痛み予測のボラティリティと関連する前島の活動

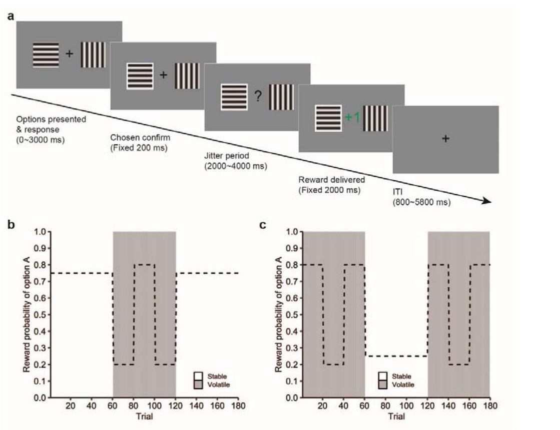
Anterior insular cortex activity associated with volatility in pain prediction.

前川亮，笹岡貴史，吉野敦雄，山脇成人
Toru Maekawa, Takafumi Sasaoka, Atsuo Yoshino, Shigeto Yamawaki
広島大学，脳・こころ・感性科学研究センター（Hiroshima University, BMK center）

Introduction

Volatility

In the reinforcement learning paradigm, volatility refers to the stability of the probability that a reward will be associated with a cue.

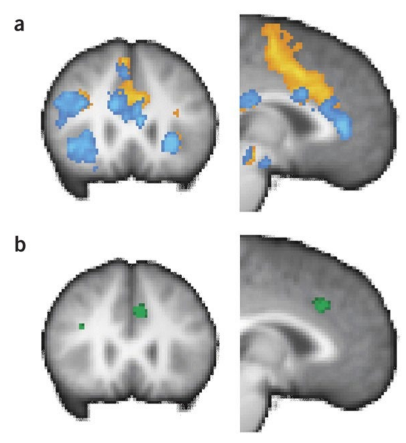


Xu et al. (2021)

Stable conditions
Participants must adapt slowly to reduce the effects of noise and to achieve stable behavior.

Volatile conditions
Participants should quickly adapt to continuous changes in the environment.

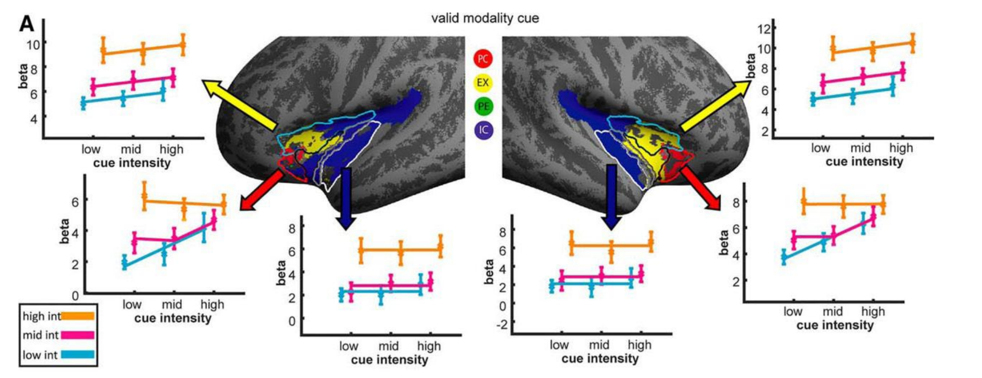
Stable ⇒ low learning rate
Volatile ⇒ high learning rate



Behrens et al. (2007)

Rewards × volatility interaction revealed activation in the ACC (green)

Pain prediction



Fazeli & Büchel (2018)

Pain perception
⇒ posterior insula
Pain prediction
⇒ anterior insula

Purpose

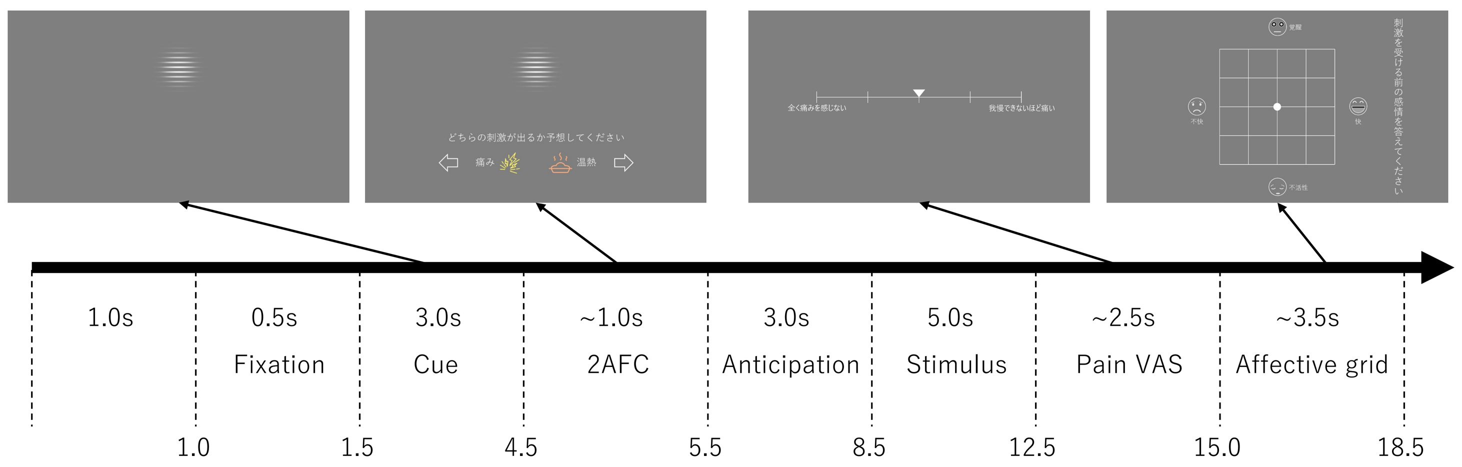
To examine brain activity related to volatility when pain is used as a stimulus.

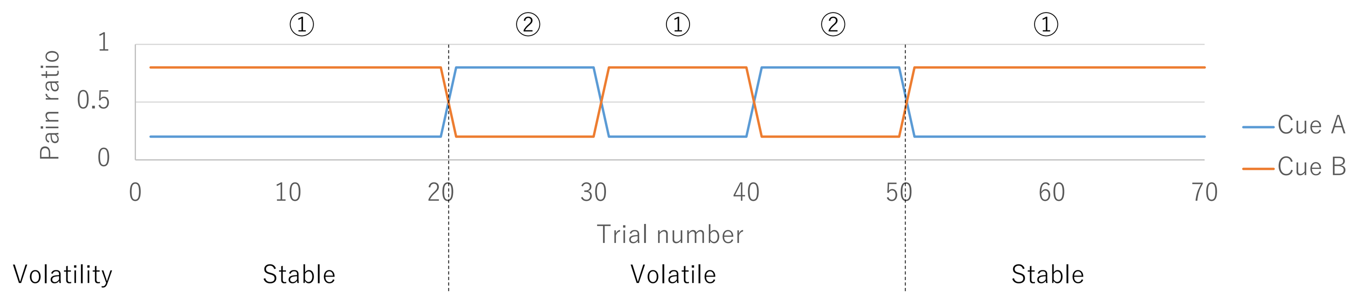
Methods

Conditions

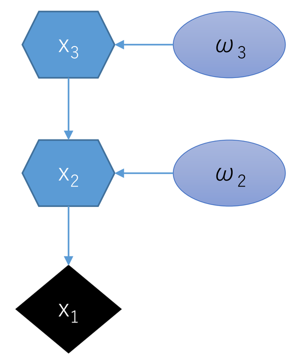
- Cue
  - A (Gabor 0°)
  - B (Gabor 90°)
- Heat stimuli
  - Pain (48°C)
  - Warm (35°C)
- Cue-stim probability
  ①A⇒P:80%, W:20% B⇒P:20%, W:80%
  ②A⇒P:20%, W:80% B⇒P:80%, W:20%
- Volatility
  - Volatile: probabilities switched every 10 trials
  - Stable: same probability lasts for 20 trials
- Physiological measures
  - PPG, Blood pressure, EDA, respiration, pupil size
- Questionnaire
  - MAIA, BDI, BRS, BPQ, JPSS

Procedure





Learning model



Learning rate and subjective volatility of each participant were estimated from their prediction responses using Bayesian hierarchical estimation.

$$x_3^{(t)} \sim N\left(x_3^{(t-1)}, exp(\omega_3)\right)$$ ➡ Volatility

$$x_2^{(t)} \sim N\left(x_2^{(t-1)}, exp\left(x_3^{(t)} + \omega_2\right)\right)$$ ➡ Probability of pain

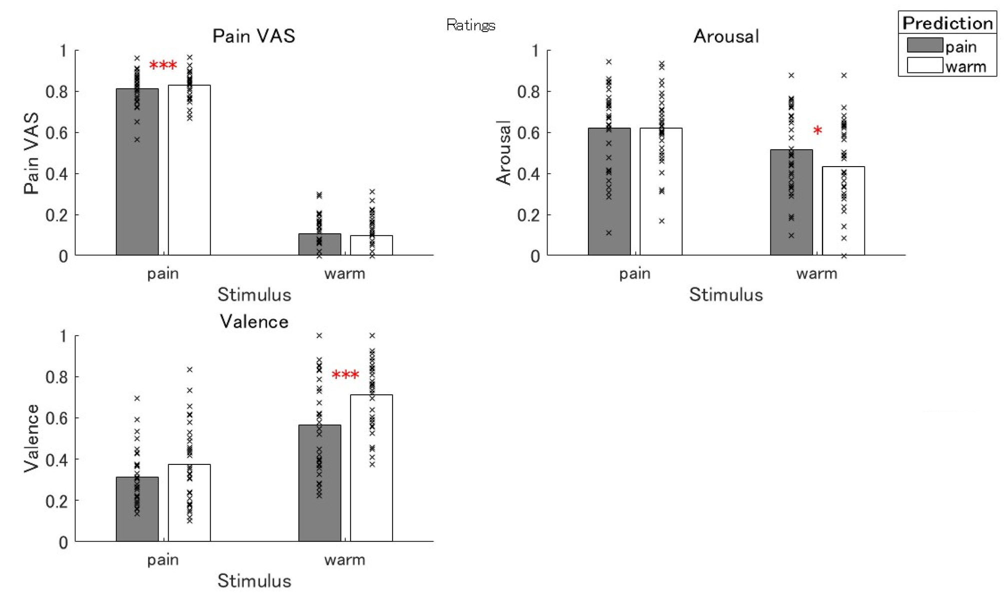
$$x_1^{(t)} \sim Bernoulli\left(s\left(x_2^{(t)}\right)\right)$$ ➡ Response

$$s(x) \triangleq \frac{1}{1+\exp(-x)}$$

Ref. Lawson et al., 2017

Behavioral results

Subjective rating

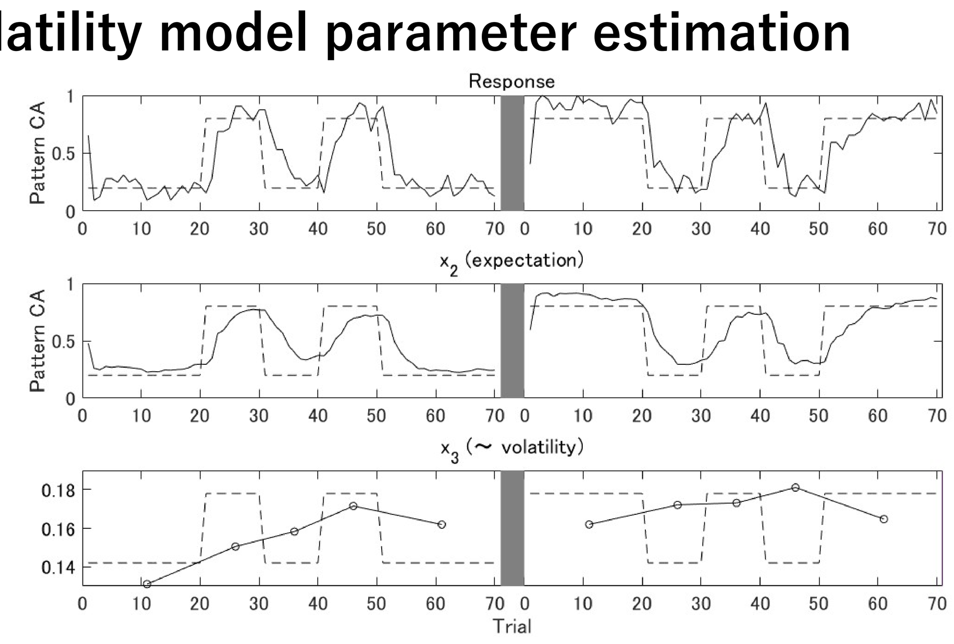


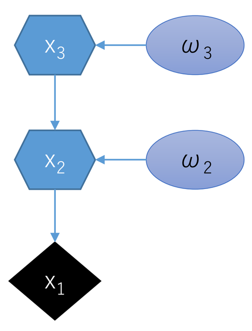
Pain perception (pain stimulation)
Warm prediction > Pain prediction

Arousal (warm stimulation)
Pain prediction > warm prediction

Valence (warm stimulation)
Warm prediction > Pain prediction

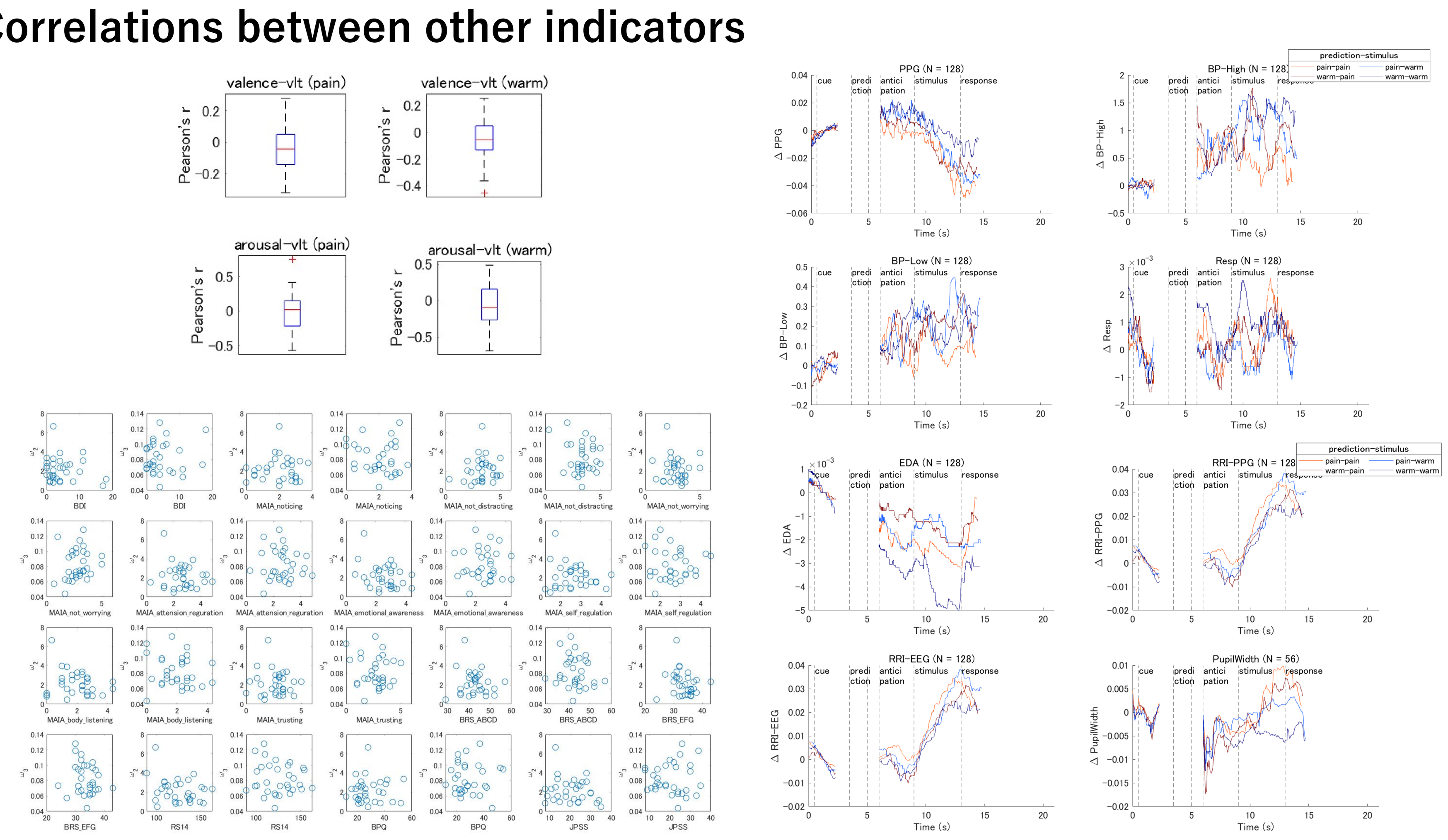
Volatility model parameter estimation





Estimate volatility parameters (x_2, x_3, ω_2, ω_3) for each participant based on prediction responses.

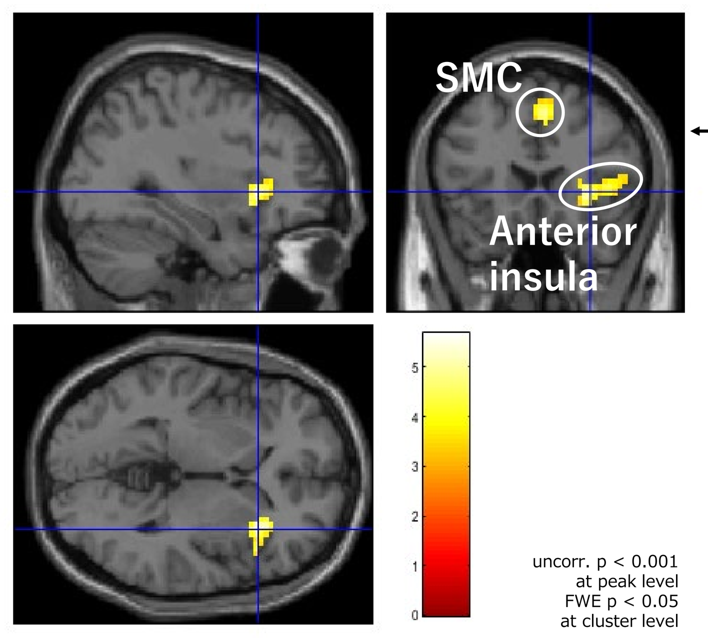
Correlations between other indicators



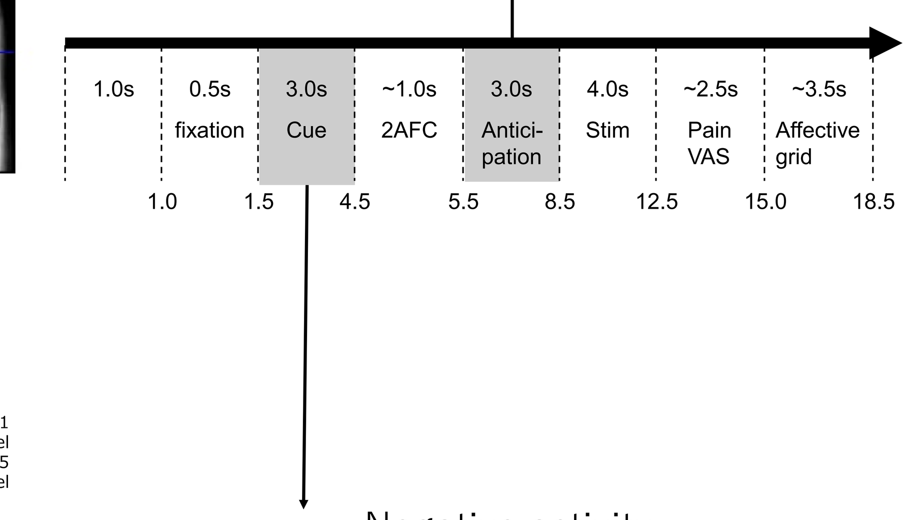
No significant correlation found between volatility parameters and emotion ratings, physiological measurements, and questionnaires

fMRI results

Activities associated with volatility analyzed by the parametric modulation

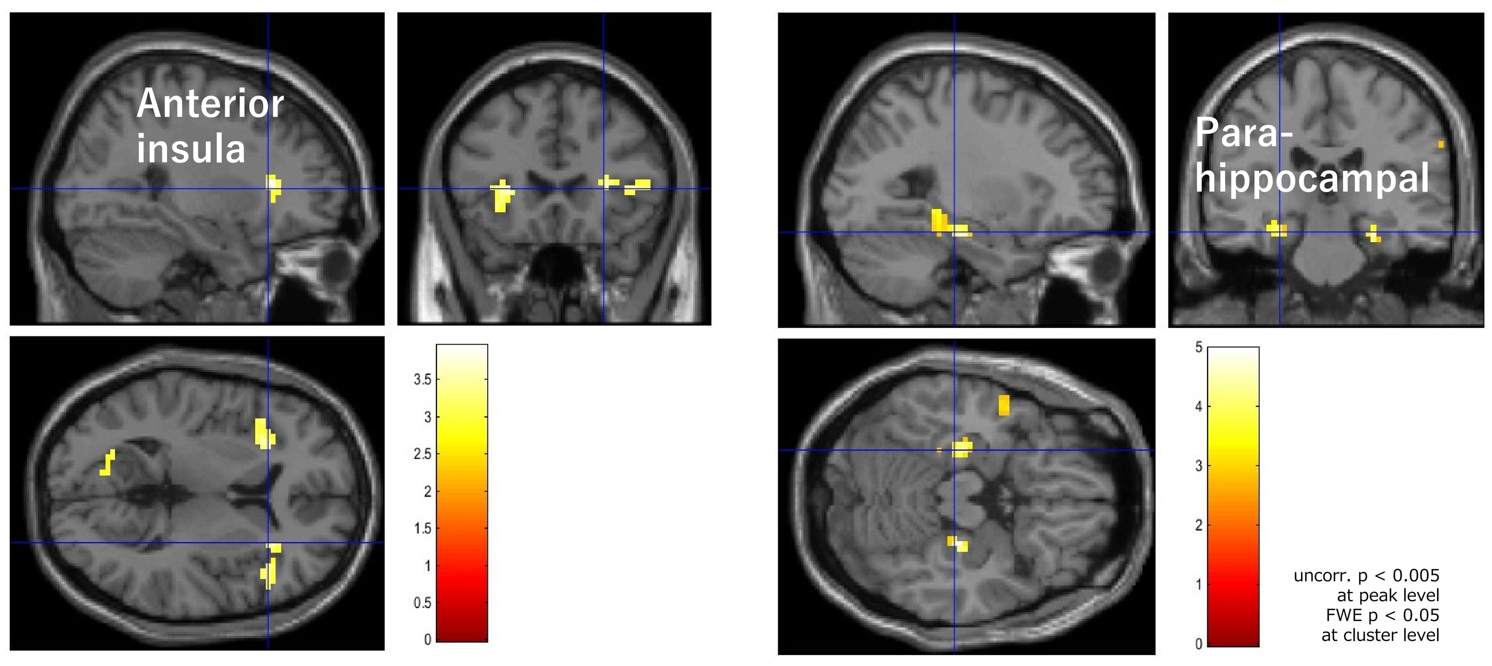


$$volatility \triangleq x_2(1-x_2) \cdot exp(x_3)$$



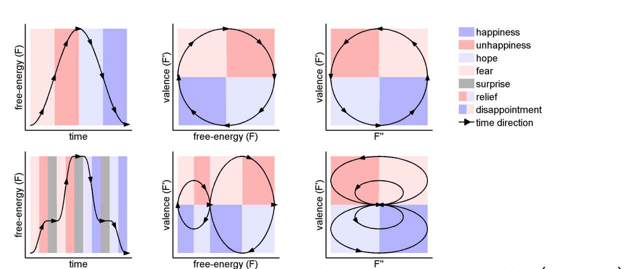
Positive activity

Negative activity



Discussion

- In the warm stimulus condition, valence was higher in warm predicted trials than in pain predicted trials.
  - ➢ Decreased free-energy was associated with better valence.



Joffily & Coricelli (2013)

- Volatility estimates for the anticipatory period were associated with activity in the anterior insula.
  - ➢ Pain-related volatility is processed in anterior insula, not ACC.
- Negative correlations with volatility (positive correlations with stability) were associated with activity in the parahippocampal gyrus.
  - ➢ Parahippocampal plays important role in memory encoding and retrieval (Brian et al., 1997).
  - ➢ In stable condition, participants have a stronger encoding of cues that is later recalled.

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