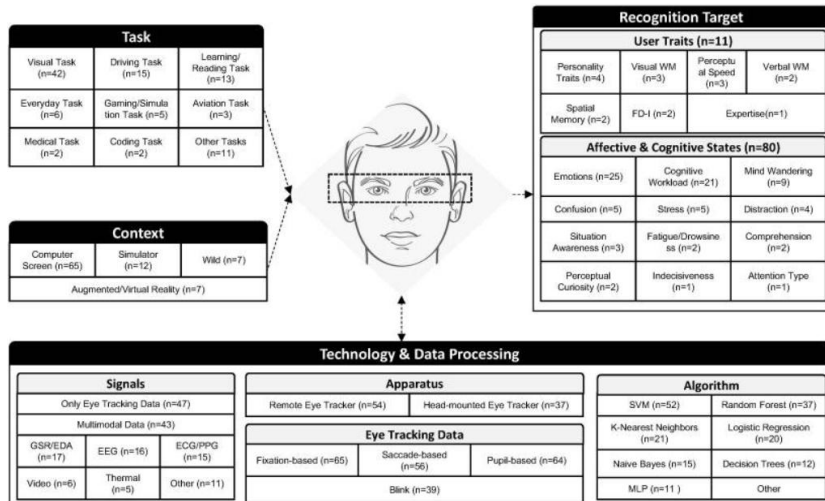


=> Proposed Solution: Adapt self-view based on user group to decrease cognitive load for cognitively challenged users and to potentially avoid meeting fatigue in a long term!

Seitz, J., et al. (2024) "Mirror, mirror in the call": Exploring the Ambivalent Nature of the Self-view in Video Meeting Systems with Self-Reported & Eye-Tracking Data. Proc. ACM Hum.-Comput. Interact. 8, CSCW2, Article 392 <https://doi.org/10.1145/368693>

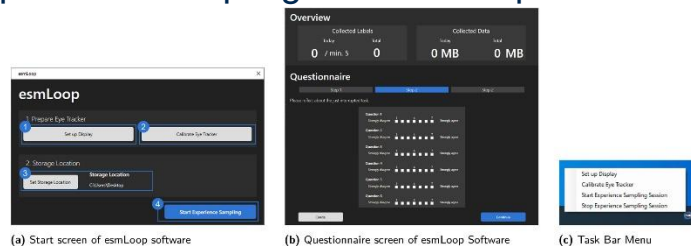
Psychological State Recognition with Eye-Tracking Data – State-of-the-Art Review and Experience Sampling Field Study

Growing number of publications, overall 90 publications identified, analyzed and classified:



Langner et al. (2025)

Field Study (n=11) collecting overall cognitive load and flow labels and eye-tracking data during working on thesis projects with our experience sampling tool esmLoop:



Langner et al. (2024)

Result: Eye movements are very individual and task-specific. It is challenging to come up with a generalizable classifier.

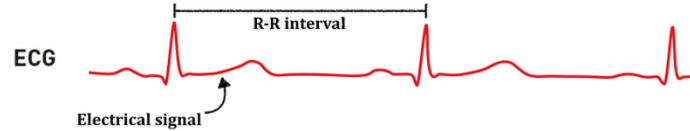
Langner, M. et al. (2025). Eye-Based Recognition of User Traits and States-A Systematic State-of-the-Art Review. J Eye Mov Res. 2025 Apr 1;18(2):8. doi: 10.3390/jemr18020008

Langner, M. et al. (2024). "Cognitive state detection with eye tracking in the field: an experience sampling study and its lessons learned" *i-com*, vol. 23, no. 1, 2024, pp. 109-129. <https://doi.org/10.1515/icom-2023-0035>

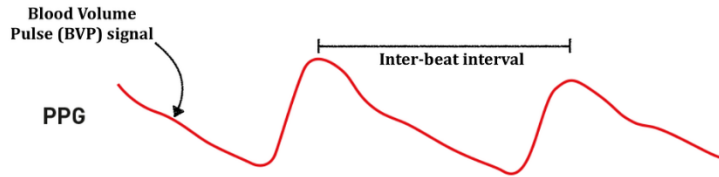
Biosignal-Adaptive Systems using ECG/PPG Sensor Technology

ECG/PPG Sensor Technology: Measuring the Activities of the Human Heart

Electrocardiogram (ECG) Sensor
(=> electrical biosignal)



Photoplethysmogram (PPG) Sensor
(=> optical biosignal)



<https://medium.com/elektra-labs/measuring-heart-rate-at-home-using-connected-sensors-64ba47f4abf>



What can we do with this (raw) data?

- The cardiovascular system is tightly linked to the autonomic nervous system (ANS) with the sympathetic branch (fight-or-flight) and the parasympathetic branch (rest-and-digest) — which regulates many psychological states such as stress, emotions, etc.
- By computing heart rate variability (HRV) we can derive markers for specific psychological states, e.g. low HRV indicates stress and negative emotions.

Flow: Survey-based vs. ECG-Biosignal based Measurement

Challenge: Recognize flow, “the holistic sensation that people feel when they act with total involvement” (Csikszentmihalyi, 1975), without interrupting humans!

Survey-based Measurement

36 items on a 7-point Likert scale provided by Jackson & Marsh (1996)

9 items on a 7-point Likert scale provided by Moneta (2012)

- My attention was focused entirely on what I was doing

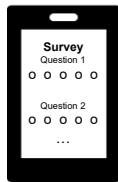
Strongly Disagree Neither Agree nor Disagree Strongly Agree

○ ○ ○ ○ ○ ○

- I was completely focused on the task at hand

Strongly Disagree Neither Agree nor Disagree Strongly Agree

○ ○ ○ ○ ○ ○



ECG-Biosignal based Measurement

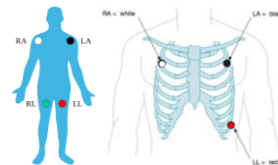
Heart Rate (HR)

LF/HF ratio

Heart Rate Variability (HRV)

Low-Frequency HRV (LF-HRV)

High-Frequency HRV (HF-HRV)



Polar H10 chestbelt

https://www.polar.com/de/produkte/fitness/fitnessherzfrequenzsensor_h10



ECG recording sites²

[1] https://www.kd2lab.kit.edu/img/article_equipment_2.jpg; [2] <https://www.cablesandsensors.com/pages/12-lead-ecg-placement-guide-with-illustrations>; https://en.wikipedia.org/wiki/Electrocardiography#/media/File:Limb_leads.svg; <https://lifeinthefastlane.com/ecg-library/basics/lead-positioning/>

=> Flow states can be classified based using ECG-biosignals by leveraging heart rate variability features (HRV) and supervised machine learning (Rissler et al. 2023)

Rissler, R., et al. (2023). To Be or Not to Be in Flow at Work: Physiological Classification of Flow Using Machine Learning. IEEE Trans. Affect. Comput. 14, 1 (Jan.-March 2023), 463–474. <https://doi.org/10.1109/TAFFC.2020.3045269>

Towards Flow-Adaptive Notification Management ...

Digital tools such as   slack    increase our ability to communicate at the workplace, but in parallel trigger interruptions. **Number of IT-mediated interruptions**, esp. through notifications, **growing massively** over last 20 years (EWCS 2015, p. 57)

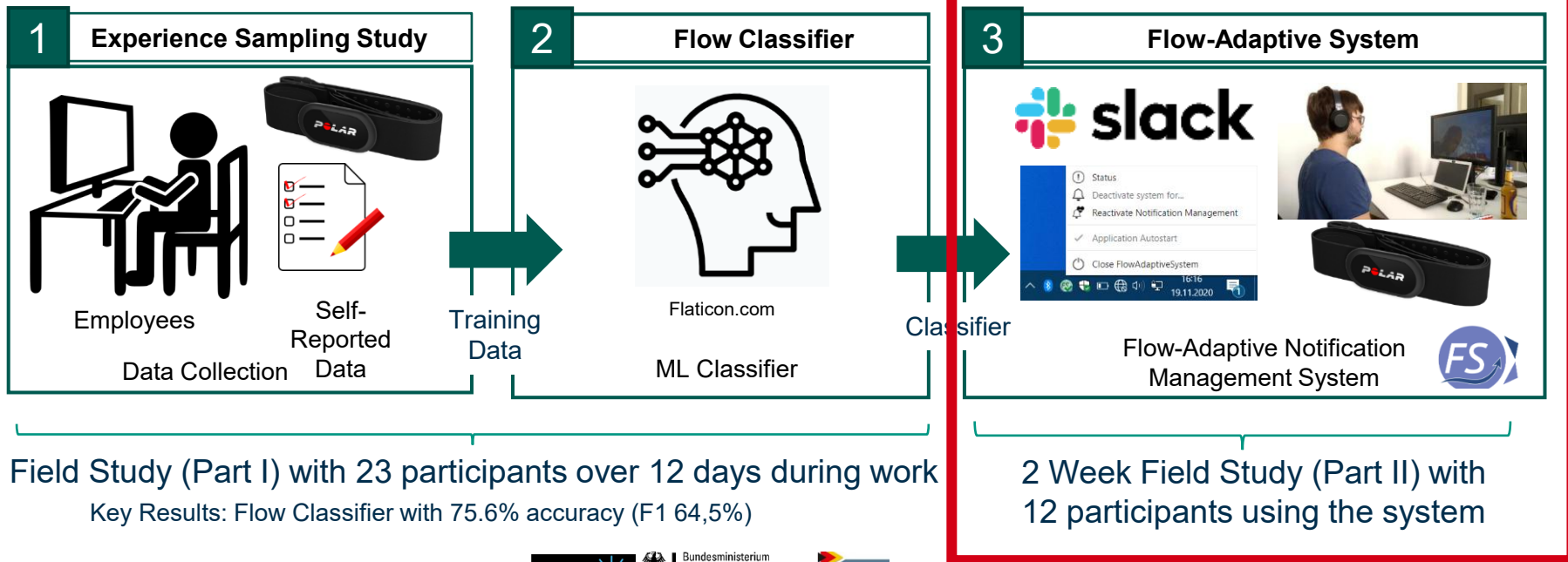


[https://www.lifewire.com/thmb/U5p-DamshnXueP7TJa8o-RdmpKU=/1920x1080/filters:fill\(auto,1\)/how-to-fix-whatsapp-notifications-not-working-1a0ba67239aa4198b15ae14f662d655c.jpg](https://www.lifewire.com/thmb/U5p-DamshnXueP7TJa8o-RdmpKU=/1920x1080/filters:fill(auto,1)/how-to-fix-whatsapp-notifications-not-working-1a0ba67239aa4198b15ae14f662d655c.jpg)

IT-mediated interruptions are known to have **negative impact** on users, in **particular flow** (Rissler et. al, 2017)

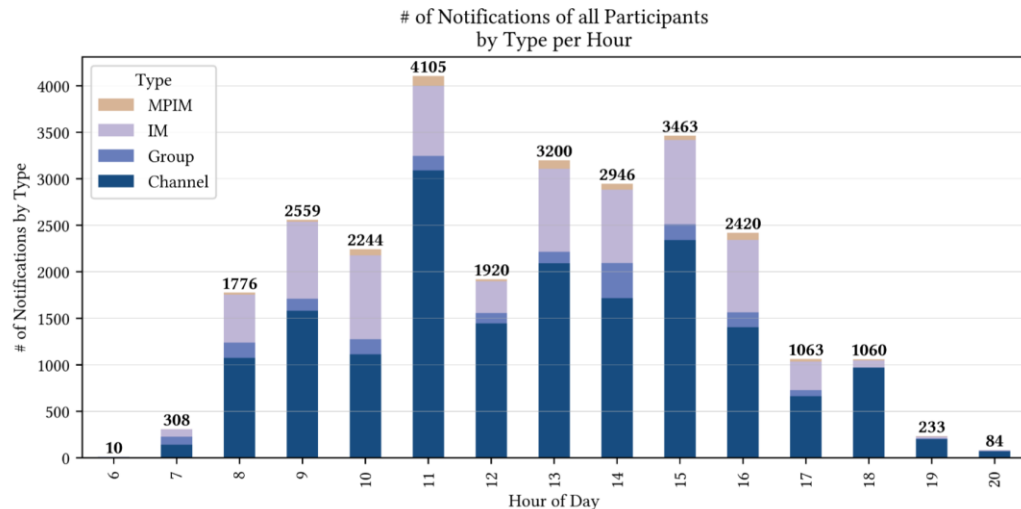
Question: Can we leverage ECG-biosignals to design a flow-adaptive notification management system? How do user respond to it?

Flow-Adaptive Notification Management: Two Field Studies



Selected Descriptive Results from 2-Week Field Study

The 12 participants were confronted with an impressive amount of notifications in Slack during the two weeks along the entire working day:



In total, **27,391 notifications** were recorded using the Slack Event API:

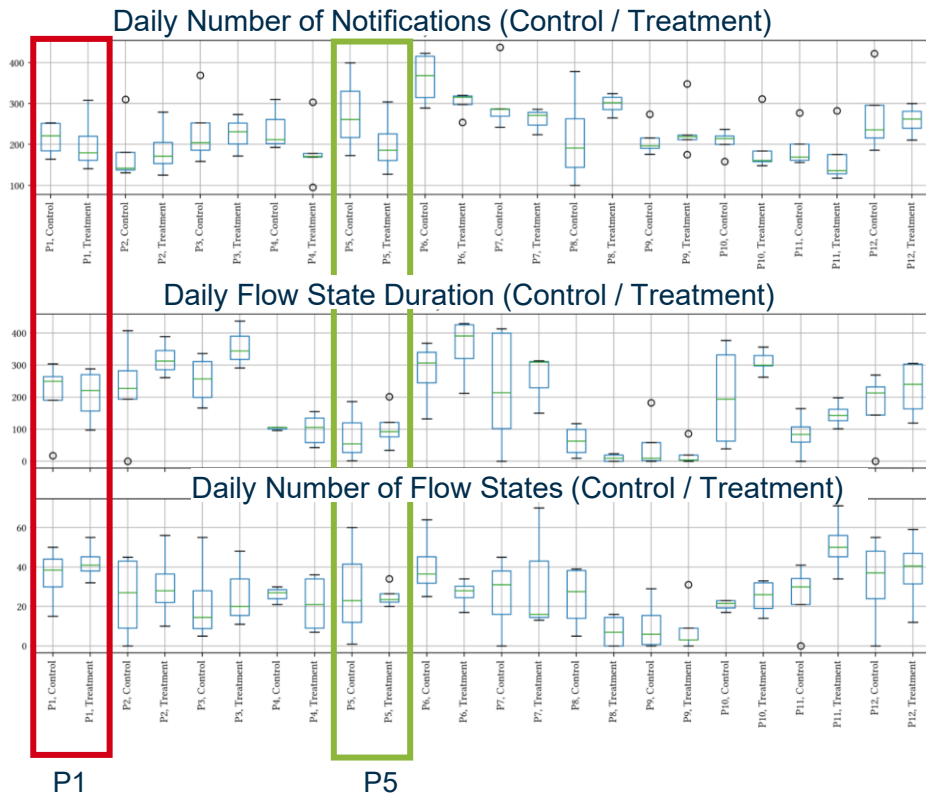
- 65% of notifications originate from messages in channels
- 26% of notifications can from instant messaging
- Group and Multiparty Instant Messages (MPIM) notifications rank third and fourth with 6% and 2%, respectively.

Selected Quantitative Results from 2-Week Field Study: Flow State Duration & #Notifications

The system disabled 38% of all incoming notifications (13.313) and increased participants' average flow state duration by 16%.

But: Large individual differences among participants:

Participant	Department
1	Operations Lead
2	Customer Support
3	Product Management
4	Software Development
5	Software Development
6	Operations Lead
7	Customer Support
8	Product Management
9	Customer Support
10	Customer Support
11	Software Development
12	Customer Support



Selected Qualitative Results from 2-Week Field Study

Participant-related Themes

- Varying affinity toward flow
- Varying ability to self-optimize
- Concerns about unlearning self-management
- Tendencies towards FoMO



Adaptive System-related Themes

- Flow recognition and adaptation accuracy perceived as high
- System usability (calibration, chestbelt, etc.) not well received
- Minimal privacy concerns
- Perceived sense of control high

Future Requirements:

- Provide opportunity for ex-post data analysis, e.g. via flow dashboards
- Integrate flow-adaptive system more deeply into workplace (e.g. calendar, email, etc.)
- Provide more personalization features

Towards Emotion-Adaptive Smartwatches ...

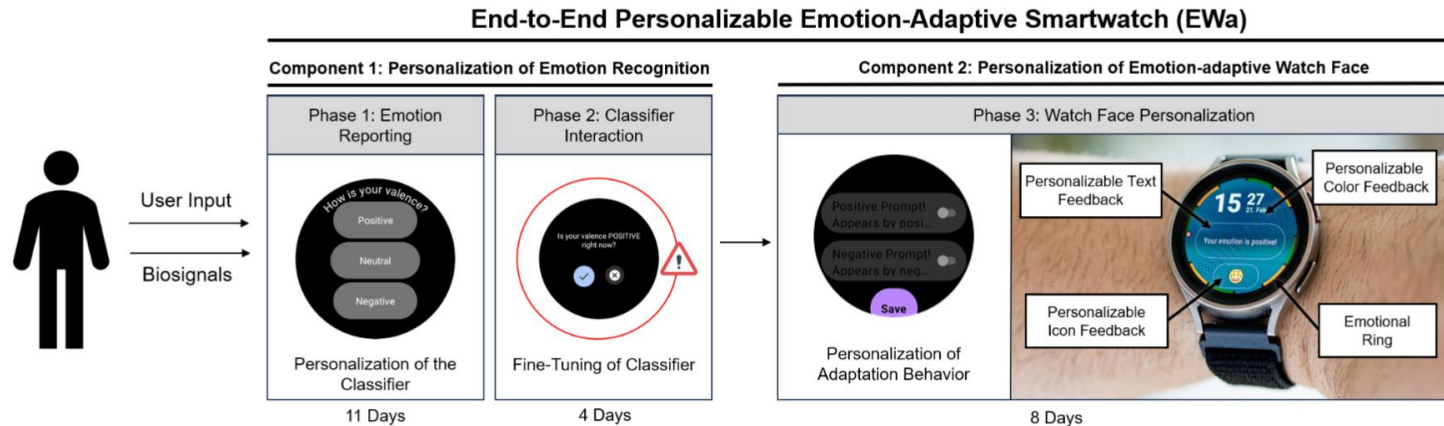
- Emotions are an integral part of daily life: They shape how we interact with others, and how we make decisions.
- Emotion-adaptive Smartwatches can support perceiving, understanding, and managing emotic
- Need for open & independent research:
 - How to build good emotion recognition models?
 - How to design effective digital microinterventions?



<https://www.slashgear.com/1703966/apple-watch-mood-tracker-how-use-feature/>

EWA: A Personalizable Emotion-Adaptive Smartwatch

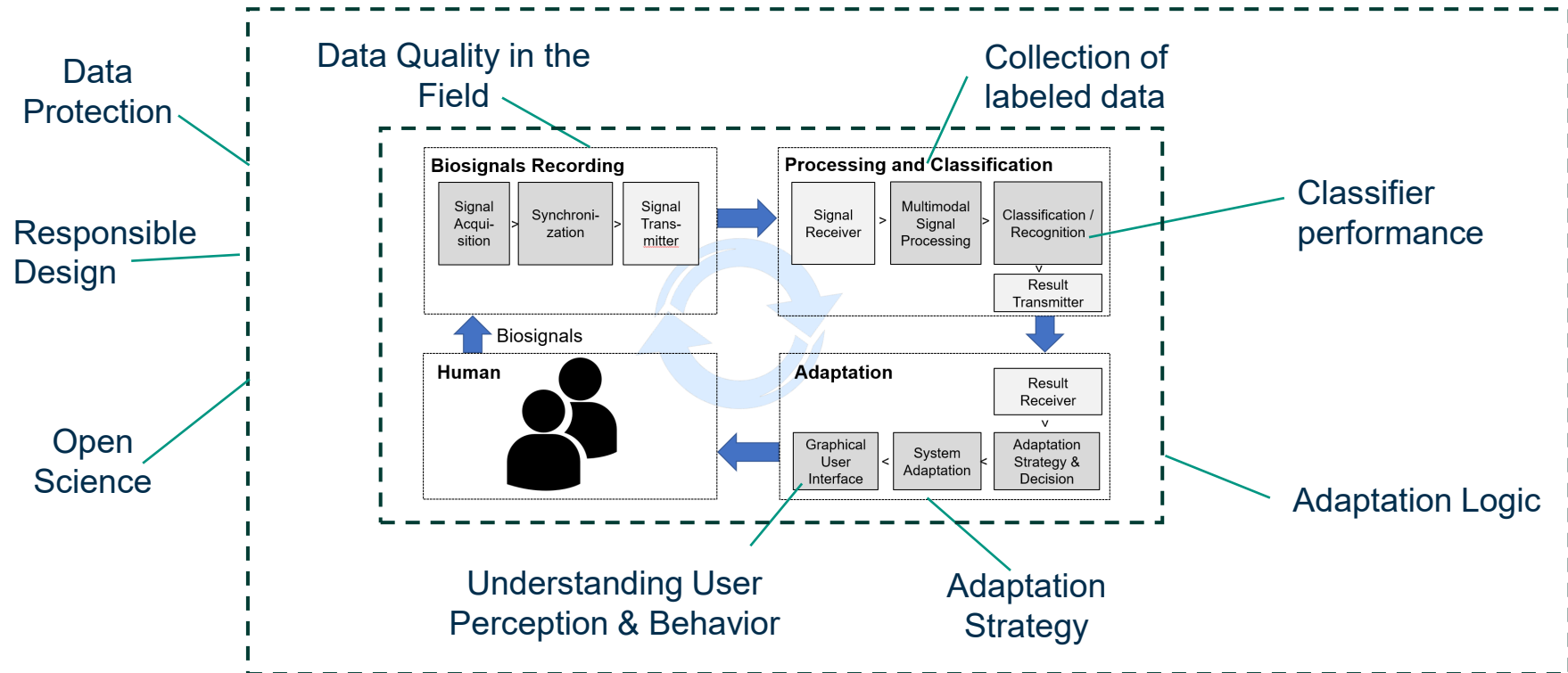
- Emotions are context-dependent and vary significantly across individuals, posing a challenge for the design of emotion-adaptive smartwatches.
- Two Step Approach: (1) a personalized emotion recognition capability and (2) a personalizable emotion-adaptive watch face.



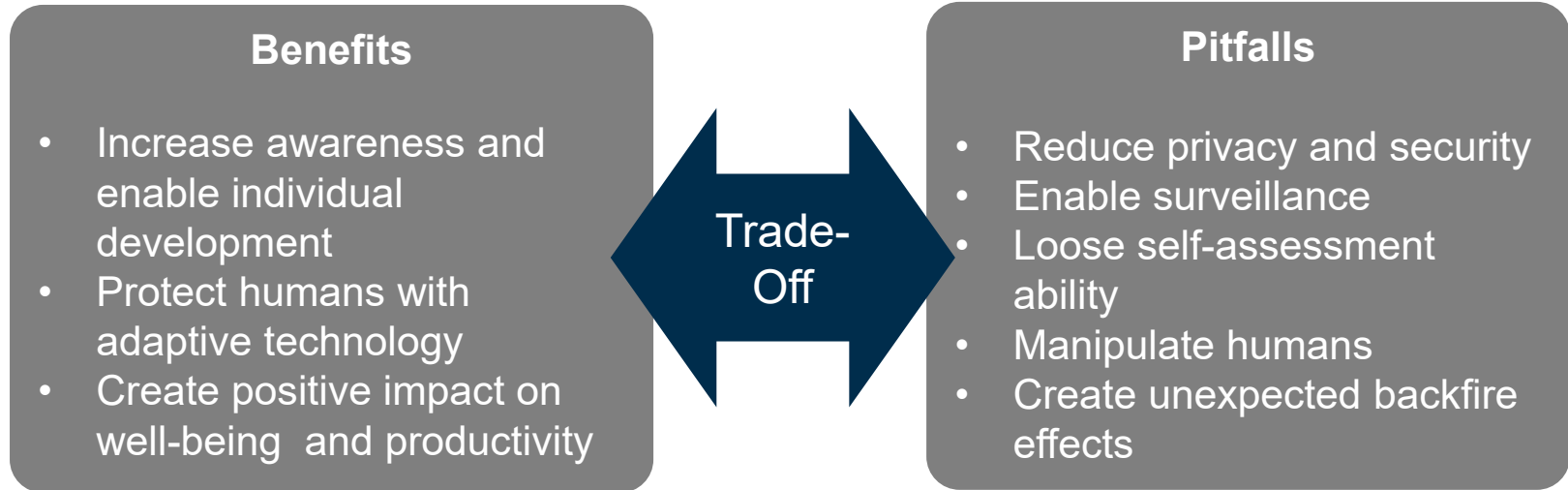
=> Results from an exploratory 3-week field study (n=11): Users positively evaluate being involved in emotion recognition and the personalization of the watchface.

Outlook & Summary

Researching and Engineering Biosignal-Adaptive Systems: Some more challenges ...

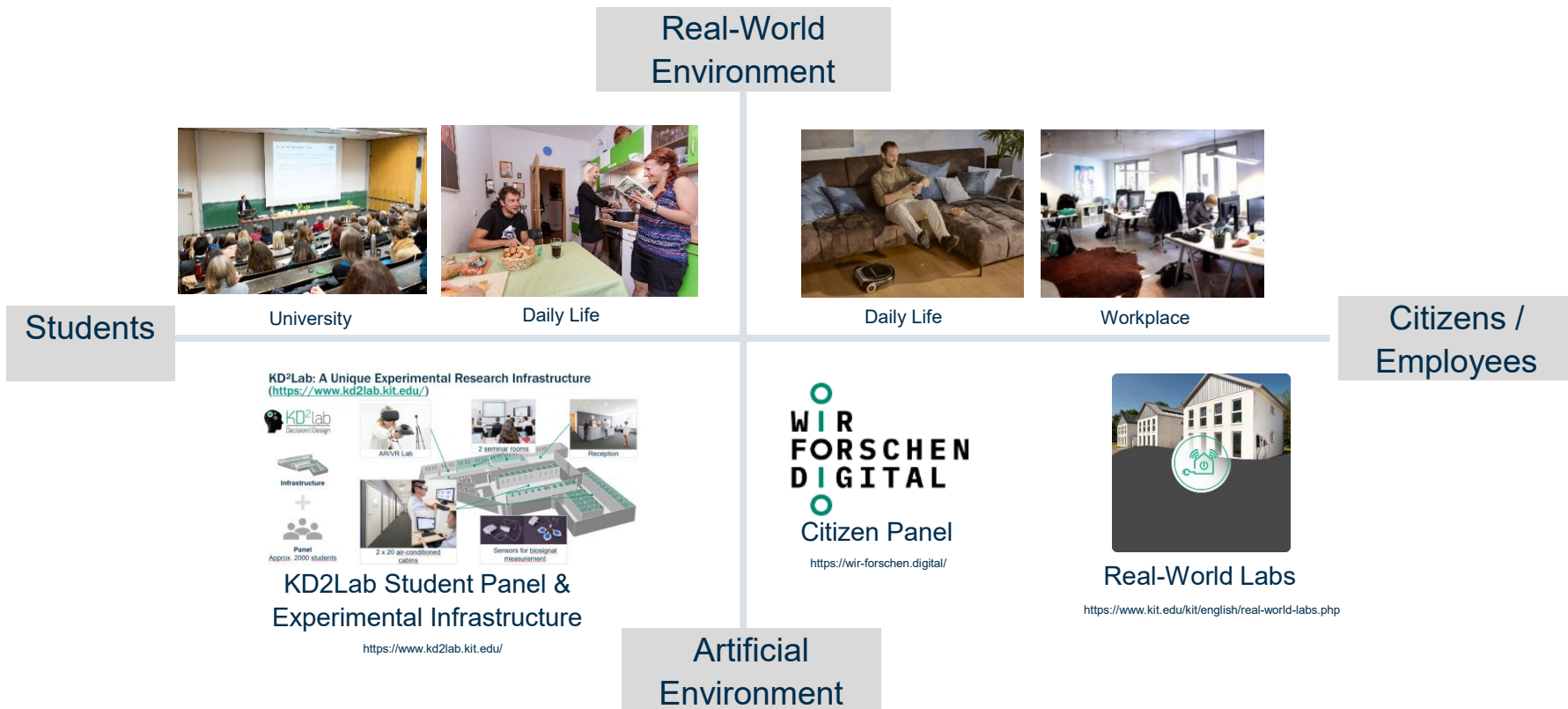


Responsible Design of Biosignal-Adaptive Systems: Benefits and Pitfalls



- ⇒ **Following human-centered design processes** for biosignal-adaptive systems is required to understand and balance design trade-offs!
- ⇒ Mixed-method approaches combining **lab and field investigations** are required.

Our Approach: Investigation of diverse human subjects in an artificial and real-world environment ...



Summary

- Biosignal-adaptive systems are a **promising solution to advance human-computer interaction** for better work & life.
- Designing biosignal-adaptive systems is **challenging**, both from a biosignal recording/processing/classification as well as an adaptation design perspective.
- Biosignal-adaptive systems should always be considered as **socio-technical systems**, where humans and information technology co-adapt continuously.

Thank you for your attention!



DFG Deutsche
Forschungsgemeinschaft

<https://kd2school.info/>



**human-centered
systems lab**

<http://h-lab.iism.kit.edu>



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