Affective expectations are modulated by the interplay between visceral signals and uncertainty of the sensory environment

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Introduction

- There is a growing consensus in perception science that expectations shape how we see the world and monitor our feelings (Allen et al., 2016; De Lange et al., 2018). In particular, the numerous theories now emphasize an important role for interoceptive inferences in shaping our exteroceptive perceptual consciousness, yet little evidence exists for this (Al et al., 2020).
- Here, using a novel perceptual learning task, we analysed how cyclic fluctuations in visceral signals in the cardiac domain influence affective perceptual inferences in a face discrimination task (Grund et al., 2022; Sherman et al. 2022).

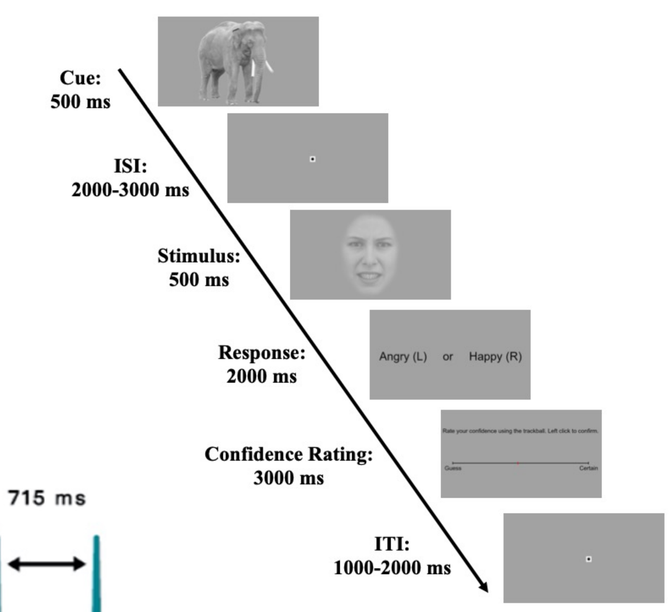
Conclusion

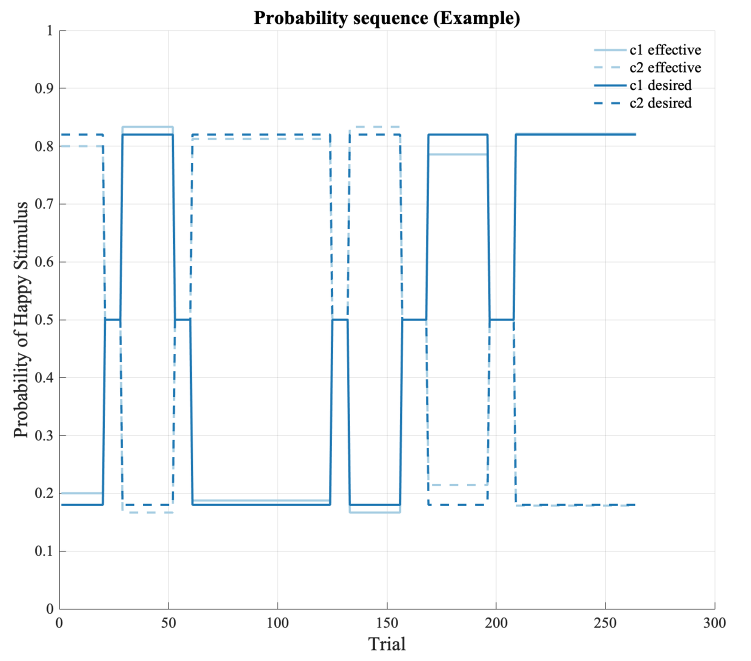
- We found evidence that the cardiac dynamics over the entire trial encode sensory uncertainty, and affective valence.
- We identified effects of these behavioural indices on confidence, choice, reaction time, and accuracy.
- These results show that there is a top-down modulation, whereby the visceral signals are adapting to the perceived characteristics of the sensory environment, as well as a bottom-up modulation, whereby the phase of the visceral signals cycles influence perceptual and metacognitive biases. Perceptual consciousness in the affective domain is modulated by this delicate balance.

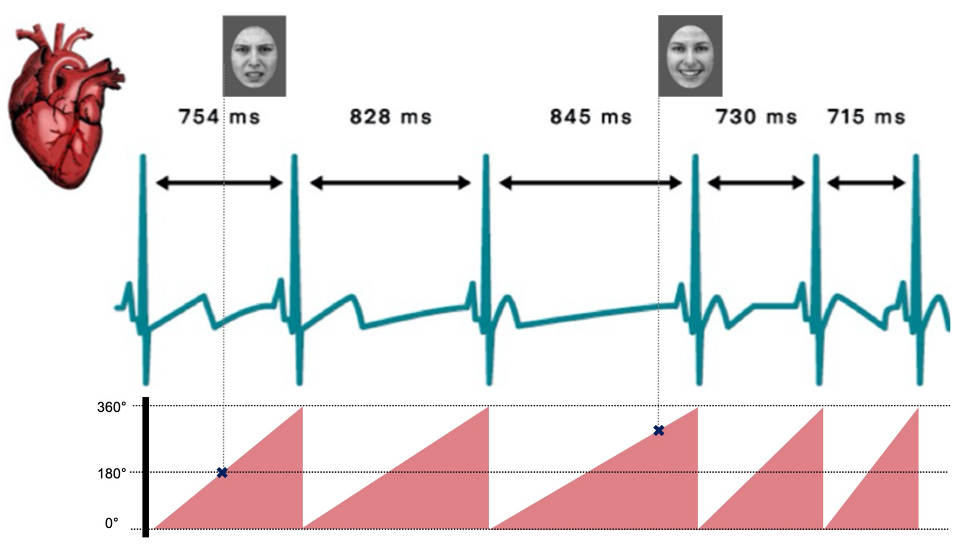
Methods

We used the Confidence Weighted Task (CWT), a novel perceptual and affective reversal learning task, while the cardiac signal was recorded. We contrasted both the sensory uncertainty or precision of the stimuli, and the expected precision of prior expectations. The behavioral analysis sample was n=245 and the physiological analysis sample was n=145, from a total sample of n=343 between 18 and 52 (231 females, median age 24).

- We tested whether sensory uncertainty, affective valence, and expectation influences a range of behaviors, such as confidence, choice, reaction time, accuracy.

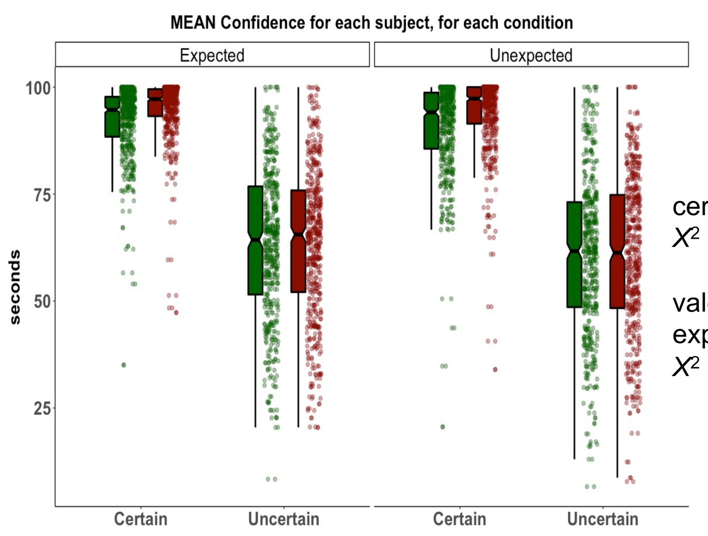






- We also tested if CWT decision-making and learning correlates with the cardiac cycle.
- Trials labelled based on cardiac phase angle.
- Behavioral parameters used individually as well as calculated in sliding window (width 45°).

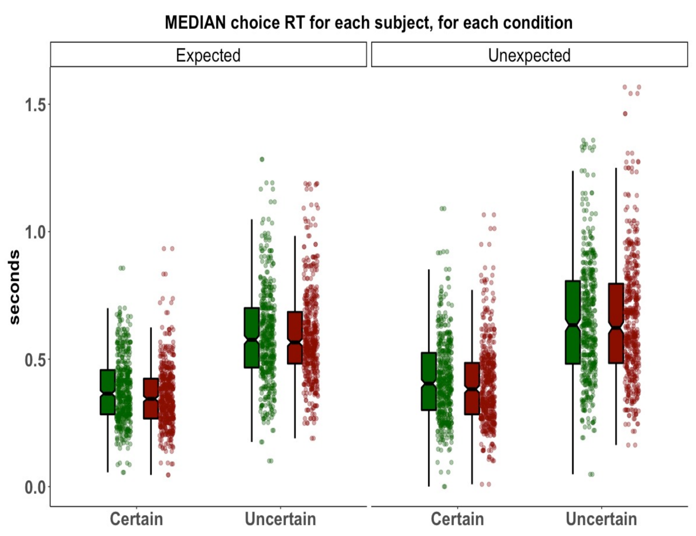
Results



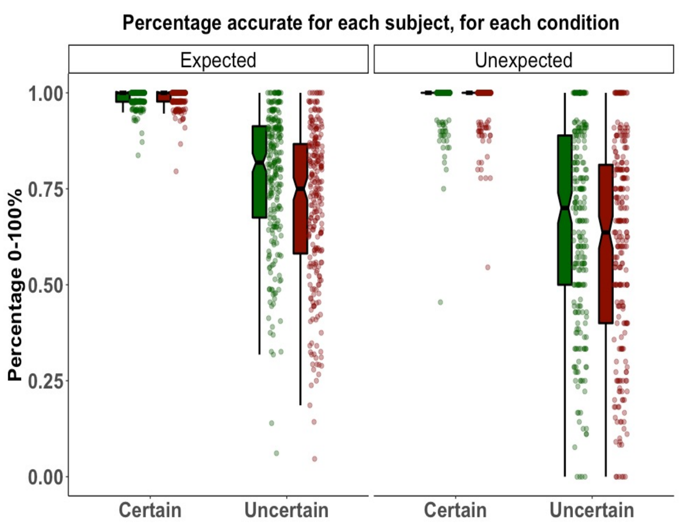
certainty : valence
X^2 = 55.3, p < .001

valence : sensory expectation
X^2 = 3.18, p = .074

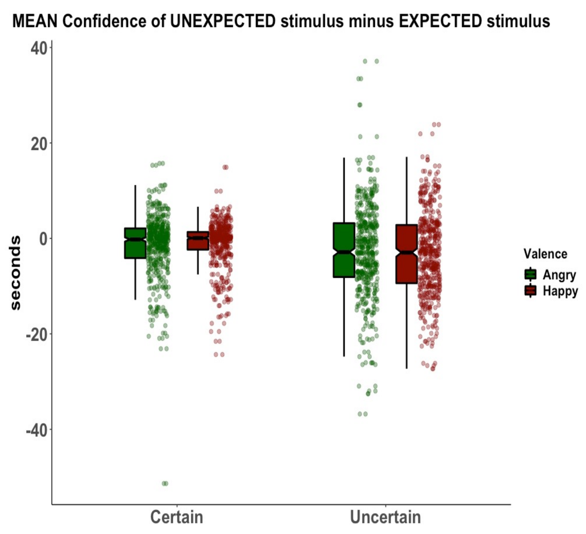
certainty : valence F = 39.86, p < .001
certainty : sensory expectation F = 4.32, p < .033



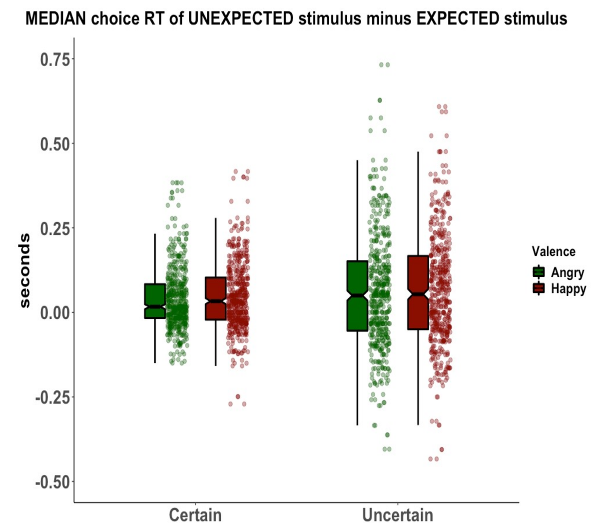
certainty : valence F = 13.71, p < .001
certainty : sensory expectation F = 4.32, p < .033



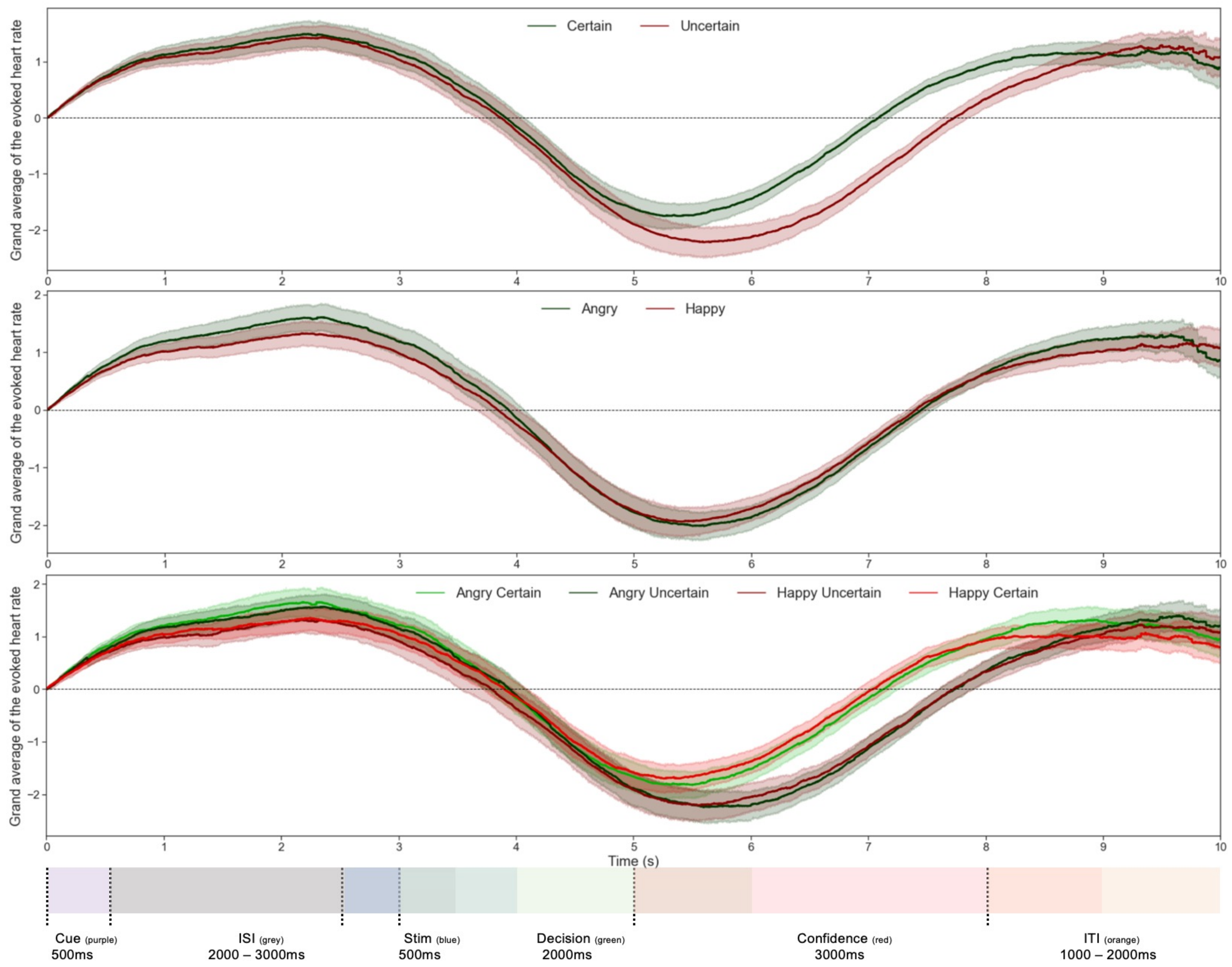
effect of certainty F = 18.43, p = .001



effect of certainty F = 10.07, p = .001



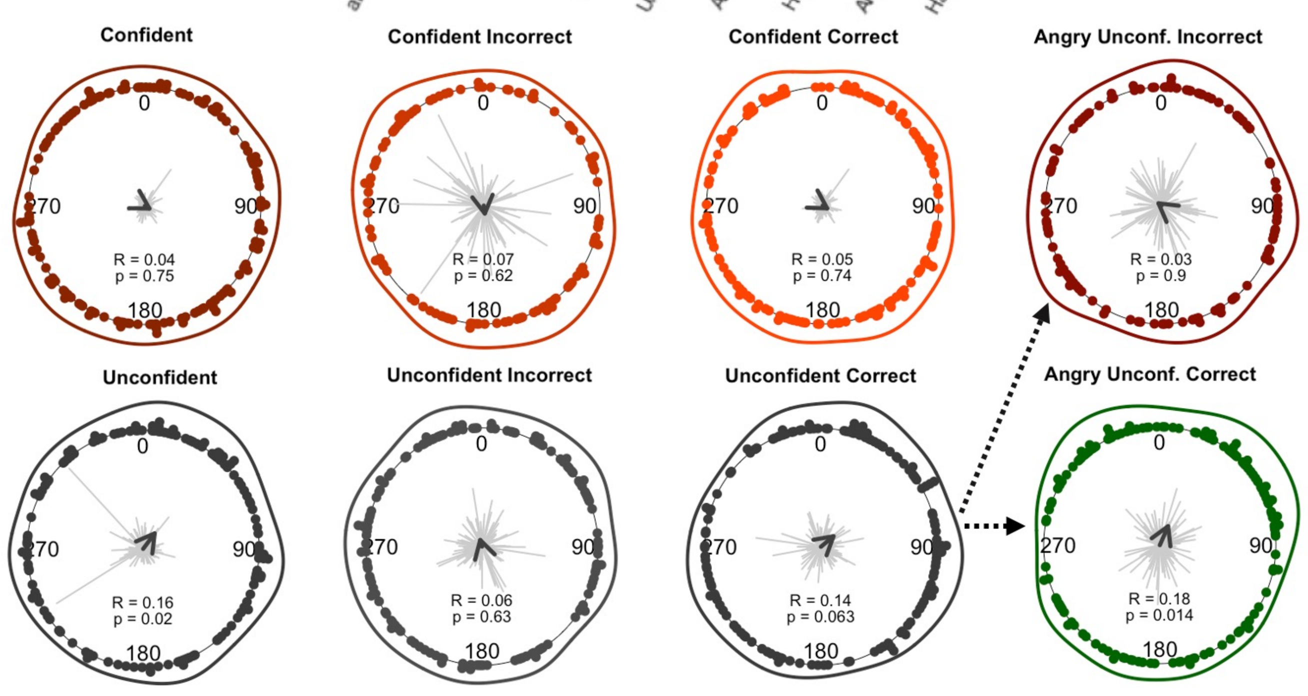
We identified a grand average effect of sensory uncertainty: during the decision-making and confidence rating phases of the trials, the heart rate decelerated for uncertain sensory stimuli in comparison to certain sensory stimuli. We identified a modest grand average effect of sensory valence: after cue presentation, there was a modest increase in heart rate for cue predicting negative affect in comparison to positive affect. The grand averages indicated no interaction effect on the heart rate dynamics.



Significance values for correlations between stim onsets cardiac angle and behaviour:

	all values	Angry	Happy	Certain	Uncertain	Ang. Cer.	Hap. Cer.	Ang. Unc.	Hap. Unc.
Cardiac angle ~ Conf.	0.38	0.17	0.85	0.62	0.15	0.62	0.29	0.008	0.93
Cardiac angle ~ Conf. (Cor.)	0.42	0.28	0.81	0.7	0.21	0.78	0.91	0.035	0.57
Cardiac angle ~ Conf. (Incor.)	0.29	0.19	0.76	0.68	0.29	0.21	0.7	0.15	0.89
Cardiac angle ~ RT	0.5	0.87	0.43	0.22	0.46	0.22	0.96	0.76	0.13
Cardiac angle ~ RT (Cor.)	0.73	0.89	0.41	0.38	0.94	0.35	0.85	0.52	0.36
Cardiac angle ~ RT (Incor.)	0.2	0.2	0.56	0.1	0.27	0.068	0.68	0.39	0.21

The cardiac angles of stimuli onsets correlated positively and significantly with confidence for uncertain sensory stimuli of negative affect (R=.032, p=.008). Breaking down by accuracy, this effect was significant for correct decisions (R=.031, p=.035), but not for incorrect ones (p=.15).



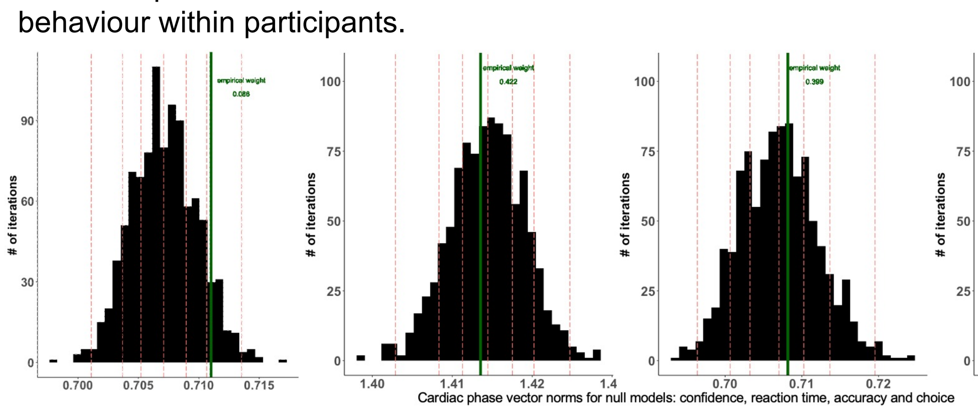
Distribution of mean angles of stimuli onsets relative to the cardiac cycle. Confidence of 70 was taken as breakpoint between confident and unconfident trials ([0-70%) unconfident trials, [70-100%] confident trials).

Participants were unconfident in their decisions more often for stimuli onsets in the early phases of the cardiac cycle – during systole – than during diastole (p = .02). Breaking down by accuracy, the uniform distribution was rejected. Further breaking down by affective valence, the ununiform distribution was accepted for unconfident correct decisions to negative sensory stimuli (p=.014).

Linear mixed effects modelling:

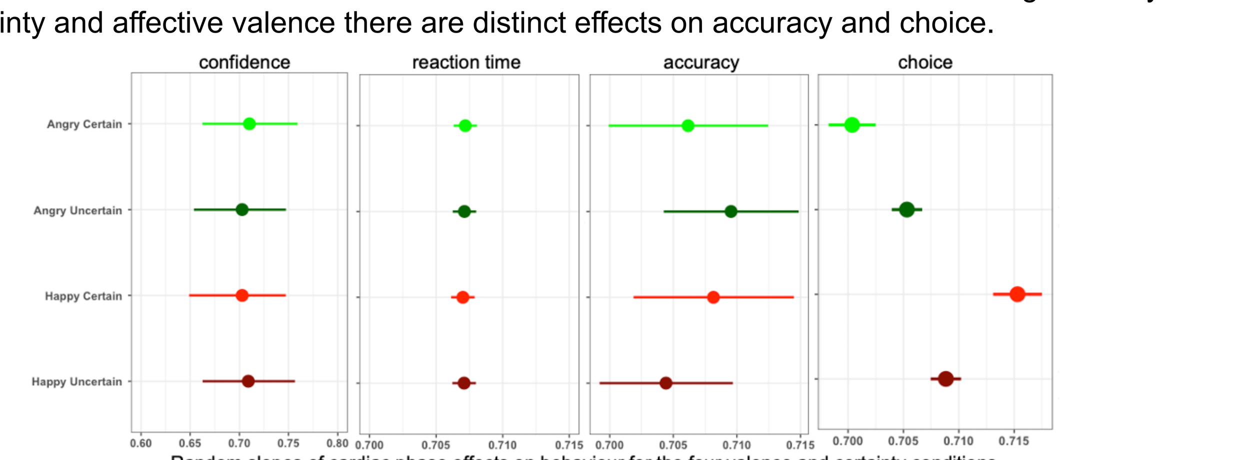
- Behaviour ~ $\beta_0 + \beta_1 * sin_{ecg} + \beta_2 * cos_{ecg}$ + 1 | subject

Significance was established by calculating the empirical vector norm from the beta weights of the empirical model to the vector norms of 1000 null models fitted after shuffling the behaviour within participants.

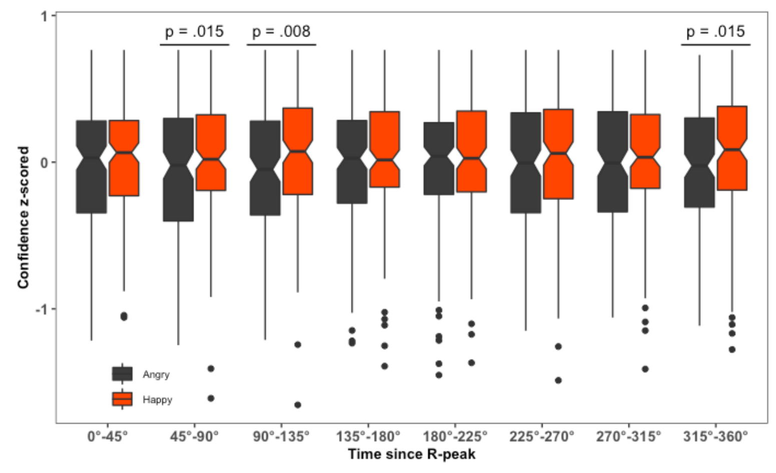


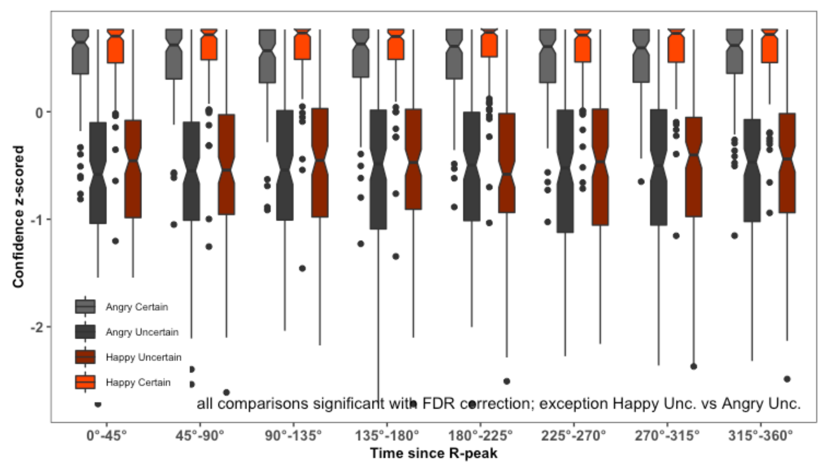
- Behaviour ~ $\beta_0 + \beta_1 * sin_{ecg} + \beta_2 * cos_{ecg}$ + (sin_{ecg} + cos_{ecg} | certainty / valence / subject)

There are different random slopes for the cardiac phase effect on accuracy and choice. The cardiac phase of the stimuli onsets alone does not influence behaviour. But when breaking down by sensory certainty and affective valence there are distinct effects on accuracy and choice.



Random slopes of cardiac phase effects on behaviour for the four valence and certainty conditions

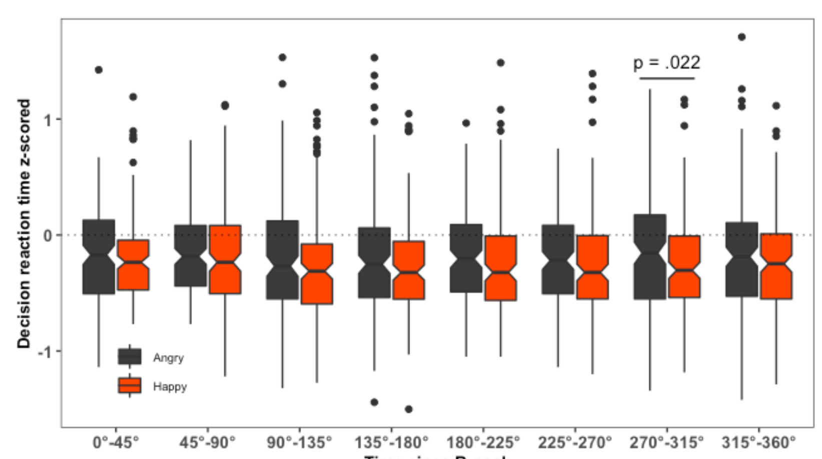


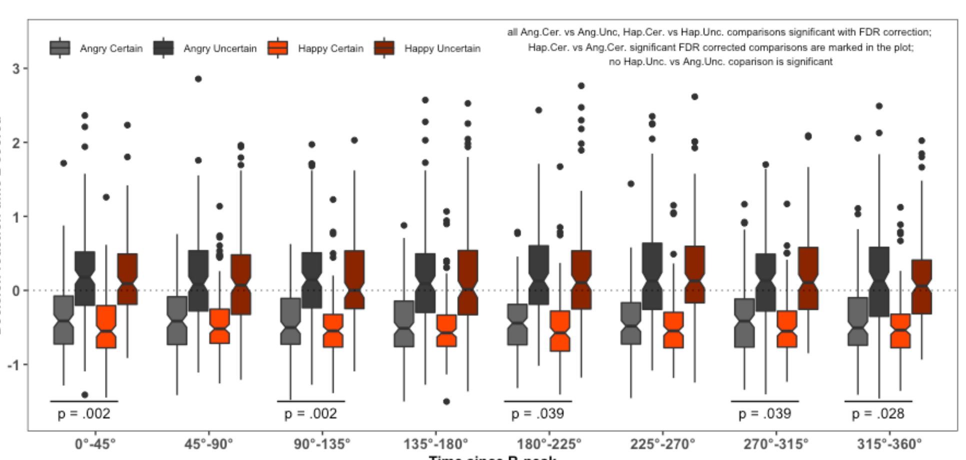


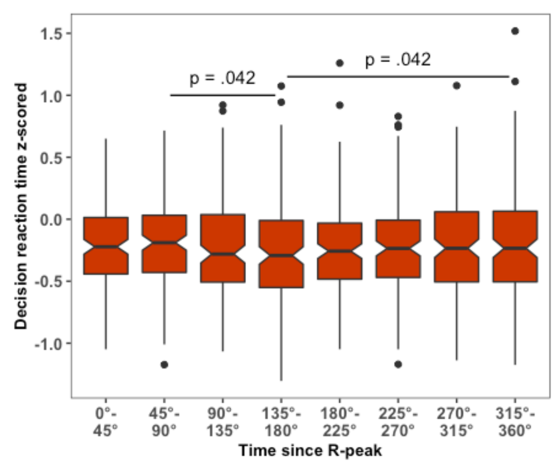
There is a significant difference in decision confidence between negative and positive stimuli during systole and late diastole.

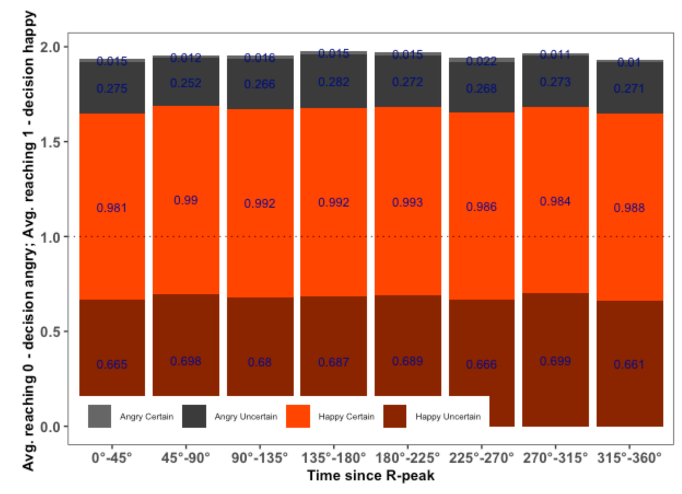
Decisions were made more rapidly during late systole and early diastole, than during early systole and late diastole.

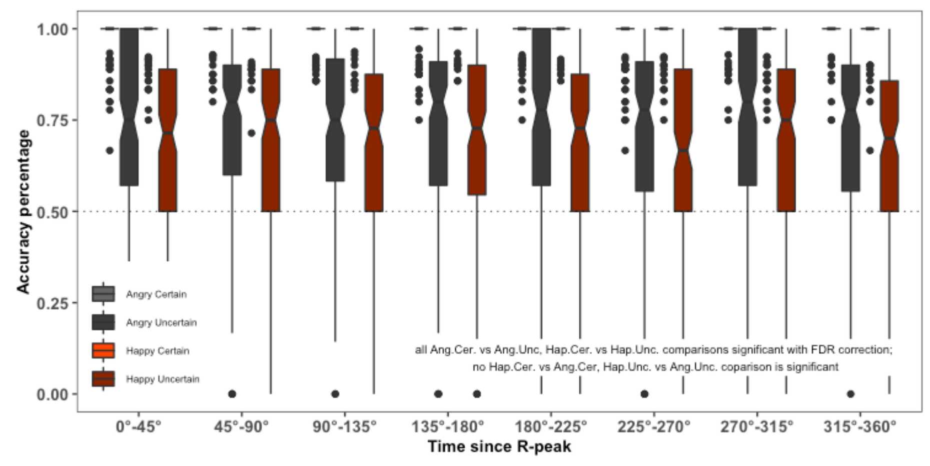
Significant difference in reaction time between negative and positive stimuli during late diastole.











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