

Individuation within the Paretic Upper-Limb:

Rehabilitation by Segmentation

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Abstract.

- Smooth execution of reaching tasks requires control of sub-movements.
- Muscle recruitment within the upper-arm workspace is highly variable after paralysis.
- We have developed the Hand-Arm Rehabilitation Interface (HARI) to characterize and rehabilitate motor impairments in hemi-paretic persons.
- We have also developed the Normalized Ideal Sinusoidal Error (NISE) metric to quantify adherence to an oscillating target

HARI Instrumentation.

- Supports arm against gravity, allowing unconstrained elbow flexion & extension.
- Goniometric data provides instantaneous biofeedback, and records for analysis.
- Isolates elbow motion for focused rehabilitation and motor characterization.



Figure: The HARI allows unconstrained elbow flexion and extension in the transverse plane. Goniometric data is recorded for post-hoc analysis.

Protocol.

- 10 Subjects: 57.8±18.4 years old 16±13 mo. post-stroke
- 10+ sessions of elbow flexion exercises: Subjects instructed to flex & extend maximally and smoothly.
- Self-selected pace; visual feedback
- Goniometric data segmented into 10° partitions
- Data evaluated for NISE, and other standard metrics of motor control

The NISE Metric.

- Movements about a joint can be compared for adherence to a sinusoidal trajectory
- Ideal comparison wave w matched for amplitude and frequency by RMS error minimization
- Repetition R divided into segments
- w (length $N = \#$ of time points in R) is convolved by index m , with pads of increasing length (index z)
- NISE can be calculated for wave segments
- $K = \text{segment width (radians)}$

$$NISE = \min \left(\frac{\sqrt{\sum_i^N (w_i^z(m) - R_i)^2}}{\sqrt{\sum_i^N (w_i^z(m))^2}} \right)_{\substack{z=1:N-1 \\ m=1:N-z}}$$

$$w_i^z = \begin{cases} \min(R) & i < m \\ C_i^z & m \leq i \leq m+z \\ \max(R) & i > m+z \end{cases} \quad \begin{aligned} P &= -\frac{\pi}{2} + \frac{\pi}{K} \\ Q &= \frac{\pi}{K} \end{aligned}$$

$$C_i^z(m) = \frac{1}{2} \left[1 + \sin \left(P + Q \frac{(i-1) - (m-1)}{z} \right) \right]$$

NISE Convolution Plots

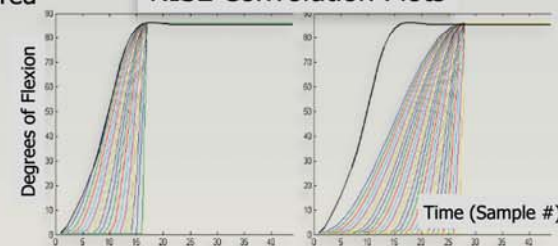
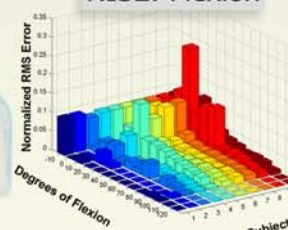


Figure: Sample plots of 2 steps in the NISE convolution: NISE error is the minimum error of matched comparison waves (w) and recorded repetition (R).

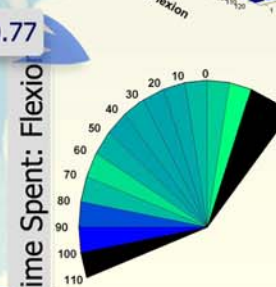
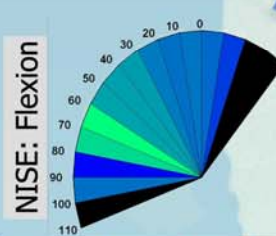
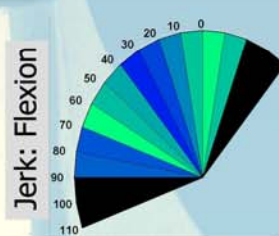
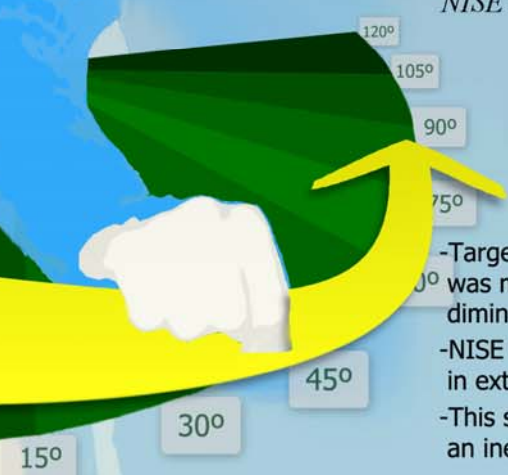
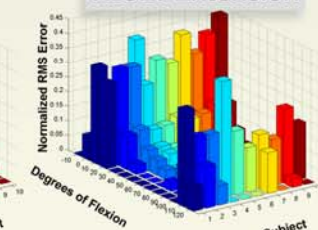
Results.

- Targeting Error (NISE) in flexion was maximal early in motion, and diminished in approach to chest.
- NISE was distributed bi-modally in extension tasks
- This suggests a spatial effect, not an inertial effect.

NISE: Flexion



NISE: Extension



$r=0.47$

$r=0.77$

-NISE signatures exhibited fair correlation to the local permanence during flexion activities ($r=0.77$ in ensemble averages across 10 subjects).

-Normalized jerk yielded a poor correlation to time spent in flexion ($r=0.47$).