Dissecting the contributions of neural activation timing and strain trajectory to muscle force during perturbed running

Carissa J. Mallonee[1], Monica Daley[2], Kiisa Nishikawa[1]
[1] Department of Biological Sciences, Northern Arizona University, Flagstaff, Arizona, USA
[2] Department of Ecology and Evolutionary Biology, University of California, Irvine, California, USA
Email: cjm872@nau.edu

Summary

Reinnervation of the lateral gastrocnemius in guinea fowl removes proprioceptive afferents but may also affect muscle intrinsic properties. During perturbed running, reinnervated guinea fowl have different neural activation timing, strain trajectories, peak force, and velocity at peak force than intact birds. The difference in force could be due to changes in activation or muscle intrinsic properties, but this cannot be determined *in vivo.* We used *in vivo* length and activation data in work loops on mouse extensor digitorum longus muscles. Stimulation timing had significant effects on all work loop variables, the interaction of strain x stimulation had significant effects on total work and velocity at peak stress, and strain had a small but significant effect on total work. The results suggest that reinnervated guinea fowl largely compensate by using feedforward activation. However, the significance of the strain x stimulation interaction also suggests a change in muscle intrinsic properties.

Introduction

Maintaining steady gait and balance when negotiating obstacles requires integration of neural and mechanical factors involved in motor control [1]. A goal of biomechanical research is to investigate the contributions of these factors and how they interact to produce force and work during locomotion [2]. Studies on guinea fowl with a proprioceptive deficit due to reinnervation of the lateral gastrocnemius muscle [3] have provided insight into how this deficit affects muscle responses to perturbed locomotion. When encountering an obstacle on a treadmill, reinnervated guinea fowl displayed earlier EMG onset, different strain trajectories, higher peak force and higher velocity at peak force than control birds whose nerves remained intact. We used the avatar approach [4] to investigate whether the earlier EMG onset or the different strain trajectories, or both, produced the observed changes in work loop variables in the reinnervated guinea fowl. The goal of the present study was to dissect the contribution of strain, stimulation timing, and their interaction on muscle peak stress, velocity at peak stress, and total work using *in vivo* data for *ex vivo* experiments.

Methods

Data from trials of one intact and one reinnervated guinea fowl were used for this study (Bl3 and GF24; https://doi.org/10.7280/D11H49). From each guinea fowl, selected representative level and obstacle strides were down-sampled for use in *ex vivo* experiments, as previously described [4]. Extensor digitorum longus (EDL) muscles from wild-type mice (n = 7) were extracted and attached to a dual-mode muscle lever system (Aurora Scientific, Inc., Series 300B, Aurora, ON, Canada) using standard techniques [4]. For each stride type (level and obstacle), the EDL muscle was tested under the following conditions: Intact strain trajectory with intact stimulation, intact strain trajectory with reinnervated stimulation, reinnervated strain trajectory with reinnervated stimulation, and reinnervated strain trajectory with intact stimulation. For intact stimulation with the reinnervated strain trajectories, the EDL muscle was stimulated 23 ms later than the reinnervated stimulation [3]. For the reinnervated stimulation with the intact strain trajectories, the EDL muscle was stimulated 23 ms earlier than the intact stimulation. Force was measured, and muscle peak stress, velocity at peak stress, and total work were calculated for analysis using a 4-way mixed model ANOVA ($\alpha<0.05$) with stride type, strain trajectory and stimulation as fixed effects and muscle as a random effect.

Results and Discussion

Stimulation timing had significant effects on total work, peak stress, and velocity at peak stress. The strain x stimulation interaction had significant effects on total work and velocity at peak stress, but not on peak stress. Strain had only a small but significant effect on total work. These results suggest that reinnervated guinea fowl compensate for the proprioceptive deficit mainly through earlier feedforward activation. However, the significant strain x stimulation interactions further suggest that the reinnervated muscles may have higher stiffness and damping than muscles from control birds following the reinnervation procedure.

Conclusions

The *ex vivo* 'avatar' technique enables the ability to distinguish the effects of strain and stimulation on muscle force that is not possible *in vivo*. The results suggest that both neural activation and altered intrinsic muscle properties contribute to changes in muscle mechanics of the reinnervated birds. Future studies should investigate how properties such as stiffness and damping change with reinnervation.

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References

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