Neuro-adaptive Tutoring Systems

Neurophysiological-based recognition of affective-emotional and cognitive states of learners for intelligent neuro-adaptive tutoring systems

04th September 2021

Katharina Lingelbach, Sabrina Gado and Wilhelm Bauer

KI Fortschrittszentrum LERNENDE SYSTEME
Universität Stuttgart
Institut für Arbeitswissenschaft und Technologiemanagement IAT
Fraunhofer IAO

Motivation and Aim of the Project
Monitoring learners' affective-emotional and cognitive states

- Exploration and decoding of **activation patterns from neurophysiological measures** to identify current **mental states** during an **interaction with technology**.
- **A neuro-adaptive system** is a system in which (1) **neurophysiological signals are recorded** in a closed human-technology loop, (2) **mental user states are interpreted** from these signals, and (3) **system behaviour is adapted [1,2]**.
- **Use case** of **neuro-adaptive tutoring systems for education and training**
- **Objectives**:
  - Improve **human-technology interaction,**
  - Elicit **positive user experience**
  - Foster **satisfaction, self-efficacy, productivity, and well-being.**

»In every job that must be done, there is an element of fun«

[1] Wolpaw et al. (2002). Brain-computer interfaces for communication and control. *Clin. Neurophysiol. Off. J. Int. Fed. Clin. Neurophysiol.*, *113*, 767–791.
[2] Zander, & Kothe (2011). Towards passive brain–computer interfaces: Applying brain–computer interface technology to human–machine systems in general. *Journal of neural engineering*, *8*(2), 025005.

Effects of Emotional Distractors on Working Memory Load

State of the Art

- Detrimental effects of emotional distraction on cognitive processes [3-6]
- Strongest emotional interference when i) **cognitive load is low** and ii) distractors' **valence deviates from neutral** [3,7]

Neurophysiological effects

- Investigating **emotion** & **cognition** with electroencephalography
    - **Emotion states: Frontal alpha** (8 – 12 Hz) **asymmetry** (FAA) [e.g., 8]
    - **Cognitive states: Ratio of frontal theta** (4 – 7 Hz) and **parietal alpha power** (WL) [e.g., 9]

Increased Right **Frontal Activity**

Increased Left **Frontal Activity**

Negative

Withdrawal

Positive

Approach

↑ **Frontal theta** / **Parietal alpha** ↑ Cognitive Load

[3] Cromheeke & Mueller (2014). Probing emotional influences on cognitive control: an ALE meta-analysis of cognition emotion interactions. Brain Struct Funct 219, 995–1008.
[4] Dolcos & Denkova (2014). Current emotion research in cognitive neuroscience: Linking enhancing and impairing effects of emotion on cognition. Emotion Review 6, 362–375.
[5] Iordan et al. (2013). Neural signatures of the response to emotional distraction: A review of evidence from brain imaging investigations. Front Hum Neurosci 7, 200.
[6] Wessa et al. (2013). Goal-directed behavior under emotional distraction is preserved by enhanced task-specific activation. Soc Cogn Affect Neurosci 8, 305–312.
[7] Shafer et al. (2012). Processing of emotional distraction is both automatic and modulated by attention: evidence from an event-related fMRI investigation. J Cogn Neurosci 24, 1233–1252.
[8] Smith et al. (2017). Assessing and conceptualizing frontal EEG asymmetry: An updated primer on recording, processing, analyzing, and interpreting frontal alpha asymmetry. Int J Psychophysiol 111, 98–114.
[9] Gevins et al. (1997). High-resolution EEG mapping of cortical activation related to working memory: Effects of task difficulty, type of processing, and practice. Cereb Cortex 7, 374–385.

Research Question

Decoding of affective-emotional and cognitive states

1. How well can we decode the interaction of mental states using theoretically supported correlates?

2. Can we predict subjective appraisal using neurophysiological correlates?

3. What effect has the feedback (appropriate vs. inappropriate) of recognized cognitive and affective-emotional states on performance and on a neurophysiological level (i.e., the feedback-related or error-related negativity?

KI Fortschrittszentrum LERNENDE SYSTEME
Universität Stuttgart Institut für Arbeitswissenschaft und Technologiemanagement IAT
Fraunhofer IAO

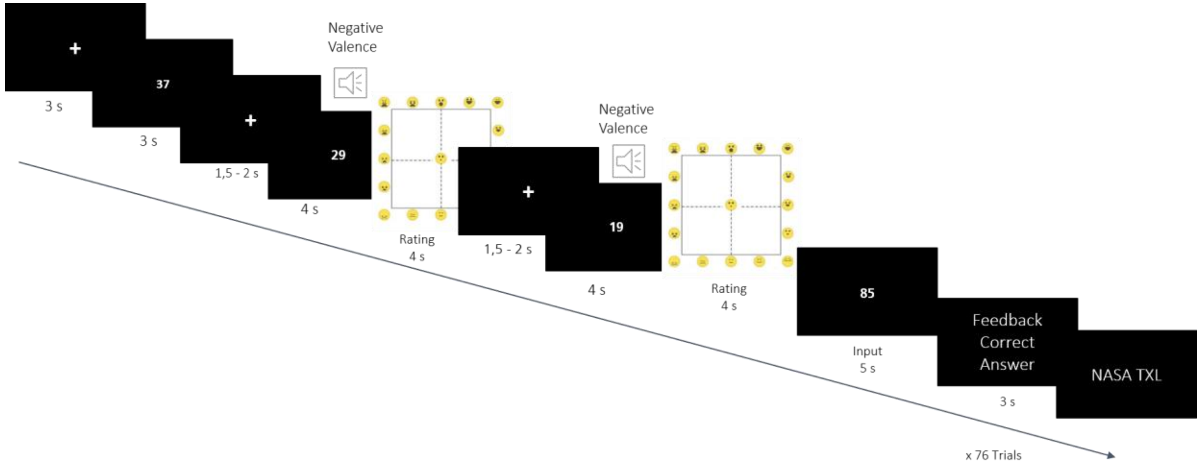
Methods and Procedure

N-Back with auditory emotional distraction

Auditory Stimuli:
Positive, Neutral, or Negative

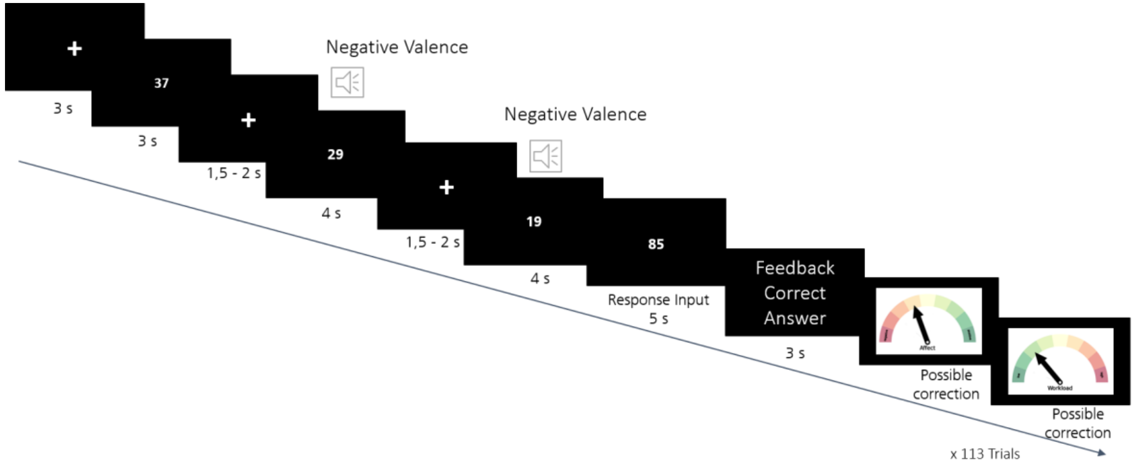
Research Question 1 & 2

- *N* = 8 (three women; *M* = 23 years; *SD* = 1.12)
- Paradigm: N-Back with auditory emotional distraction [3-5]
- EEG, EDA (electrodermal activity), behavioural measures and subjective ratings (Emoji-Grid, NASA TLX)



Research Question 3

- *N* = 7 (four women; *M* = 25.48 years; *SD* = 2.66).
- Paradigm: N-Back with auditory emotional distraction [3-5]
- EEG, EDA (electrodermal activity) and behavioural measures



[10] Lingelbach et al. (2021). "Investigating the Emotion-Cognition Interaction: Effects of Affective Distractors on Working Memory Load," in The 3rd International Neuroergonomics Conference, Munich, Germany, September 11-16, 2021, (in-press).
[11] Lingelbach et al. (2021). "What I feel and what I say: Decoding neurophysiological correlates of cognitive and affective states," in The 3rd International Neuroergonomics Conference, Munich, Germany, September 11-16, 2021, (in-press).
[12] Gado, Lingelbach, et al. (2021). "Real-time feedback of subjective affect and working memory load based on neurophysiological activity," in The International Conference, HCI International 2021, Washington DC, USA, July 24-29, 2021, Proceedings (in-press). Springer.

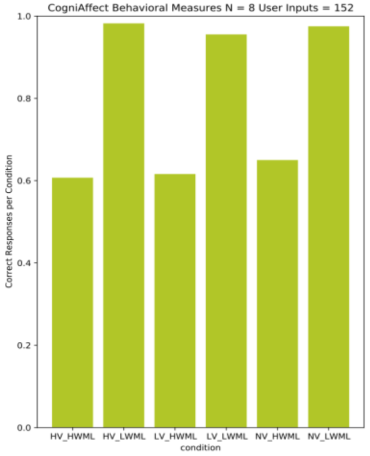
KI Fortschrittszentrum LERNENDE SYSTEME
Universität Stuttgart Institut für Arbeitswissenschaft und Technologiemanagement IAT
Fraunhofer IAO

Data Collection

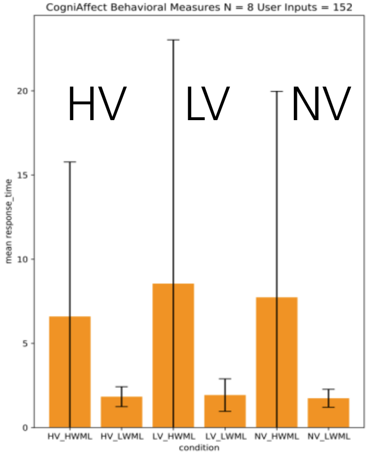
Overview of the Measures

Neurophysiological Data: EEG, EKG, EDA

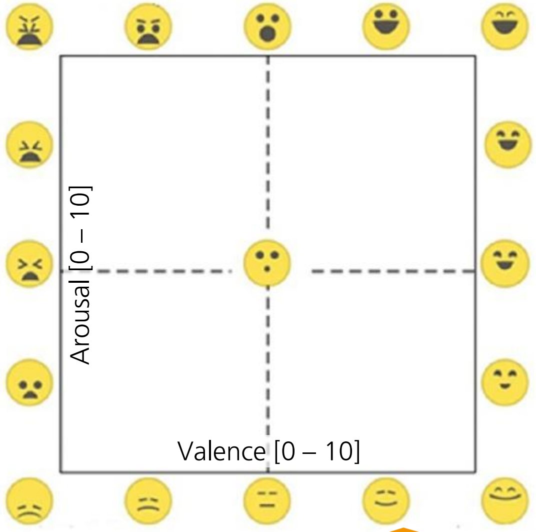
Accuracy



Response Time

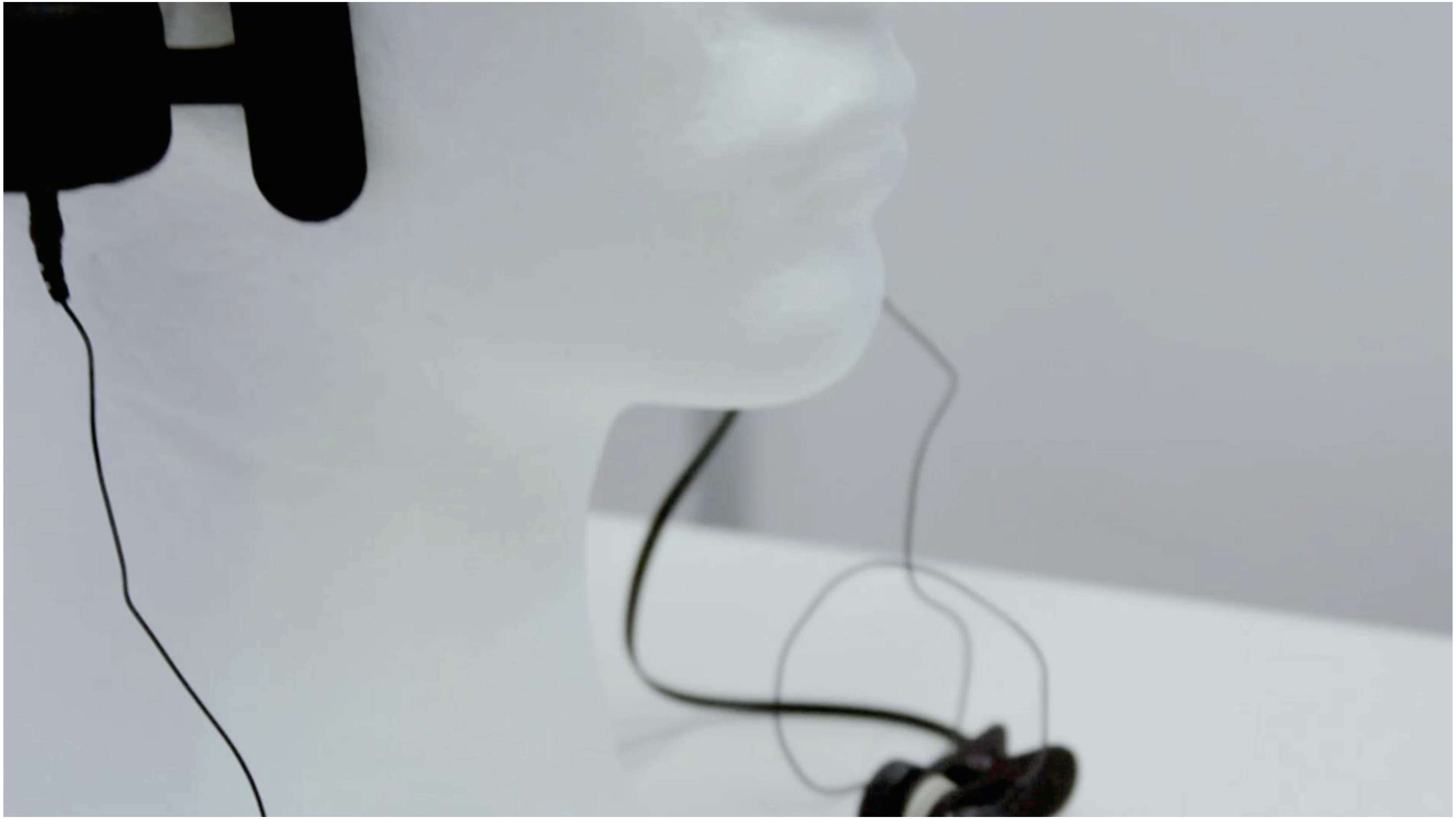


Behavioral Data:
Accuracy, Response Time



Subjective Ratings:
Affect and Arousal (EmojiGrid) [6], Effort (NASA TLX) [7]

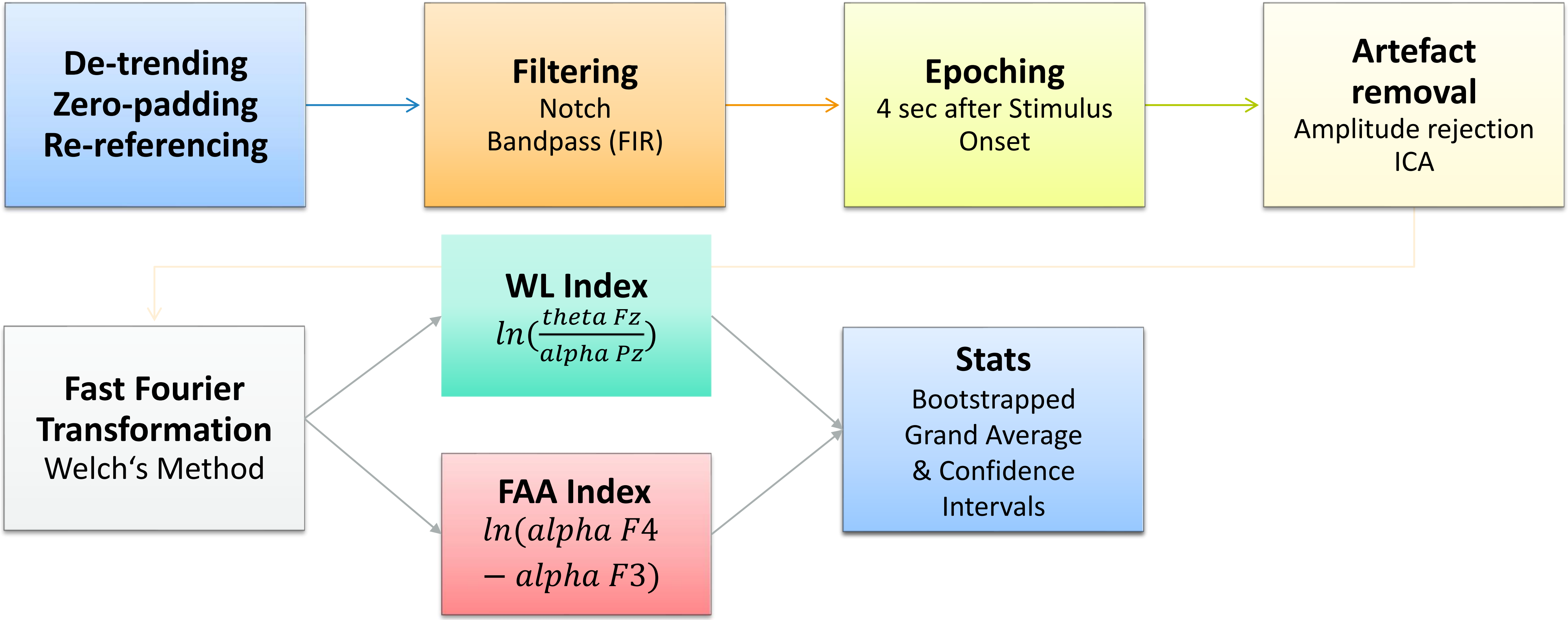
[13] Toet & van Erp (2019). The EmojiGrid as a tool to assess experienced and perceived emotions. *Psych*, *1*(1), 469-481.
[14] Hart & Staveland (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In *Advances in psychology* (vol. 52, pp. 139-183). North-Holland.



[15] Link: https://youtu.be/usoU87BaEyY

EEG Processing Pipeline

Calculating the EEG correlates



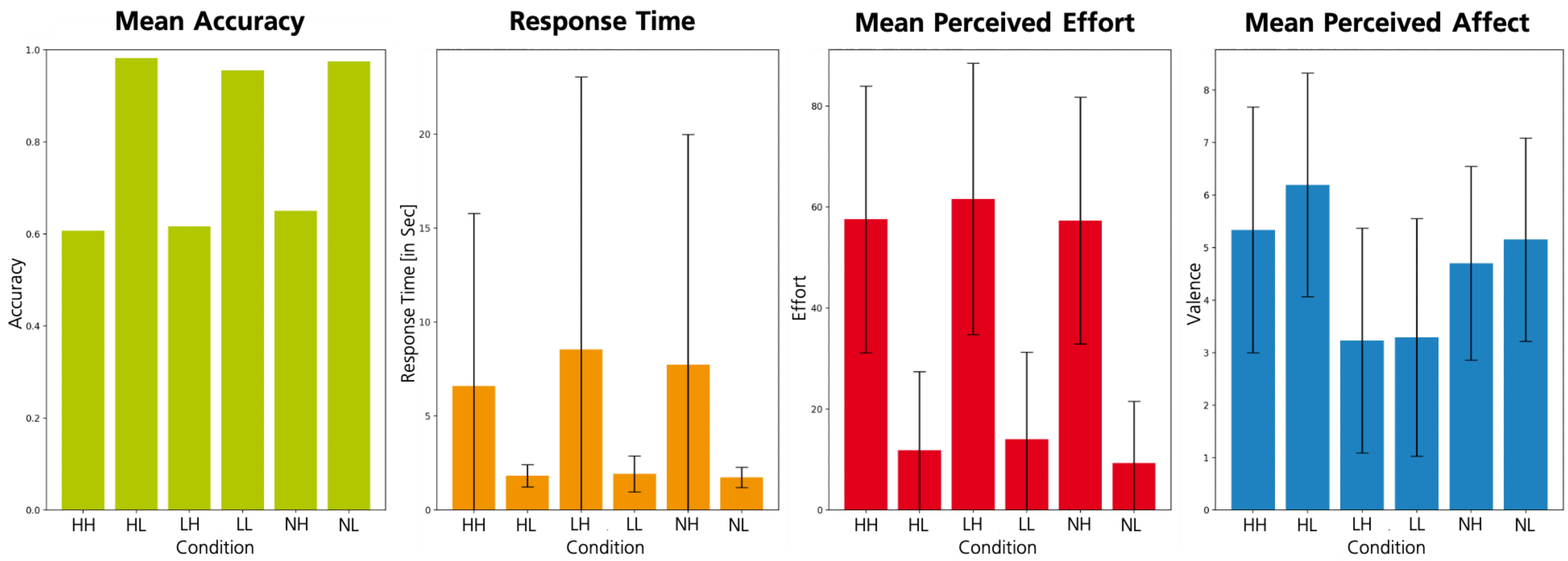
[10] Lingelbach et al. (2021). "Investigating the Emotion-Cognition Interaction: Effects of Affective Distractors on Working Memory Load," in The 3rd International Neuroergonomics Conference, Munich, Germany, September 11-16, 2021, (in-press).
[11] Lingelbach et al. (2021). "What I feel and what I say: Decoding neurophysiological correlates of cognitive and affective states," in The 3rd International Neuroergonomics Conference, Munich, Germany, September 11-16, 2021, (in-press).
[12] Gado, Lingelbach, et al. (2021). "Real-time feedback of subjective affect and working memory load based on neurophysiological activity," in The International Conference, HCI International 2021, Washington DC, USA, July 24-29, 2021, Proceedings (in-press). Springer.

Question 1

Decode interacting states

Results

Behavioral and Subjective Measures

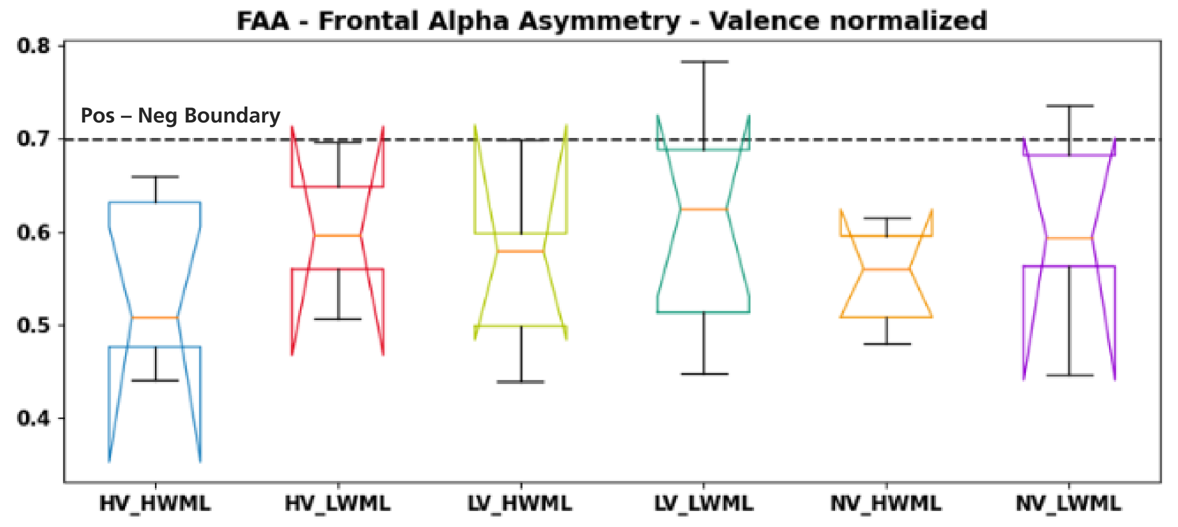


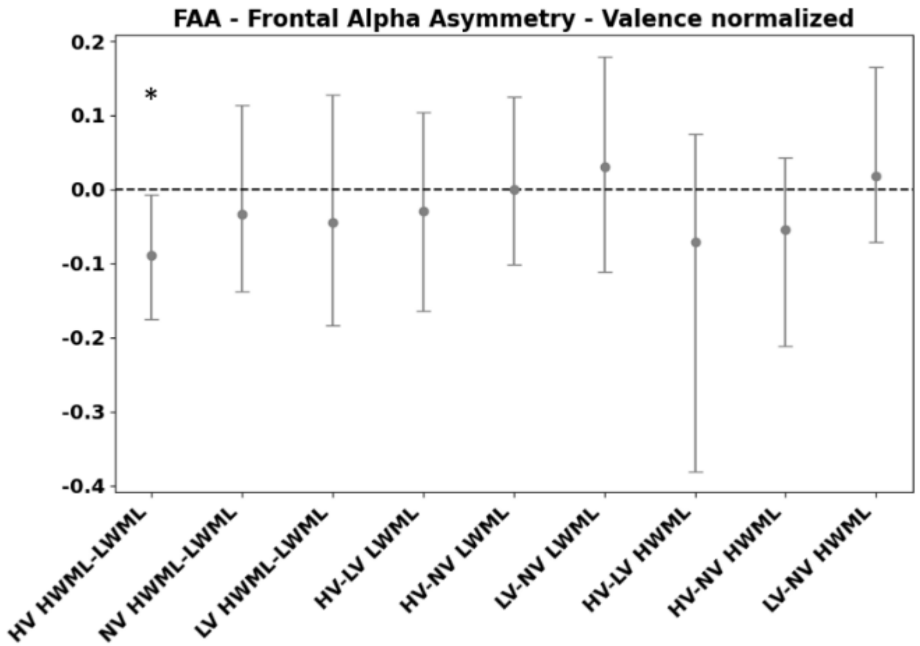
Conditions: **HH**: High Valence – High Working Memory Load, **HL**: High Valence – Low Working Memory Load, **LH**: Low Valence – High Working Memory Load, **LL**: Low Valence – Low Working Memory Load, **NH**: Neutral Valence – High Working Memory Load, **NL**: Neutral Valence – Low Working Memory Load. Error Bars: Standard Deviation.

High Valence - High WL, High Valence - Low WL, Low Valence - High WL, Low Valence - Low WL, Neutral Valence – High WL, Neutral Valence – Low WL

Effects of Emotional Distractors and WML

Frontal alpha asymmetry





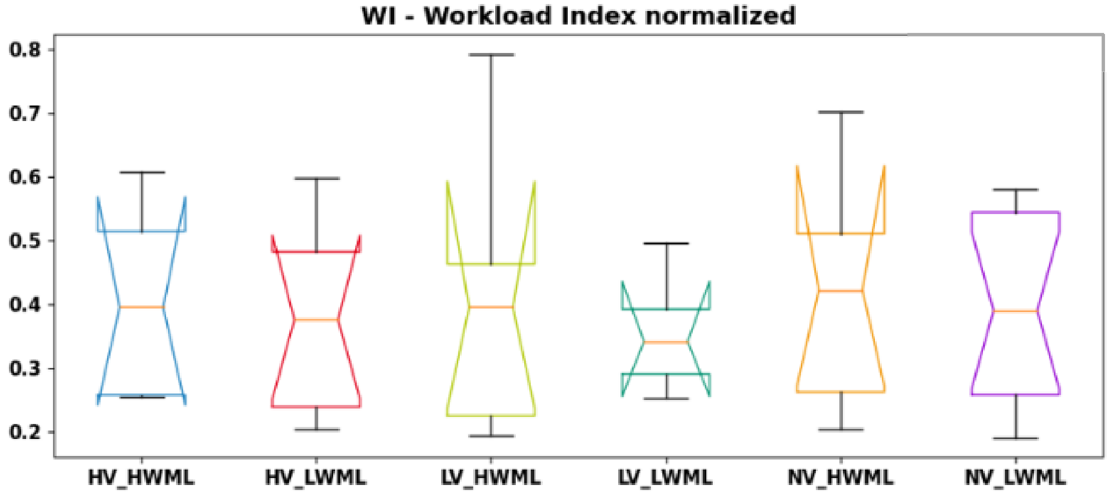
1 Emotional processing is altered by the level of working memory load

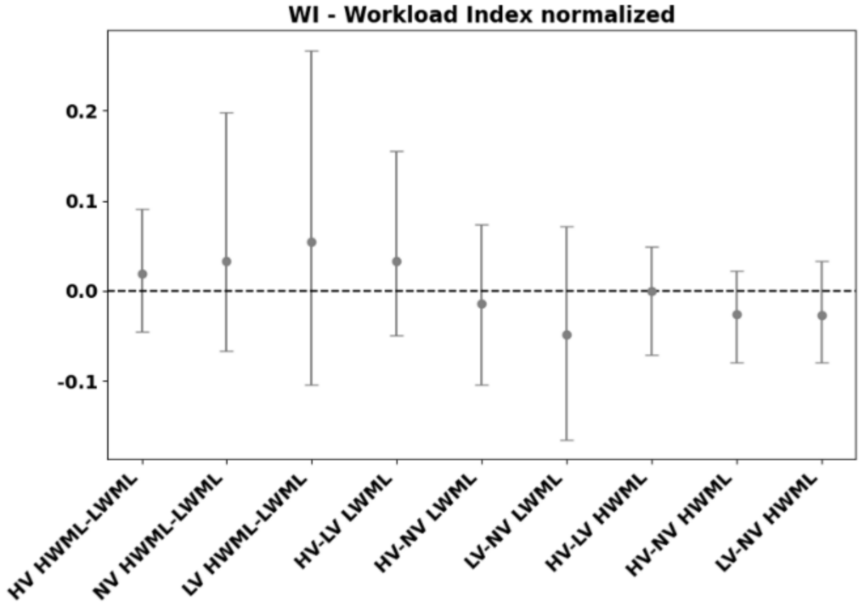
- reduced FAA values and, therefore **less positive evaluation for positive stimuli under high working memory load**
- **emotional evaluation** was rather **negative** independent of the condition

KI Fortschrittszentrum LERNENDE SYSTEME
Universität Stuttgart Institut für Arbeitswissenschaft und Technologiemanagement IAT
Fraunhofer IAO

Effects of Emotional Distractors and WML
Working Memory Load

High Valence - High WL, High Valence - Low WL,
Low Valence - High WL, Low Valence - Low WL,
Neutral Valence – High WL, Neutral Valence – Low WL





2 Neutral stimuli seem to have the strongest emotional interference effects during working memory load compared to positive and negative stimuli (non-significant trend).

- There were no significant differences between the conditions.

KI Fortschrittszentrum LERNENDE SYSTEME
Universität Stuttgart Institut für Arbeitswissenschaft und Technologiemanagement IAT
Fraunhofer IAO

Question 2

Predict subjective appraisal

Decoding of Mental States

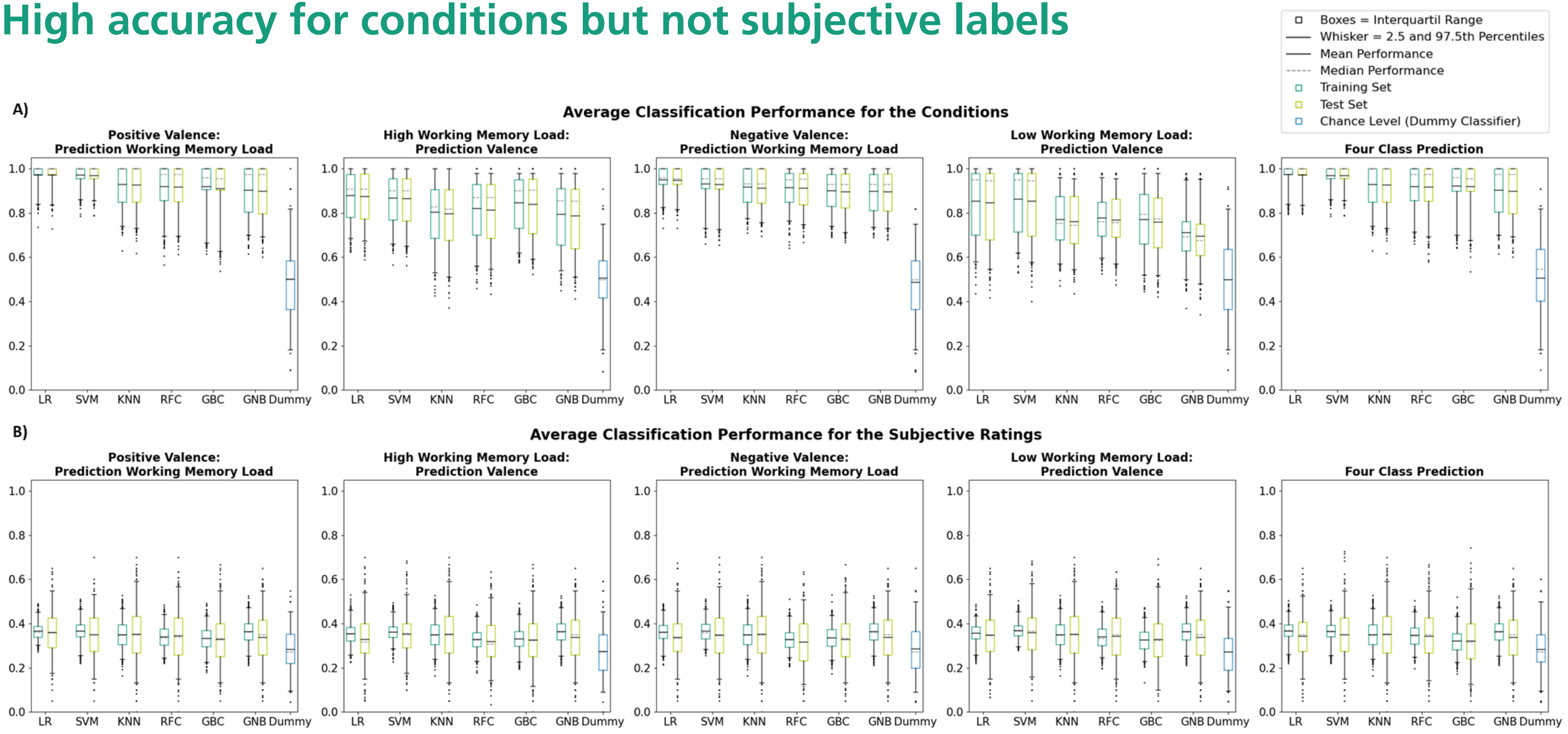
ML Classifiers and Established Neuronal Correlates (FAA and WL Index)

- **Predictive Features**
  - channels and frequency used to calculate the indices (frontal alpha asymmetry: F3 – alpha, F4 – alpha; and working memory load coefficient: Fz – theta, Pz – alpha)
  - Hjorth measures of mobility (proportion of standard deviation of the frequency spectrum) of the respective channels
  - Hjorth measures of complexity (change within the frequency band) of the respective channels
- Average classification accuracy of the training and test set (**balanced accuracy**) is compared to an **empirical baseline (dummy classifier)**
- **Classifiers**:
  - LR: Logistic Regression,
  - SVM: Support-Vector Machine,
  - KNN: k-Nearest Neighbor,
  - RFC: Random Forest Classifier,
  - GBC: Gradient Boosting Classifier,
  - GNB: Gaussian Naïve Bayes
- **Classical ML pipeline** with Train-Test Split (80:20), Inner-Outer-Cross-validation, GridSearch for Hyperparameter Optimization
- **Monte Carlo Simulation** (100 repetitions) to compute **bootstrapped confidence intervals**

[11] Lingelbach et al. (2021). "What I feel and what I say: Decoding neurophysiological correlates of cognitive and affective states," in The 3rd International Neuroergonomics Conference, Munich, Germany, September 11-16, 2021, (in-press).

(Offline) Decoding of Mental States

High accuracy for conditions but not subjective labels



KI Fortschrittszentrum LERNENDE SYSTEME

Universität Stuttgart
Institut für Arbeitswissenschaft und Technologiemanagement IAT

Fraunhofer IAO

Results of Study 1
A matter of choosing the ground truth

- Research Question 1: **We could successfully predict cognitive states under different affective-emotional conditions and affective-emotional states under low and high working memory load.**
  - Classification performance of the affective-emotional states was lower compared to the cognitive state recognition
  - Potential Explanation: EEG Signatures indexing cognitive states are more robust and distinguishable compared to signatures indicating affective-emotional states

- Research Question 2: **We could not predict subjectively rated labels from neurophysiological signals.**
  - Decrease in decoding performance might be explained by modulating effects, such as social desirability, cognitive dissonance for self-image maintenance, or limited ability to reliably estimate past experiences.

Question 3
Effect of feedback

Study 2 User Reactions to the Feedback

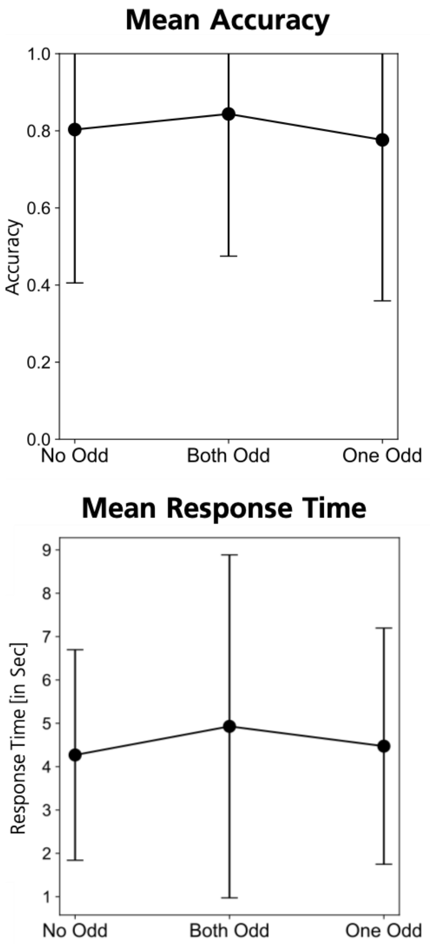
Acceptance and Experience

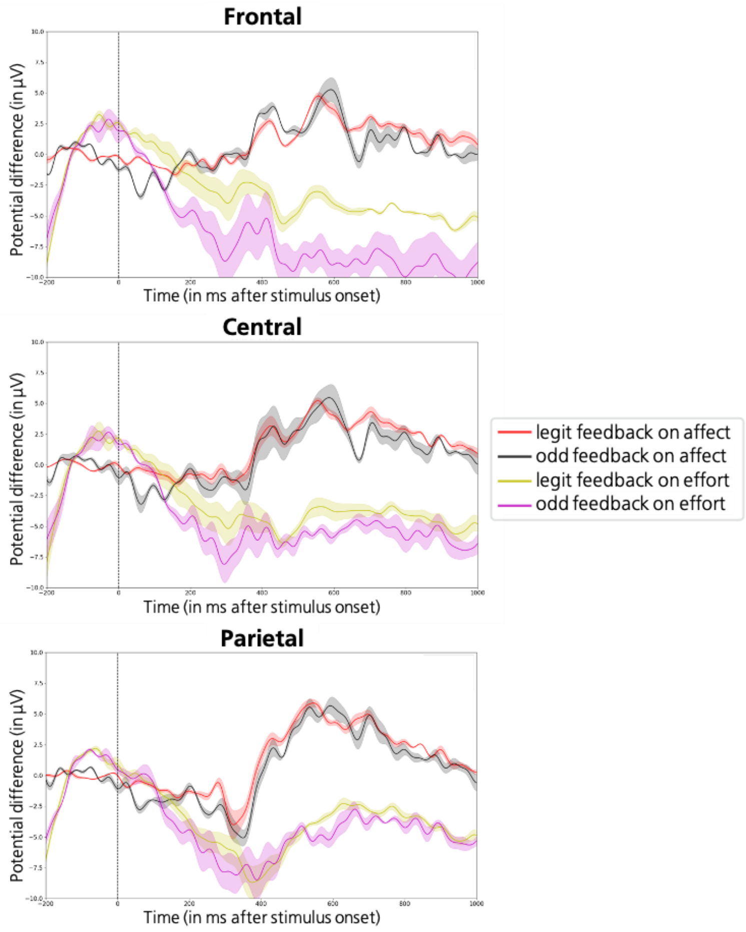
- Explore users' **feedback error tolerance**
- Adequate or inadequate sham **feedback**
- Feedback: 80% consistent with the experimental condition (adequate feedback) and 20% inconsistent (inadequate feedback)
- Possibility to **correct** the feedbacked states according to own perception by clicking in the respective field

[12] Gado, Lingelbach, et al. (2021). "Real-time feedback of subjective affect and working memory load based on neurophysiological activity," in The International Conference, HCI International 2021, Washington DC, USA, July 24-29, 2021, Proceedings (in-press). Springer.

Results of Study 2
Users' Reactions on Feedback

- **More likely to correct inadequate feedback**
- Increased working memory load did not change the probability to adjust a feedback.
- **No influence of the feedback condition on participants' performance** (accuracy and response time).
- No differences between the feedback conditions on a neurophysiological level (ERPs)
- **Evaluation: wish for detailed explanation on the underlying computations**





[12] Gado, Lingelbach, et al. (2021). "Real-time feedback of subjective affect and working memory load based on neurophysiological activity," in The International Conference, HCI International 2021, Washington DC, USA, July 24-29, 2021, Proceedings (in-press). Springer.

Conclusion

Research is formalized curiosity. It is poking and prying with a purpose (Zora Hurston)

1 Emotional processing is altered by the level of working memory load with strongest effects on positive stimuli

2 Neutral auditory distractors seem to induce additional workload compared to emotional stimuli

3 Reference-based more objective labels could be predicted but not the individual subjective label.

! Future research is necessary to investigate new approaches that not only explain the consequences of the interaction, but the interaction process itself and predict it!

Implications of this research include (1) higher context sensitivity and (2) holistic evaluation of identified mental states in **safety-critical environments**, e.g., during driving or in human-computer interactions.

Thank you for your attention!

Katharina Lingelbach
Fraunhofer IAO
Human-Technology Interaction
Neurocognitive Systems
katharina.lingelbach@iao.fraunhofer.de
+49 711 970 5342

References

[1] Wolpaw, J. R., Birbaumer, N., McFarland, D. J., Pfurtscheller, G., & Vaughan, T. M. (2002). Brain-computer interfaces for communication and control. *Clin. Neurophysiol. Off. J. Int. Fed. Clin. Neurophysiol.*, *113*, 767–791.

[2] Zander, T. O., & Kothe, C. (2011). Towards passive brain–computer interfaces: Applying brain–computer interface technology to human–machine systems in general. *Journal of neural engineering*, *8*(2), 025005.

[3] Cromheeke, S., & Mueller, S. C. (2014). Probing emotional influences on cognitive control: an ALE meta-analysis of cognition emotion interactions. *Brain Structure and Function*, *219*(3), 995-1008.

[4] Dolcos, F., and Denkova, E. (2014). Current Emotion Research in Cognitive Neuroscience: Linking Enhancing and Impairing Effects of Emotion on Cognition. *Emotion Review* 6, 362–375. doi: 10.1177/1754073914536449

[5] Iordan, A. D., Dolcos, S., and Dolcos, F. (2013). Neural signatures of the response to emotional distraction: a review of evidence from brain imaging investigations. *Front Hum Neurosci* 7, 200. doi: 10.3389/fnhum.2013.00200

[6] Wessa, M., Heissler, J., Schönfelder, S., and Kanske, P. (2013). Goal-directed behavior under emotional distraction is preserved by enhanced task-specific activation. *Soc Cogn Affect Neurosci* 8, 305–312. doi: 10.1093/scan/nsr098

[7] Shafer, A. T., Matveychuk, D., Penney, T., O'Hare, A. J., Stokes, J., and Dolcos, F. (2012). Processing of emotional distraction is both automatic and modulated by attention: evidence from an event-related fMRI investigation. *J Cogn Neurosci* 24, 1233–1252. doi:10.1162/jocn_a_00206

[8] Smith, E. E., Reznik, S. J., Stewart, J. L., and Allen, J. J. B. (2017). Assessing and conceptualizing frontal EEG asymmetry: An updated primer on recording, processing, analyzing, and interpreting frontal alpha asymmetry. *Int J Psychophysiol* 111, 98–114. doi:10.1016/j.ijpsycho.2016.11.005

[9] Gevins, A., Smith, M. E., McEvoy, L., and Yu, D. (1997). High-resolution EEG mapping of cortical activation related to working memory: Effects of task difficulty, type of processing, and practice. *Cereb Cortex* 7, 374–385. doi:10.1093/cercor/7.4.374

[10] Lingelbach, K., Gado, S., Vukelić, M, and Rieger, J. W. (2021). "Investigating the Emotion-Cognition Interaction: Effects of Affective Distractors on Working Memory Load," in The 3rd International Neuroergonomics Conference, Munich, Germany, September 11-16, 2021, (in-press).

[11] Lingelbach, K., Gado, S., Vukelić, M, and Rieger, J. W. (2021). "What I feel and what I say: Decoding neurophysiological correlates of cognitive and affective states," in The 3rd International Neuroergonomics Conference, Munich, Germany, September 11-16, 2021, (in-press).

[12] Gado, S., Lingelbach, K., Bui, M., Rieger, J. W., and Vukelić, M. (2021). "Real-time feedback of subjective affect and working memory load based on neurophysiological activity," in *The International Conference, HCI International 2021, Washington DC, USA, July 24-29, 2021, Proceedings* (in-press). Springer.

[13] Toet, A., & van Erp, J. B. (2019). The EmojiGrid as a tool to assess experienced and perceived emotions. *Psych*, *1*(1), 469-481.

[14] Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In *Advances in psychology* (vol. 52, pp. 139-183). North-Holland.

[15] Video Link: https://youtu.be/usoU87BaEyY

KI Fortschrittszentrum LERNENDE SYSTEME

Universität Stuttgart
Institut für Arbeitswissenschaft und Technologiemanagement IAT

Fraunhofer IAO