SELECTIVE RECORDINGS OF MOTOR SIGNALS FROM THE CORTICOSPINAL TRACT

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Abstract

The feasibility of selective recordings of motor signals from the corticospinal tract was investigated. In cats under Ketamine anesthesia, the motor cortex around the cruciate sulcus was stimulated with a tungsten microelectrode. A pulse train was used to evoke muscle twitches in various parts of the forelimb to identify the corresponding regions of the motor cortex. Once a cortical area was identified, a single stimulus pulse was applied without moving the stimulation electrode. The evoked potentials descending through the lateral corticospinal track (LCST) were recorded from the cervical spinal cord with silicone substrate multi-contact electrodes. Multiple acquisitions were averaged to eliminate the afferent activity from the recordings. Selectivity of the electrode between various sets of traces recorded during stimulation of different points in the motor cortex was calculated. The preliminary data show that significant levels of selectivity can be obtained both epidurally and intradurally.

Introduction

The lateral corticospinal tract (LCST) is the principal motor pathway, in human, which originate in the frontal lobe of the cerebral cortex. The fibers of the LCST decussate at the junction of the spinal cord and medulla, and descend in the dorsolateral portion of the lateral column of the spinal cord white matter. These fibers primarily control distal limb muscles and they are the targeted group of nerve fibers for recording in this project. The lateral corticospinal track becomes close to the surface below medulla in the white matter and makes up a large portion of the spinal cord at the cervical level. The main objective of this study to demonstrate the feasibility of selective recordings from the LCST fibers at the cervical level with multi-contact electrodes placed over the surface of the cord intradurally or epidurally.

Methods

Experimental Set-up

Five adult cats (2.6-4.0 kg) were used in this study. Anesthesia was induced with Xylazine (0.8 mg/kg, IM) and Ketamine (20 mg/kg, IM). Atropine (0.044 mg/kg, IM) and Dexamethazone (2 mg/kg, IM) were administered early in the experiment to prevent secretions in the airways and CNS edema, respectively. The trachea was intubated and the cat was ventilated mechanically. The femoral vein and artery were catheterized for administration of drugs and monitoring the arterial blood pressure. Anesthesia was maintained by intravenous administration of Ketamine using an infusion pump (10 mg/kg/hr). The cat was placed in a stereotaxic frame and the body temperature was maintained between 37-39°C using a regulated heating pad. ECG, rectal temperature, and expiratory CO_2 (3-5%) were monitored throughout the procedure. The spinous process of the first thoracic vertebra was clamped to stabilize the cervical spinal column in a horizontal position. Dorsal laminectomy (C3-C7) and craniotomy were performed to expose the spinal cord and the left or right motor cortex around the cruciate sulcus.

Spinal Cord Recording Procedure

One of the three electrode designs with multiple contacts (Fig. 1) was placed either epidurally or intradurally between the cervical spinal roots C5 and C6. In the cases of electrode design 3, which had two sets of contacts along the cord, only the waveforms recorded from the contacts placed at C5/C6 border were used in this analysis. The recording contacts were connected to the positive inputs of multi-channel Grass amplifiers. The negative inputs of the amplifiers were connected to the reference electrodes on each side. A tungsten microelectrode (0.1 MΩ) was inserted at selected points into the motor cortex at a depth of 1500 μm from the pia surface. A pulse train (PW=0.2 ms, f=330 Hz, duration=45 ms) was applied to evoke muscle twitches in various parts of the front limb and occasionally in the hind limb, and thereby identify the corresponding areas of the cortex. Once a location was identified, a single pulse (PW=0.2 ms, I=400 μA) was applied to evoke volleys in the descending lateral corticospinal tract (LCST). In some experiments, the cortical stimulation train did not elicit muscle twitches later during the experiment without a substantial change in the recorded amplitudes. In these cases, the spinal cord recordings were continued by allowing at least a millimeter between the cortical stimulation sites to assure that different groups of fibers were activated within the LCST. A hundred to 256 acquisitions were averaged for each stimulus site, using spike-triggered-averaging, depending on the background neural activity level. Peak-to-peak amplitudes of the largest volleys that occurred within 2 milliseconds after the stimulus were used to form a measurement vector for each set of acquisition during stimulation of a unique point in the motor cortex. The selectivity indices for each vector (Eq. 2) and the overall selectivity for the given electrode design and implantation-method (Eq. 3) were calculated as described below.

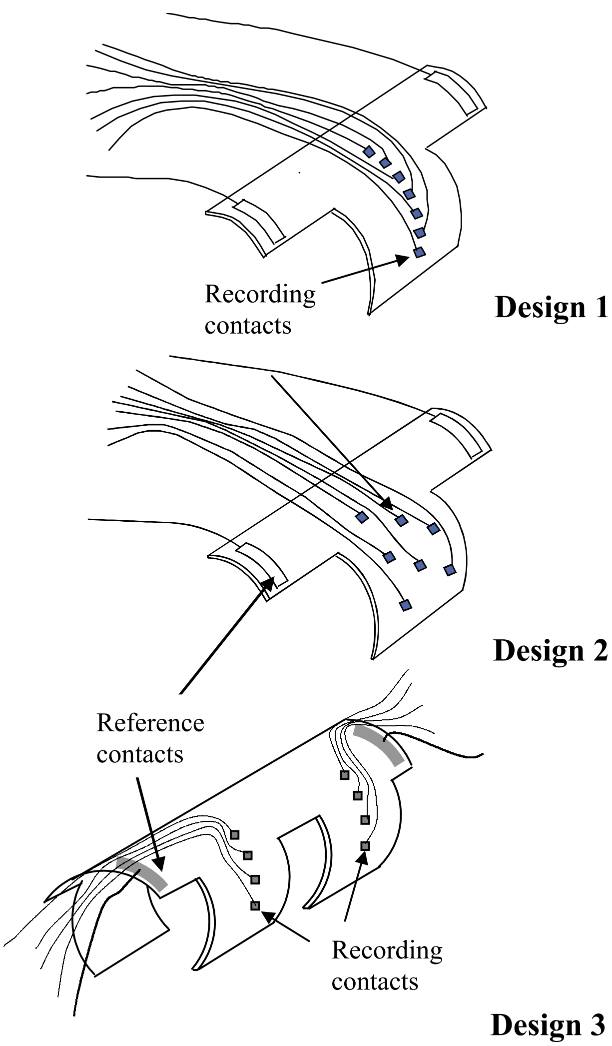

Figure 1. Multi-contact electrode designs used for epidural and intradural recordings of the cortically evoked volleys from the LCST. The separation between the reference contacts were 14 mm in designs 1 and 2, and 20 mm in design 3. The inter-contact separation was 0.8 mm in design 1 and about 1.8 mm in design 3. The contacts in design 2 were placed along diagonal lines within a rectangular area of 4.5 mm (longitudinal) by 5 mm (radial). The exposed contact area of each contact was approximately 250µm x 250µm. Contact impedance values were betwen 7-20 kΩ at 1 kHz.

Data Analysis

Several definitions have been proposed as a measure of selectivity for multi-contact recordings of peripheral nerve activity [1-3]. The selectivity index of Christensen *et al.* was modified here for the spinal cord: A vector was formed for each cortical stimulation site by taking the peak-to-peak amplitude of the evoked compound action potentials from each one of the contacts of the spinal electrode. These multi-dimensional vectors were normalized such that each has a unit length. The Euclidean distance between these vectors was calculated using the following equation:

$$d_{i,j} = \frac{100}{\sqrt{2}}\sqrt{(V_i(1)-V_j(1))^2+(V_i(2)-V_j(2))^2+\ldots+(V_i(N)-V_j(N))^2}$$
(Eq. 1)

for all i and j combinations. N is the dimension of the vectors, i.e. the number of the contacts used.

The average distance between a given vector i and others determined the selectivity of the electrode for a particular vector (or cortical stimulation site) represented by i (Eq. 2). The overall selectivity of the electrode for a subset of stimulation sites was found by averaging the selectivity indices for individual sites within the set (Eq. 3).

$$S_i = \frac{1}{Z}\sum_{j=1}^{Z} d_{ij} \qquad \text{(Eq. 2)}$$

where Z is the number of stimulation sites in the subset.

$$S = \frac{1}{Z}\sum_{i=1}^{Z} S_i \qquad \text{(Eq. 3)}$$

Results

A set of raw traces recorded with design 2 following stimulation of a unique point in the motor cortex is shown in Figure 2. The first spike to the left is the stimulus artifact. The main neural component arrives around at time equals 2 ms and it is followed by smaller components with larger delays. Notice that the large neural component is recorded at different amplitudes by various contacts.

In Table 1, the implantation method, the type of the electrode used, and the site of implantation are shown for all the procedures in all cats. The mean of the maximum selectivity values for two, three, and four vector discriminations were 21±15%, 14±10%, and 11±8% with the extradural electrodes (n=3) and 26±10%

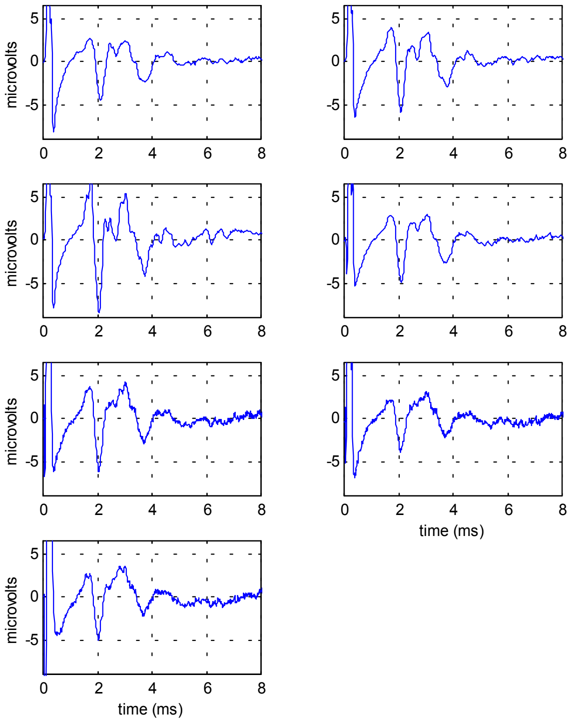

Figure 2. Raw traces acquired with electrode design 2 from C5/C6 using a stimulus amplitude of 400 µA.

, [illegible]%, and 13±10% with the intradural electrodes (n=4). These two sets of selectivity values were significantly different when the data from the same type of electrodes (excluding electrode design 3) with similar implantation techniques were compared using a paired t test (t=0.013). The selectivity indices obtained with extradural implantation of design 3 were 22±17%, 14±11%, and 13±10% (n=2). The selectivity varied from trial to trial. The maximum and minimum selectivities for two, three, and four vector discrimination were 51%, 34%, 29% (Design 2, intradural implant) and 7%, 5%, and 4% (Design 1, extradural implant), respectively.

Proc. No	Cat No	Implant Method	Electrode Design	Implant Site
1	1	Extradural	1	C5/C6
2	2	Intradural	1	C5/C6
3	2	Intradural	2	C5/C6
4	3	Extradural	1	C5/C6
5	3	Extradural	2	C5/C6
6	3	Intradural	2	C5/C6
7	4	Extradural	3	C5/C7
8	5	Extradural	3	C4/C6
9	5	Intradural	1	C5/C6

Table 1: Implantation methods, electrode designs, and implantation sites that are used in each procedure.

Conclusions

The results of this study show that selective recording from the spinal cord surface (without penetrating the pia matter) is feasible with multi-contact electrodes. Furthermore, placing the electrode extradurally causes only a small reduction in selectivity. A method that utilizes multiple parameters from the recorded waveforms to form the measurement vectors may improve the calculated selectivity values and reduce the variation. This requires further analysis of the recorded signals. The large variation in the selectivity values can also be due to the fact that the location of the stimulation points in the motor cortex change from trial to trial thereby resulting a variation in the activation pattern of the fibers in the cord.

The findings of this study suggest that one can extract multi-channel voluntary motor signals from the corticospinal tract with non-penetrating electrodes from the cervical spinal cord. Such an electrode may serve as a Spinal Cord–Computer Interface in high level spinal cord injury patients.

References

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Acknowledgments

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