Cortical brain mapping of the rat forelimb using fMRI at 9.4T by direct nerve stimulation

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Purpose

The brachial plexus provides the motor and somatosensory innervation to the upper extremity. Brachial plexus injuries can result in debilitating partial or complete loss of function of the affected upper extremity. Current treatment options are often limited to surgical reinnervation of the injured nerves. Past fMRI studies have been focused on mapping the rodent somatosensory system using direct forepaw stimulation. This study aims to refine our current knowledge of the cortical representation of three major nerves of the upper extremity: musculocutaneous, ulnar and median nerves. This is achieved by direct electrical nerve stimulation during fMRI acquisition using a 9.4T scanner. This effort is part of a larger goal of developing a cortical maps for both motor and sensory nerves of the rodent upper extremity and developing a rodent model for brachial plexus injuries and surgical nerve repair.

Methods

15 Sprague Dawley rats were used to study the musculocutaneous (5 rats), the ulnar (5 rats) and the median (5 rats) nerves. The brachial plexus of each rat was exposed on the right upper arm, and the nerve in question was isolated and secured to a stainless steel electrode (AISI 304, Plastics1 – Roanoke, Virginia). The right femoral artery and vein were used for invasive blood pressure monitoring and for continuous IV drug administration. A tracheotomy allowed for mechanical ventilation during the fMRI acquisition. Isofluorane (1%) was administered during the surgical portions of the procedure. Once the rat was transferred to the scanner the Isofluorane was turned off. A continuous infusion of Pancurium Bromide (2mg/kg/hr) and Domitor (0.1mg/kg/hr) was used during the fMRI acquisition. Four separate stimulation protocols that differed in current level (0.5 mAmp or 1.0 mA) or frequency (5 Hz or 10 Hz) were used. A duration of 1 ms was used for every nerve stimulation protocol. A bipolar beryllium copper electrode was placed in the left forepaw to serve as a control. The forepaw stimulation protocol included a current of 2.0 mAmp, frequency of 10 Hz, and a duration of 3 ms. Each nerve and forepaw stimulation sequence began with an OFF period of 40 seconds followed by three repetitions of ON for 20 seconds and OFF for 40 seconds (total scan time 3minutes 40seconds). Gradient echo scans (Single shot EPI, TE = 18.39 ms, TR = 2 ms, MTX 96 x 96, FOV = 4 cm, Number of repetitions = 110, 10 contiguous 1mm slices, acquisition time = 3 minutes 40 seconds) were acquired on a 9.4T Bruker MRI scanner. Physiologic monitoring included invasive blood pressure, arterial blood gases, pulse oximetry, temperature, respiratory rate, inspired / expired O2 and CO2. These parameters were maintained under normal physiologic ranges. Activation was determined by a **F** test with a P-value threshold of 0.005 using AFNI software. The anatomical scans were registered to an ideal anatomy using FLIRT software (ref 1).

Results and Discussion

Each nerve showed a distinct representation in the motor and sensory regions of the cortex (Figure 1). Increased frequency (10Hz) and current intensity (1.0 mA) showed greater levels of cortical stimulation and sometimes extended to the other cortex. The three nerves in this study are among five of the major nerves to the upper extremity. The musculocutaneous nerve provides motor innervation to the coracobrachialis, the biceps brachii, brachialis, pronator teres and flexor carpi radialis. Beyond the elbow, the musculocutaneous nerve becomes the lateral cutaneous nerve of the antibrachium, a sensory nerve the forelimb and forepaw. The median nerve provides the motor innervation to the flexor digitorum sublimis and profundus, palmaris longus and pronator quadratus. The median nerve divides into three common volar digital nerves, each of which divides further to form two proper volar digital nerves supplying the sensory input to the first through fourth digits. The ulnar nerve stimulates the flexor carpi ulnaris and flexor digitorum profundus, and intrinsic muscles of the forepaw as well as the sensory input to the fourth and fifth digits. Though the motor and sensory regions of the three nerves can be seen in the slices shown below, there is some overlap in the activation across the nerves. This makes sense as the three nerves provide sensory innervation to the digits, and there is overlap in some motor functions like wrist flexion. This study provides a refinement of our understanding of the specific motor and somatosensory cortical representations of the brachial plexus. Further studies are warranted to refine the individual sensory and motor inputs of each nerve.

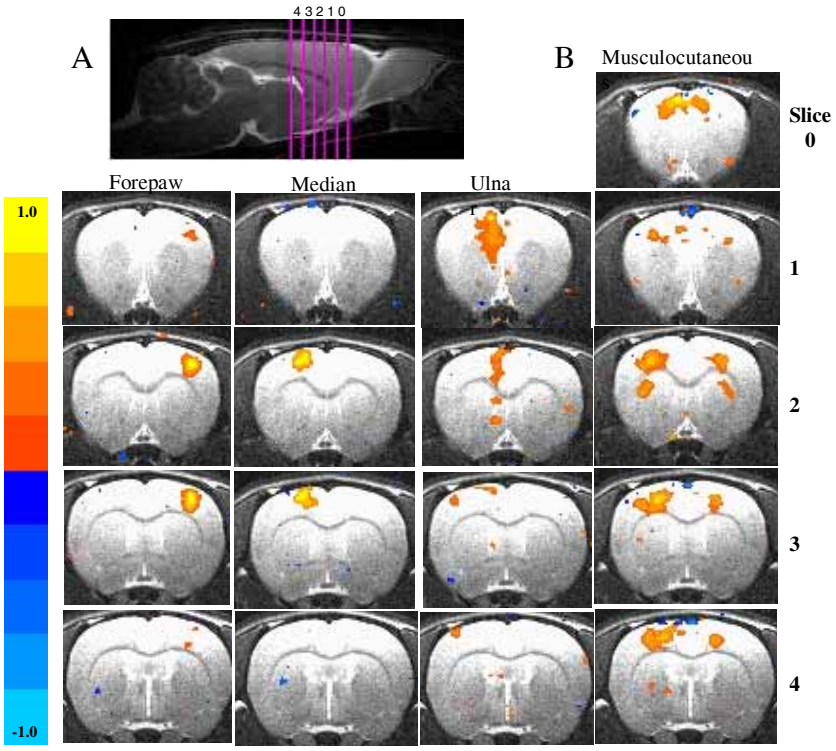

Figure 1: A – Shows a sagittal view of the rat brain. Slice three is on the anterior commissure. Each slice thickness is 1mm. **B –** Shows multiple coronal slices of the forepaw, and the median, ulnar, and musculocutaneous nerves. The forepaw signal corresponds to the left forepaw stimulation. The median, ulnar and musculocutaneous nerve signals reflect the right-sided nerve stimulation. The stimulation protocol is as follows: Forepaw (2mA, 10Hz, 3ms), Median (1mA, 10Hz, 1ms), Ulnar (0.5mA, 10Hz, 1ms), Musculocutaneous (1mA, 5Hz, 1ms). Notice bilateral activation when the right musculocutaneous nerve is stimulated.

References

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