Cardiorespiratory Contributions to Sense of Agency and Voluntary Action Initiation

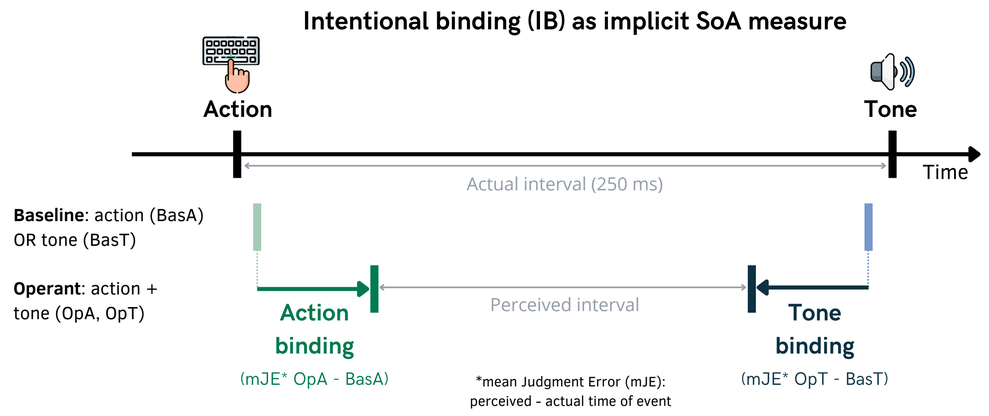
Gerosa, M.[1,2], **Haggard, P.**[3], **Villringer, A.**[1,2], **& Gaebler, M.**[1,2]

[1] Department of Neurology, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig;
[2] Berlin School of Mind and Brain, Faculty of Philosophy, Humboldt-Universität zu Berlin, Berlin;
[3] Institute of Cognitive Neuroscience, University College London, London.

OSF preregistration and poster PDF here:

INTRODUCTION

- **Sense of agency (SoA)**, the experience of controlling one's own actions and their effects [1], is traditionally thought to arise from successful sensorimotor integration [2].
- **Interoceptive signals** are proposed to contribute to **generation, control and self-attribution of motor acts**, with SoA arising from the reciprocal integration of interoceptive and sensorimotor prediction [3-4].
- **Voluntary action initiation** found to be **coupled with cardio-respiratory fluctuations** [5-6], which may provide a predictable reference frame in subjective agentic experiences [7].
- Yet, *whether* and *how* this coupling between voluntary action and cardio-respiratory signals influences SoA is still unclear [8-9].



RESEARCH AIMS

Investigate the link between cardio-respiratory signaling, voluntary action initiation and SoA.

Does the **cardio-respiratory phase bias for voluntary action initiation**, in turn, **influence SoA**, indexed by intentional binding?
- *H1: maximal distribution of action onsets in SYS and in EXP*
- *H2: stronger IB for actions at SYS vs. DIA, and EXP vs. INSP*

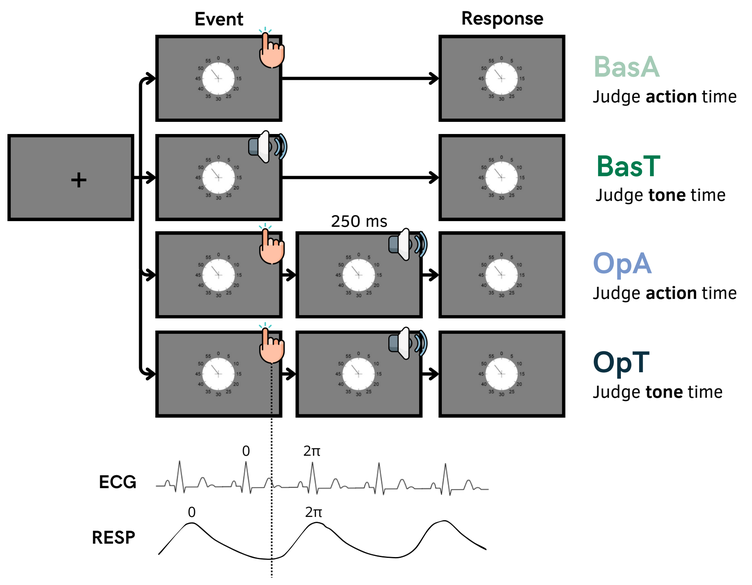
Does the **congruency between action and tone time** in same or different cardio-respiratory phases further influence SoA?
- *H3: stronger IB for actions & outcomes occurring in different vs. same cardio-respiratory phases*

Effect of **combined cardio-respiratoy phase-locking** on SoA?

METHODS

Intentional Binding task:
- **4 conditions** (blocked):
  - Block type: Baseline x Operant
  - Judged event: Action x Tone
- **60 trials each**
- Within-subjects, repeated measures

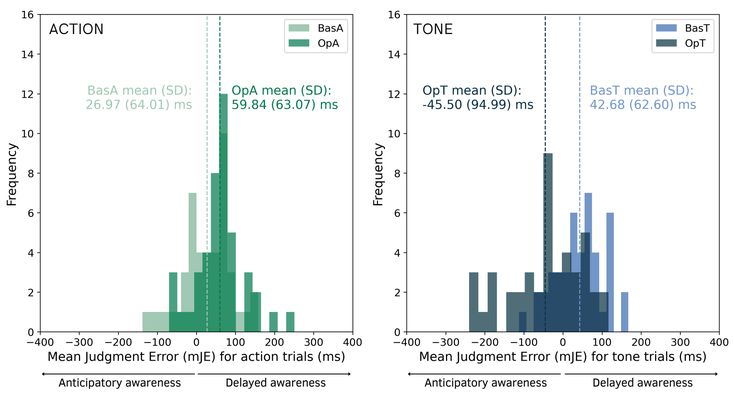
Participants:
- *n* = 44 (23F, 21M)
- Age: 28.70 ± 7.24 years (range: 18-44)
- Right-handed, normal BP (113.68/74.61 mmHg)



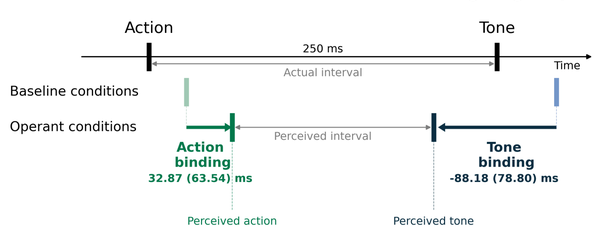
RESULTS

IB task: behavioral measures

Distribution of judgment errors in Baseline vs. Operant blocks



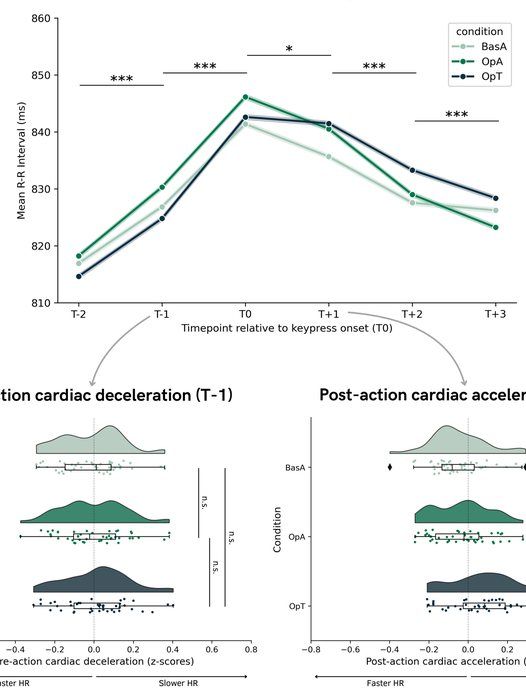
Schematic overview of action and tone binding at group level



Action and tone binding shifts in line with prior literature [1,10].

ECG analysis: pre-post RR changes

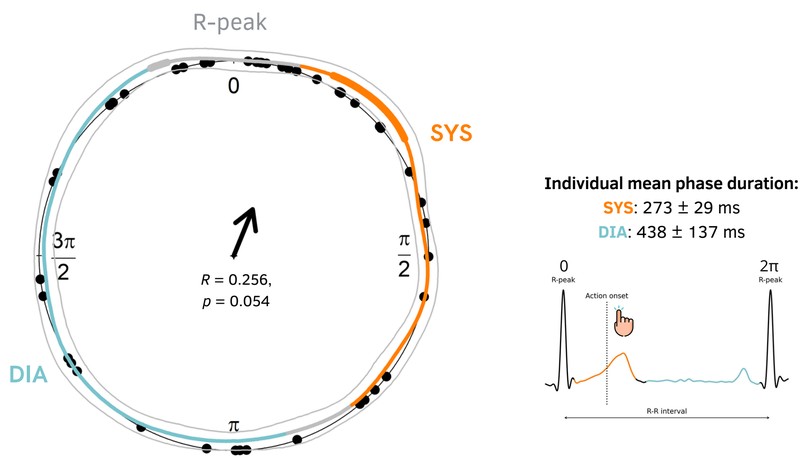
Pre- and post-action onset changes in RR interval



Pre-action cardiac deceleration regardless of condition, but delayed post-action cardiac acceleration when reporting tone time (OpT) vs. action time (BasA, OpA)

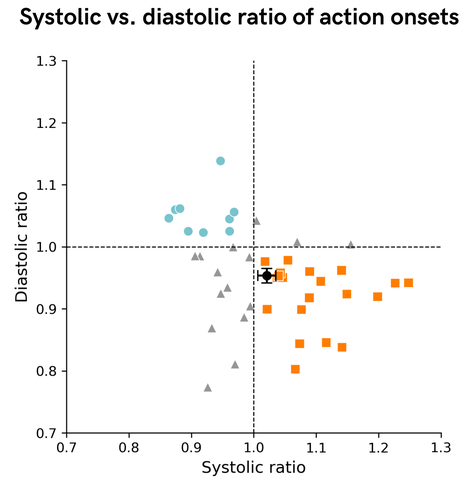
ECG analysis: circular and binary

Distribution of mean action onsets relative to cardiac cycle



Individual mean phase duration:
SYS: 273 ± 29 ms
DIA: 438 ± 137 ms

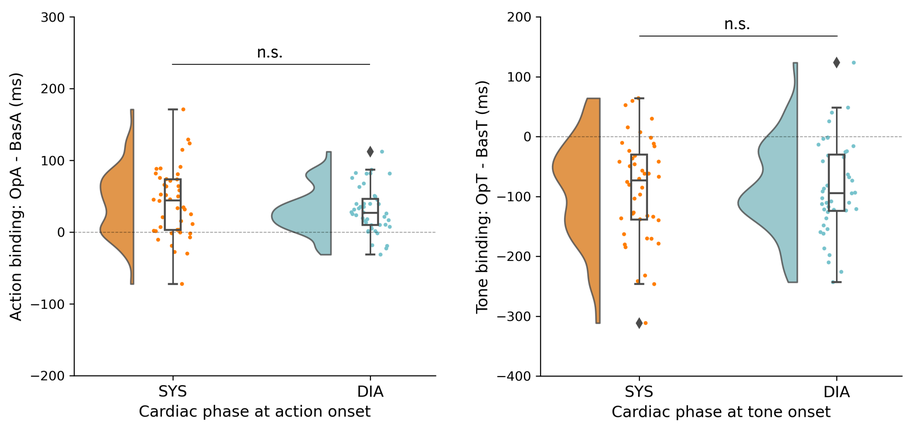
Systolic vs. diastolic ratio of action onsets



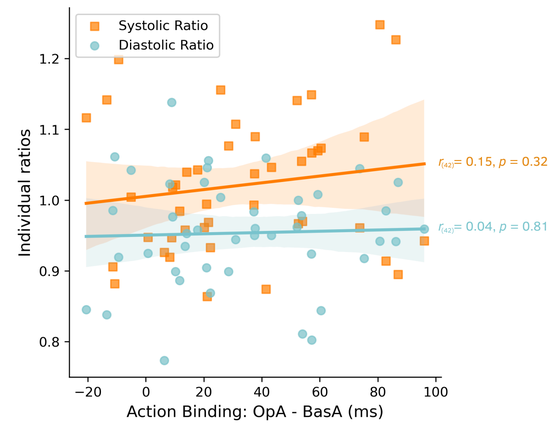
H1 Non-significant trend towards non-uniformity of distribution (M = 0.12 π, ϱ = 0.256), but non-parametric bootstrapping shows significant accumulation of action onsets in early systole (0.19 - 0.34 π).

H1 Significantly larger ($t_{(43)}$= 3.13, p = 0.003, Cohen's d = 0.77) ratio of action onsets in systole (1.02 ± 0.1) as compared to diastole (0.95 ± 0.08), when normalized by the relative phase proportion in RR interval.

Effects of cardiac phase at action/tone onset on intentional binding



Correlation of cardiac phase ratios with action binding



H2 No significant effect of cardiac phase at action onset on action binding ($t_{(43)}$= 1.62, p = 0.11), nor of cardiac phase at tone onset on tone binding ($t_{(43)}$= -0.41, p = 0.69).

No correlation between individual systolic/diastolic ratios of action onsets and action binding.

TAKE-HOME MESSAGE

- **Slight tendency for action initiation in early systole**, with more participants showing a preference for systole over diastole for initiating voluntary keypresses, in line with [5];
- **No clear cardiac phase benefit on SoA**, i.e., no evidence that cardiac phase bias for voluntary action generation modulates the subjective experience of controlling the action and its effects, in line with [8];
- **General pre-action cardiac deceleration** reflecting action preparation and exteroceptive attention, but **differential post-action cardiac acceleration timescales** dependent on the to-be-reported event.
- Next step: does respiratory phase play a role in modulating action initiation and subsequent SoA?

REFERENCES

[1] Haggard, P. (2017). Nat Rev Neurosci, 18(4), 196–207. [2] Blakemore, S. J., Wolpert, D., & Frith, C. (2000). Neuroreport, 11(11), R11-6. [3] Marshall, A. C., Gentsch, A., & Schütz-Bosbach, S. (2018). Front Psychol, 9(FEB), 1–14. [4] Seth, A. K., Suzuki, K., & Critchley, H. D. (2012). Front Psychol, 3(JAN), 1–16. [5] Kunzendorf, S., Klotzsche, F., Akbal, M., Villringer, A., Ohl, S., & Gaebler, M. (2019). Psychophysiology, 56(5), 1–16. [6] Park, H. D., Barnoud, C., Trang, H., Kannape, O. A., Schaller, K., & Blanke, O. (2020). Nat Comm, 11(1). [7] Park, H.-D., & Tallon-Baudry, C. (2014). *Philos Trans R Soc B: Bio Sci*, *369*(1641), 20130208. [8] Koreki, A., Goeta, D., Ricciardi, L., Eilon, T., Chen, J., Critchley, H. D., Garfinkel, S. N., Edwards, M., & Yogarajah, M. (2022). *Sci Rep*, 1–10. [9] Herman, A. M., & Tsakiris, M. (2020). *Affect Sci*, *1*(3), 155–171. [10] Moore, J. W., & Obhi, S. S. (2012). *Conscious Cogn*, *21*(1), 546–561.

Icons from: Flaticon, Freepik

gerosa@cbs.mpg.de
@martager.bsky.social

MGe is supported by the Graduate School Scholarship Program of the Deutscher Akademischer Austauschdienst (DAAD).