Towards a System-Level Physiology of Stimulus Anticipation, Visual Perception, and Decision Confidence

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BACKGROUND

- The brain constantly communicates with visceral organs such as the heart and lungs, which also communicate between each other[1]. Here, we investigate these interactions throughout stimulus anticipation, visual stimulus detection, and post-perceptual decision-making processes by using a visual threshold detection task.

STIMULUS ANTICIPATION

- Heart rate decreases during stimulus anticipation, known as "Anticipatory Cardiac Deceleration" (ACD)[2]. This may facilitate exteroceptive processing by attenuating baroreceptor 'noise'.
- Stimulus anticipation may also decrease the cortical responses to each heartbeat, known as Heartbeat Evoked Potentials (HEP)[3] (HEP computation is illustrated on the right side).
- Respiration also modulates the heart rate constantly due to respiratory sinus arrhythmia[4]. Interactions between the anticipatory and respiration-based heart rate modulation is not characterized yet.

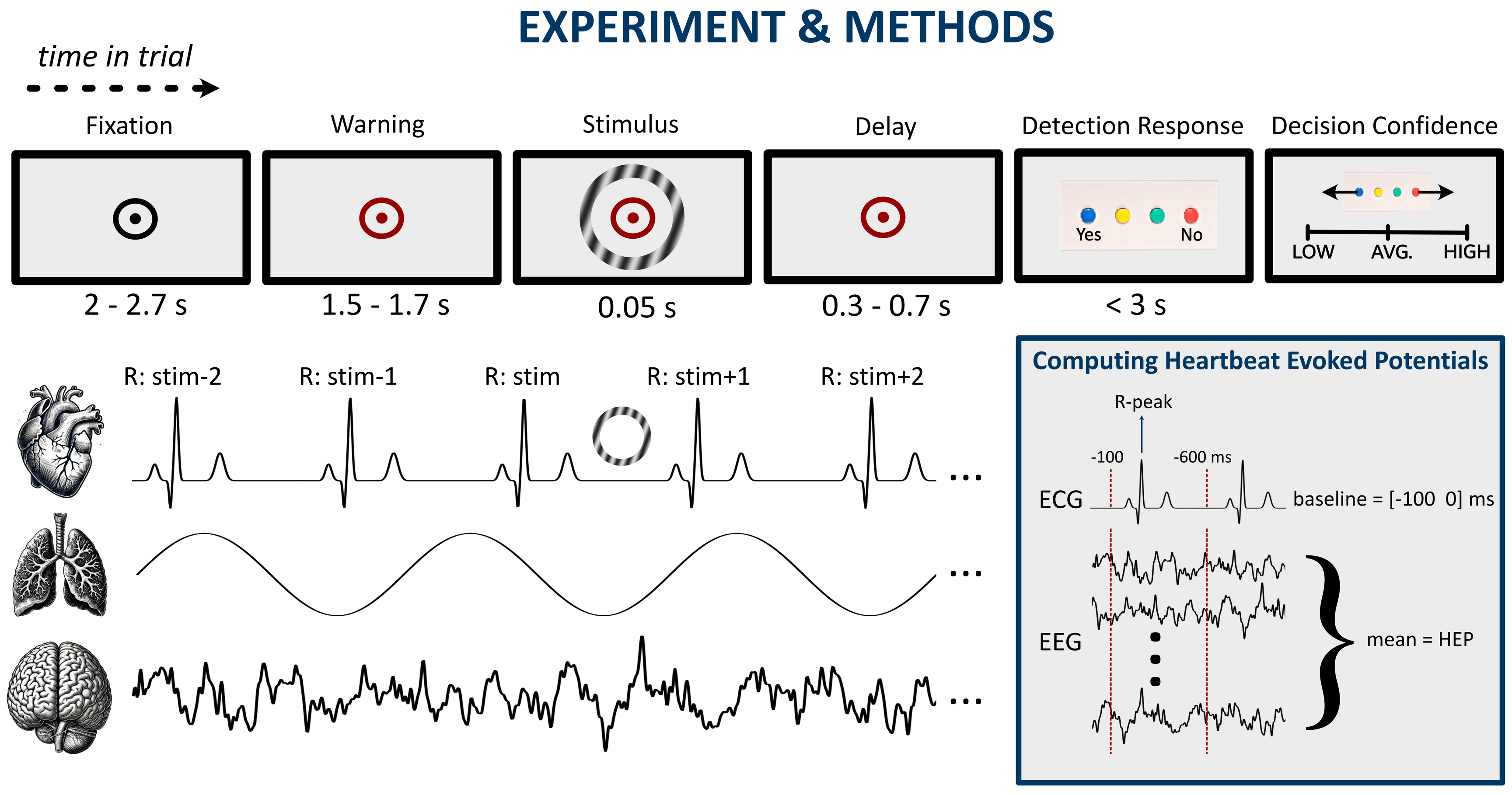
CARDIORESPIRATORY STATE AT STIMULUS ONSET

- Cardiac and breathing phases at stimulus onset may modulate perceptual performance, but the findings are inconsistent. Some results suggest that increased baroreceptor activity at systole decreases perceptual performance[5], while others find null results[6].

POST-PERCEPTUAL PROCESSES

- After stimulus onset, ACD is reversed and heart rate increases again. This acceleratory rebound is larger when subjects are confident about their perceptual decisions in a somatosensory task[4]. Generalization across sensory domains has not been tested.
- Post-stimulus HEPs between stimulus onset and confidence report may predict decision confidence levels. HEPs from this time window are not widely studied yet, unlike pre-stimulus HEPs.

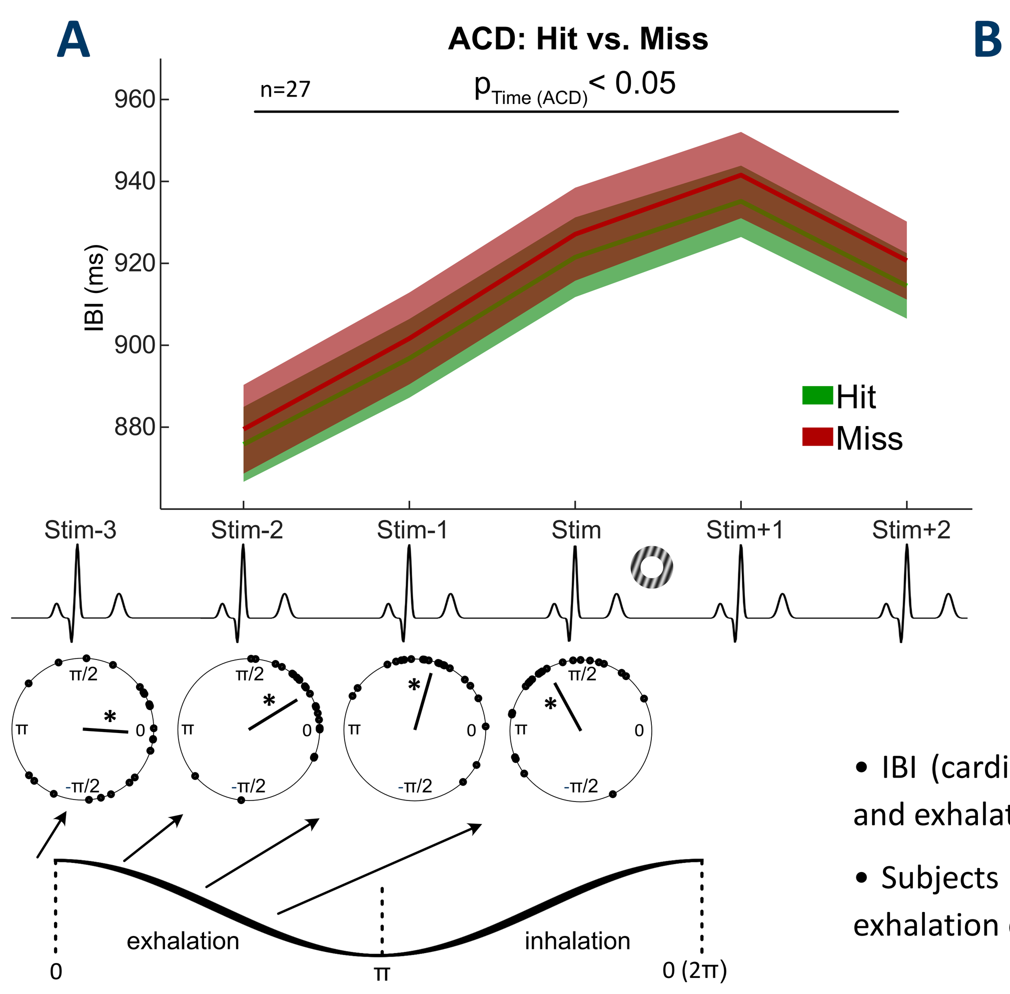
EXPERIMENT & METHODS

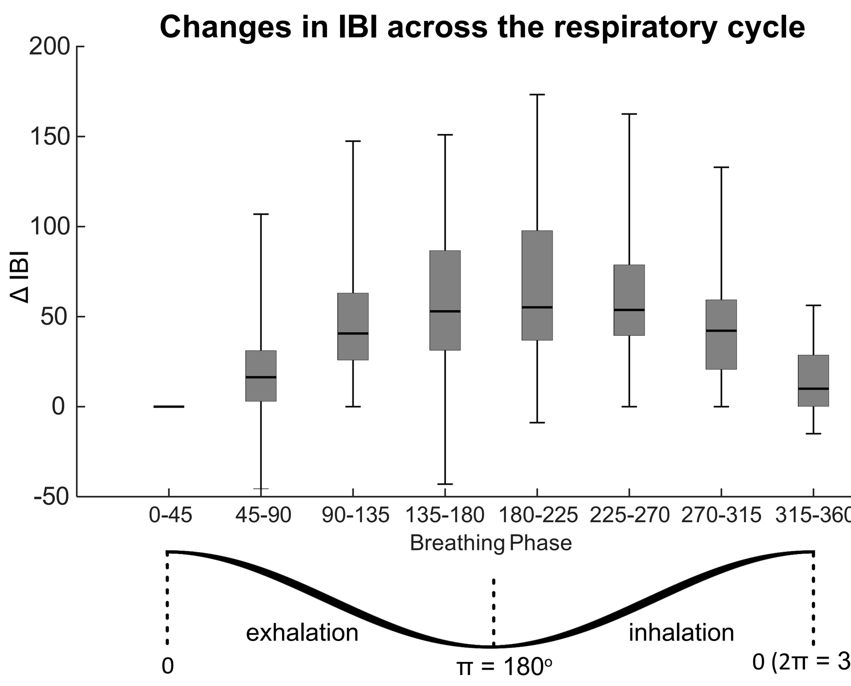


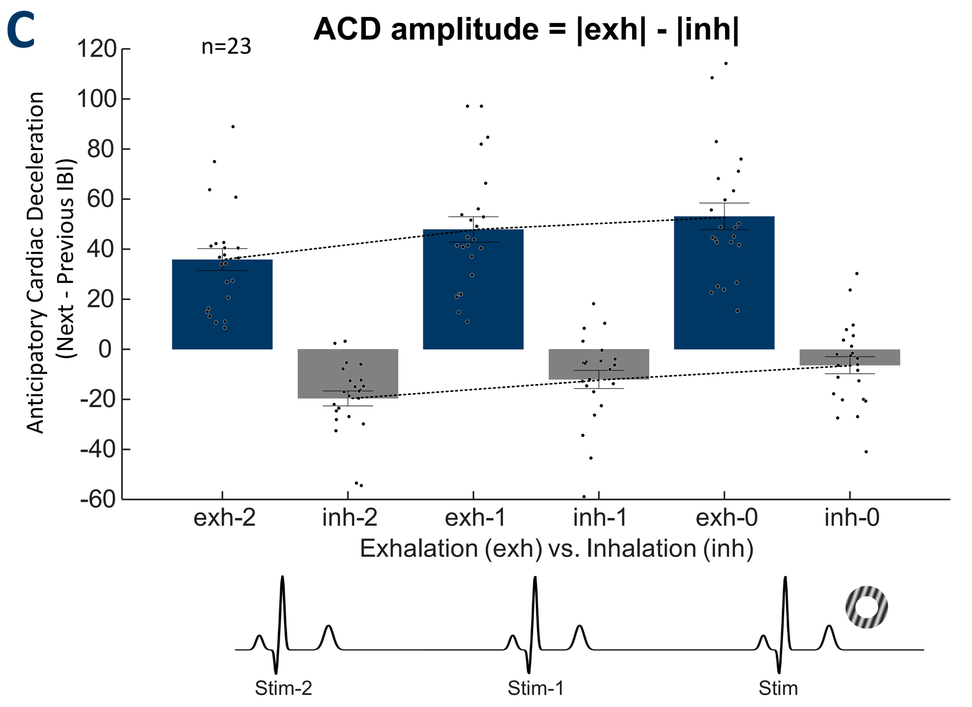
- First row summarizes a single trial. Each subject underwent 6-8 blocks of 60 trials each (87% stimulus present, 13% stimulus absent).
- Contrast was dynamically adjusted with the QUEST algorithm if accuracy in the last 10 trials was not between 40-80% (~60% hit rate).
- n=28 young and healthy subjects participated (12 male, 16 female; age: 25.82 ± 0.57 (mean ± s.e.m.)). 1 subject was excluded due to not completing the minimum number of trials. 4 more subjects were excluded from only breathing-related analyses due to low signal quality. Non-overlapping 4 subjects were excluded from confidence-related analyses because their median confidence was 100%.

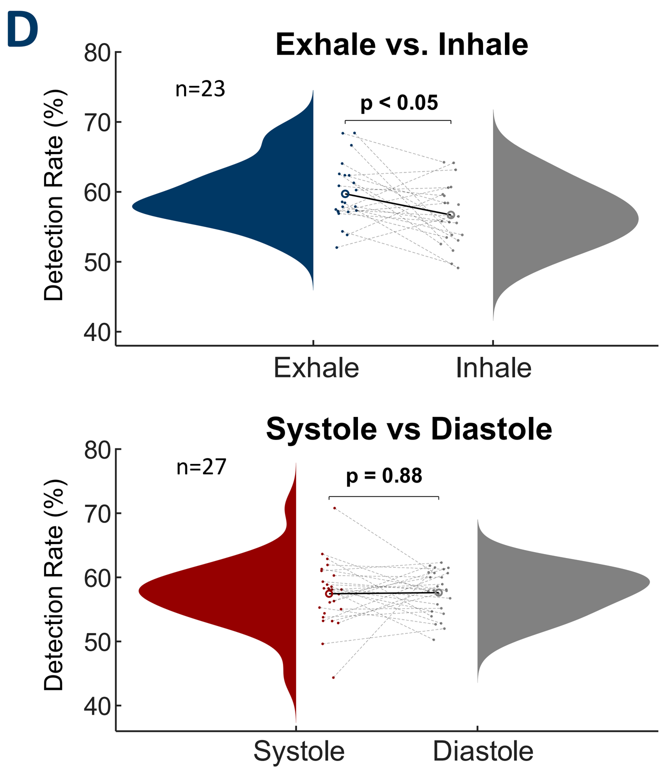
RESULTS

The Interplay Between Respiratory and Anticipatory Heart Rate Modulation



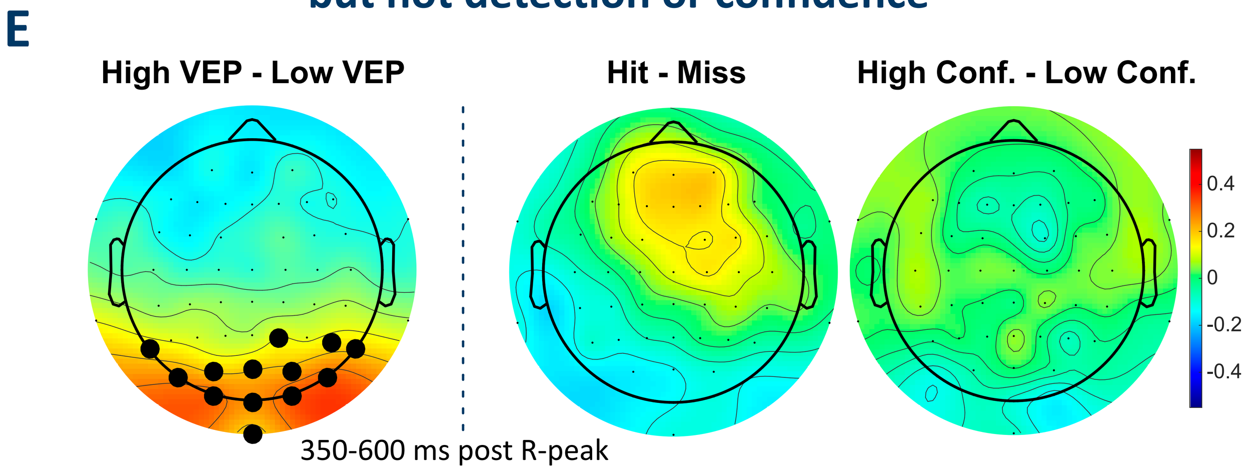






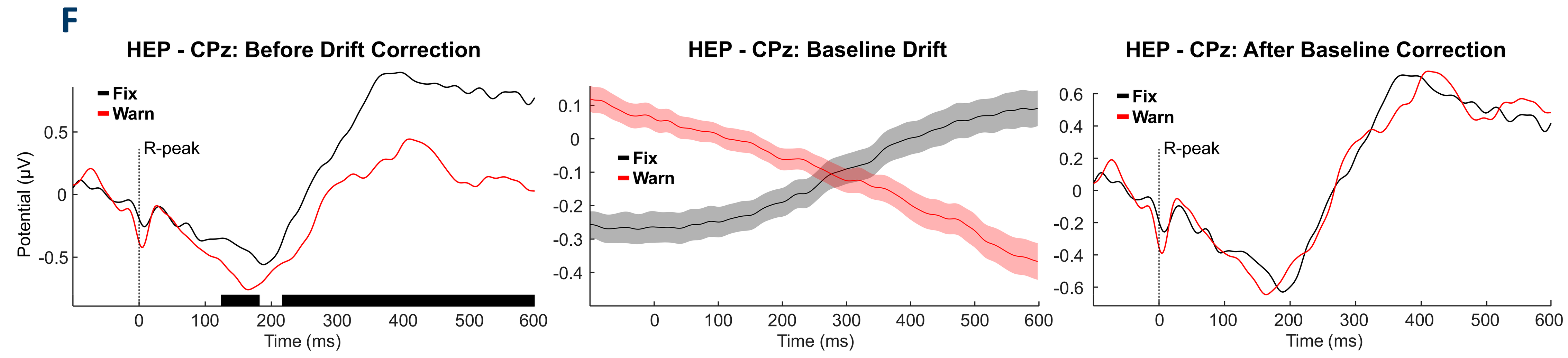
- IBI (cardiac period) increases during stimulus anticipation (**A-top**) and exhalation (**B**).
- Subjects adjust their breathing phase to advancing phases of exhalation during the anticipatory window (**A-bottom**).
- Respiratory sinus arrhythmia slows the heart rate during exhalation, and speeds it up during inhalation ($p_{Breathing}$<0.05). Cognitive effect of anticipation exerts a gradually increasing effect of cardiac deceleration (p_{Time}<0.05), irrespective of the breathing phase ($p_{[Time\ x\ Breathing]}$=0.24).
- Breathing phase (**D - top**), but not cardiac phase (**D - bottom**) modulates visual detection rate.

HEP amplitude predicts visual ERPs but not detection or confidence



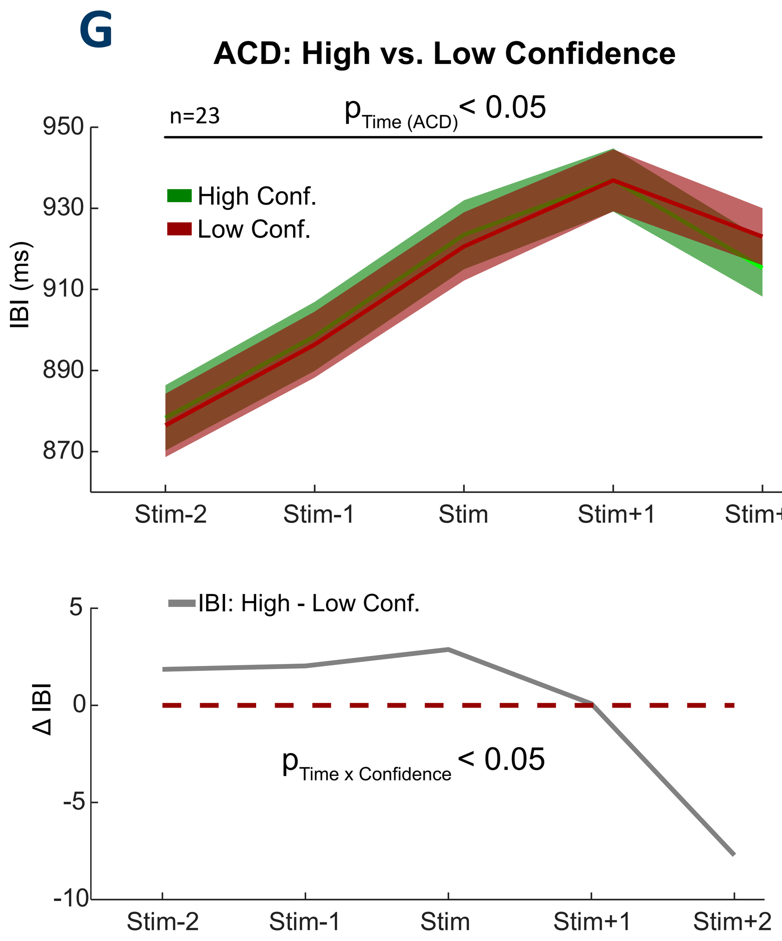
- HEPs from the 'Warning' period are higher in a parieto-occipital cluster (thick black electrodes) in trials with high visual ERP (VEP) in response to the stimulus (**E - Left**).
- No significant difference was found in the average HEP amplitudes between Hit vs. Miss (**F - middle**), or High vs. Low confidence conditions (**E - right**).

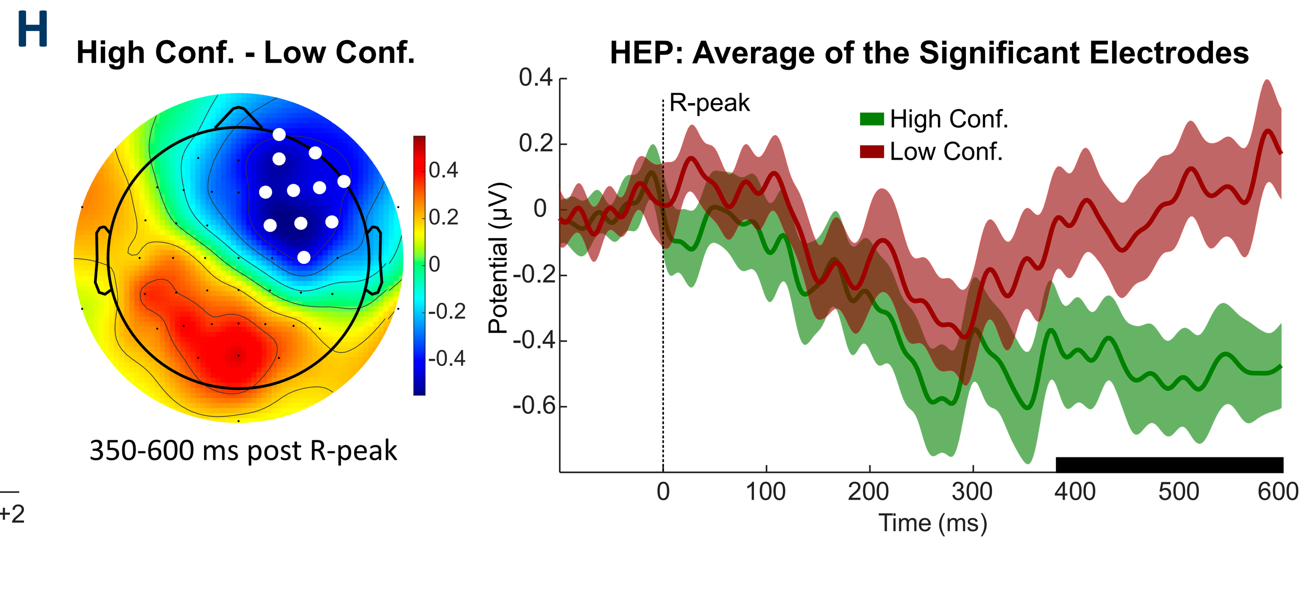
No Effect of Stimulus Anticipation on HEP Amplitude



- After only traditional baseline subtraction (**F - Left**), HEPs seem to decrease significantly (thick black bars) in the 'Warning' period.
- However; this difference is caused by differing amounts of non-ECG-locked baseline drifts (Contingent Negative Variation (CNV)[7]) (**F - Middle & Right**).

Increased Post-Perceptual Heart Rate Acceleration and Decreased Fronto-Central HEP Amplitude under High Confidence





- High confidence is associated with a larger acceleratory rebound (**G**), similar to the results from Grund et al. (2022)[4], which used a somatosensory detection task.
- HEPs time-locked to the first post-stimulus R-peaks show significant decrease in a right fronto-central cluster (**H**).

DISCUSSION

- Stimulus anticipation increases cardiac deceleration during exhalation, and decreases cardiac acceleration during inhalation. Subjects adjust their breathing phase to exhalation throughout the anticipatory window. Since stimulus detection rates are also higher when stimulus onset coincides with exhalation, this adjustment might be adaptive.
- Pre-stimulus HEP amplitudes in a parieto-occipital electrode cluster positively correlates with visual ERP amplitudes, but the correlation does not transfer to behavioral parameters of stimulus detection and confidence.
- Stimulus anticipation decreases heart rate (ACD), but not the cortical responses to the heartbeats (HEP), in contrast with the baroreceptor hypothesis[2,8], but in line with a recent preprint[3].
- Since our 'Delay' window is quite short (0.3 - 0.7 s), post-perceptual results include motor response confounds and are preliminary at best. We will conduct a follow-up experiment with an extended delay. Instantaneous heart rate and HEPs in an extended delay period might contribute to our '*gut feeling*' about a recent decision, hence modulating our decision confidence.

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