What is the role of primary motor cortex in Eye-Hand coordination? A TMS study

James MATHEW[1], Alexandre EUSEBIO[2], Frédéric DANION[1]

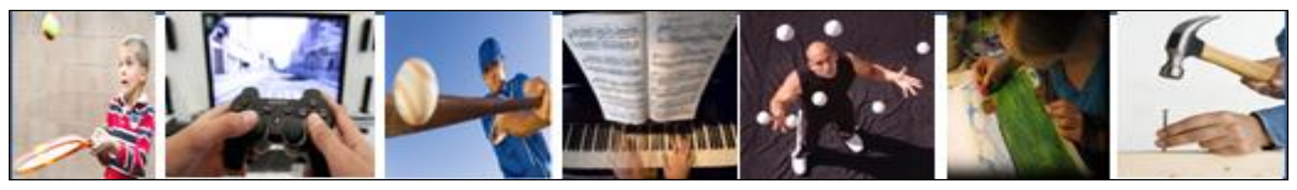
[1] Institut de Neurosciences de la Timone, UMR 7289, CNRS-AMU, Campus Santé Timone, Marseille, France

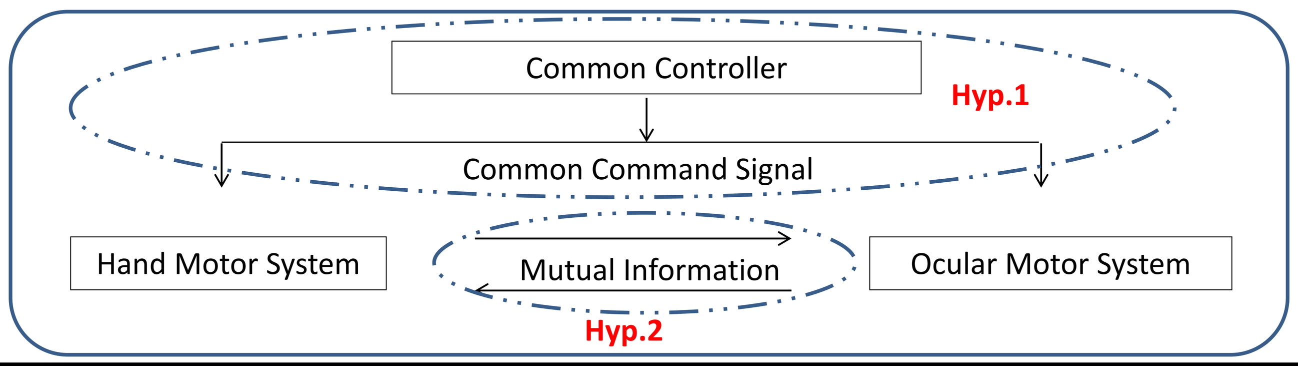
[2] Department of Neurology and Movement Disorders, La Timone University Hospital, APHM, Marseille, France

Perception and Action in Complex Environments

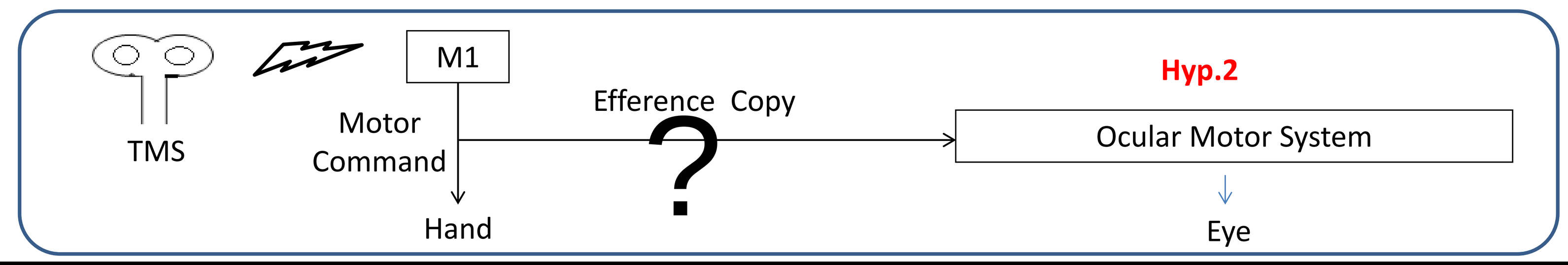
INTRODUCTION

- Effective coordination of eye and hand actions is crucial in daily activities.
- Possible neural mechanisms underlying eye-hand coordination:
- **Hyp.1:** A common command signal is driving both ocular and hand motor systems and the two systems share (at least partially) a common neural controller [1,2].
- **Hyp.2:** Ocular and hand actions are controlled by independent systems that interchange signals to improve performance [3,4].





- In line with the hypothesis of mutual coupling (H2), it is proposed that the oculomotor system has access to an estimate of the current hand position by means of a forward model that receives the arm efferent copy [5,6].
- ***The goal of the current study is to explore the effect of Transcranial Magnetic Stimulation (TMS) over the hand area of the primary motor cortex (M1) on smooth pursuit during a eye-hand coordination task.***



METHOD

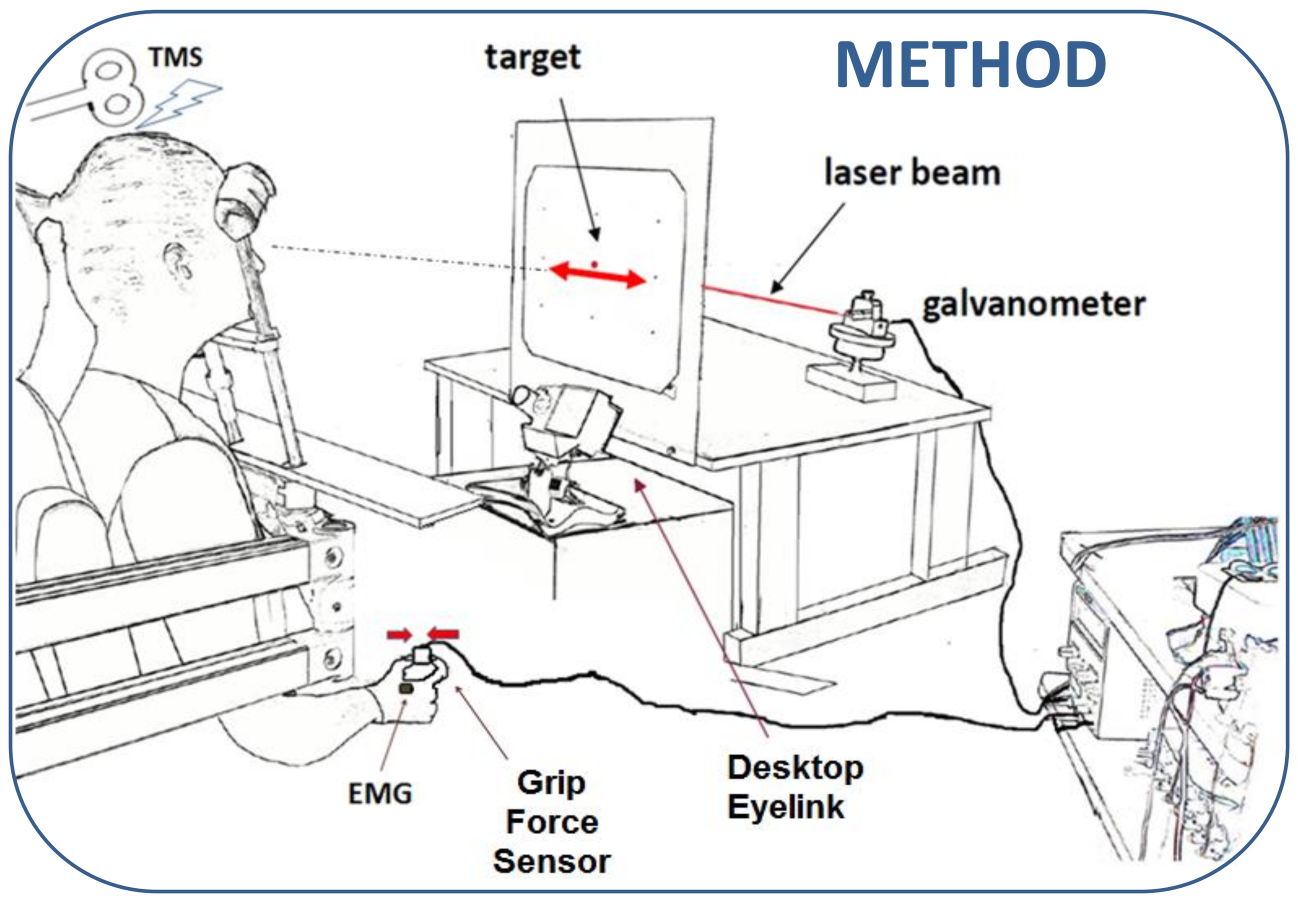
SELF-MOVED TARGET

- Subjects had to modulate their grip force in a random manner (1-5N) so as to animate the horizontal motion of a visual target.
- While doing so, they had to track the resulting target motion with their eyes.

EXTERNALLY-MOVED TARGET

- Target trajectories were imposed by the experimenters, still subjects had to track the target with their eyes.

	Self Moved Target		Externally Moved Target	
NoTMS	Self	Self-Mimic	Ext	Ext-Tact
TMS	Self-T	Self-Mask-T	Ext-T	Ext-G-T



EXPERIMENTAL DESIGN

Each subject (N=9) performed 1 block of 10 trials (30s each) in each of the 8 conditions

- **Self** : the subject drives the target motion by modulating his/her grip force
- **Self-T** : same as Self but occasionally (4 times per trials) involuntary grip force pulse is triggered by TMS (thereby leading to a transient target jump).
- **Self-Mask-T** : same as Self-T but the visual target jump induced by TMS is masked.
- **Self-Mimic** : same as Self but occasionally (4 times per trial) a transient target jump that mimics the effect of TMS is delivered (along with the TMS click).

- **Ext** : target trajectories collected during Self are played back (hand is relaxed)
- **Ext-T** : same as Ext but occasionally (4 times per trial) TMS is applied.
- **Ext-G-T** : same as Ext-T but TMS is applied while exerting constant grip force (3N)
- **Ext-Tact** : the experimenter moves the target by placing his hand over the (relaxed) hand of the subject holding the force sensor.

RESULTS

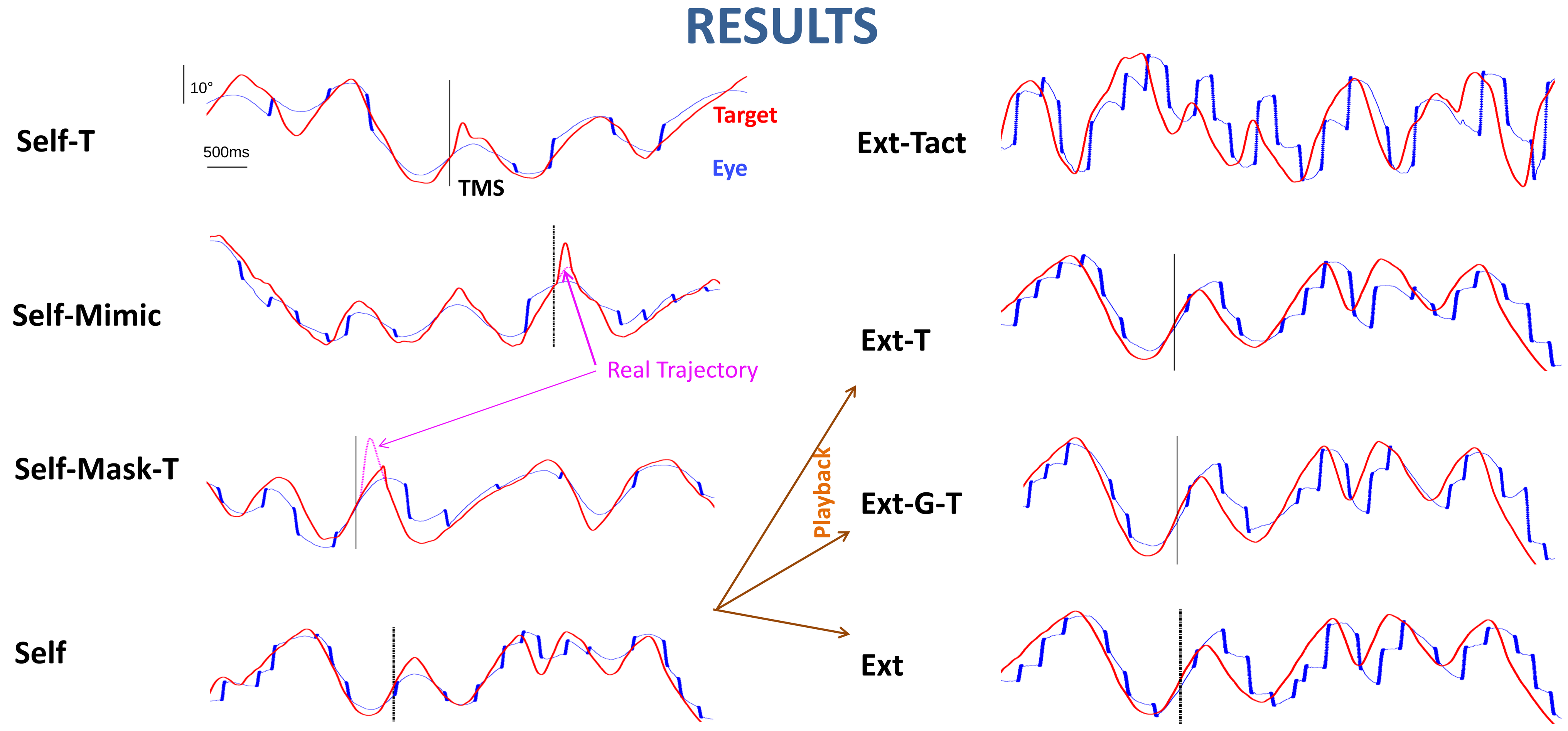


Fig.1: Typical trials by the same subject in all conditions.

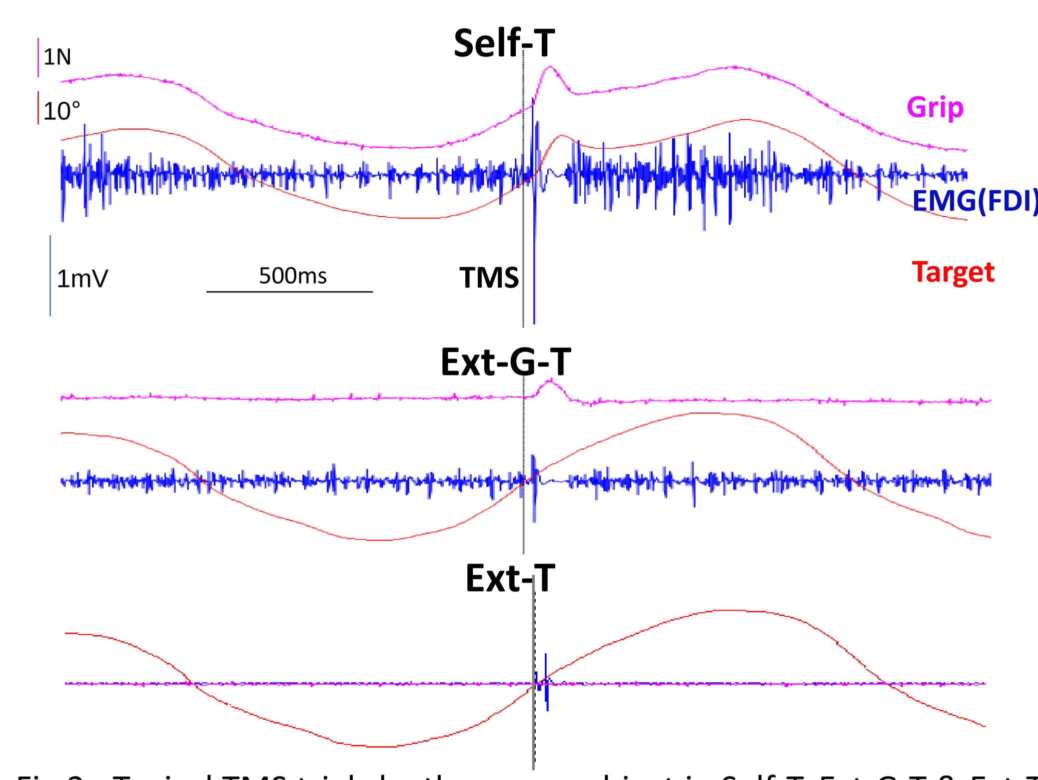


Fig.2: Typical TMS trials by the same subject in Self-T, Ext-G-T & Ext-T; TMS was applied during rightward motion of the target. For the self-moved condition, Motor Evoked Potentials (MEP) induced by TMS led to a transient increase in grip force that resulted in a target jump. For the externally-moved conditions, MEPs were also induced but did not perturb current target motion.

Question 1: Is SELF > EXTERNAL?

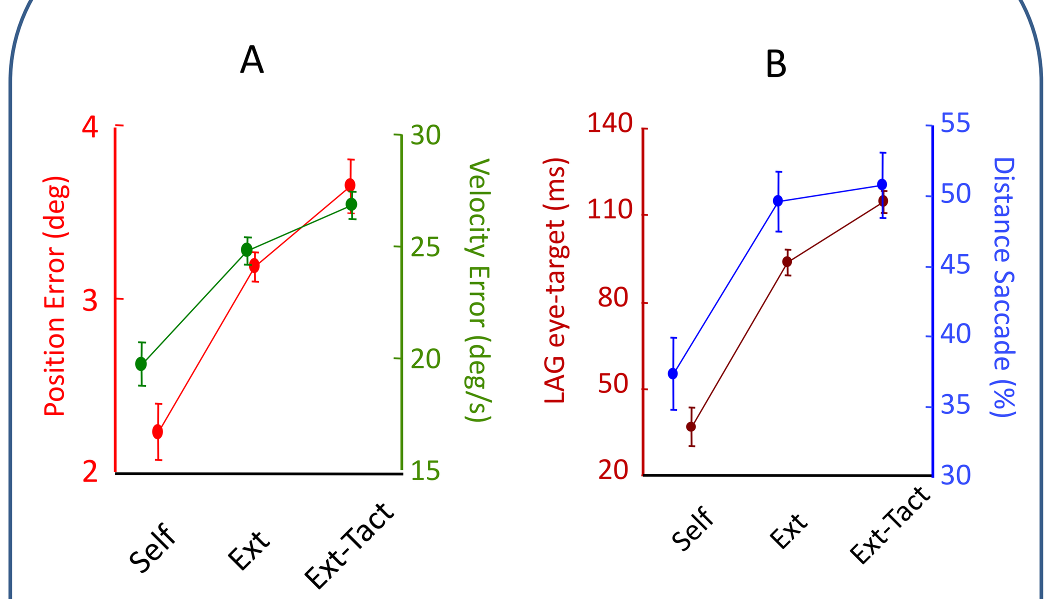


Fig.3: Mean group eye-tracking performance in the non-TMS conditions. Position error (A), velocity error (A), eye-target Lag (B) and percentage of total distance covered by saccades (B) were computed over entire trials. Anovas and post-hoc led to the conclusion that eye tracking was more accurate under Self than Ext (p<0.001). The provision of tactile information in Ext-Tact did not benefit to eye tracking performance. Those results are consistent with the key role of hand efferent signals during Self.

Question 2 : What is the effect of TMS during EXTERNAL tracking?

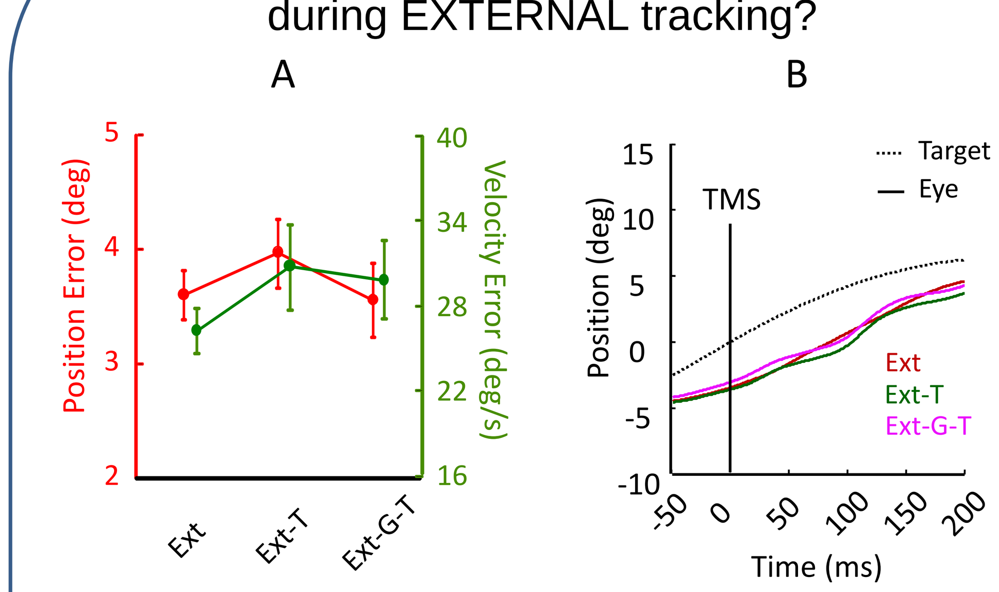


Fig.4: Mean group position error (A), velocity error (A), and mean eye-target position (B) within the next 200ms that followed TMS during EXTERNAL. For both errors Anova showed no significant differences across 3 external conditions (p>0.18). This implies that, no matter whether the hand was activated or not, TMS over M1 hand area had virtually no effect on eye performance when tracking an externally-moved target (see B). This clarification was mandatory before investigating the possible effects of TMS during eye-hand coordination task.

Question 3: What is the effect of TMS during SELF tracking?

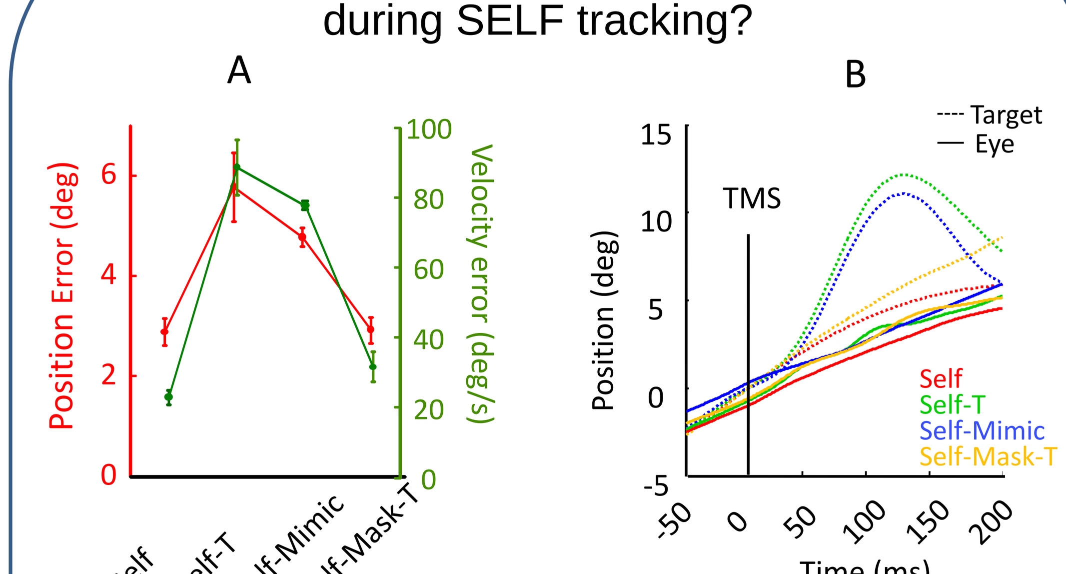


Fig.5: Mean group position error (A), velocity error (A), and mean eye-target position (B) within the next 200ms that followed TMS during SELF. For both errors Anova showed significant differences across the 4 self conditions (p<0.001). Post-hoc analyses showed a significant alteration in performance following TMS in Self-T compared to Self, but a similar alteration was observed when mimicking the visual effects of TMS (Self-Mimic). When the visual consequences of TMS on target motion were masked (Self-Mask-T), performance became similar to Self.

CONCLUSION

In agreement with earlier observations [6-9], the current results showed that eye tracking performance is improved when the target is self-moved as compared to when being externally-moved. We also found that the provision of tactile feedback during external conditions did not benefit much, thereby confirming the key role of hand motor signals.

Concerning the effect of TMS, previous research reported that TMS over Frontal Eye Field (FEF) affects smooth pursuit eye movement within the next 22 to 175ms for an externally-moved target [10,11]. In contrast our data showed that eye tracking performance was poorly influenced after TMS over M1 hand area (Ext=Ext-T=Ext-G-T).

Regarding the effect of TMS during Eye-Hand coordination, we did find an increase in tracking error, but a very similar observation was noticed when we mimicked the visual effect of TMS on target motion (Self-T=Self-Mimic). Furthermore tracking accuracy was no longer altered by TMS when its visual consequences on target motion were minimized (Self=Self-Mask-T). Overall the results of this TMS study suggest that **the output of M1 has limited contribution to eye tracking performance during Eye-Hand coordination**.

BIBLIOGRAPHY

[1] Scarchilli & Vercher (1999), Exp Brain Research 124: 42-52
[2] Miall & Reckess (2002), Brain Cognition 48: 212-26
[3] Engel et al (2000), J Neurophysiology 84: 1149-56
[4] Maioli et al (2007), J Neuroscience 27: 7168-73
[5] Arif et al (2002), J Neuroscience 22: 7721-72
[6] Vercher et al (1995), J Neurophysiology 76: 1133-44
[7] Steinbach & Held (1968), Science 161: 187-188
[8] Chen et al (2016), J Neurophysiology (Epub ahead of print)
[9] Landelle et al (in revision), J Neurophysiology
[10] Tanaka & Lisberger (2002), J Neurophysiology 87: 802–18
[11] Gagnon et al (2006), J Neuroscience 26: 458-66

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