Characterizing proprioceptive recovery after stroke using robotics

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In our daily lives, we use sensorimotor control to execute and modify movements throughout our environment. Neurologic injury, such as stroke can have devastating effects on both motor and proprioceptive function. Clinically, functional recovery after stroke is thought to be highly dependent on the recovery of motor function. However, few studies have examined the role of proprioception in stroke recovery. Recently, our lab has developed robotic tests that allow for more sensitive measurement of proprioceptive deficits after stroke. While proprioceptive deficits occur in > 50% of stroke survivors, these deficits rarely receive directed treatment. Here we characterize recovery of proprioceptive deficits over the first 6 months post-stroke.

One hundred fifteen subjects with stroke performed two robotic tests of proprioception at four timepoints post-stroke (1, 6, 12 and 24 weeks). For both tasks, subjects sat in the wheelchair base of the KINARM exoskeleton with their arms supported against gravity. In each task, visual feedback of the arms and hands was occluded. Task 1: Position Matching (PM) Task (Fig. 1A) – The robot moved the stroke affected arm to one of nine pseudorandom locations. When the robot stopped moving, subjects mirror-matched the position of the affected arm with the unaffected arm. Subjects made 6 movements to each of 9 targets for a total of 54 movements. Task 2: Kinesthetic Matching (KIN) Task (Fig. 1B) - The robot moved the stroke affected arm to one of three locations. Subjects were instructed to mirror-match the speed, direction and magnitude of the robotic movement with their opposite arm as soon as they felt the robot begin to move. Subjects made 36 movements, 6 movements each in 6 directions. All subjects were evaluated on a battery of clinical measures at each of the four timepoints to evaluate functional ability (Functional Independence Measure (FIM)), motor function of the arm and hand (Chedoke-McMaster Stroke Assessment (CMSA), Purdue Peg Board (PPB)) and static position sense (Thumb Localizer Test (TLT)). Approximately 200 control subjects completed each of the robotic tasks to provide healthy control values.

In Figure 1, a control subject performs normally on the position matching task (C/E = 0.83, Shift = 1.7cm, Var = 3.4cm). We observed that some subjects with stroke had rapid improvements in proprioception and other subjects exhibited impairments over the entire course of recovery on our robotic proprioceptive measures (Fig. 2). Figure 2A demonstrates a subject who initially had significant difficulty matching position of the robot marked by large variability in matching target position (C/E = 0.6, Shift = 3.5cm, Var = 12cm), but vastly improved by 6 weeks post-stroke (C/E = 0.8, Shift = 1.9cm, Var = 5cm). Figure 2B displays a subject that does not improve over the course of the 6 month testing (1 week post-stroke: C/E = 0.09, Shift = 9.8cm, Var = 8.8cm; 24 weeks post-stroke: C/E = 0.45, Shift = 7.8cm, Var = 4.1cm). We found that approximately 50% of subjects had significant proprioceptive impairments on both the PM task (47%, N = 54) and the KIN task (52%, N = 60) at 1-week post-stroke. By 24-weeks post-stroke we found that in both tasks, on average, of those subjects with impairments at 1-week post-stroke, 30% were still impaired compared with performance of healthy controls (Fig. 3). For PM Variability, those that improved to normal by 6 weeks improved their variability score by 70% (N = 39). For those that did not improve to normal by 6 weeks, many subjects worsened (N = 17), and for those that improved (N = 22) only improved their PM Variability score by 30%.

Proprioceptive recovery in stroke has received limited attention in the stroke-recovery literature, likely due to the difficulty of measuring proprioceptive impairment. Here we highlight the importance of inter-individual differences in proprioceptive recovery after stroke. We observed that many subjects had sustained deficits, and without significant improvements in proprioception the chance of improving past 6 weeks post-stroke decreased drastically. These results highlight an important issue in stroke recovery and rehabilitation - how do we best identify individual differences in post-stroke impairments and create a treatment plan that is most beneficial to their recovery? These results suggest two separate types of recovery, one that is rapid and is consistent with the classical dogma that most recovery happens over the first 6 weeks post-stroke, and the other is slower and only makes incremental changes even over the first 6 months post-stroke. Through technology, like robotic measurement, we may be better able to provide targeted measurement and in turn more personalized treatment after stroke.

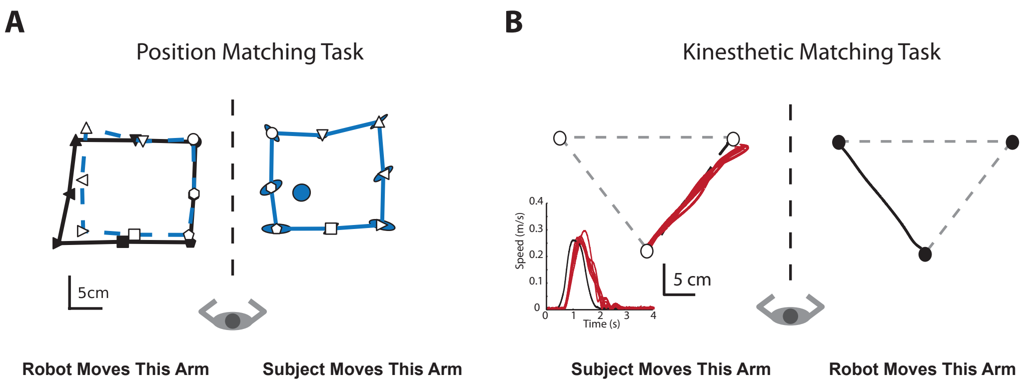

Figure 1: Position Matching Task (A) and Kinesthetic Matching Task (B) examples of control data. A) The robot moved the subjects' left arm and the subject matched with the right. Subject demonstrates typical performance of controls and is able to preserve the area of the workspace (Contraction/Expansion (C/E) = 0.83), little x,y translation of the workspace (Systematic Shift = 1.7cm), and low variability about matched target location (Variability (Var) = 3.4cm - ellipses indicate one SD of variability in a single target location). B) The robot moved the subjects' right arm and the subject matched with the left. Subject demonstrates the ability to match the direction, magnitude and speed of the robotic movement. Normal ranges for both tasks were calculated from control data of ~200 subjects.

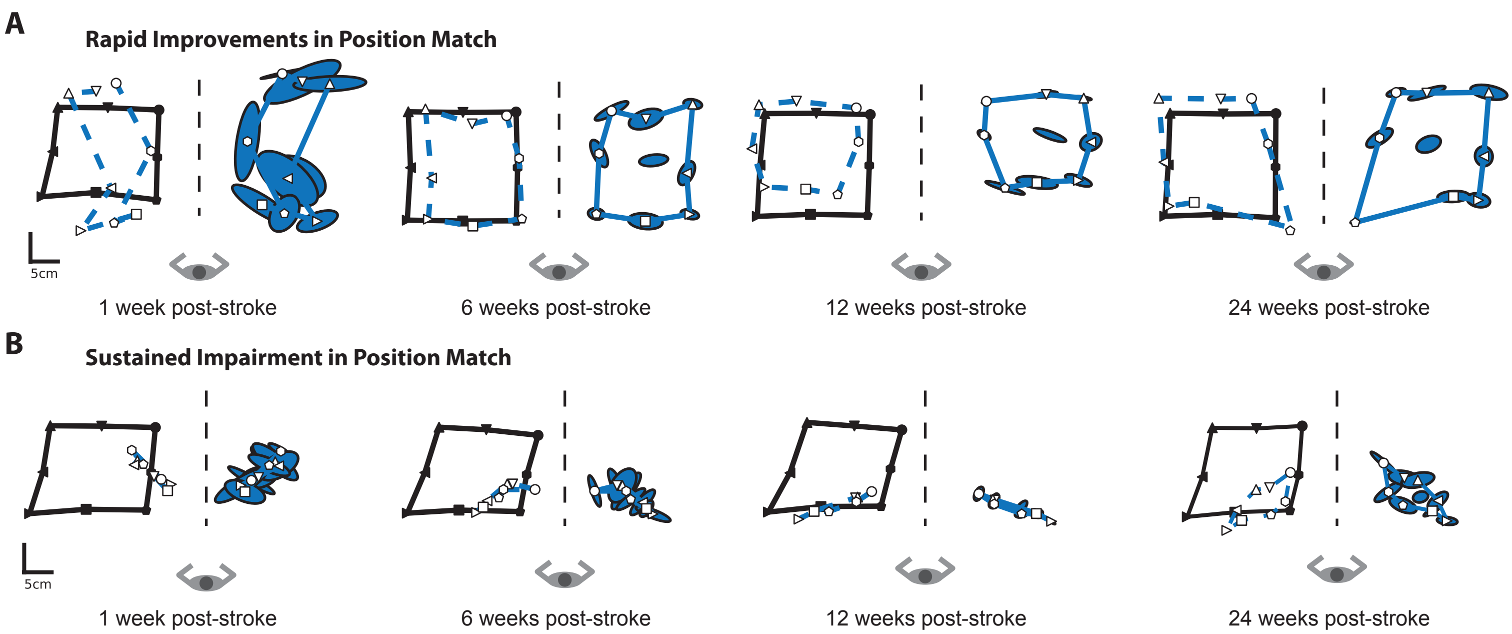

Figure 2: Examples from the Position Matching Task over the four timepoints for a subject that quickly returns to normal proprioception (A) and a subject that has persisting position match deficits over 6 months post-stroke. In both tasks, subjects exhibited different types of recovery behaviour, some individuals made large gains in proprioceptive recovery in the first 6 weeks (where the majority of gains are thought to be made), while some individuals had sustained impairments or only incremental improvements over the first 6 months post-stroke.

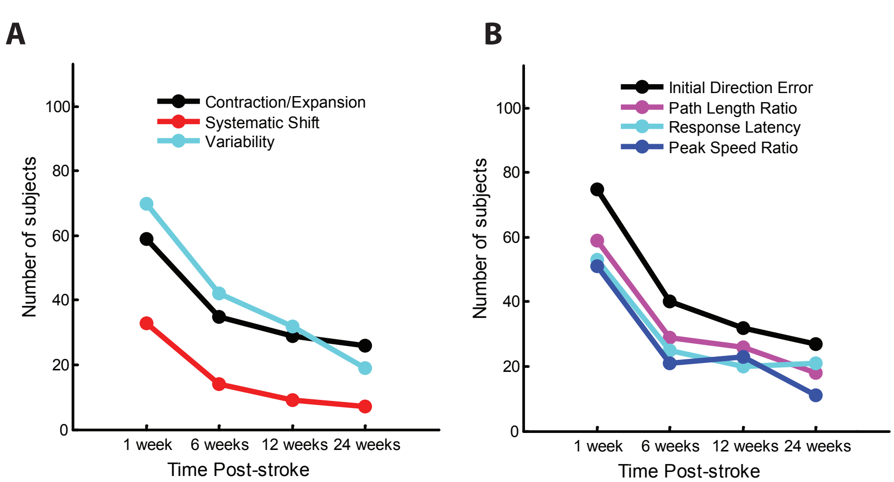

Figure 3: For each measure in the position match (A) and kinesthetic matching (B) tasks, we measured 3 and 4 parameters, respectively. We found that ~50% of subjects had significant deficits in all parameters in both tasks (except Shift in PM). Notably, for those individuals with significant impairments, 30% of these subjects still had impairments even at 6 months post-stroke. In the kinesthesia task (B), we measured ability to match the direction of the robot (Initial Direction Error), ability to match the length of the movement (Path Length Ratio), sensory response time (Response Latency) and ability to match the speed of the robot (Peak Speed Ratio).