Perturbation motor corrections correlate with features of reaching and are independent of proprioceptive impairments post-stroke

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Stroke is a leading cause of long term disability that can cause impairments of sensory and/or motor functions depending on the location of the damage. We used robotic technology to objectively and quantitatively assess the unique impairments specific to an individual subject with stroke. Voluntary motor control and perception of limb geometry have previously been investigated in subjects with stroke using a visually guided reaching task and a limb matching task, respectively. Recent theories of motor control have emphasized the importance of limb afferent feedback in voluntary motor control. Therefore, we have designed a postural perturbation task to assess the use of limb afferent feedback for motor action. We hypothesize that impairments in perturbation metrics will be independent of impairments in matching metrics because the matching task uses limb afferent feedback for perception instead of for action. Contrastingly, we hypothesize perturbation metrics will correlate with reaching metrics due to the important role of limb afferent feedback in voluntary motor control. Finally, we hypothesize all three tasks will correlate with the ability to do activities of daily living (Functional Independence Measure- FIM).

Subjects with subacute stroke (n=29) were assessed in a KINARM exoskeleton robot that permits arm motion in the horizontal plane. In the matching task, subjects perceived the position of their robotically controlled arm and mirror matched the limb geometry with their voluntarily controlled arm without visual feedback of limb position. In the reaching task, subjects reached quickly and accurately to a visual target with visual feedback of hand position. In the perturbation task, subjects were perturbed out of a visual target by a step torque and were required to return quickly and accurately to the target without visual feedback of hand position. Both arms were assessed in all 3 tasks and only 18 subjects with stroke were assessed in the reaching task. Fisher Exact Probability Tests were used to determine if impairments were independent between tasks.

Figure 1 displays two exemplar subject with stroke, one with impairments only in the matching task, and the other with impairments only in the perturbation and reaching tasks. Across subjects, impairments in all three limb matching parameters were significantly independent of impairments in perturbation correction parameters. In contrast, most impairments in reaching parameters were significantly correlated with impairments in larger endpoint errors post-perturbation. Postural perturbation task parameters in subjects less than 28 days post-stroke were also correlated with the FIM motor subscore (p=0.02, r=0.57).

The independence of impairments in limb afferent feedback for motor action and sensory perception indicate that these functions should be assessed separately. As well, subjects with stroke should be given different rehabilitation interventions depending on how the use of limb afferent feedback is impaired.
Exemplar subjects. Performance of two subjects with stroke (both affected primarily on the right side of the body) in all three tasks. (A) Perturbation task right hand paths and endpoint positions (square markers). Trials responding to elbow flexion, elbow extension, shoulder flexion, and shoulder extension perturbations are shown in blue, red, green, and black, respectively. (B) Perturbation task right hand speed profiles for shoulder extension perturbations and corresponding first hand speed minima (circle markers). (C) Reaching task right hand paths are shown in different colours for each of the 4 visual targets. (D) In the matching task, subjects mirror-matched the endpoint positions of the robotically controlled right arm (green trace) with their voluntarily controlled left arm (blue trace; mirror superimposed into the right workspace, blue dashed trace). Subject #1 (left) performed the perturbation task well, incurring small endpoint errors and quickly responding to the perturbation. Subject #1 performed well in the reaching task, producing relatively straight reaching trajectories with small corrective movements. Subject #1 displayed impairments in the matching task, with expansion and shift of the workspace, as well as substantial endpoint variability for some proprioceptive targets. Subject #2 (right) was impaired in the perturbation task, as displayed by larger endpoint errors and later first hand speed minima. Subject #2 was impaired in the reaching task, as displayed by more variable reaching trajectories. Subject #2 performed well in the matching task, mirror-matching the workspace area with minimal endpoint variability.