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RESEARCH ARTICLE

The effects of self-reinnervation of cat medial and lateral gastrocnemius muscles on hindlimb kinematics in slope walking

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Abstract The aim of this study was to investigate the effects of self-reinnervation of the medial (MG) and lateral gastrocnemius (LG) muscles on joint kinematics of the whole hindlimb during overground walking on surfaces of varying slope in the cat. Hindlimb kinematics were assessed (1) with little or no activity in MG and LG (short-term effects of self-reinnervation), and (2) after motor function of these muscles was presumably recovered but their proprioceptive feedback permanently disrupted (long-term effects of self-reinnervation). The stance phase was examined in three walking conditions: downslope (−50%, i.e. −26.6°), level (0%) and upslope (+50%, +26.6°). Measurements were performed prior to and at consecutive time points (between 1 and 57 weeks) after transecting and immediately suturing MG and LG nerves. It was found that MG-LG self-reinnervation did not significantly change hip height and hindlimb orientation in any of the three walking conditions. Substantial short-term effects were observed in the ankle joint (e.g., increased flexion in early stance) as well as in metatarsophalangeal and knee joints, leading to altered interjoint coordination. Hindlimb kinematics in level and upslope walking progressed back towards baseline within 14–19 weeks. Thus in these two conditions the cats were walking without any detectable kinematic deficits, despite the absence of length feedback from two major ankle extensors. This was verified in a decerebrate preparation for four of the five cats. In contrast, ankle joint kinematics as well as interjoint coordination in downslope walking gradually progressed towards, but never reached their baseline patterns. The short-term effects can be explained by both mechanical and neural factors that are affected by the functional elimination of MG and LG. Permanent changes in kinematics during downslope walking indicate the importance of proprioceptive feedback from the MG and LG muscles in regulating locomotor activity of ankle extensors. Full recovery of hindlimb kinematics during level and upslope walking suggests that the proprioceptive loss is compensated by other sensory sources (e.g. cutaneous receptors) or altered central drive.

Keywords Locomotion · Kinematics · Stretch reflex · Nerve injury · Cat

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Introduction

Surgical self-reinnervation, which involves transecting and suturing specific nerve branches, is a procedure applied in animal models to emulate a nerve lesion induced through trauma and its subsequent surgical repair in humans. This intervention involves a paralytic phase (i.e., no muscle excitation) followed by a recovery phase in which regenerating motoneuron axons re-occupy motor endplates in the reinnervated muscle (Sanes and Lichtman 1999). Subsequently, feedback can increase in a muscle during shortening as well as lengthening contractions, as long as the central drive is increasing. The animal may increase motor performance during upslope walking by increasing central drive and therefore provide compensation for the absence of positive force feedback. In contrast, length feedback is much stronger during active lengthening than during active shortening of a muscle and, therefore, driven mainly by external forces and mechanical changes in a complex musculoskeletal system. Thus, active lengthening is not in general related simply to central drive. A longer period of training might be required for the animal to adapt by tuning intrinsic muscular properties. Furthermore, if disruption of cross-joint and inhibitory force feedback by the reinnervation results in preservation of normal changes in the length of the whole limb during locomotion (see above), then there might be little stimulus for the animal to adapt central drive.

In conclusion, the long-term effects of MG-LG self-reinnervation on hindlimb kinematics during walking are dependent on the slope of the walking surface. This can partially be explained by different contractile conditions of the MG and LG muscles between downslope walking and level as well as upslope walking. Most likely a combination of effects of changes in autogenic and heterogenic length feedback as well as positive force feedback due to self-reinnervation are involved. This indicates that proprioceptive feedback from individual muscles is important for the control of limb kinematics.

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