

Through the eye to the brain: Modulating arousal via pupil-based neurofeedback

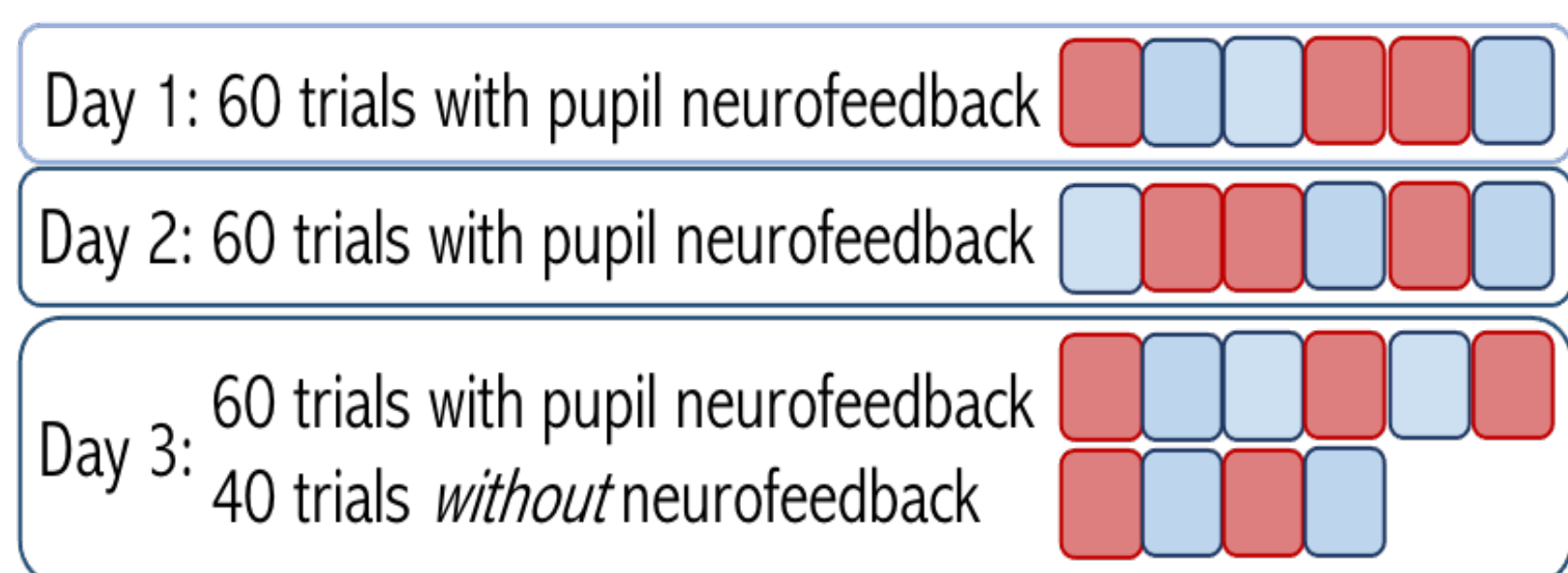
BACKGROUND: There is evidence for a link between activity of the locus coeruleus (LC), a small brainstem structure and the main source of noradrenaline in the central nervous system, and changes in pupil size⁽¹⁻⁴⁾. Building on this, we pursued a novel idea investigating whether volitional modulation of pupil size...

- i. can be trained via pupil-based neurofeedback (pupil-NF)
- ii. is linked to changes in LC activity
- iii. modulates electrophysiological and cardiovascular arousal markers

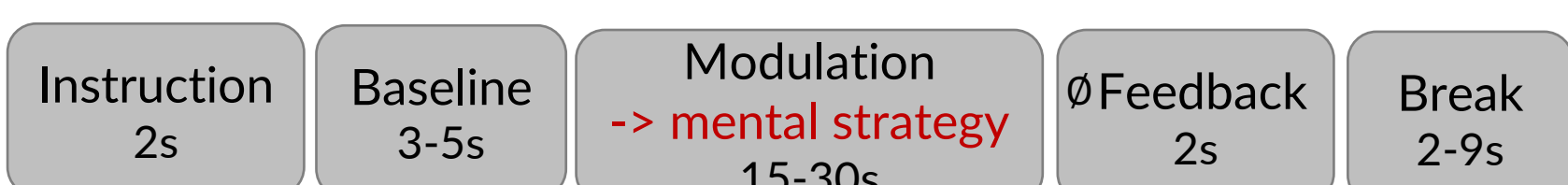
METHODS

- i. Healthy participants received 3 days of training to learn to modulate (up- and downregulate) pupil size via the use of mental strategies and pupil-NF
 - pupil-NF cohort I & II, III (n = 27; n = 25; n = 23): veridical feedback on pupil size; cohort III partially re-recruited from cohort I and II for EEG on Day 3
 - control group (n = 27): same amount of training but no veridical feedback
 - pupil data: pre-processing pipeline adapted from⁽⁵⁾.
 - computed baseline-corrected pupil diameter during modulation (pupil diameter - \emptyset baseline pupil diameter)

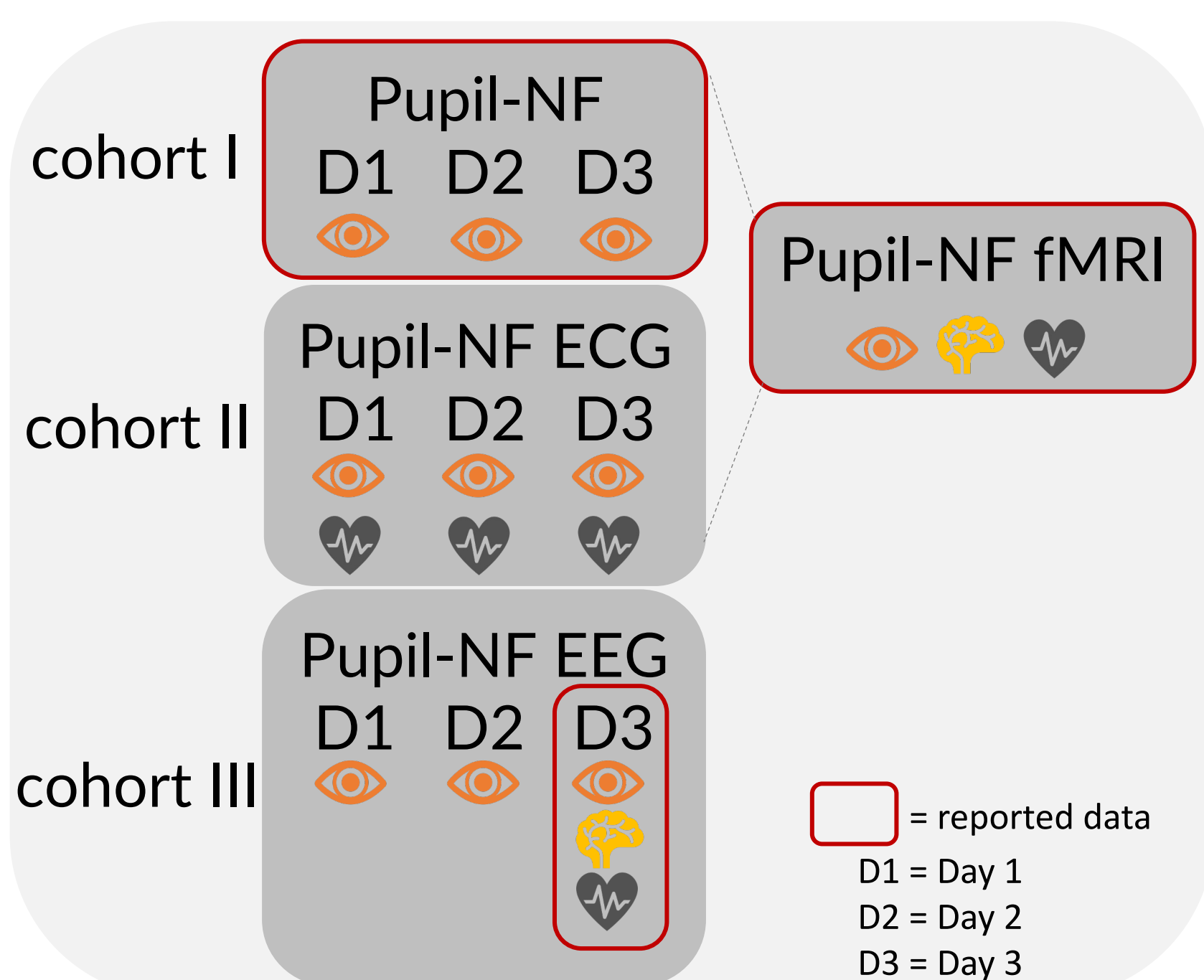
DIRECTION: UP vs. DOWN



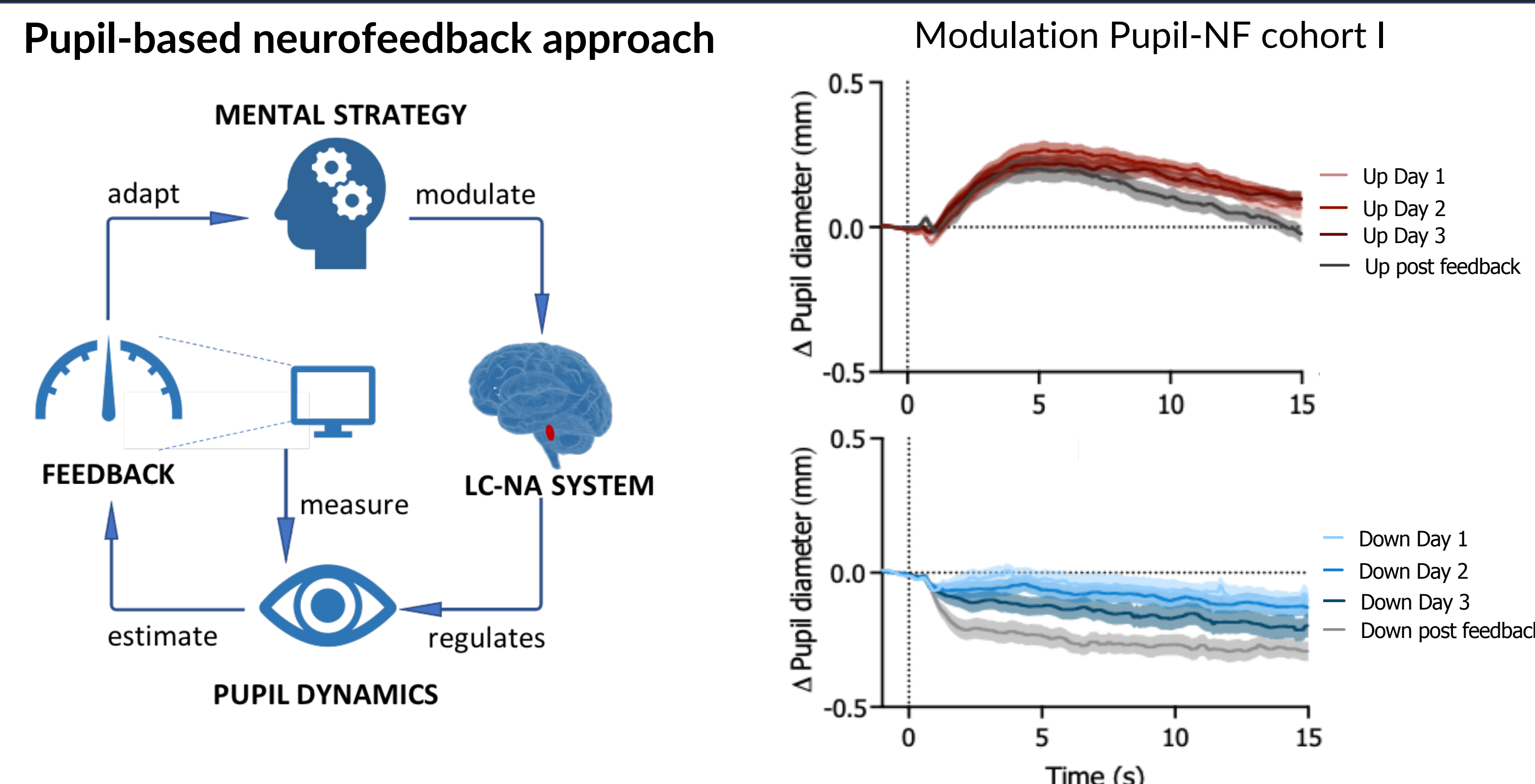
TRIAL DESIGN



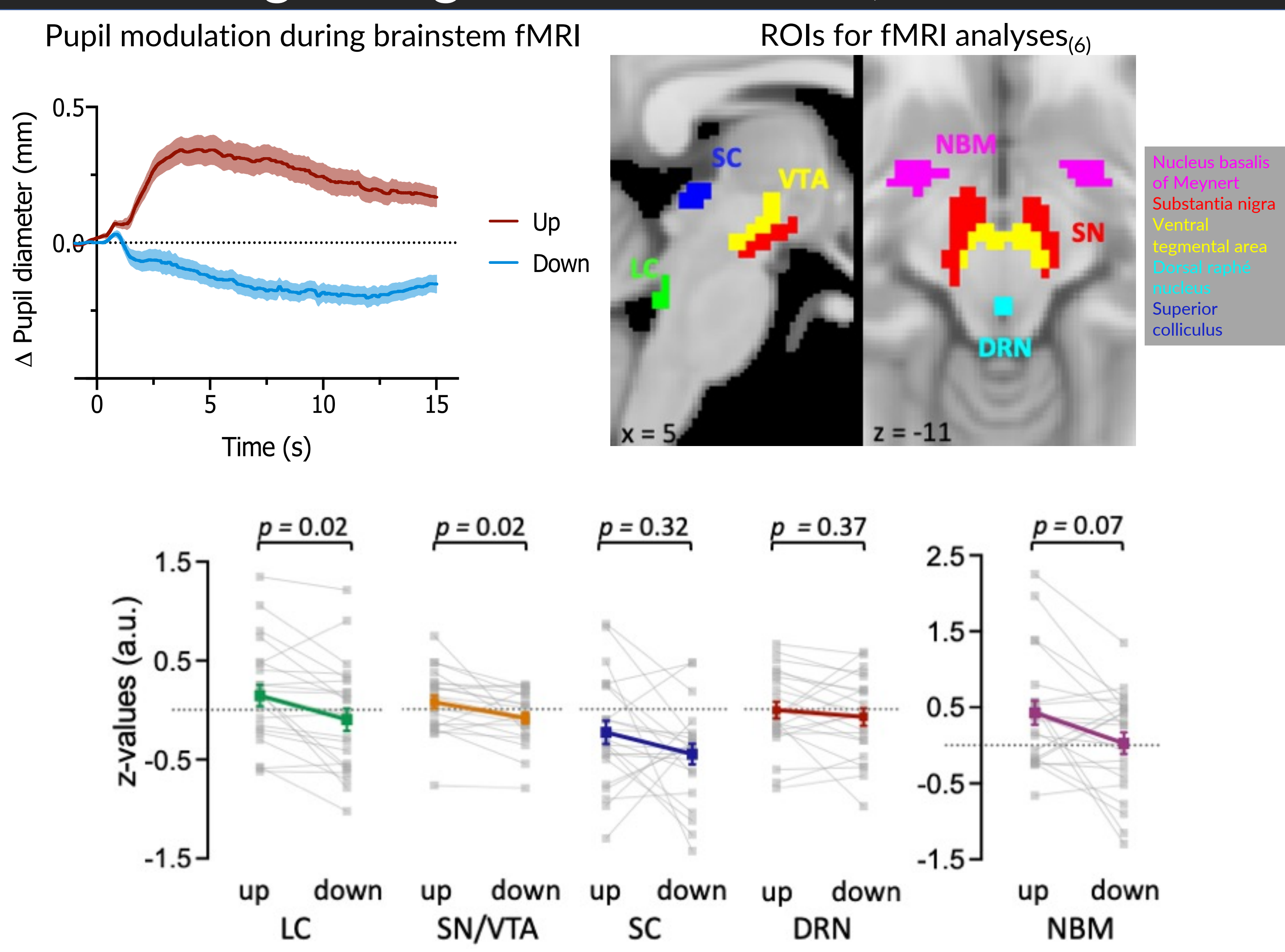
- ii. 25 participants of pupil-NF cohort I & II performed volitional pupil modulation with pupil-NF during 3T fMRI (1.8mm x 1.8mm x 1.8mm ; partial field-of-view to cover brainstem)
- iii. 23 participants (pupil-NF cohort III) performed volitional pupil modulation during EEG recordings on the last day of training (Day 3)
- iv. Throughout fMRI and EEG sessions, cardiac data was recorded by means of pulse oximetry/ECG



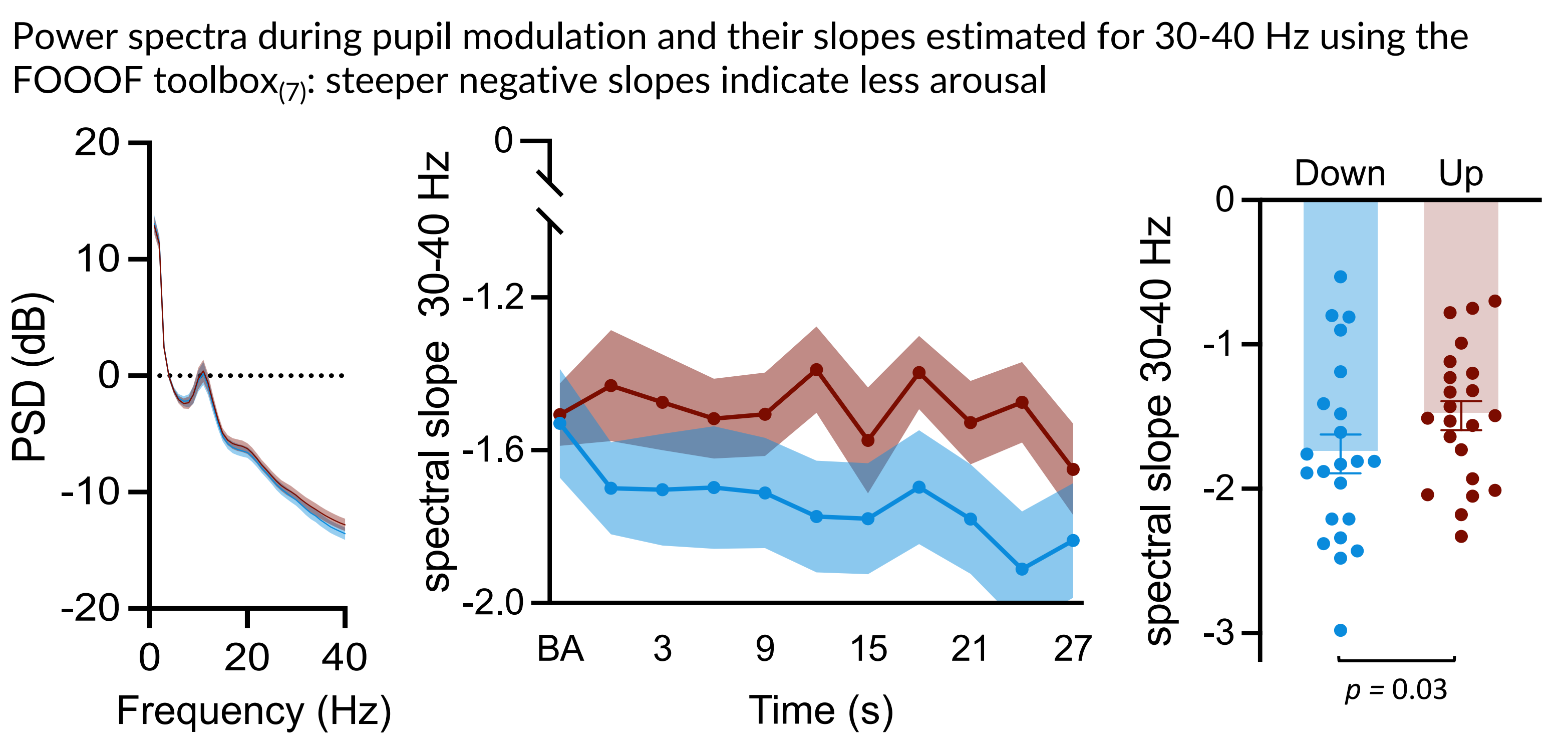
We can learn to self-regulate pupil size via mental strategies and pupil-based neurofeedback



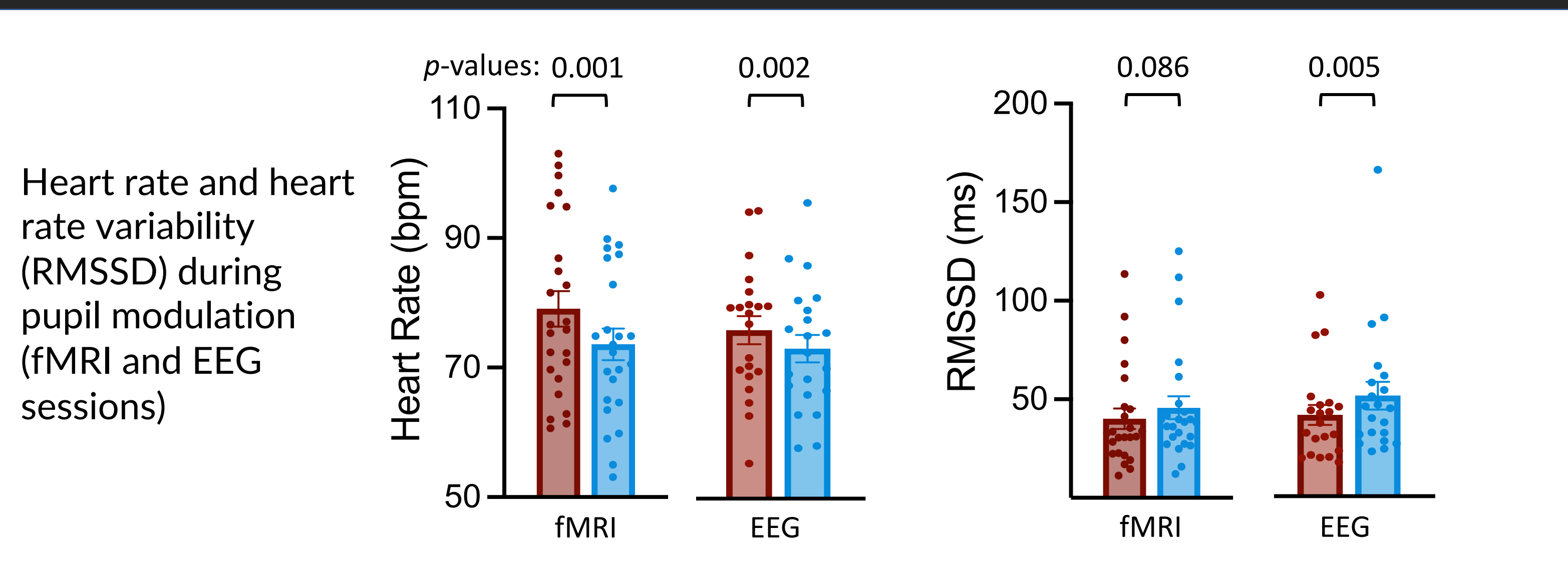
Such self-regulation is associated with BOLD activity changes in the locus coeruleus and other arousal-regulating brainstem areas,



with changes in electrophysiological arousal markers



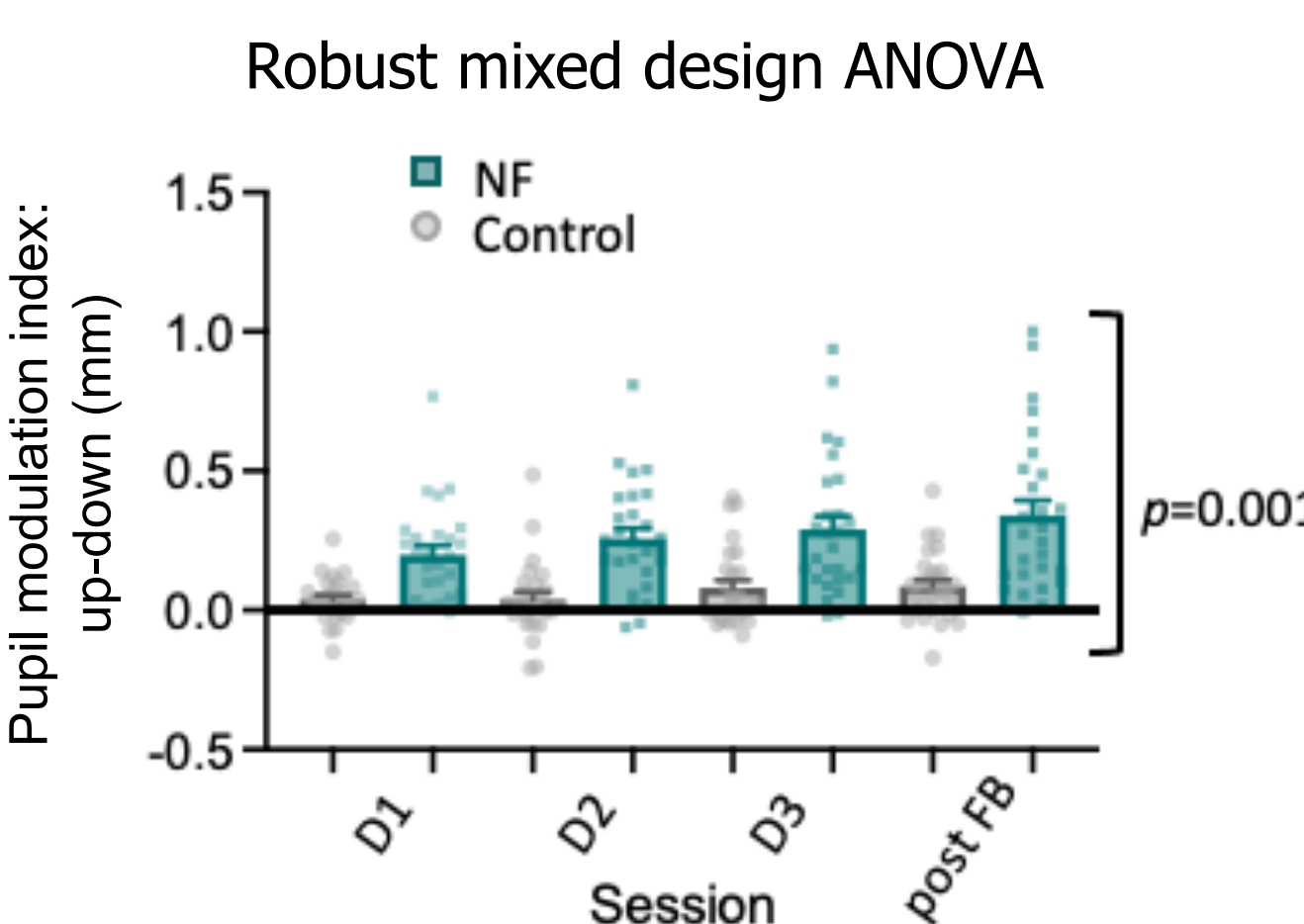
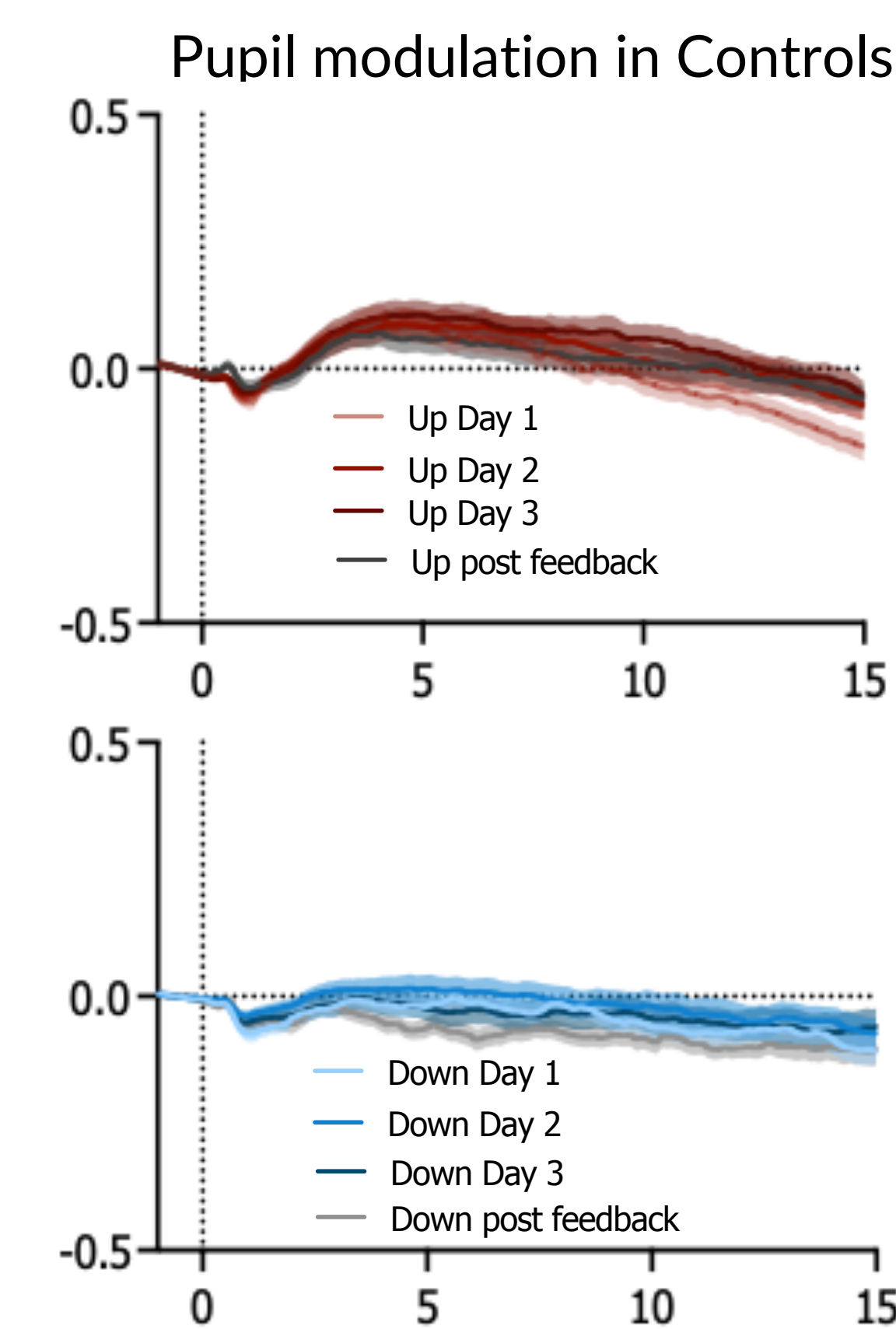
and cardiovascular arousal markers



- 1 Aston-Jones & Cohen, 2005
- 2 Zerbi et al., 2019
- 3 Murphy et al., 2014
- 4 Joshi et al., 2020
- 5 Kret & Sjak-Shie, 2018
- 6 Bianciardi, 2021
- 7 Donoghue et al., 2020
- 8 Woolrich et al., 2004
- 9 Brooks et al., 2008
- 10 Pedroni et al., 2019

Additional Information

Self-regulation of pupil size is clearly reduced in the control group that received no veridical feedback



fMRI (pre-)processing

common approach

- high-pass filter
- motion correction
- spatial smoothing (3mm FWHM)

additional steps

- ICA and PNM₍₈₎ to de-noise the data
- optimal HRF convolution (FLOBS₍₉₎)

EEG (pre-)processing

- Automatic pipeline⁽¹⁰⁾
- PSD calculated using Welch's method (1-45 Hz)
- Estimation of the spectral slope using the FOOOF toolbox⁽⁷⁾

Next big question

What are the effects of pupil-NF in applied contexts?

Sarah Meissner, Marc Bächinger, Sanne Kikkert, Jenny Imhof, Silvia Missura, Manuel Carro Dominguez, Nicole Wenderoth

Neural Control of Movement Lab,
Department of Health Sciences and Technology, ETH Zürich, Switzerland

sarah.meissner@hest.ethz.ch

@Sarah__Meissner