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2.8.3: Reflex Function

Recruitment Modulation of Force Fields Organized in the Frog's Spinal Cord

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ABSTRACT

Convergent force fields organized in the frog's spinal cord could be used as a new Functional Neuromuscular Stimulation (FNS) technique to restore motor function using electrical stimulation of the spinal interneurons. We studied the recruitment modulation of these force fields to four parameters of the electrical microstimulation stimulus train. The parameters modulated were the stimulation frequency, the pulse duration, the pulse amplitude, and the train duration. We found that all four parameters can be used to modulate the force level, and that all the parameters but train duration also affect the force rate of rise. Furthermore, we found that the vectorial structure of the fields was not affected by the force modulation, as the normalized fields were nearly identical. These early results demonstrate the possibility of modulating the action of the fields while retaining their useful convergent property.

INTRODUCTION

Microstimulation of the gray matter of the spinalized frog's spinal cord produces motor responses that can be described as force fields. These force fields show convergence to an equilibrium point, and the path of the equilibrium point through time predicts free limb motion in the majority of the trials [1,2]. Furthermore, the fields were shown to sum up vectorially in the majority of the cases studied [3].

We are currently investigating the applicability of those force fields as a FNS technique to restore function to paralyzed limbs. The recruitment modulation caused by variations in four of the stimuli parameters are being investigated. Their effects on the time history of the force production, and the overall structure of the fields are being characterized, as well as the effects on free limb motion.

METHODS

Force fields were elicited by microstimulating the spinal cord in what we estimated to be the lateral and intermediate neuropil zone. The stimulus consisted of a train of anodic current impulses. The mechanical forces at the ankle were measured using a six-axis force transducer (ATI 310). We limited our analysis to the x-y plane which corresponded approximately to the horizontal plane. Fields were constructed by measuring forces at several different spatial locations, constructing a tesselation of the points, and interpolating each vector within a triangle by a linear interpolation based on the three corner vectors (see Fig. 1).

We investigated the effects of four stimulation parameters: pulse amplitude (PA), pulse duration (PD), stimulation frequency (SF), and train duration (TD). We analyzed the effects on the time history of the forces, and on the equilibrium position and structure of the active fields, i.e fields reconstructed from the total recorded force minus the passive force.

Results reported are from eight sites in three frogs. SF and PA effects were studied for three sites, and PD and TD were studied at one site each.

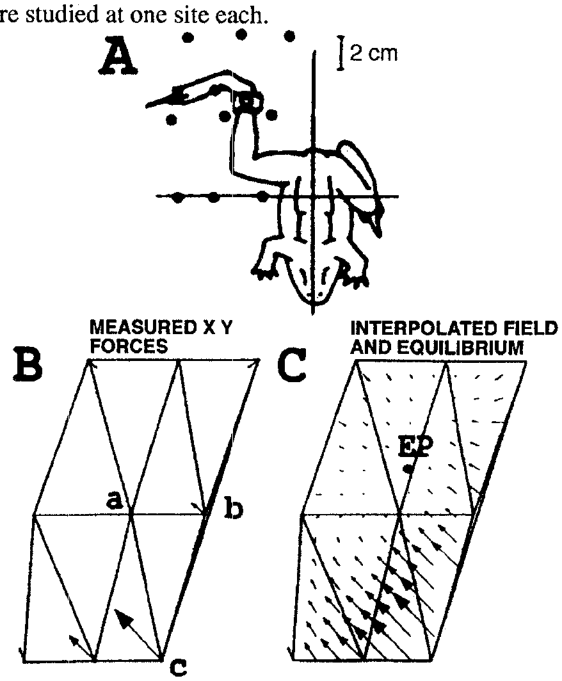

Figure 1. The method of construction of a force field. A, a collection of forces is recorded at several locations (circles). B, a minimum perimeter tessellation of the points is constructed. C, the interpolated field is used to find any equilibria (EP). (Adapted from [2])

RESULTS

figure 2 shows the effect of the four stimulus parameters on the time response of the active force magnitude at one position for four different sites. Only one stimulation parameter was modulated for each panel, while the others remained fixed. All four parameters successfully modulated the amplitude of the force produced. Three of the four parameters (PD, SF, and PA) also modulated the rate of force production, while TD did not modulate the force rate of rise. The decay of the force response was quite variable and often presented plateaus that lasted for over 1 s. Maximal force magnitude increased linearly with stimulus parameter value for the four parameters studied (Fig. 3). Parameters were not raised to a level that produced a plateau in the force response, although our preliminary results seem to indicate that the field structure changes before a plateau is reached.

For the fields shown on Fig. 2, the amplitude of the force was modulated without the structure of the active force field being modified. Figure 4 shows the active force field at SF=40Hz and the equilibrium position at the five frequencies listed on Fig. 2. The equilibrium position moved by less than 5 mm, and the largest difference between the normalized fields obtained at different frequencies was 0.16 N.

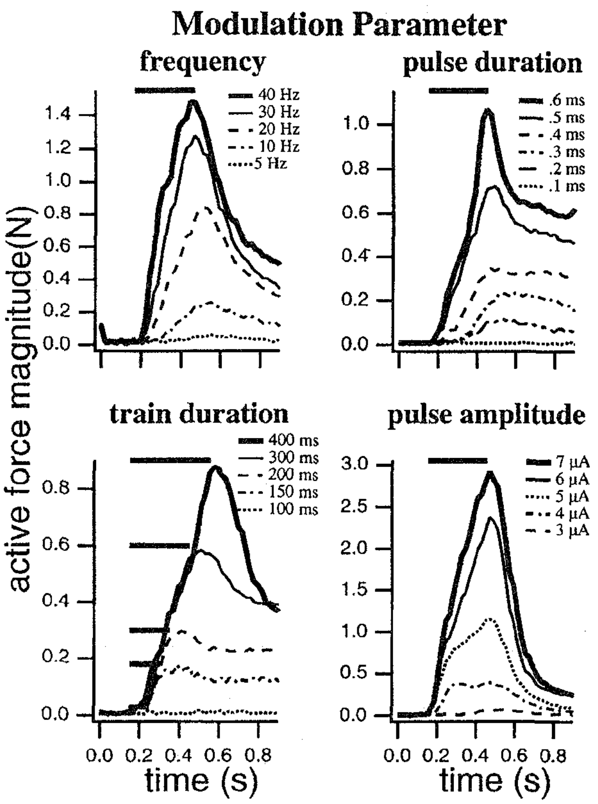

Figure 2. Time history of the active force response for four stimulus parameters. The thick horizontal bars indicate the period during which the stimulation train was ongoing.

DISCUSSION

The force time course for interneuronal stimulation shows some similarities with electrical stimulation of muscles and nerves. The force rate of rise is affected by SF, PA, and PD as is the case with nerve and muscle stimulation, although the effect of PA and PD is not as marked for nerve and muscle stimulation (personal data). The effect of train duration on force amplitude is novel, and does not show in muscle stimulation. At the SF used, muscle force would have plateau well within 200 ms. Another marked difference is the "off" time of the field, which is significantly longer than the one encountered in muscle stimulation.

The change in field structure that occurs at high stimulation level is similar to the spillover effect that can be observed during muscle stimulation. The effect may be used functionally, as spillover of one finger flexor to the other is used in FNS hand grasp system.

CONCLUSIONS

We have shown the feasibility of modulating the force response of convergent force fields organized in the spinal cord via modulation of the stimulation parameters. Ongoing work is focusing on producing graded summation of force fields, and on investigating the effects of modulation on free limb motion.

ACKNOWLEDGMENTS

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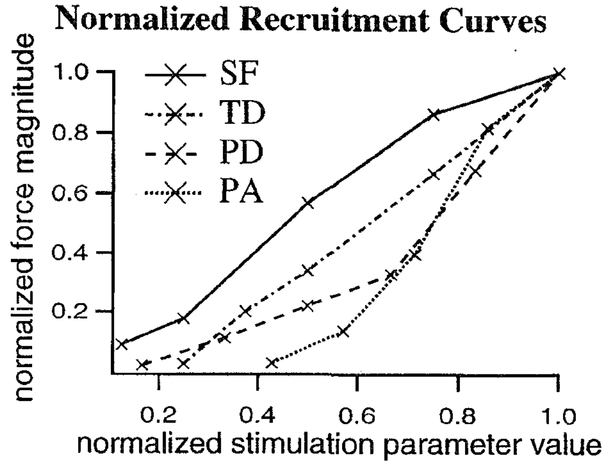

Figure 3. Normalized force magnitude versus the normalized stimulation parameters value for the responses shown on Fig. 2.

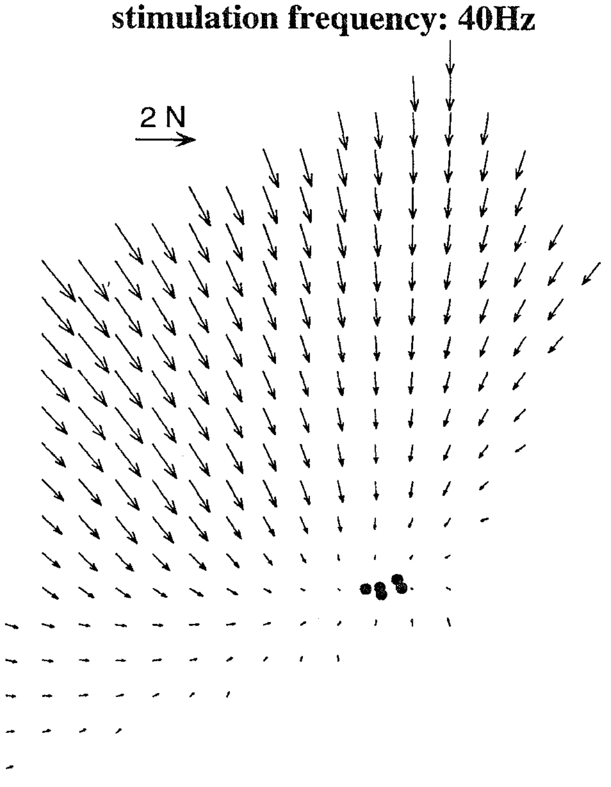

Figure 4. Force field obtained at SF=40Hz, and the equilibrium position of the fields obtained with SF=5, 10, 20, 30, and 40Hz.