Motor control is impaired in both the affected and the unaffected arm after stroke and shows a limited time window of recovery

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Longitudinal studies of motor recovery after stroke have largely relied on clinical assessments, such as the Fugl-Meyer Upper Extremity Motor Assessment (FM-UE), and show that recovery generally reaches a plateau by 3-6 months after stroke. In this study, we set forth to characterize spontaneous recovery of upper extremity motor control after stroke, using kinematic measures that we hypothesized are better able to distinguish true recovery from functional compensation. We have previously demonstrated impaired reaching kinematics in both affected and unaffected arms in patients with chronic stroke. Using functional principal components analysis (FPCA), these deficits can be quantified in terms of increased trajectory bias (differences in *mean* trajectories) and variance (differences in *variability* around those means), compared to healthy control subjects. Here, we investigated the time-course of motor recovery in both arms after stroke using clinical measures of upper extremity motor impairment (FM-UE), motor function (Action Research Arm Test [ARAT]), and reaching kinematics.

Newly diagnosed ischemic stroke patients (n=15, mean age=56.6 yrs, 8M, 7 dominant side affected) with residual unilateral arm impairment participated in this study. Patients were evaluated at five time points during the first year after the stroke (within 2 weeks of stroke, then at week 4, week 12, week 24, and week 52 post-stroke). Some patients started testing at week 4 due to later recruitment (n=3), or being too impaired to perform the task at the early time point (n=1). Subjects performed visually-guided, center-out, gravity-supported planar reaching movements to eight radially-arrayed targets (8 cm distance) for each arm. This task was designed as an assay of basic motor control that minimizes the effect of strength and the use of compensatory strategies that may contribute to other measures of motor recovery.

For trajectories of the form $(X_i(t), Y_i(t))$, FPCA expresses each motion as the linear combination of a shared collection of basis functions and motion-specific weights or scores such that

$$X_i(t) = \mu_X(t) + \sum_{k=1}^{3} c_{ik}^X \phi_k^X(t) \text{ and } Y_i(t) = \mu_Y(t) + \sum_{k=1}^{3} c_{ik}^Y \phi_k^Y(t) \quad (1)$$

Here $\mu_X(t)$ and $\mu_Y(t)$ are population mean functions, $\phi_k^X(t)$ and $\phi_k^Y(t)$ are shared basis functions and the c_{ik}^X and c_{ik}^Y are the motion-specific scores. Shared mean and basis functions are estimated from the population, and scores are estimated from individual trajectories. Trajectory distributions at the population level can be understood through the scores; in particular, we compute squared Mahalanobis distances ($MD_i^2 = (\boldsymbol{c_i} - \bar{\boldsymbol{c}})^T \Sigma^{-1} (\boldsymbol{c_i} - \bar{\boldsymbol{c}})$) for each score, and decompose these distances into subject- and target-specific biases and variances with respect to a reference group of neurologically healthy controls (n=11, mean age=58.4, 8M). Statistical comparisons were made using all available subjects and targets in a generalized estimating equation framework. Changes over time, or comparisons with control subjects, were modeled as fixed effects, and within-subject correlations were modeled using a uniform correlation structure. Reported p-values are based on robust test statistics.

Initial trajectories with both the affected and unaffected arms showed greater bias and variance compared to healthy controls (Figure 1). From the first time point to week 4, we found significant improvements in both bias and variance for the affected arm (p=0.003 and 0.018, respectively). For the unaffected arm, there was improvement in trajectory variance (p=0.003) but not in bias (p=0.096). After week 4, we saw no further improvements in our kinematic measures for either arm. The affected arm remained markedly worse than controls after 4 weeks and despite room for further improvement did not do so. It is unclear from our current data (recruitment and data collection still ongoing) whether the unaffected arm was at ceiling compared to controls after four weeks. We conclude that there is a limited, approximately four-week time window for spontaneous recovery of proximal upper extremity motor control, perhaps for both arms. Interestingly, we continued to see improvements in the FM-UE and ARAT in the affected arm beyond 4 weeks (Figure 2). This suggests that recovery of strength or learning of compensatory strategies can occur through separate mechanisms.

Figure 1. Bias and variance for the trajectories of affected and unaffected arms in stroke, and healthy controls.

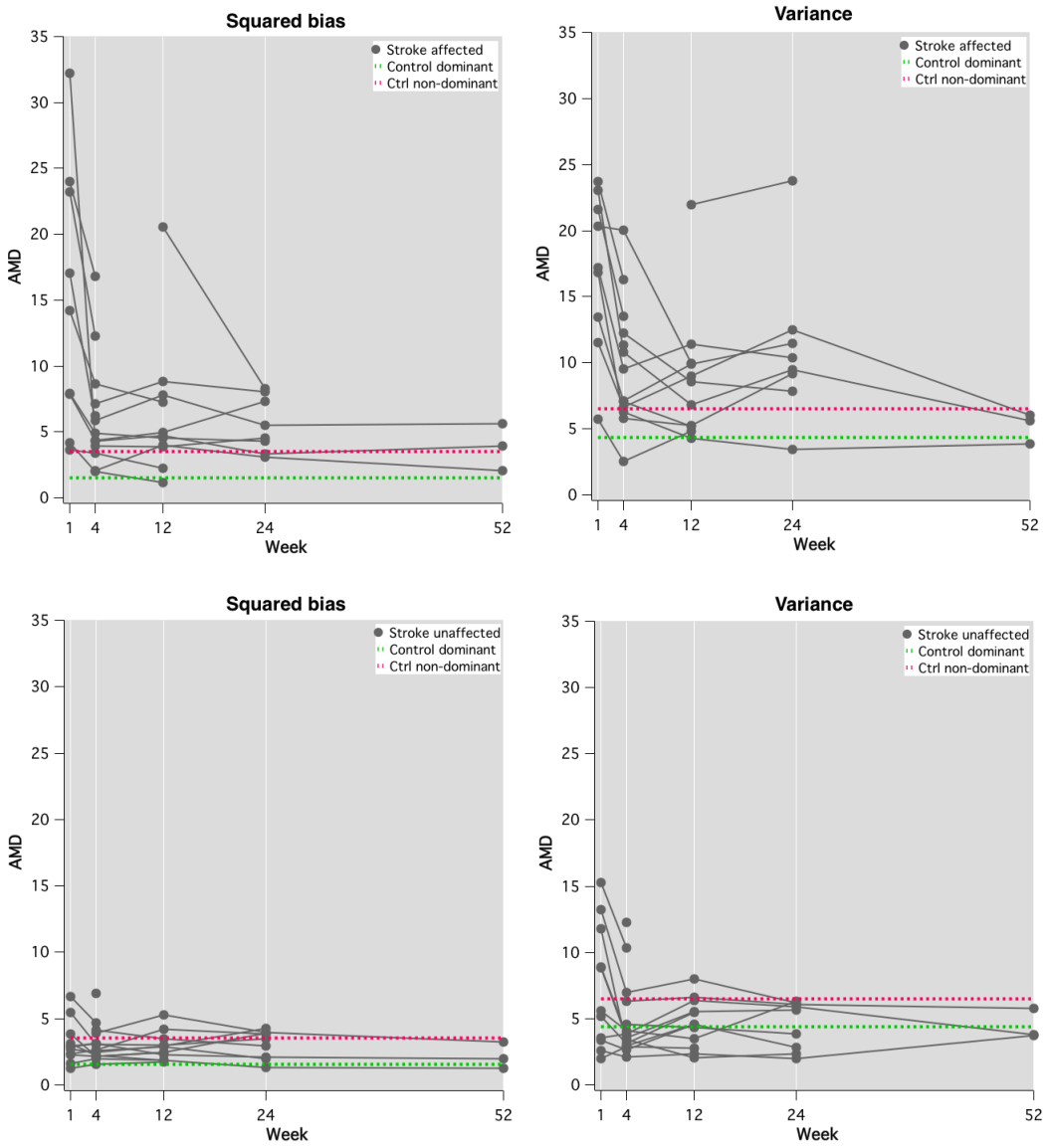

Figure 2. FM-UE and ARAT scores for stroke subjects during the first year after stroke. Recovery in clinical test scores continues beyond the fourth week after stroke, a phenomenon that is more evident in those tests that allow for compensatory mechanisms like the ARAT, indicating that behavioral adaptations to impairment are not limited within the narrow window of motor recovery.