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Anatomical correlates of proprioceptive impairments following acute stroke: A case series

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ABSTRACT

Background: Proprioception is the sensation of position and movement of our limbs and body in space. This sense is important for performing smooth coordinated movements and is impaired in approximately 50% of stroke survivors. In the present case series we wanted to determine how discrete stroke lesions to areas of the brain thought to be critical for somatosensation (thalamus, posterior limb of internal capsule, primary somatosensory cortex and posterior parietal cortex) would affect position sense and kinesthesia in the acute stages post-stroke. Given the known issues with standard clinical measures of proprioception (i.e. poor sensitivity and reliability) we used more modern quantitative robotic assessments to measure proprioception.
Methods: Neuroimaging (MRI, n = 10 or CT, n = 2) was performed on 12 subjects 2–10 days post-stroke. Proprioception was assessed using a KINARM robot within the same time frame. Visually guided reaching was also assessed to allow us to compare and contrast proprioception with visuomotor performance.
Results and Conclusions: Proprioceptive impairments were observed in 7 of 12 subjects. Thalamic lesions (n = 4) were associated with position sense (n = 1) or position sense and kinesthesia (n = 1) impairments. Posterior limb of the internal capsule lesions (n = 4) were associated with primarily position sense (n = 1) or kinesthesia (n = 2) impairments. Lesions affecting primary somatosensory cortex and posterior parietal cortex (n = 2) were associated with significant position sense and kinesthesia impairments. All subjects with damage to hypothesized structures displayed impairments with performance on the visually guided reaching task. Across the proprioceptive tasks, we saw that position sense and kinesthesia were impaired to differing degrees, suggesting a potential dissociation between these two components of proprioception.

1. Introduction

Proprioception is a term used to describe the knowledge of the location and movement of our limbs in space [1]. Classically, it has been considered to have two subcomponents: position sense and kinesthesia. Position sense is the perception of static limb location, whereas kinesthesia is the sensation of limb or joint motion [2].

Proprioceptive impairment following stroke has been reported to occur in approximately 50% of patients [3–5]. While many post-stroke studies focus on motor function, impairments in proprioception have been linked to postural instability [6], impaired motor recovery [7], safety concerns, as well as longer hospital stays and decreased functional independence at discharge [8,9]. Proprioception can also predict long-term motor recovery after stroke [10,11] and has been strongly correlated with motor recovery of the hemiplegic arm after stroke [12]. However, the relationship between lesion location and specific proprioceptive impairment remains poorly understood.

Prior studies attempting to link neuroimaging and proprioception in stroke have relied on finger position sense or proprioception measured by standard clinical assessment [13–17]. These studies have reported proprioceptive impairments following thalamic lacunar stroke [14,15,17], posterior limb of the internal capsule stroke [16] and cortical stroke [13,16].

Most clinical tests of proprioception involve a patient's ability to discriminate between the upward or downward position of a digit when passively moved [18]. This test and other clinical assessments of proprioception such as the thumb localizing test [19], are based on ordinal scales, show relatively poor inter-rater reliability and lack sensitivity

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[20,21]. Further, these tools were not designed to differentiate between impairments in position sense and kinesthesia following stroke.

Robotic assessments have recently been developed to quantitate sensorimotor impairments following stroke [5,22,23]. These robotic assessments are relatively quick to administer and can quantitate position sense reliability [5], while also providing insight into other aspects of proprioception, such as kinesthesia [24]. Further, subjects can easily complete a brief battery of robotic tasks to assess various aspects of behavior, including motor function. This allows the observer to compare and contrast differences in sensory versus motor performance after a stroke. Pairing these assessment methods with lesion analysis after stroke may allow for an improved ability to interpret the behavioral consequences of a particular stroke lesion location.

The present study examined twelve stroke survivors with acute lesions to structures believed to be involved with proprioception and evaluated their performance on three different robotic tasks. Comparisons were made of the subjects' performance on tasks measuring position sense, kinesthesia and a standard motor task (visually guided reaching). We hypothesized that damage to the following structures: ventral posterior lateral (VPL) nucleus of the thalamus, the posterior limb of the internal capsule (PLIC), the post-central gyrus (S1) and posterior parietal cortex (PPC) would produce measureable impairments in sensorimotor function. Further, we made comparisons to two acute stroke subjects without damage to these brain areas to demonstrate a behavioral dissociation based on lesion location.

2. Methods

2.1. Subjects

A total of 12 subjects with first diagnosis of clinical stroke were recruited from the Foothills Medical Centre (FMC) or the Dr. Vernon Fanning Centre (VFC) in Calgary, Alberta, Canada. Ten cases were chosen based on lesions identified on neuroimaging to VPL thalamus, PLIC, S1 or PPC. Two cases were chosen because they had no damage to these regions. Subjects had no other neurological diagnoses (including previous stroke) and cognition and language were sufficient to follow the instructions required to complete the assessments. Neuroimaging was conducted a mean of 1.5 days (SD 2.2) post-stroke and clinical magnetic resonance imaging (MRI) or computed tomography (CT) scans were obtained according to the standard acute stroke protocol at the Foothills Medical Centre for use in the present study. Axial T2-weighted FLAIR (fluid attenuated inversion recovery) images were used to depict lesion location. Subjects participated in both a clinical and robotic assessment a mean of 7.3 days (SD 3.7) post-stroke. This study was approved by the University of Calgary Research Ethics Board.

2.2. Lesion Delineation

Although we based inclusion in the study on the appearance of the stroke lesions on the clinical neuroimaging scans, in order to accurately quantify the burden of lesion in our hypothesized areas we performed a region of interest (ROI) analysis. Regions of interest for each area (thalamus, posterior limb of the internal capsule, post-central gyrus and superior parietal lobule) were first drawn on the T1 Montreal Neurological Institute (MNI) template brain with MRIcron [25] (www.mricro.com) using both a white matter atlas [26] and Myeloarchitectonic Atlas [27]. Lesion location of each subject was then demarcated directly on corresponding slices of the T1-weighted MNI template brain in MRIcron by closely examining the FLAIR and diffusion weighted imaging (DWI) for those with MRI and CT for those without. This procedure is consistent with previously reported methods [28–30]. ROI analysis was performed using Non-Parametric Mapping (NPM) software (available with the MRIcron software package). This provided the percentage of each ROI that was damaged in each subject and the percentage of an individual's lesion that was located within the borders of each ROI. Lesion volume was also obtained through NPM.

2.3. Robotic Assessment

Robotic assessment was performed using a KINARM robotic exoskeleton (BKIN Technologies Ltd., Kingston, Ontario, Canada) (see Fig. 1A). Subjects were seated in the wheelchair base with both arms supported against gravity by the robotic exoskeleton in the horizontal plane (~80° shoulder flexion) and the exoskeleton was adjusted to fit each subject's body dimensions (height, limb segment length) by the study therapist. The robot allowed subjects to move freely in the horizontal plane with flexion and extension movements of the elbow joints and shoulder joints. The KINARM monitored and recorded arm movement, and applied mechanical loads to the shoulder and elbow joints during passive movements used in the position matching and kinesthesia tasks.

2.4. Arm position matching task

The arm position matching task (Fig. 1B) was used to quantify position sense of the upper extremities. This task was performed without vision, as previously described in detail by Dukelow and colleagues [5]. The position matching task required the subject to move his/her unaffected/less affected arm (active arm) to mirror match the end position of the stroke affected arm that was passively moved by the KINARM (passive arm). The robot moved the subjects' passive arm to nine different spatial locations pseudorandomly, with the subject matching each location with the active arm before moving onto the next trial. The passive arm was moved to each target 6 times for a total of 54 trials. Three parameters were derived from the end point position of the active hand for all trials. Variability in the x and y direction (var_{xy}) measured trial to trial consistency of the end position of the active arm. Spatial contraction/expansion ($cont/exp_{xy}$) measured the ratio of the total area of workspace matched by the active arm relative to the passive arm. Systematic shifts ($shift_{xy}$) measured consistent errors between active and passive arms. Consistent errors were measured as the mean error between passive and active hands for each target location across all trials in the x direction, y direction and combined xy. The average of these mean errors in the combined xy coordinate then denoted the magnitude of systematic shift. Normal ranges for each parameter were derived from the 95% confidence interval from 170 control subjects with consideration for age, sex and handedness [31]. Overall, we found that 95% of controls failed 1 or fewer parameters on the arm position matching task. Thus, we created a task failure threshold for subjects with stroke of 2 or more parameters [31].

2.5. Arm kinesthesia task

This kinesthesia task (Fig. 1C) was used to examine kinesthesia of the upper extremities. This task (also previously described) [24] was administered without vision of the upper extremities. This task required the subjects to use their active (unaffected/less affected) arm to mirror match the *movement* of their passive (stroke affected) arm that was being moved by the KINARM. Prior to the start of each trial, the subject's hands were moved to one of three pre-set mirrored locations in the workspace. The passive arm was then moved to one of two other target locations by the robot and subjects were instructed to use their active arm to mirror match the speed, direction and distance of the movement as soon as they felt the robot move, thereby attempting to mimic the passive movement in real time. A total of 6 movement directions were performed 6 times each for a total of 36 trials.

Four parameters were used to measure the temporal and spatial (x,y) aspects of movements of each subject [24]: Response Latency (RL) — the time between movement initiation (point where subject reached 10% of hand speed maximum) of the passive arm and active arm. Peak Speed Ratio (PSR) — the ratio of maximum passive arm speed

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