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Research Report

The role of vertebral column muscles in level versus upslope treadmill walking—An electromyographic and kinematic study

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ABSTRACT

To gain insight into the neural mechanisms controlling vertebral column movement and its role in walking, we performed kinematic and electromyographic (EMG) studies on cats during level and upslope treadmill walking. Kinematic data of the limbs and vertebral column were obtained with a high-speed camera synchronized with EMG recordings from levels T10, L1, and L5 of m. longissimus dorsi (Long). During a single-step cycle at all upslope angles, vertebral movement in the lateral (left–right), cranial–caudal (forward–backward), and dorsal–ventral (upward–downward) directions was observed. Lateral movements were produced by forelimb take-off and hindlimb landing, and forward and upward movements were produced by hindlimb extension. During the single-step cycle, each of the three epaxial muscles, m. multifidus, m. iliocostalis, and Long, showed two bilateral EMG bursts. The onset of the EMG bursts coincided with the left–right movements, suggesting that epaxial muscle activity depresses lateral movement. The termination of the EMG bursts correlated with the forward and downward phase of the step cycle, suggesting that contraction of the epaxial muscles produces forward and downward movements. EMG bursts of the epaxial muscles increase the stiffness and produce inwardly movements to decrease the lateral movements of the vertebral column and the termination of EMG bursts control the movements into cranial and ventral direction of the vertebral column. The results suggest that the rhythmic EMG bursts in the epaxial muscles are produced by pattern generators, and the timing of EMG bursts among the different levels of the epaxial muscles are altered by walking condition input via peripheral afferents and descending pathways.

1. Introduction

For terrestrial animals, walking and running are basic activities of life. Sherrington (1911) initiated studies in the early 1900s of the neuronal control of locomotion. Since that time, much effort has gone into examining control of limb movements (Mori et al., 2004). Locomotion, however, is not only achieved by isolated limb movements, but also by

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integrated activity of multiple body parts, including the neck, trunk, forelimbs, hindlimbs, and tail. Because the trunk region is the largest part of the body and is centrally located, the center of gravity locates in the trunk during most types of movements. Adequate control of trunk movement and posture appears to be a prerequisite for the maintenance of body equilibrium during various motor tasks. Despite its obvious importance in generating locomotion, little is known about the neuronal control of trunk movement.

During stable and symmetrical walking in the absence of significant head–neck movement, vertebral column movements are elicited by limb and trunk muscle activity. One of the purposes of the present experiments is to confirm the hypothesis that limb movement influences vertebral column position, which is a critical factor in generating motion during walking. Furthermore, the present paper investigates neuronal control of the trunk muscles. Trunk muscles contain both extensors (i.e., epaxial muscles) and flexors (i.e., hypaxial muscles) (Carlson, 1978; Crouch, 1969). The epaxial muscles include a medial group (intertransversari muscles) – m. interspinalis and m. multifidus (Multi) – and a lateral group – m. longissimus (Long) and m. iliocostalis (Ilio). The epaxial muscles have large cross-sectional areas and are distributed lengthwise along the vertebral column, suggesting that epaxial muscles are the primary force for vertebral column movements. Contraction of muscles in the lateral group might produce multidirectional movements, including lateral bending and vertical motion, as well as internal rotation of the vertebral column (unpublished results). Long and Ilio are connected to the iliac crest of the pelvis both directly and indirectly through the lumbodorsal fascia. The hypaxial muscles include the psoas major, iliopsoas, and thin abdominal muscles. The psoas major and iliopsoas produce a ventroflexion movement that helps support the lower vertebral column against gravity (Macpherson and Fung, 1998; Macpherson and Ye, 1998; Macpherson and Fung, 1999). The psoas major and iliopsoas connect the lumbar vertebrae to the pelvis and femur. These muscles have large cross-sectional areas, produce ventroflexion, and help support the lower trunk against gravity. The abdominal muscles (m. rectos abdominus, m. obliquus externus abdominus, internus abdominus, and m. transverses abdominus) are thin and do not contribute much to tonic activity during the stance phase. It is unlikely that these muscles participate significantly in vertebral column movement. Because the epaxial muscles strongly influence vertebral column movement, we investigated the role of Long in treadmill walking in cats.

Epaxial muscles show two EMG bursts during a single-step cycle of stable treadmill locomotion (Carlson, 1976; Engberg and Lundberg, 1969), and this activity is thought to increase the stiffness of the vertebral column. It has been postulated that the trunk is an integral part of body motion and receives sensory input from many parts of the body that stabilizes it along its length (Merbner et al., 1997). Studies of the neuronal control of the trunk under changing walking conditions will contribute to the verification of this hypothesis. For example, during upslope and downslope treadmill walking, there are changes in posture, hindlimb kinetics, and hindlimb muscle activity patterns (Carlson-Kuhta et al., 1998; Smith et al., 1998, Trank et al., 1996). Postural orientation during upslope and downslope walking involves adjustments of the head, trunk, forelimbs, and hindlimbs. We have extended this work by examining the influence of both forelimb and hindlimb movements when cats maintained a stable head and tail position.

English (1980) showed the synchronized EMG bursts at different levels of Long during level walking. This fact might indicate that the neuronal control at different level of a single epaxial muscles during level walking is synchronized control among the different levels. In the present experiments, we studied the relation of EMG activity patterns among the different levels of epaxial muscles when vertebral column movements were altered by increasing the angle of upslope walking.

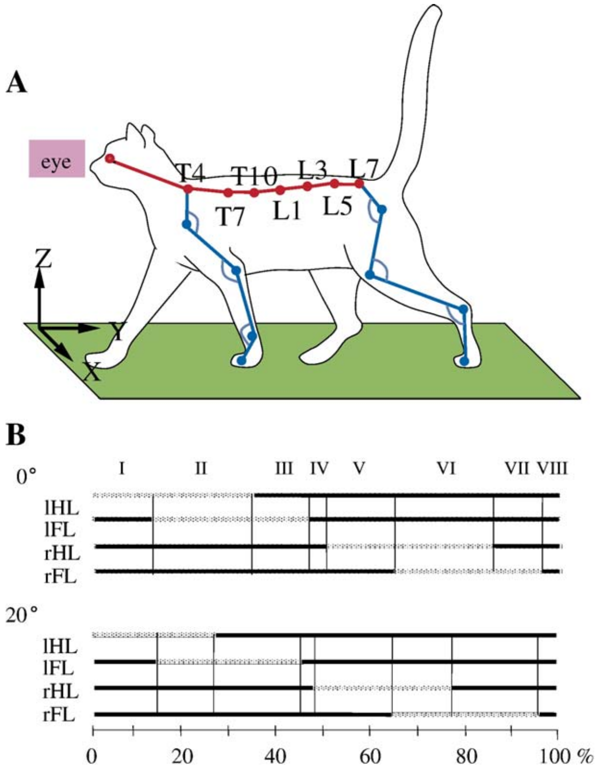

Fig. 1 – (A) Marker positions on walking cats. Positions of markers on the trunk, forelimbs, and hindlimbs; the corresponding six joints; and the coordinates for the three-dimensional motion analysis system. (B) Gait diagrams for level walking and upslope walking at 20° in three cats (Nos.1, 4, 5). Thick line and hatched line represent stance period and swing periods, respectively. The single-step cycle at all grades was divided into eight phases (I–VIII) based on support combinations. Phase I: lHL-rHL-rFL (tripod); phase II: rHL-rFL (ipsilateral couple); phase III: lHL-rHL-rFL (tripod); phase IV: lHL-lFL-rHL-rFL (quadruped); phase V: lHL-lFL-rFL (tripod); phase VI: lHL-lFL (ipsilateral couplet); phase VII: lHL-lFL-rHL (tripod); phase VIII: lHL-lFL-rHL-rFL (quadruped). Increasing the upslope grade affected phases II and VI.