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Responsibility Assignment in Redundant Systems

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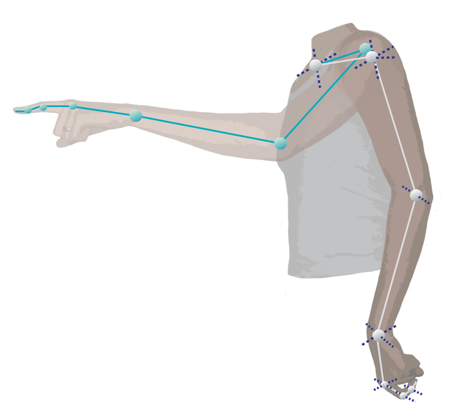
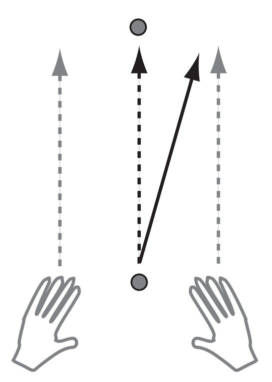
Introduction



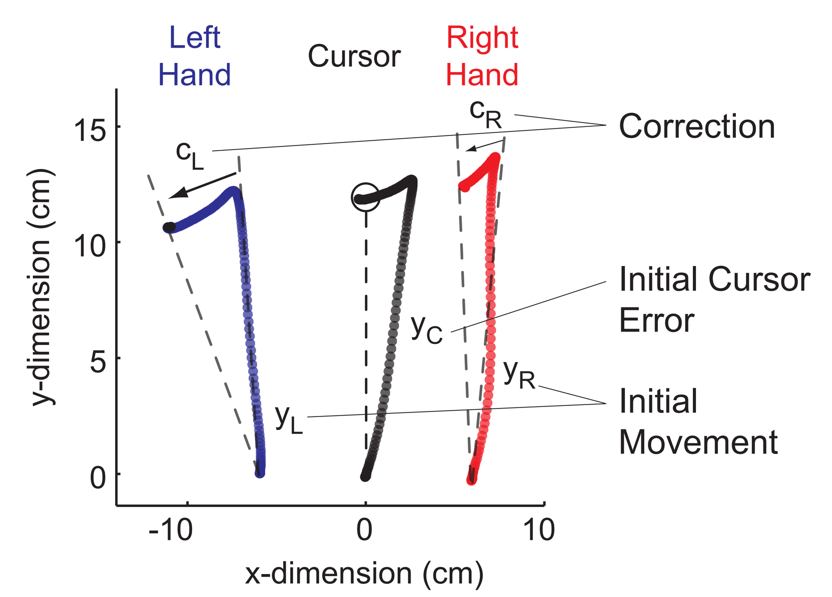
Natural reaching movements are highly redundant

Redundancy is a fundamental feature of biological motor systems. When reaching, we use all 13 degrees of freedom between the sterno-clavical joint and the finger tip.
The motor system exploits redundancy by distributing work across all effectors, thereby reducing effort and signal-dependent noise.

But when an error occurs during a redundant movement - **how does the motor system assign the error to the joints involved?**



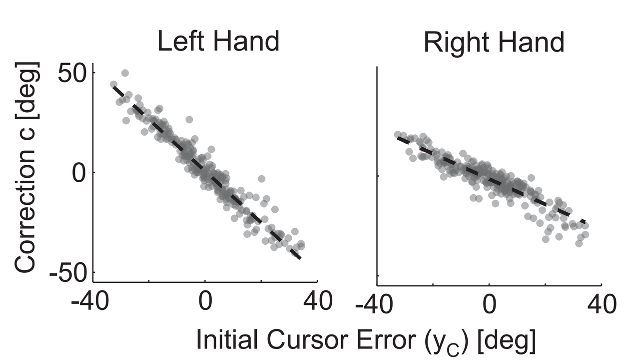
- A cursor is presented at the spatial midpoint between the hands
- The hands are not visible.
- Both hands are used together to move the cursor to the target.
- A visual rotation is applied to the cursor.
- The error could be assigned and corrected with either hand.



Responsibility needs to be assigned for correction and adaptation

Correction

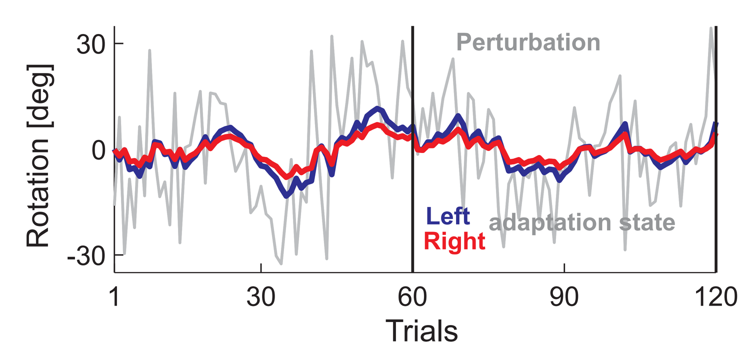
Correction gain (*g*): how much does a hand correct for an initial cursor error within trial n.



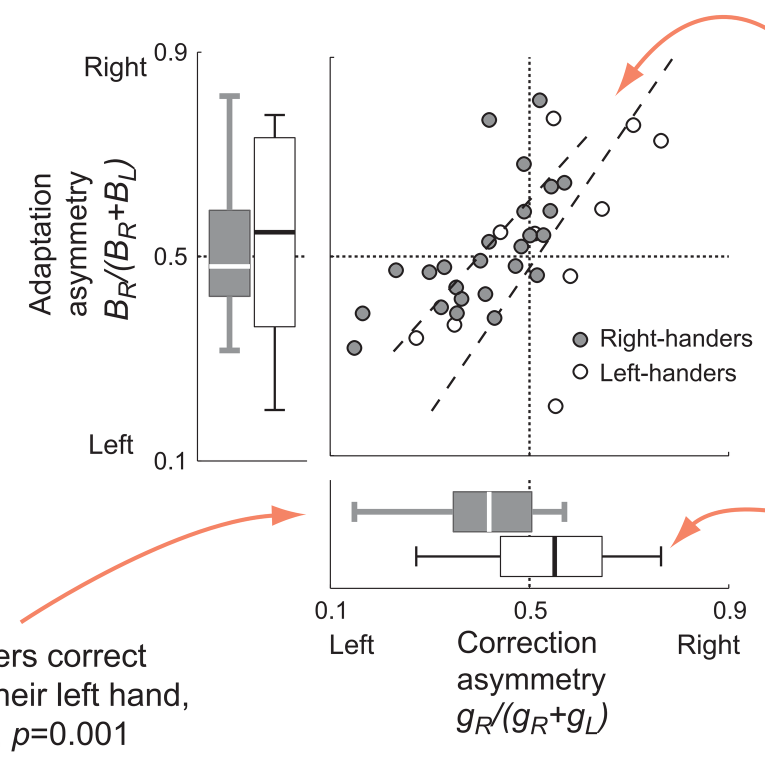
... measured by the linear regression of correction against initial cursor error.

Adaptation

Adaptation gain (*B*): how much does a hand change the initial direction on trial n+1.



... measured as parameters of a trial-by-trial model of initial movement direction ($y_{L/R}$).



Adaptation and Correction asymmetry are closely related. *r*=0.60, *p*<0.001. Responsibility assignment is solved jointly for correction and adaptation.

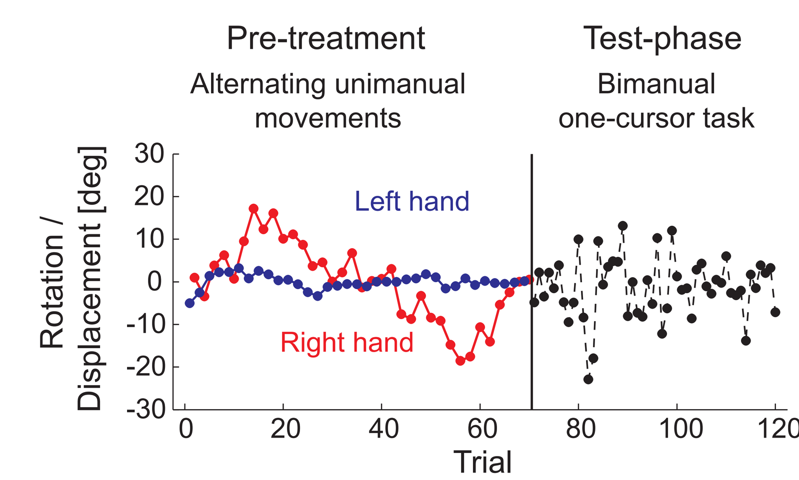
Right-handers correct more with their left hand, *t*(24)=-3.63, *p*=0.001

Asymmetry is *negatively* related to the handedness score. *r*=-0.55, *p*=.004. The more a hand is used in everyday life, the less it is used for correction.

Modifying responsibility assignment

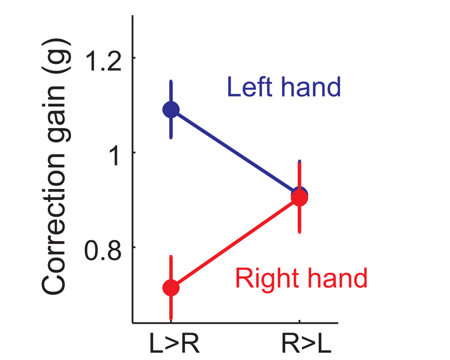
Why would the non-dominant hand correct more?

- The non-dominant hand is faster at correcting
  No, the non-dominant hand has slower correction onsets in unimanual tasks, t(24)=-2.19, p=.039
- The non-dominant hand contributes more to the movement
  No, the dominant hand moves 5mm further, t(24)=2.35, p=.027
- The non-dominant hand is noisier and is therefore "the scapegoat".
  If that is true, can we modify responsibility assignment by pretreating hands with large errors?



One hand sees larger visual rotation errors than the other.

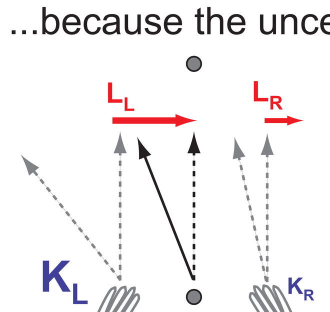
The pretreatment influenced the correction gains, *F*(1,16)=5.38, *p*=0.34.



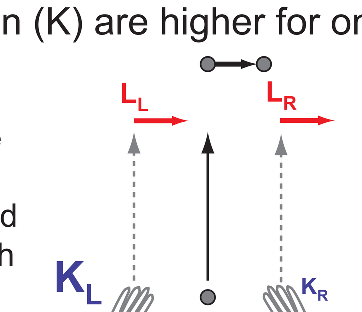
The hand exposed to bigger errors in the unimanual task corrects more in the bimanual task.

Estimation vs. Control

Asymmetries can arise...
...because the uncertainty and Kalman gain (K) are higher for one hand.

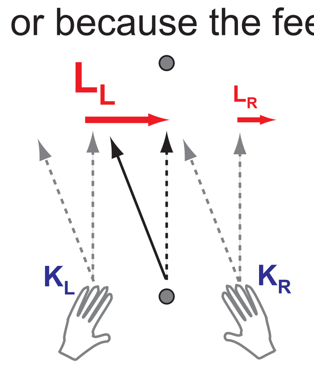


Cursor rotations would change the estimate more for the more uncertain hand. The correction would be made preferentially with that hand.

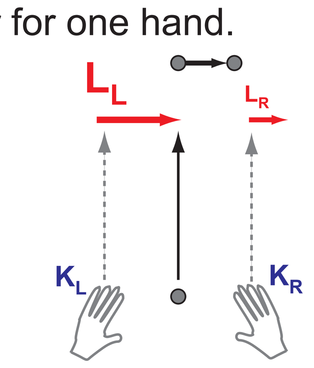


Target displacements do not change the estimates of the hands. Therefore corrections should be symmetric.

... or because the feedback gain (L) is higher for one hand.

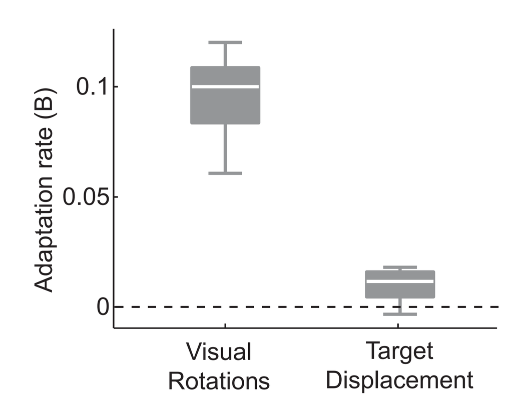


Feedback gains multiply the distance between cursor and target to give the correction.



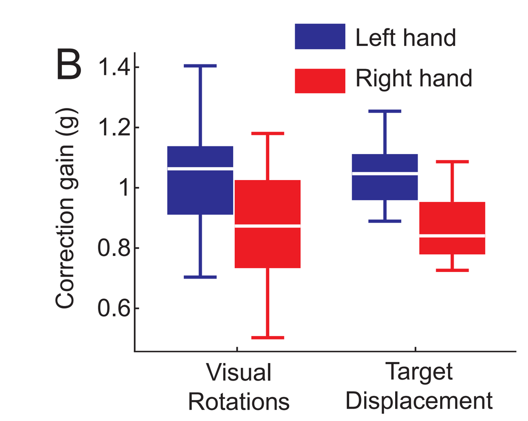
Therefore asymmetries should be the same, no matter what the source of the error is.

Thus, we tested adaptation and correction during random target displace-



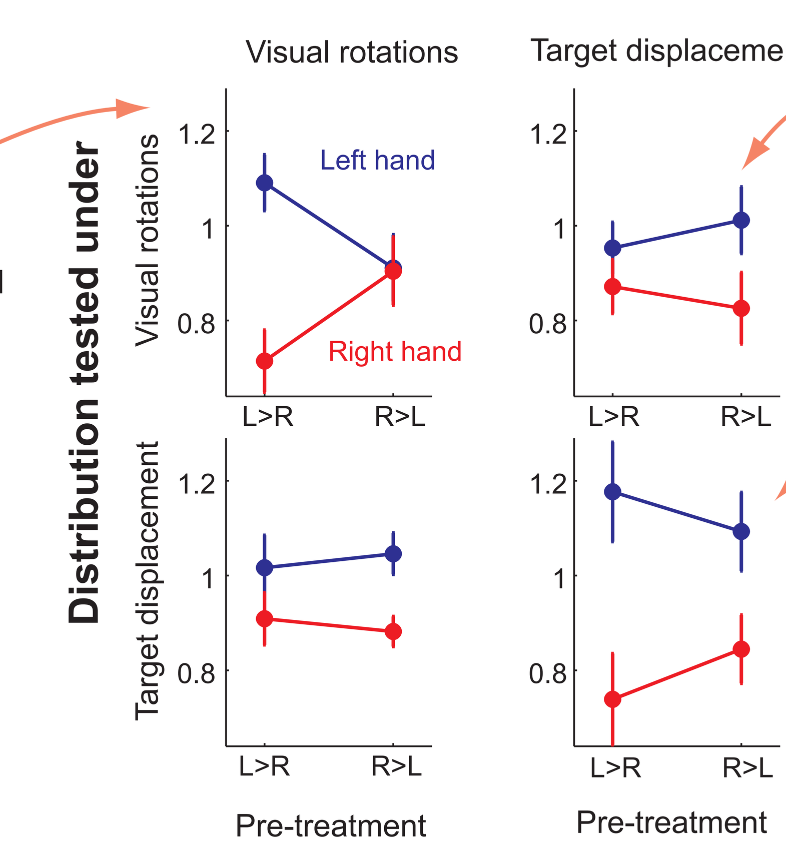
As shown before (Diedrichsen et al. (2005), adaptation is much lower when targets are displaced.
Only random visual rotations change the forward model on a trial-by-trial basis.

Estimation vs. Control



Despite this difference, the correction asymmetry (more on the left) is the same in both conditions.
=> Best explained by change in feedback gains.

Can these feedback gains be influenced by exposure to large target errors?



The original result for visual rotations

No effect is found, when errors in pre-treatment and test are different!

The effect also holds when pretreating and testing with target displacements, *F*(1,7)=9.42, *p*=0.018.

Discussion

- The motor system assigns responsibility jointly for correction and adaptation.
- There is a bias in responsibility assignment towards the non-dominant hand.
- A difference in uncertainty (Kalman gains) can explain asymmetry for visual rotations, but not for target displacements.
- A difference in feedback gains can explain the consistent asymmetry in both conditions.
- The specificity of the pretreatment effect suggests a more complicated mechanism that assigns the error to the most likely cause, specific for different error types.

Acknowledgements

This work has been supported by Grants from the BBSRC (BB/E009174/1) and the NSF (BSC 0726685). We thank Niall Lally for assistance in data collection, and Richard B. Ivry and Erin Heerey for comments.