Decoding Effector-Specific Parametric Grip-Force Anticipation From fMRI Data

G.Caccialupi [a, b], T.T. Schmidt [a], F. Blankenburg [a, b]

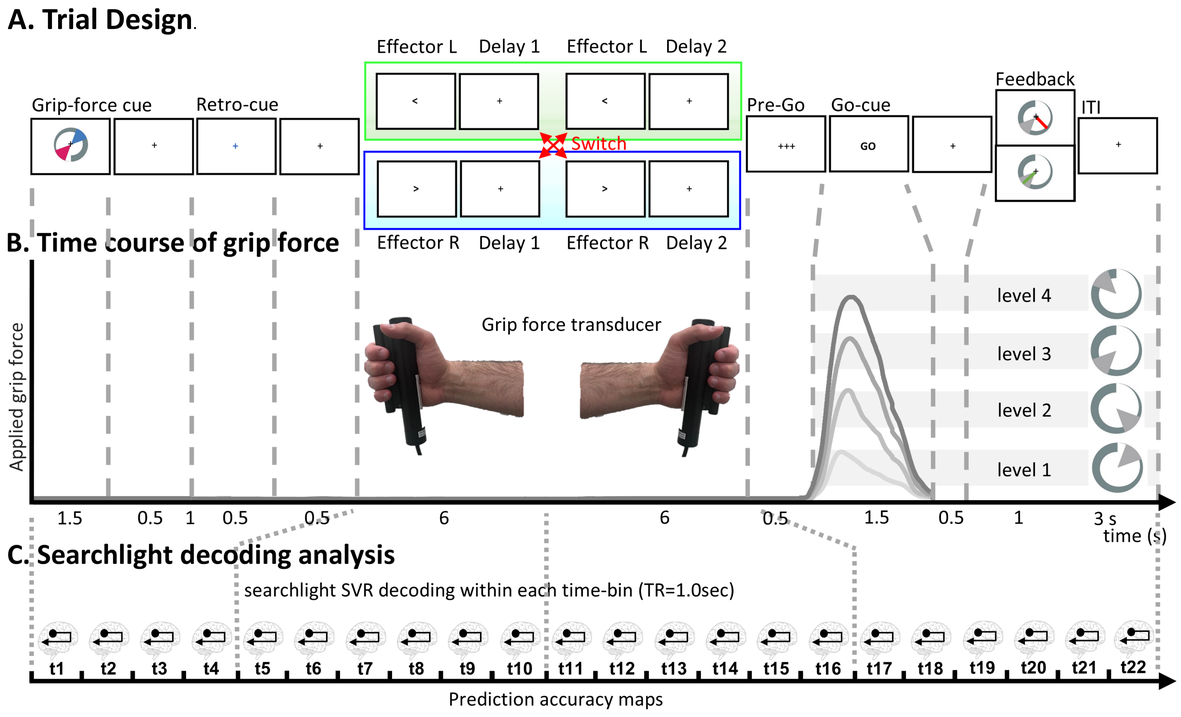
[a] Neurocomputation and Neuroimaging Unit (NNU), Freie Universität Berlin, Berlin, Germany
[b] Berlin School of Mind and Brain, Humboldt Universität zu Berlin, Berlin, Germany

INTRODUCTION

- Neuroscientific research indicates a complex interplay of action selection, motor planning, and working memory (WM) maintenance in the delayed execution of a graded grip-force.
- fMRI studies have shown that activity in premotor and parietal brain-regions covaries with the intensity of upcoming grip force [1].
- Furthermore, time-resolved MVPA of fMRI data suggests that the neural representation of grip-force intensities undergoes a transformation during a WM delay period, where the vmPFC initially encodes the intended force intensity, which is subsequently converted into a motor code in the l-IPS and l-PMd before execution [2].
- Yet, it remains unclear whether information about grip-force intensities is parametrically encoded in in effector-specific brain regions, and how it is transformed through WM delay until motor execution.
- To address this, we employed a delayed grip-force task during fMRI in which the hand used was switched in 50% of trials.

METHODS

A. Trial Design.



Participants performed a delayed grip-force task during fMRI. Each trial (**Figure 1A**) started with the presentation of a *grip-force cue*, representing two of four possible grip-force intensity levels as coloured sectors (red or cyan). A *retro cue* indicated which grip-force intensity had to be maintained during two 6-second *delay periods* (Delay 1, 2). Moreover, *effector cues* (Effector L, R) indicated whether the right or the left hand should be prepared for execution or whether the hand should be switch after half of the WM delay. Participants performed the grip-force task upon display of a *pre-Go* (0.5 s) and a *Go-cue* (1.5 s). Grip force was assessed by two non-magnetic grip-force transducers (Current Designs, HHSC-1x1-GRFC-V2) and subjects received feedback on their performance (**Figure 1B)**.

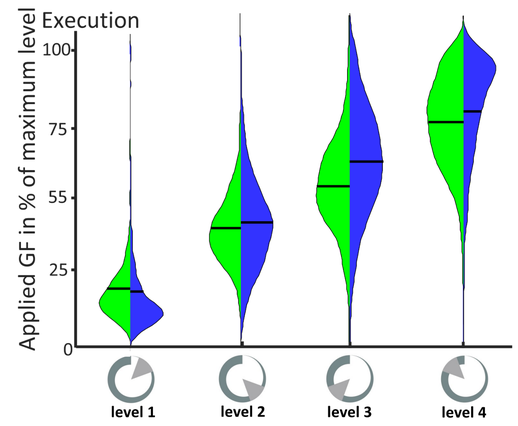
fMRI data was acquired in four runs of 21.20 min, with an EPI sequence (64 channel head coil, 48 slices, TR= 1 sec, 2x2x2 voxels) on a 3T Siemens Prisma fit at the *Center for Cognitive Neuroscience Berlin* (*CCNB*). We used multivoxel pattern analysis (MVPA) with a searchlight (r=4voxel) to test whether (contralateral) brain regions entailed information about grip-force anticipation during the two *delay periods*, and how this information was transformed from cue presentation up to motor execution. Beta-estimates of a finite impulse response (FIR) model (including each of eight trial types and 22 consecutive time bins; **Figure 1C**) were entered into a four-fold cross-validated support vector regression (SVR) decoding schema [3]. A time-resolved decoding analysis was applied within every time-bin of the trial (t1-t22) [4, 2]. Four independent decoding analyses were conducted to test above chance-prediction accuracy within each delay period and for each cued hand. To test for regions exhibiting above-chance decoding during the *cue period*, *delay periods*, and *motor execution*, we computed t-contrasts on t3-t4, t8-t10, t14-t16, and t19-t20 respectively.

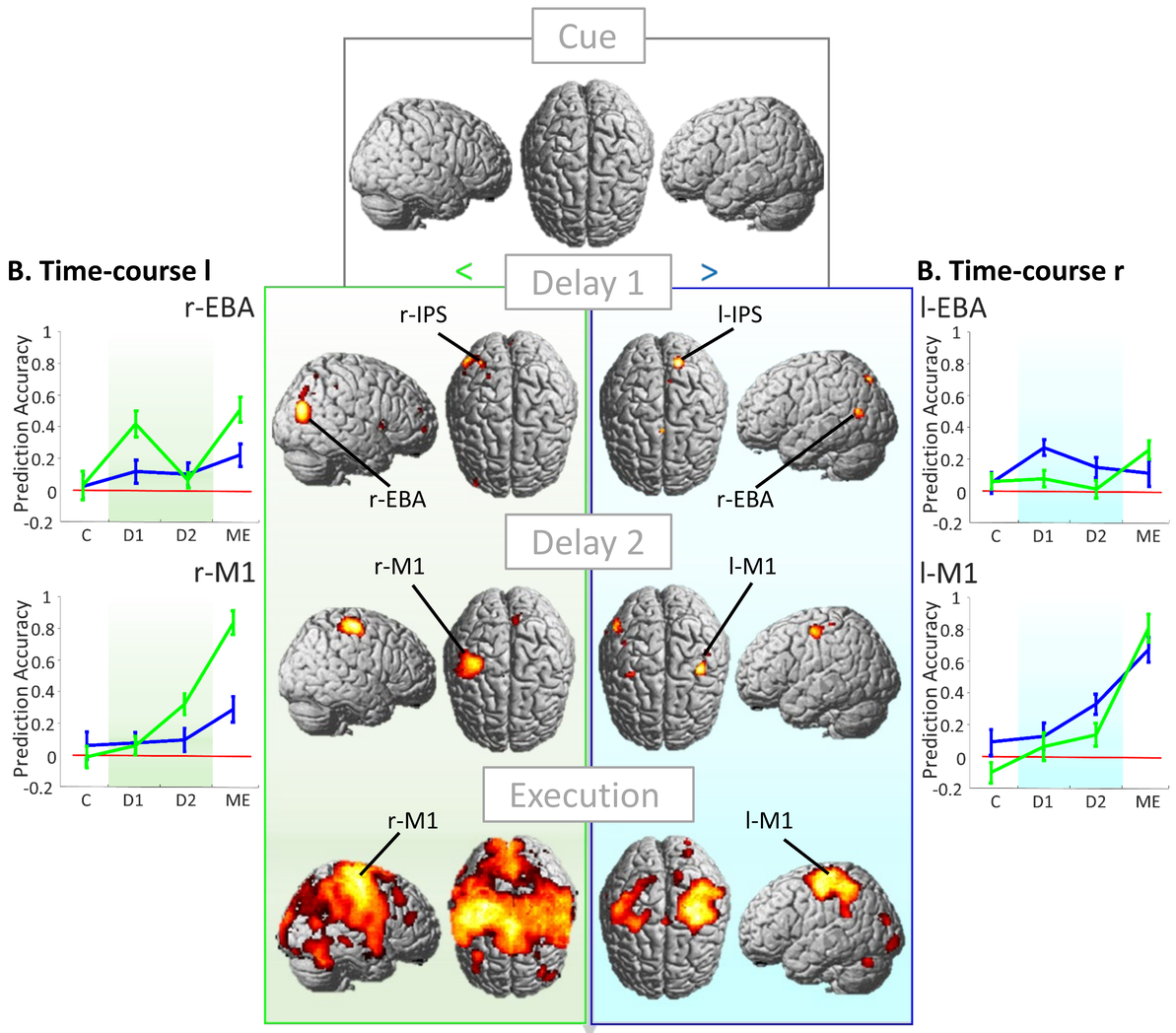
[1] van Nuenen et al. (2012), Weight-Specific Anticipatory Coding of Grip Force in Human, The Journal of Neuroscience, 5272–5283.
[2] Caccialupi et al. (2025), Decoding Parametric Grip-Force Anticipation From fMRI Data, Human Brain Mapping, Human Brain Mapping, 46(3), e70154..
[3] Hebart et al. (2015), The Decoding Toolbox (TDT): a versatile software package for multivariate analyses of functional imaging data, Frontiers in Neuroinformatics.
[4] Schmidt et al. (2017), Content-Specific Codes of Parametric Vibrotactile Working Memory in Humans, The journal of Neuroscience, 9771–9777.
[5] Ariani et al., (2024), Cortical Areas for Planning Sequences Before and During Movement, Journal of Neuroscience 45, no. 3: e1300242024.
[6] Boettcher et al. (), Output Planning at the Input Stage in Visual Working Memory., Science Advances 7, no. 13: eabe8212.
[7] Hommel (2006). How We Do What We Want: A Neuro-Cognitive Perspective on Human Action Planning. In W. Van Wezel, R. Jorna, & A. Meystel (Eds.), Planning in Intelligent Systems (1st ed., pp. 23–56).

RESULTS

N=25 participants were included in the behavioural analysis (age: 30 ± 6.31, 4 female). Violin plots display (**Figure 2A**) the distribution of applied forces in terms of 4 force intensity levels and used hand (L-hand represented in green, R-hand in blue). All trials were included in the fMRI analysis, except for trials in which the participants applied force during the delay period (cutoff: mean grip-force ≥ 5% of maximum force) or performed the task with the non-cued hand.

A. Behavioural performance





- Group-level analysis revealed two lateralized networks for effector-specific grip-force intensity coding, including: contralateral posterior-IPSs and EBAs during Delay 1, and contralateral M1s during Delay 2 and Execution (results are shown at p<0.05 FWE corrected in **Figure 3**).
- Time-courses of prediction accuracies within peak-activity voxels illustrates effector-specific increase in contralateral regions (see **Figure 3B r**, and **l)**.
- A control univariate analysis on an HRF-convolved GLM was conducted. Parametric activity modulation was only found in contralateral M1 during execution, which shows that MVPA results were not mostly driven by univariate effects.
- The preliminary performance of cross-effector decoding and representational similarity analysis suggest that bilateral anterior-IPS might encode effector unspecific information on grip-force intensities.

CONCLUSION

- Our results extend the current literature on motor planning by showing above-chance decoding in contralateral M1, pIPS and EBA across two delay periods. The lateralization suggests effector-specific coding of anticipated grip-force intensities during WM.
- Consistently with previous fMRI MVPA studies [5], we found M1 prior to movement execution. SVR results indicate maintenance of effector-specific information in parametric codes of grip-force intensity.
- Interestingly, we also found contralateral p-IPS and EBA during the first delay period, which might reflect the first stage of transformation process during motor planning from the selection of an intended action to the preparation of the motor movement [6]. It aligns with predictions of ideomotor theories postulating contribution of primary sensory regions for the selection of to-be performed movements [7].
- Overall, our findings integrate and extend previous reports on the temporal unfolding of neural-correlates of movement planning, from action-selection and maintenance of a motor-plan to motor-execution.