The role of visual feedback in movement control in individuals with Multiple Sclerosis

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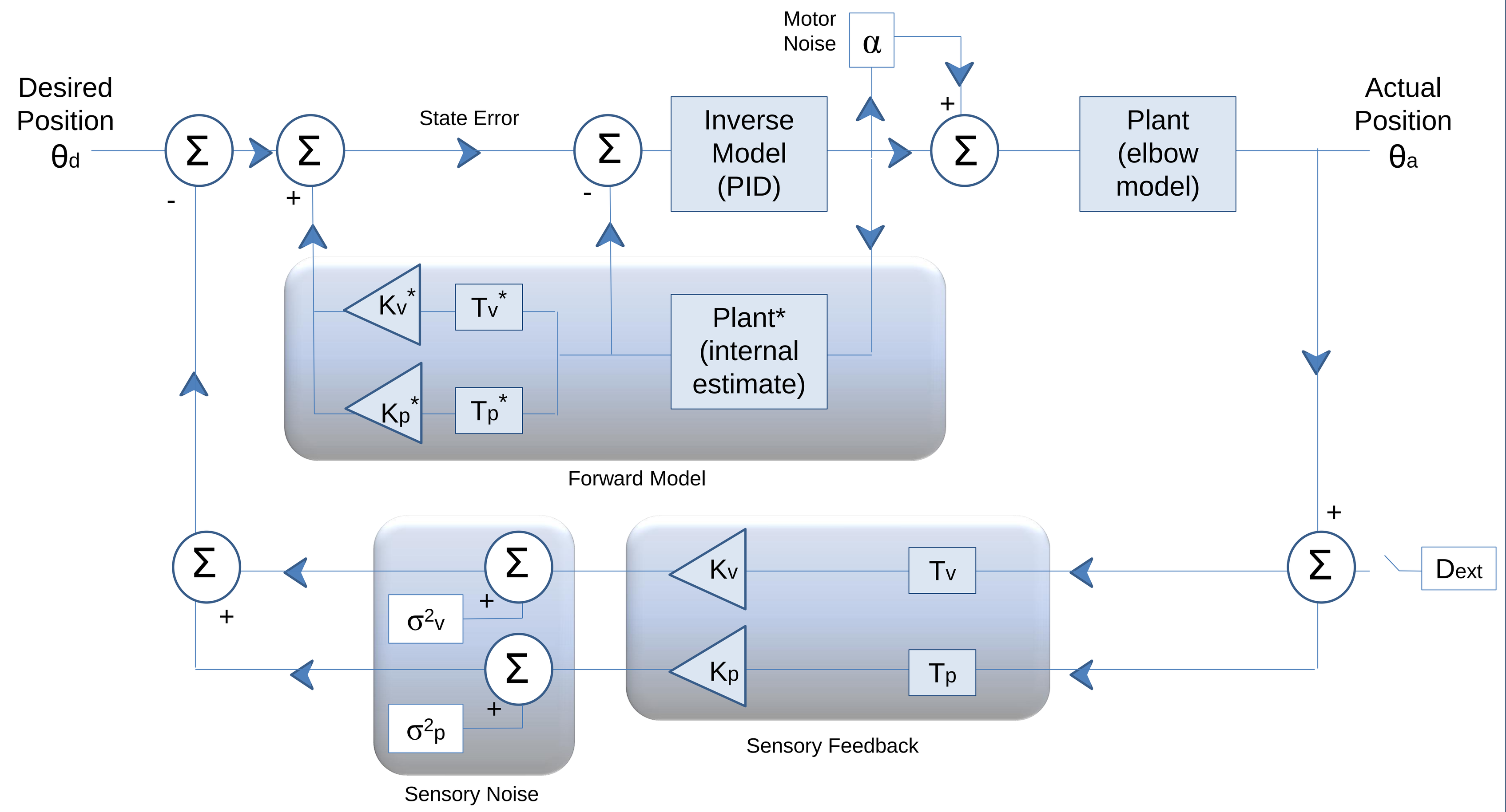
Introduction

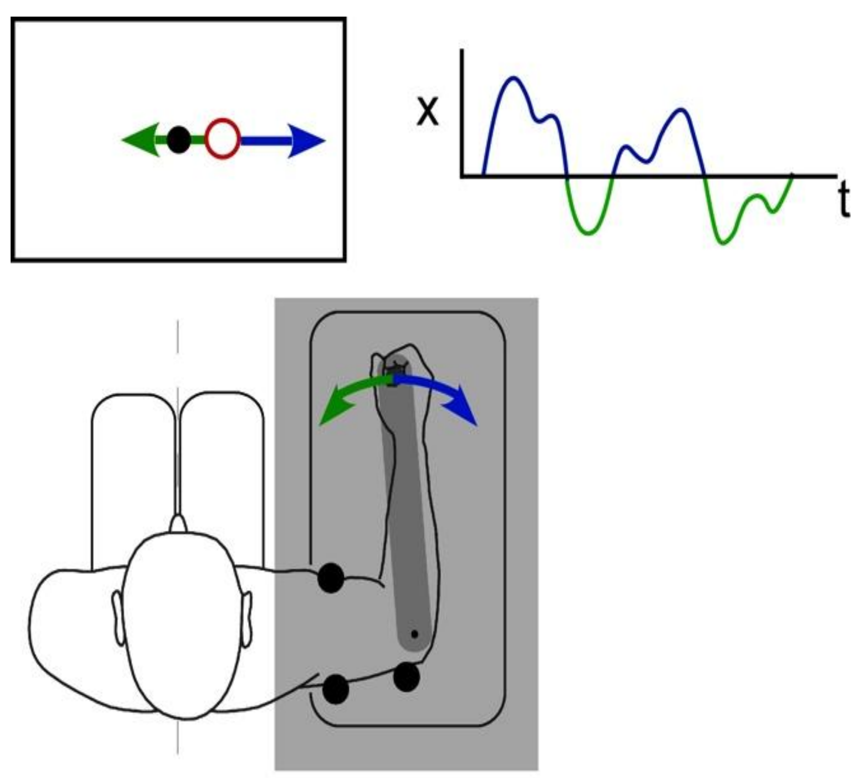
Tremor and dysmetria in the arms and hands are significant contributors to disability in individuals with MS [1]. Those with MS have often have difficulty with "closed-loop" movements, particularly during endpoint acquisition. Closed-loop compensation of perturbations in arm location requires accurate prediction of sensory feedback of limb position. Disruptions in sensory information can lead to poor prediction of motor consequences and cause instability (tremor) in the motor system. We have previously reported that poor prediction of both visual processing time and limb kinematics contribute to tremor in MS. However, we were previously unable to distinguish whether these factors are causally linked. Using a systems identification analysis, we examined whether increased sensory delays contribute to inaccurate predictions of limb kinematics in persons with MS, and why these issues manifest primarily during compensatory tracking movements.

Model



Model of Human Neuromotor Control. Control of 1-D joint movement can be modeled – to a first approximation – as a multi-input (desired position, external perturbation), single-output (position) linear, time-invariant system informed and controlled by delayed, weighted sensory feedback (visual and proprioceptive), a predictive forward model to compensate for long sensory and system delays, and a neural controller to minimize deviation from the desired position (here modeled as a PID controller [2]). Signals are degraded by sensory noise (visual and proprioceptive) and motor noise associated with excitation-activation dynamics and muscle unit recruitment.

Methods



Experimental setup. Subjects performed a series of pursuit and compensatory tracking tasks about the elbow joint using a 1-D robotic manipulandum. The goal of the tasks was to stabilize a computer generated cursor (red ring) on a target (black circle) during a continuous perturbation of the cursor or target. Kinematic analysis and systems identification techniques were used to characterize a sensorimotor control model for each individual subject.

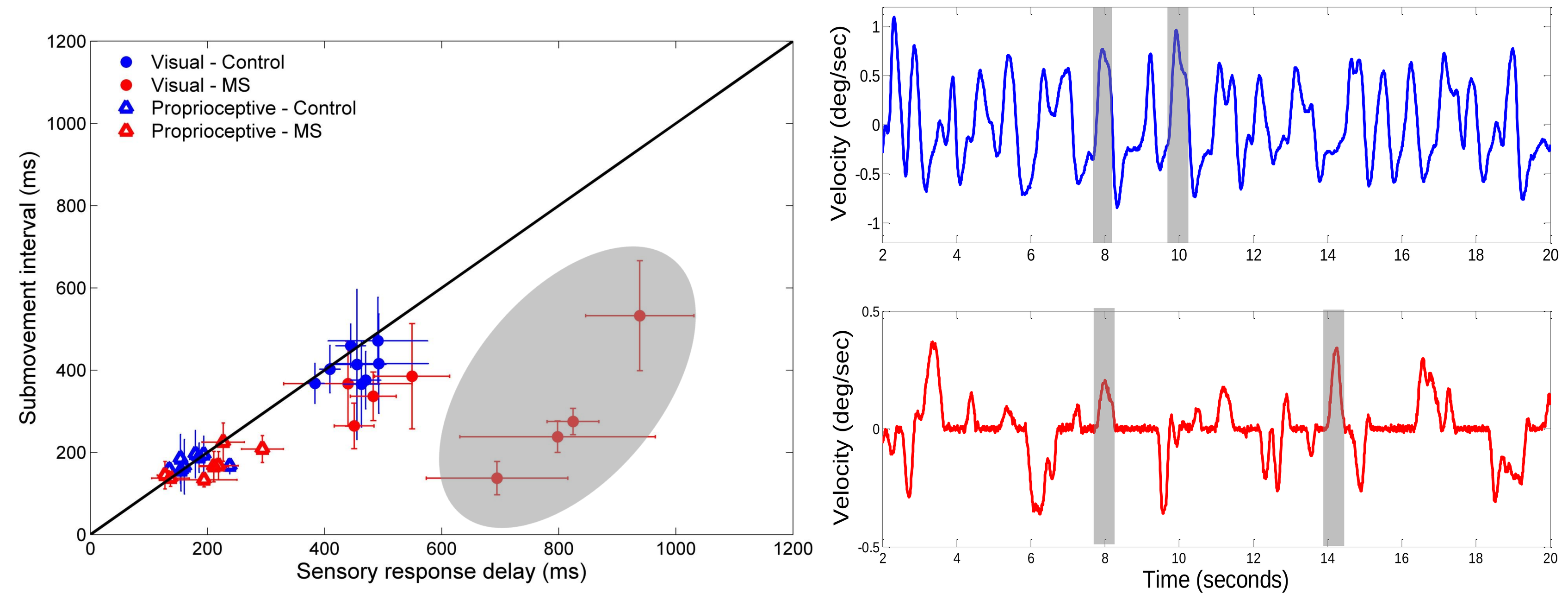
Experiment description, analysis, and estimated model parameters

Experiment	Parameter Measured		Analysis
Processing Delays	T_v & T_v^*	Visual Loop Delay	Cross correlation with perturbation/Kinematic analysis
	T_p & T_p^*	Proprioceptive Loop Delay	
Motor Noise	α	Multiplicative feedforward noise	Linear fit of variance vs. average torque
Active Wrist Dynamics	J	Rotational Inertia	Bootstrapped model fit to each subject's position vs. torque frequency response function (FRF)
	B	Viscosity	
	K	Stiffness	
System and Sensory Gains, Internal Estimates	K_v	Visual Feedback Gains	Bootstrapped model fit to each subject's position vs. perturbation frequency response function (FRF)
	K_p	Proprioceptive Feedback Gains	
	K_d K_p, K_i	Derivative, proportional, integral gains	
	J* B* K*	Expected inertia, viscosity, and stiffness	

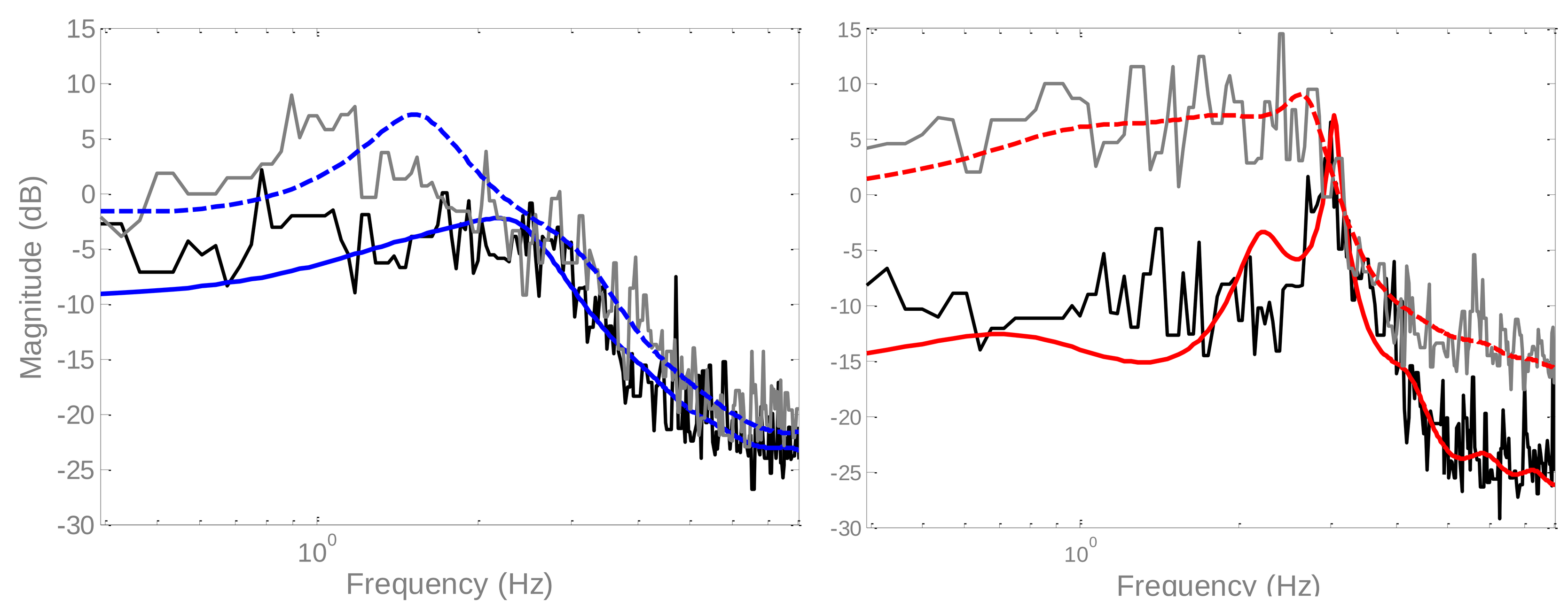
Results

Subject Characteristics: 7 subjects with MS with kinetic tremor and ataxia and 7 age-and gender-matched healthy control subjects (5 women, 7 right-handed, ages 25-61). (* - right hand only)

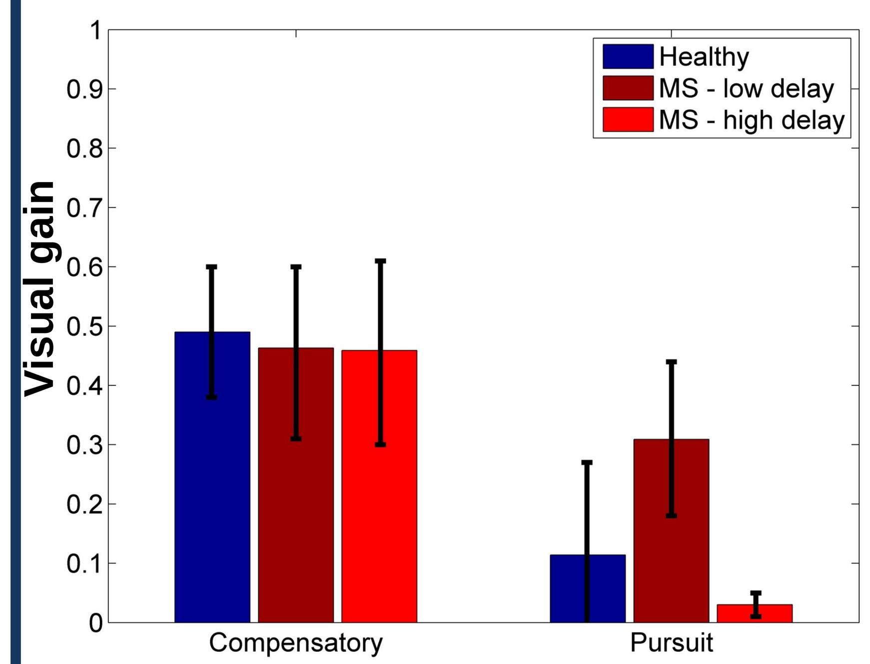
	Age	Gender	Dominant Hand	MS Type	EDSS	Tremor Score*	Ataxia Score*	Tremor Frequency*	Tremor Amplitude*
1	25	M	R	PR	7	3	2	3.65Hz	1.2
2	45	F	R	RR	2	1	1	3.29Hz	0.2
3	29	F	R	SP	7	2	2	2.79Hz	0.4
4	41	M	R	RR	6	3	2	2.57Hz	1.2
5	31	F	R	RR	2	2	1	4.27Hz	0.5
6	68	F	L	RR	1	3	3	5.03Hz	3.0
7	57	F	R	PP	7	1	1	2.36Hz	0.3



Analysis of intermittency and calculation of visual response delay. (L) Submovement interval (expected sensory response delay) vs. sensory response delay (circles –visual; triangles –proprioceptive) for control (blue) and MS (red) subjects. **(R)** Velocity profile for a visual compensatory task for subject with MS (red) and matched control (blue). Sample submovement intervals (defined as the distance between two zero-crossings in velocity) are highlighted.



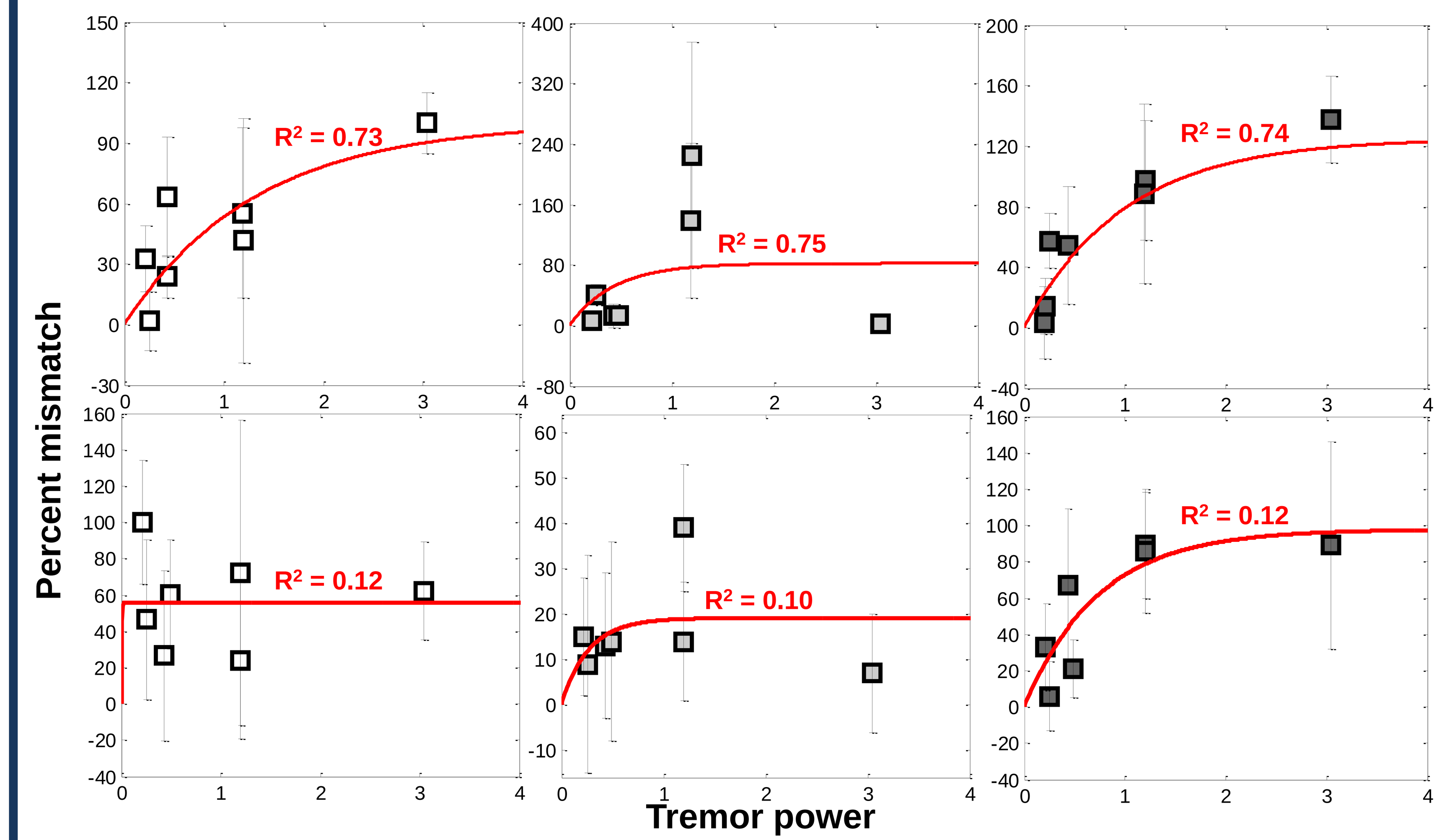
Frequency response functions (FRFs) for compensatory and pursuit tracking. Empirical FRFs for high frequency compensation (black) and tracking (gray) and the model fits (blue: control; red: MS) for subject 3 with MS and age-matched control. Response to the perturbation was more attenuated in the subject with MS at all frequencies, except for a large resonance corresponding to the tremor. This trend was characteristic of our two subject groups.



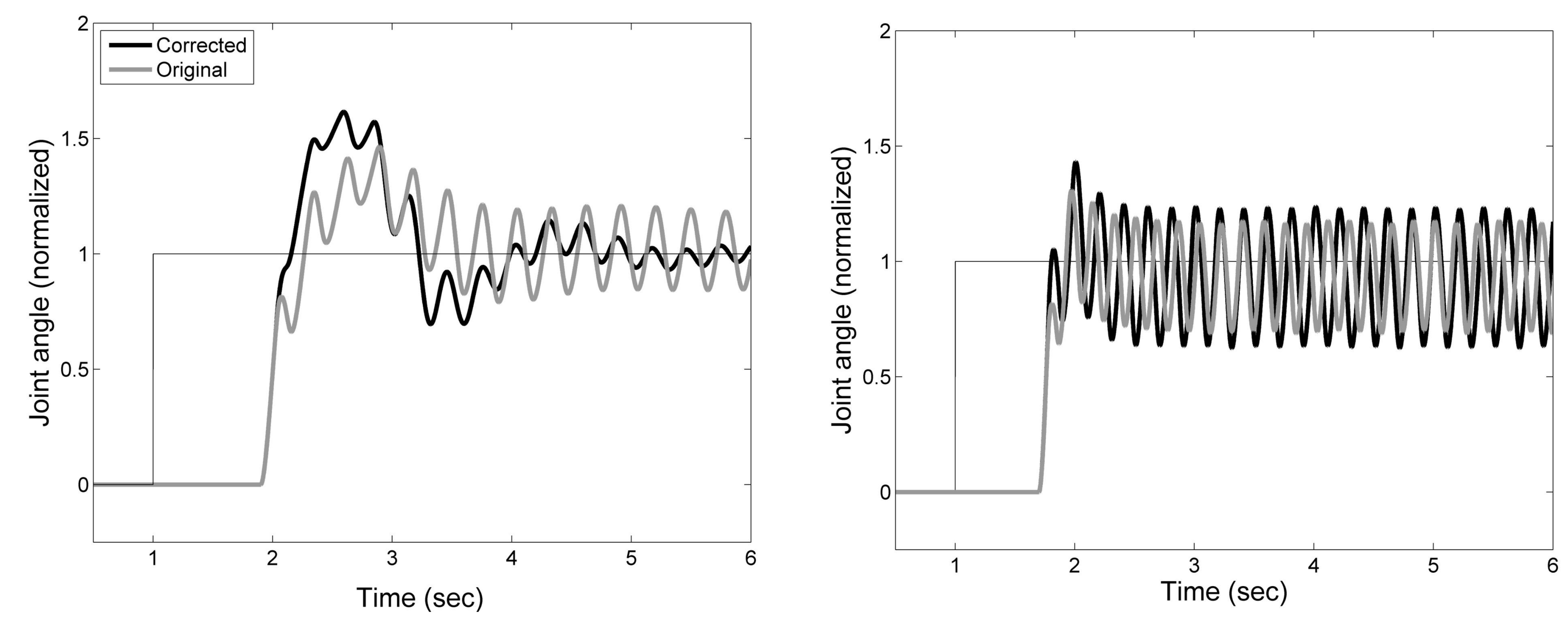
Visual Gain. During compensatory tracking, subjects with and those without MS weight the visual information used in the task equally, despite decreasing reliability of visual information across groups (healthy with normal visual delay; MS and normal visual delay; MS and increased visual delay).

During pursuit tracking, subjects with a visual delay mismatch (i.e. high visual delay) reduce their reliance on visual feedback. Interestingly, those with MS and no visual delay mismatch slightly increase their reliance on visual information during pursuit tracking.

Results



Percent mismatch in limb dynamics vs. tremor power. Increased clinical assessment of tremor (spiral tracing task) is associated with larger mismatches in inertia and stiffness during compensatory tracking. During pursuit tracking, the size of mismatches decreases, and inertia is no longer correlated with tremor power.



Model simulation Model response to a step input using a subject's parameter estimates (gray) and the same model with the mismatch in plant dynamics corrected (black). In subjects with TAS=2, mismatched dynamics stabilizes the system, while in subjects with TAS=3, the mismatch has a detrimental effect.

Conclusions

- We investigated whether two measures which are correlated with tremor, visual delay mismatch and mismatches between actual and expected limb dynamics, are related to each other.
- Subjects with MS and large delay mismatches act to reduce their reliance on visual feedback when possible (hence the significant reduction in visual gain during pursuit tracking).
- Inaccuracies in estimates of limb dynamics are reduced in tasks where visual feedback is reduced, accounting for improved performance during pursuit tracking tasks in MS.
- While it is possible that incorrect estimates of limb dynamics arise independently, most plausible explanations (poor proprioceptive feedback, structural damage) would not be task-dependent.
- Simulations suggest that the mismatch between actual and expected limb dynamics may be an adaptive response to a visual delay mismatch, rather than arising independently.
- An inability to compensate for increased visual feedback delays may be the primary cause of intention tremor in those with MS.

References

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