Investigating the Modulation of Spatio-temporal and Oscillatory Power Dynamics by Perceptible and Non-perceptible Rhythmic Light Stimulation

Katharina Lingelbach

12th International Conference on Applied Human Factors and Ergonomics

Neuroergonomics & Cognitive Engineering

26. May 2021

CARL VON OSSIETZKY UNIVERSITÄT OLDENBURG

Universität Stuttgart
Institut für Arbeitswissenschaft und Technologiemanagement IAT

Fraunhofer IAO

Motivation and State-of-the-Art (1)

- **Rhythmic light stimulation** bears great potential to evoke **steady-state visual evoked potentials (SSVEPs)**
  - well suited for **Brain-Computer Interface (BCI) applications** due to their high signal-to-noise ratio (SN)

- **frequency-modulated (FM) protocols** allow for less perceptible visual stimulation
  - decreased eye fatigue and increased user comfort [6,7,8].
  - **Carrier frequency** (usually a high frequency, e.g., 40 Hz) is modulated by a second frequency (i.e., the **modulation frequency**, e.g., 30 Hz)
  - SSVEPs are evoked at the **frequency of the difference** (40 – 30 = 10 Hz).

$$signal = A + FV * \sin(2 * \pi * Fc * t + (M * \sin(2 * \pi * Fm * t)))$$

- *A:* amplitude of the current intensity
- *FV:* fluctuation of the current intensity span
- *Fc:* carrier frequency
- *Fm:* modulation frequency (30 Hz),
- *M* the modulation index (*M* = 2) (2),
- *t* the time vector

[1] Dreyer A M, Herrmann C S (2015) Frequency-modulated steady-state visual evoked poten-tials: a new stimulation method for brain-computer interfaces. *J Neurosci Methods 241*, 1–9
[2] Dreyer A M, Herrmann C S, Rieger J W.: Tradeoff between User Experience and BCI Classification Accuracy with Frequency Modulated Steady-State Visual Evoked Potentials. *Front Hum Neurosci 11*, 391
[3] Lingelbach, K., Dreyer, A. M., Schöllhorn, I., Bui, M., Weng, M., Diederichs, F., ... & Vukelić, M. (2021). Brain oscillation entrainment by perceptible and non-perceptible rhythmic light stimulation. *Frontiers in Neuroergonomics, 2*, 9.

Motivation and State-of-the-Art (2)

- **Strongest EEG power modulations** are elicited when the stimulation source is
  - positioned in the centre of the visual field
  - stimulation source is directly fixated [1,9].
  - → However, this is **impractical for most real-world applications**

- **Potential real-world environments** for rhythmic light stimulation are in a **car interiors or cockpits**

- Real-world applications of rhythmic light stimulation require:
  - **high user comfort**, e.g., by using **less perceptible rhythmic stimulation**
  - **feasibility** to allow integration of the stimulation in everyday life environments and associated tasks, e.g., by not requiring direct fixation on the light source

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Research Question

- We were interested in the topographical modulations measured via **visual event-related potentials (ERPs)** and **oscillatory power modulations** of rhythmic light stimulations suitable for the application in real-world environments

- We investigated four protocols varying in their **perceptibility** and **locus of fixation**:
  - **perceptible frequency-modulated (FM) rhythmic light stimulation** with amplitudes of the flickering intensity **above a previously estimated individual threshold**
  - **non-perceptible FM rhythmic light stimulation** with amplitudes of the flickering intensity **below a previously estimated individual threshold**
  - **overt attention** with the focus directly on the light source
  - **covert attention** with the focus indirectly on the light source

Methods

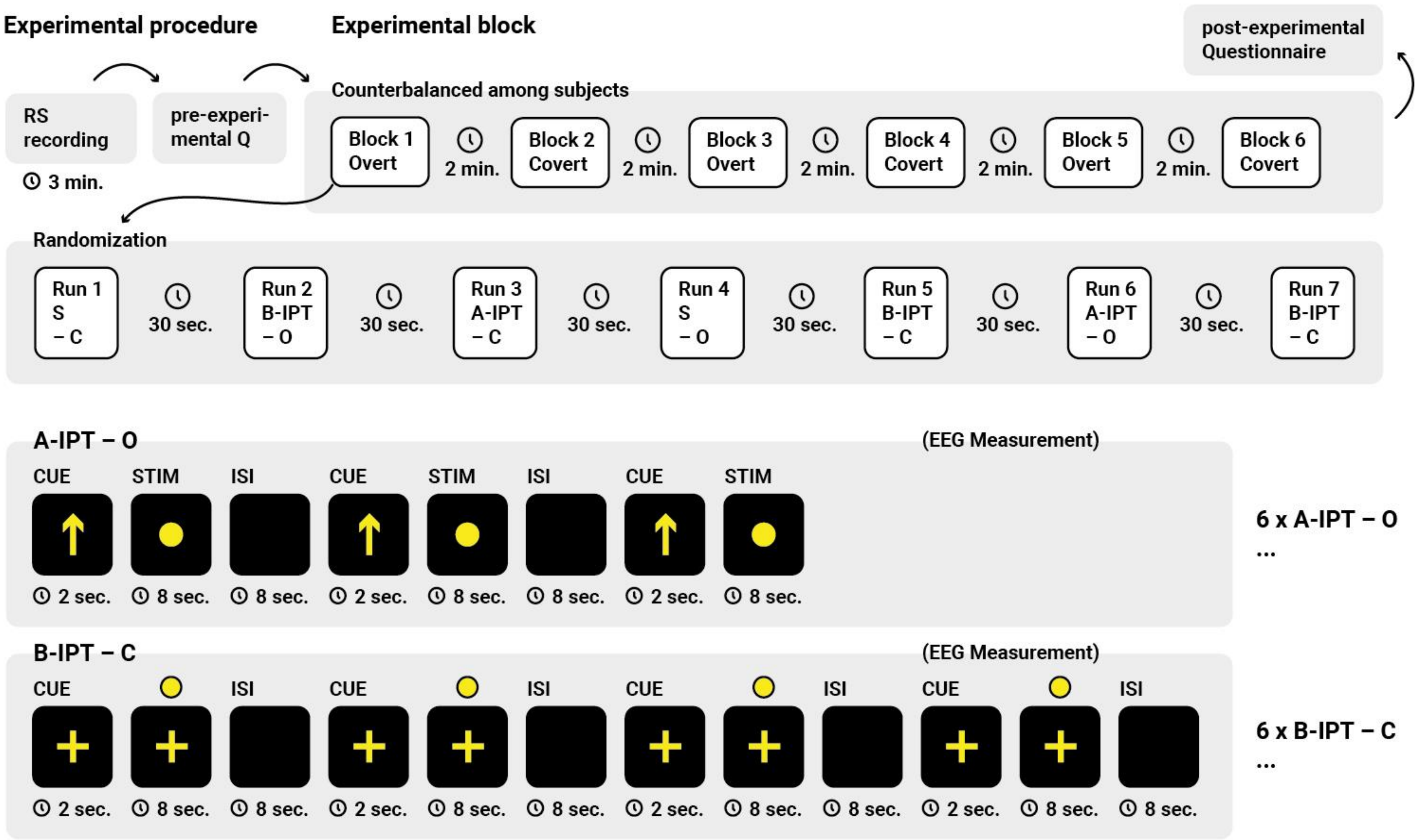
[3] From Lingelbach, K., Dreyer, A. M., Schöllhorn, I., Bui, M., Weng, M., Diederichs, F., ... & Vukelić, M. (2021). Brain oscillation entrainment by perceptible and non-perceptible rhythmic light stimulation. *Frontiers in Neuroergonomics, 2*, 9.

- **Sample**
  - EEG data from 12 participants
  - ten men, age: $M = 26.83$, $SD = 3.80$
  - corrected-to-/normal vision
  - visual acuity > 0.7
- **Technical Set-Up**
  - LED with 1 m distance to the nasion (covering 1.14° of the visual field)
  - 10 Hz stimulation with **carrier frequency** = 40 Hz and **modulation frequency** = 30 Hz

    $$signal = A + FV * \sin(2 * \pi * 40 * t + (2 * \sin(2 * \pi * 30 * t)))$$ [1,2]
  - **covert condition with crosshair positioned 10 cm below the LED** as fixation point (5.7 ° of the visual field)
  - Perceptibility threshold estimation via the **method of constant stimuli** in a pre-session
    - above the individual perceptibility threshold intensity: **IPT + 2mA (A-IPT)**
    - below the individual perceptibility threshold intensity: **IPT - 2mA (B-IPT)**

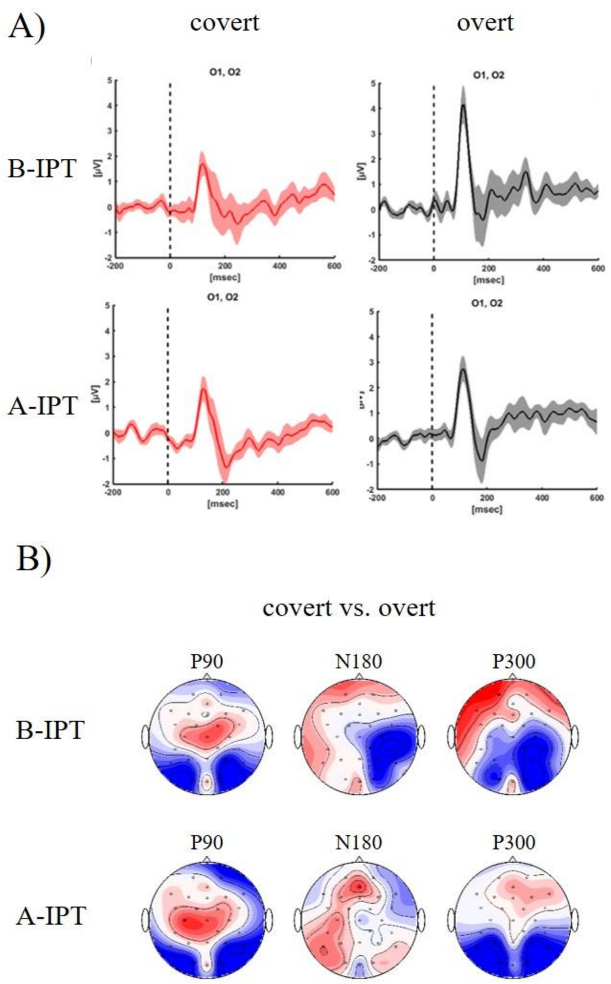
[1] Dreyer A M, Herrmann C S (2015) Frequency-modulated steady-state visual evoked poten-tials: a new stimulation method for brain-computer interfaces. *J Neurosci Methods 241*, 1–9
[2] Dreyer A M, Herrmann C S, Rieger J W.: Tradeoff between User Experience and BCI Classification Accuracy with Frequency Modulated Steady-State Visual Evoked Potentials. *Front Hum Neurosci 11*, 391

Procedure – Main Session



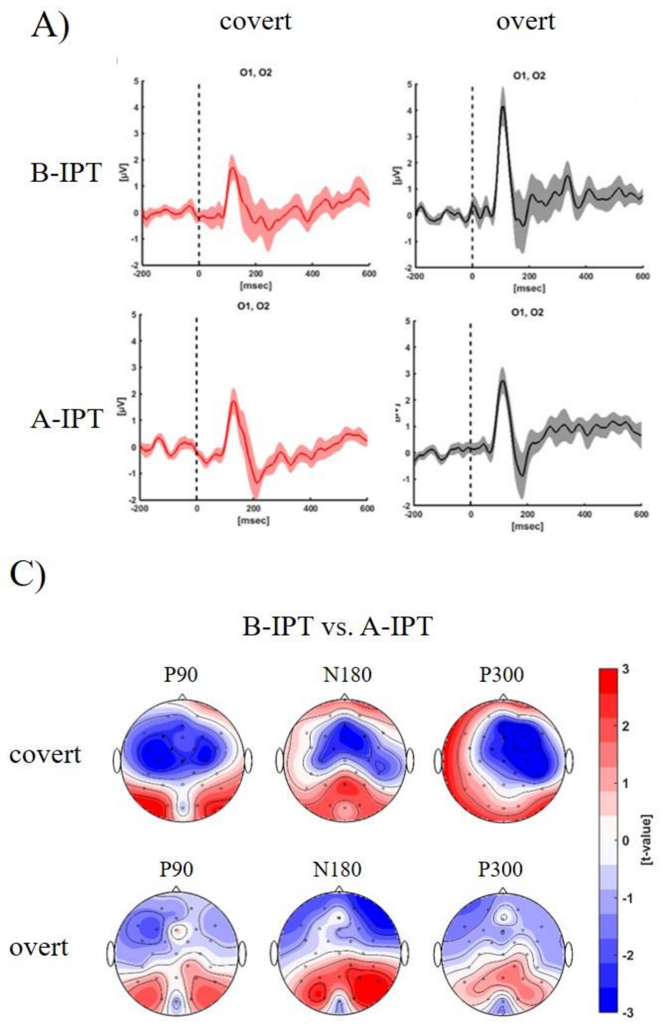
EEG Results – ERP
covert vs. overt

- **Overt attention – A-IPT**
  - strongest deflection of the components in electrodes overlying occipital regions
- **Covert attention – B-IPT**
  - **reduced positive deflections** in parieto-occipital electrodes (P90 and P300) and **increased negative deflection in the N180**
  - **P300 enhanced in frontal electrodes**
- **Covert attention – A-IPT**
  - reduced positive deflections in parieto-occipital electrodes in early and late components (i.e., P90, P300).



EEG Results – ERP

B-IPT (non-perceptible) vs. A-IPT (perceptible)



- **Covert attention**
  - significant differences between A-IPT and B-IPT in early components
- **Covert attention – B-IPT**
  - P90 and P300 were significantly reduced and N180 was enhanced in fronto-central electrodes
- **Covert attention – A-IPT**
  - stronger negative deflections in the N180 in parieto-occipital electrodes

Discussion

- **Oscillatory power modulations**
  - similar for the four stimulation protocols
  - increased oscillatory power in the first harmonic response (beta band power) in occipital electrodes for the covert compared to the overt condition during non-perceptible stimulation → suitable for BCI applications [19].
- **Event-related potentials**
  - early components: processing of psychophysical stimulus features (e.g. contrast, motion, and color [22,23])
  - lately induced ERPs: cognitive information processing
- **Attention effect**
  - enlarged positive deflections when the stimulation source was overtly attended
  - attention-related sensory gain control mechanisms for improved acuity of visual perception within the spotlight
- **Conclusion**
  - **entrainment effects represented in both ERPs and power** even **for a non-perceptible stimulation** and **without directly fixating** on the light source.
  - strong potential for naturalistic non-clinical applications to enhance neuronal activity and cognitive processes.

Thanks for your attention

Thanks to all authors of the contribution

Katharina Lingelbach, Isabel Schöllhorn, Alexander M. Dreyer, Frederik Diederichs, Michael Bui, Michael Weng, Jochem W. Rieger, Ina Petermann-Stock, and Mathias Vukelić

Contact:

Katharina Lingelbach

University of Oldenburg and Fraunhofer IAO
Germany

Katharina.Lingelbach@iao.fraunhofer.de