The role of the dorsal premotor cortex in learning associative cues during object lifting

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Introduction

- For skilled object lifting, it is necessary to anticipatory scale the fingertip forces to the weight of the object.
- Humans can quickly learn an association between an arbitrary visual cue, such as colour, and object weight.
- The dorsal premotor cortex (PMd) is known to play a role in making the association between the cue and the object weight.
- However, the precise timing of its involvement during the object lifting movement and the learning process is unclear.

- *Research question: Is PMd more important during the lifting or holding phase of an object lifting movement in associative learning?*

Experimental procedures

- 20 participants (12 females, 24.8±2.0 years)
- Object lifting task with 3 weights: light, medium, heavy.
- Weights were associated with colours/patterns.
- Objects were lifted in 5 blocks of 3 trials for each weight. Weights were presented in a random order.
- Washout trials were performed with a single weight.

- 4 conditions, with washout trials in between:
  - PMd_{lift}: PMd during lifting
  - PMd_{hold}: PMd during holding
  - $Sham_{lift}$: Vertex during lifting
  - $Sham_{hold}$: Vertex during holding

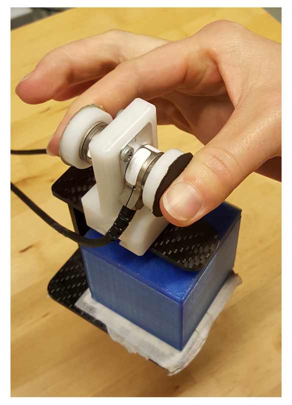

Fig2. Top: manipulandum in which objects were placed. Participants lifted the objects by placing the fingers on the force sensors. Bottom: objects used in the experiment.

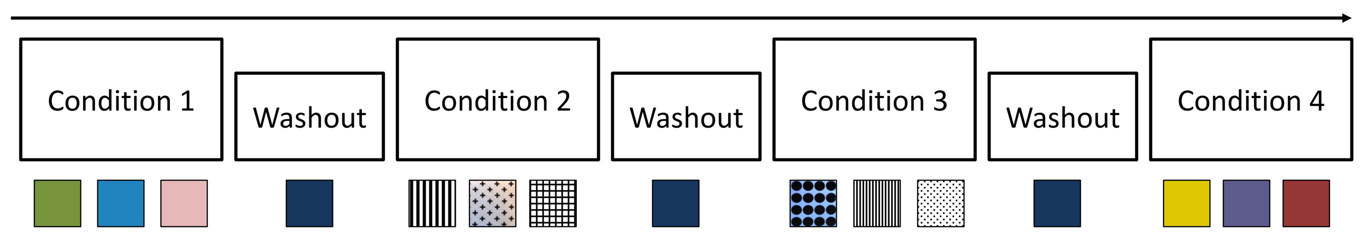

Fig3. Example of experimental time line. Conditions were separated by washout trials (10 lifts) and counterbalanced across participants. Object combinations (colours or patterns) were randomized across conditions.

Learning across blocks

Learning was seen in all conditions. TMS over PMd reduced learning in the first block, dependent on stimulation intensity (see right panel).

- PEs of LFR decreased across training blocks.
  - In block 1: PMd > Sham, dependent on stimulation intensity.
  - PMd: decrease over blocks, dependent on stimulation intensity.
- GFR: no significant effects.

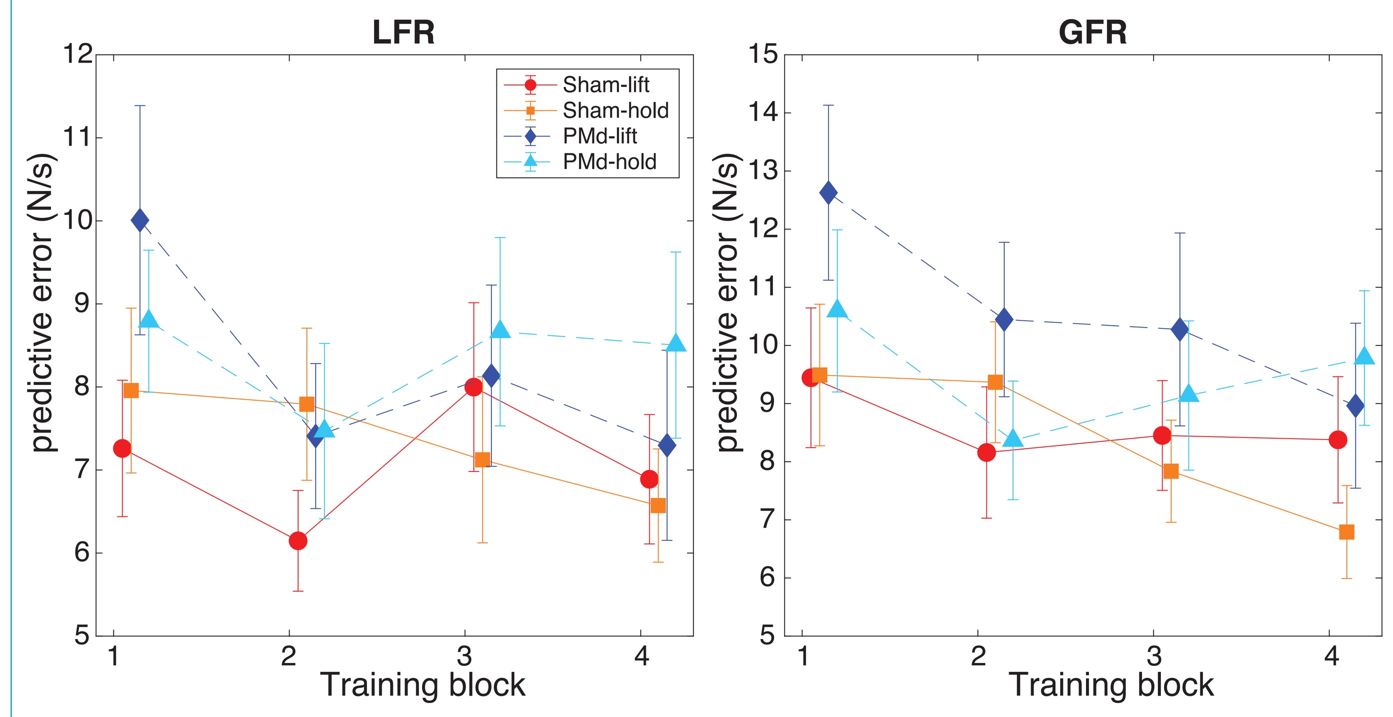

Fig5. Predictive errors (PEs) for the first peak of load force rate (LFR, left) and grip force rate (GFR, right). PEs were calculated with respect to the last training block (block 5) and averaged over object weight. Error bars represent standard errors.

Stimulation intensity and MEPs

Predictive errors depended on stimulation intensity, but not MEPs.

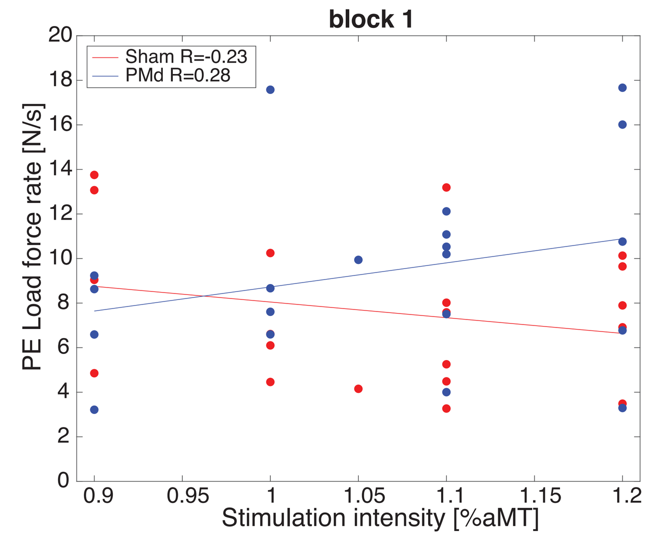

Fig6. Interaction of Location x Stimulation intensity effect for predictive errors of first peak of load force rate (LFR) in the first block. Note that PEs increase with intensity for PMd, but decrease for Sham, although both correlations were not statistically significant.

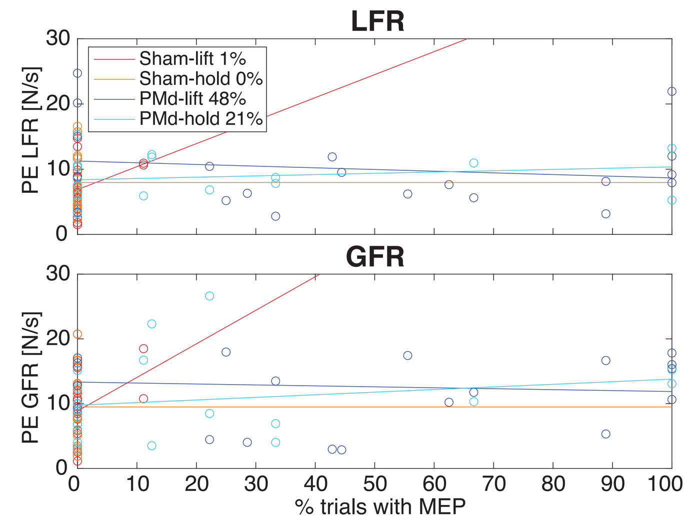

Fig7. Predictive errors (PE) for first peak of load force rate (LFR) and grip force rate (GFR) against % trials with MEPs. No correlation was significant. In the legend the average % trials with MEPs across participants is shown for each condition.

TMS procedures

- Transcranial magnetic stimulation (TMS) was applied at lifting (starting at object contact) or holding (starting 500 ms after lift-off) with 3 pulses at 10 Hz.
- Electromyography of the first dorsal interosseous muscle was sampled to measure motor evoked potentials (MEPs).
- TMS was applied at 90-120% active motor threshold (aMT). Intensity was adjusted for each participant, until MEPs were not visible.

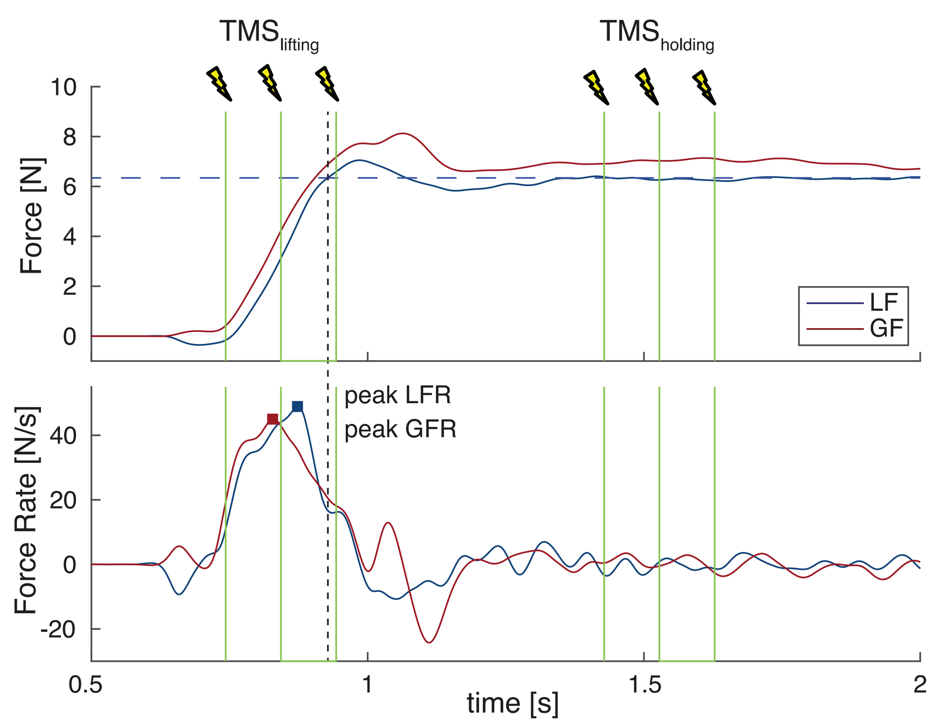

Fig1. Example of trial, TMS conditions and parameters. TMS was applied at lifting (starting at object contact) or at holding (500 ms after lift-off, dashed line), with 3 pulses at 10 Hz. Measured parameters were the first peak of load force rate (LFR) and grip force rate (GFR).

Data Analysis

- Parameters
  - First peak of grip force rate (GFR)
  - First peak of load force rate (LFR)
- Predictive errors (PEs) were calculated with respect to the last block.
- MEPs were visually identified in the first block.
- Location (PMd, Sham) x Time (4 blocks) x TMS (lift, hold) repeated measures ANOVA, also with covariate 'stimulation intensity'.

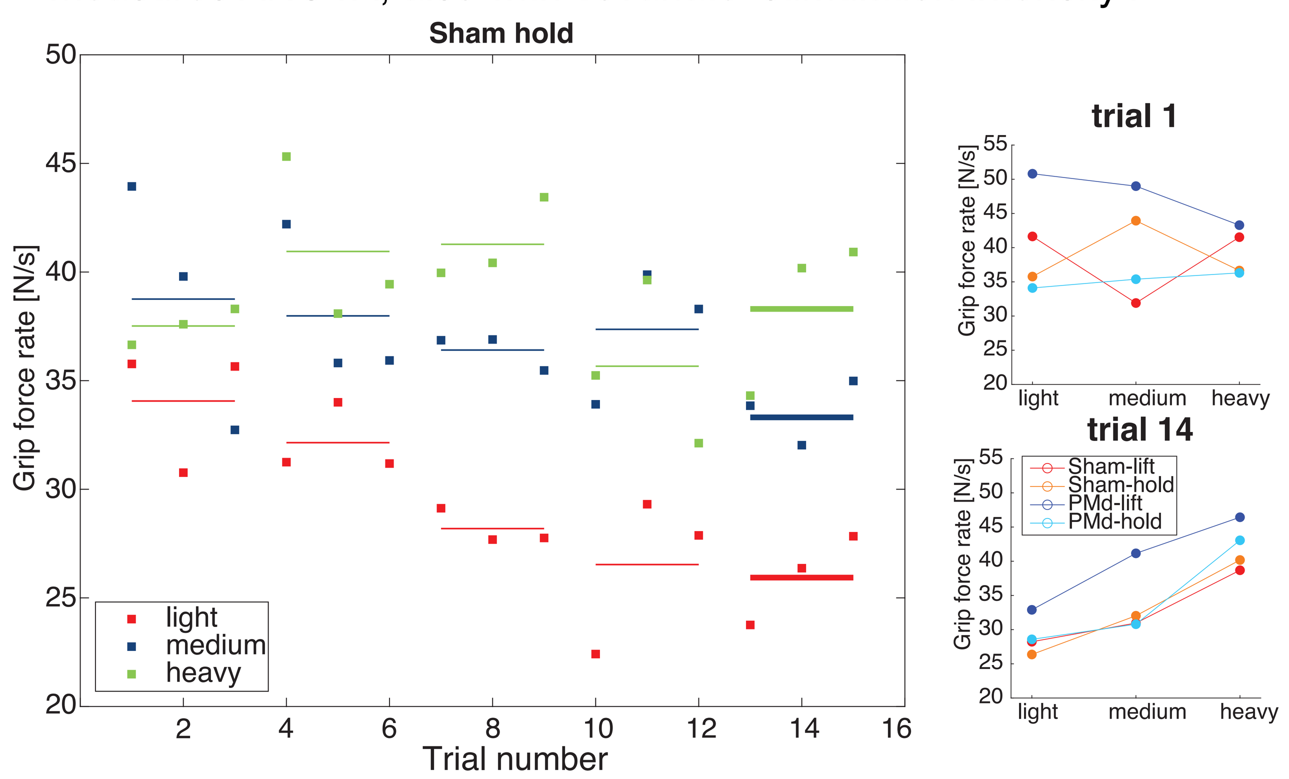

Fig4. Left: Average first peak grip force rate in the $Sham_{hold}$ condition for all trials. Considering the variability from trial to trial, trials were averaged in 5 blocks of 3 trials (horizontal lines). Predictive errors (PEs) were calculated by taking the absolute difference with respect to the last block (thick lines). PEs were averaged over object weights in further analyses. Right: Average first peak grip force rate for trial 1 and 14 in each condition. Note that in trial 1, weights were not anticipated, whereas scaling towards object weight is seen in trial 14 (after learning).

Learning in first block

TMS over PMd resulted in larger errors, dependent on stimulation intensity.

- LFR: PMd > Sham
  - Trial 1 and 3: Pmd_{lift}>others, dependent on stimulation intensity.
- GFR decreased over trials.
  - Trial 1: PMd > Sham, dependent on stimulation intensity.

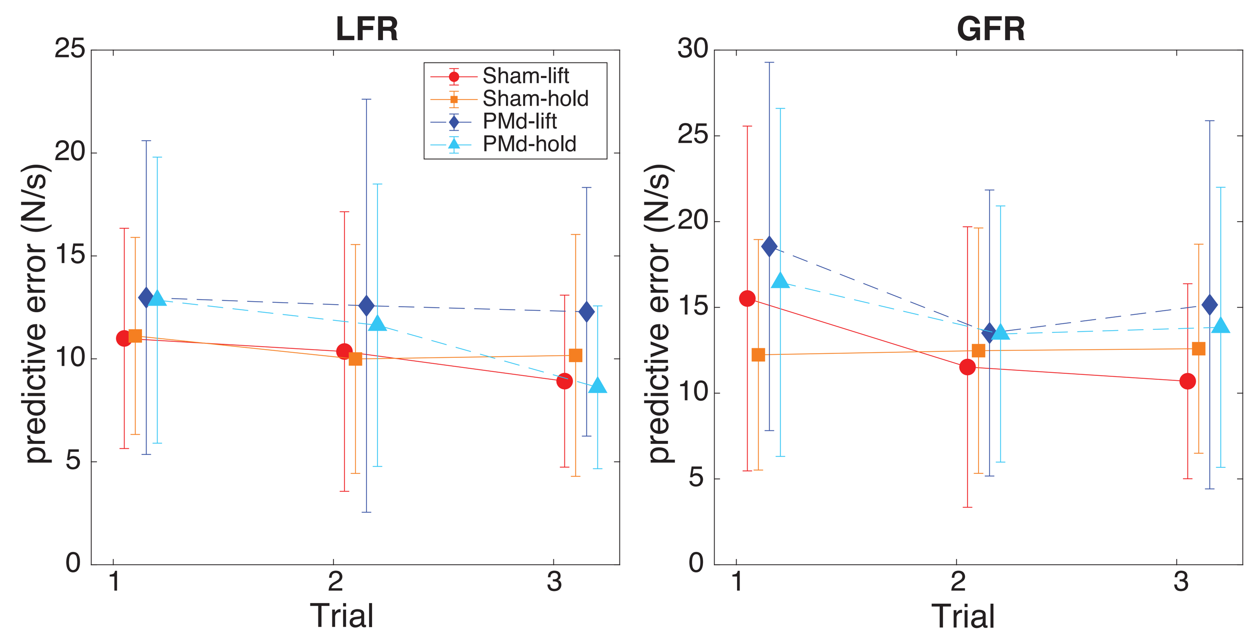

Fig8. Predictive errors (PEs) for the first peak of load force rate (LFR, left) and grip force rate (GFR, right), for the three trials in the first block. PEs were calculated with respect to the last training block (block 5) and averaged over object weight. Error bars represent standard errors.

Conclusions

- Associations between colour and weight were learned in all conditions.
- Most learning was done in the first block, or even in the first trial.
- With stimulation over PMd, learning was a bit slower in the first block (more errors).
- There were few indications that PMd was important at a specific time point, suggesting that PMd is active throughout the movement.
- Effects depended on stimulation intensity, suggesting that higher stimulation of PMd had larger effects on learning.
- However, overall the effects found were small and data was variable.

Overall, it seems that PMd is important early in learning and not at a specific time point.

Acknowledgements

Supported by Fonds Wetenschappelijk Onderzoek grants (FWO post-doc fellowship, 12X7118N, and PhD fellowship, 1141320N, Belgium) to Vonne van Polanen and Mareike Gann.