Mechanomyographic responses to maximal eccentric isokinetic muscle actions

DOUGLAS B. SMITH1, TERRY J. HOUSH,1 JEFFREY R. STOUT,2 GLEN O. JOHNSON,1 TAMMY K. EVETOVICH,1 AND KYLE T. EBERSOLE1

1Center for Youth Fitness and Sports Research, School of Health and Human Performance, University of Nebraska at Lincoln, Lincoln 68588-0229; and 2Exercise Science Department, Creighton University, Omaha, Nebraska 68178

Smith, Douglas B., Terry J. Housh, Jeffrey R. Stout, Glen O. Johnson, Tammy K. Evetovich, and Kyle T. Ebersole. Mechanomyographic responses to maximal eccentric isokinetic muscle actions. J. Appl. Physiol. 82(3): 1003-1007, 1997.—The purpose of the present investigation was to examine the mechanomyographic (MMG) responses to maximal eccentric isokinetic muscle actions. Eight adult male volunteers [age 22 ± 2 (SD) yr] performed maximal eccentric muscle actions of the leg extensors at 60, 90, 120, and 180°/s on a Cybex 6000 isokinetic dynamometer. MMG was detected by a piezoelectric crystal contact sensor placed over the vastus lateralis muscle. Test-retest intraclass correlations ranged from R = 0.88 to 0.97 for peak torque and from R = 0.97 to 0.98 for root mean square MMG amplitude values. There was no significant (P > 0.05) velocity-related change in eccentric peak torque; however, there was a significant (P < 0.05) increase in MMG between 60 [119 ± 44 (SE) mV] and 180°/s [302 ± 128 mV]. These findings indicated a velocity-related dissocation between MMG and peak torque for maximal eccentric isokinetic muscle actions.

Recent studies have utilized mechanomyography (MMG) to record and quantify the sounds produced by contracting skeletal muscle (1-6, 10-12, 14, 16, 19-20, 23-31, 33-36, 39). Barry and Cole (3) and Orizio et al. (23, 24) have suggested that the muscle sounds recorded as MMG are a function of three components: 1) a gross lateral movement of the muscle at the initiation of a contraction that is related to the different regional distribution of the contractile elements, 2) smaller subsequent lateral vibrations generated at the resonant frequency of the muscle, and 3) pressure waves generated by the dimensional changes of the fibers of the active motor units. The relative contributions of these components to the MMG signal, however, are unknown (24).

MMG can be used to examine various aspects of muscle function. Gordon and Holbourn (16) speculated that the sounds produced by contracting muscles are reflective of the “mechanical counterpart” of the motor unit activity as measured by electromyography (EMG). Simultaneous measurements of EMG and MMG can be used to monitor the dissociation between the electrical and mechanical events (excitation-contraction coupling) that occur with fatigue (4), examine factors related to electromechanical and phonomechanical delay (30), and provide diagnostic information about muscle disease (5).

Most previous studies have examined MMG responses during isometric contractions (26, 29, 31, 36, 39). A recent investigation by Dalton and Stokes (11), however, reported a positive, linear relationship between MMG and force during dynamic submaximal concentric (r² = 0.88) and eccentric (r² = 0.81) muscle actions of the biceps brachii. Petitjean et al. (30) also reported a linear relationship for the MMG-force relationship (r² = 0.85) for the biceps brachii and greater MMG amplitude during fast compared with slow movements. Dalton and Stokes (11) and Petitjean et al. (30) concluded that like EMG, MMG can be used to detect changes in force during dynamic contractions. With the exception of the results of the studies by Dalton and Stokes (11) and Petitjean et al. (30), little is known about MMG responses to dynamic muscle activity, and no previous studies have measured MMG activity of the leg extensors during eccentric isokinetic muscle action at various angular velocities. Therefore, the purpose of this study was to examine the MMG responses to maximal eccentric isokinetic muscle actions of the leg extensors at angular velocities ranging from 60 to 180°/s.

Methods

Subjects

Eight male volunteers [age 22 ± 2 (SD) yr, height 179.4 ± 2.7 cm, mass 82.1 ± 9.5 kg] participated in this study. The study was approved by the University Institutional Review Board for Human Subjects, and all subjects completed a health history questionnaire and signed a written informed consent form before testing.

Experimental Procedures

Eccentric peak torque values of the dominant leg extensors (based on kicking preference) were determined at 60, 90, 120, and 180°/s by using a calibrated Cybex 6000 isokinetic dynamometer (Fig. 1). Each subject was seated on the Cybex 6000 in a position that allowed for a 90° angle between the thigh and torso. The knee joint was aligned with the dynamom-
eter input shaft, and the shin pad was placed just proximal to the malleoli. A seat belt was fastened across the subject’s chest and waist to allow for stabilization during testing. At each angular velocity, the subject performed three submaximal practice trials (followed by a 1-min rest) and three maximal eccentric muscle actions. The highest peak torque at each angular velocity was selected as the representative score. Three minutes of rest were given between testing at each angular velocity. The order of the test velocities (60, 90, 120, and 180°/s) was randomized for each subject. Measurements of peak torque and MMG were repeated 48 h after the initial test to examine test-retest reliability.

The MMG signal (Fig. 1) was detected by a piezoelectric crystal contact sensor (bandwidth 0.02–2,000 Hz; model 21050A, Hewlett-Packard) that was placed over the lateral surface of the vastus lateralis midway between the head of the greater trochanter and the lateral condyle of the femur. A stabilizing ring was used to ensure consistent contact pressure of the sensor as recommended by Bolton et al. (6), and double-sided foam tape helped to hold the sensor in place. Micropore surgical tape was also applied over the piezoelectric contact sensor to prevent movement during testing. The raw MMG signal was stored on a personal computer (model 7100/80 AV Power PC, Macintosh) and expressed as root mean square (rms) amplitude by computer software (model MP100, Biopac Systems Santa Barbara, CA). The sampling frequency was 1,000 points/s, and the MMG signal was low-pass filtered at 100 Hz (2nd-order Blackman filter). For each angular velocity, the MMG amplitude (i.e., rms) was calculated from the muscle action with the highest peak torque for a time period that corresponded to a 90° range of motion. For example, at 60°/s the amplitude for 1.5 s of the MMG was calculated, whereas at 120°/s the amplitude for 0.75 s was calculated. This allowed for comparisons among the knee angular velocities, which were based on a standardized range of motion of 90°.

Statistical Analysis

One-way repeated measures analysis of variance with Tukey post hoc procedures were used to determine differences across knee angular velocities for peak torque (N·m) and MMG (mV). The test-retest reliability was estimated by an intraclass correlation coefficient (R) and a paired t-test. An α of 0.05 was considered significant for all analysis.

RESULTS

Peak Torque Analysis

Figure 2 provides a graphic description of the relationship between peak torque (N·m) and knee angular velocity. There was no significant (P > 0.05) velocity-related change in eccentric peak torque. Intraday reliability correlations for the peak torque measures ranged from R = 0.88 to 0.97 with no significant (P > 0.05) differences in peak torque among knee angular velocities.
Differences between mean values for test vs. retest at any knee angular velocity.

**MMG Analysis**

Figure 3 provides a graphic description of the relationship between MMG and knee angular velocity. There was a significant ($P < 0.05$) increase in MMG between $60 \pm 119$ and $180^\circ/s$.

Intraclass reliability correlations ranged from $R = 0.97$ to 0.98 with no significant ($P > 0.05$) differences between mean values for test vs. retest at any knee angular velocity.

**DISCUSSION**

### Peak Torque

The present study found that there was no significant ($P > 0.05$) change in peak torque with increases in angular velocity during maximal eccentric muscle actions of the leg extensors. This is in agreement with previous studies (8, 9, 37, 38) and is consistent with the conclusions of Stauber (32), who reported “the tension recorded at a given sarcomere length during an eccentric muscle action would be greater than that during a isometric action and independent of velocity until the velocity of stretch exceeded binding rate of the cross-bridges.”

### MMG

In the present study, the MMG amplitude increased as angular velocity increased during maximal eccentric muscle action even though peak torque remained constant. We propose the following hypotheses to explain these results:

- **Actin-myosin cross-bridge activity.** Oster and Jaffe (28) reported that in isolated muscle preparations, “vibratory motions may conceivably arise from the making and breaking of cross links.” Therefore, it is possible that as the angular velocity of the eccentric muscle action increased, there was a more rapid “making and breaking” (28) of cross bridges (i.e., they were pulled apart more rapidly), which, in turn, caused increased vibration of the myosin heads and/or turbulence within the intracellular medium, resulting in increased MMG amplitude. This hypothesis, however, is not supported by recent findings (34) using isometric contractions that suggest that the pattern of MMG activity is due to motor control mechanisms and not to contractile processes intrinsic to the muscle fiber. Additional research is necessary to examine the contribution of intrinsic contractile processes to the MMG signal during dynamic muscle actions.

- **Fiber recruitment.** Recruitment of muscle fibers generally follows the size principle (7, 17) in which slow-twitch small-force units are recruited first and demands for larger forces are met by recruitment of increasingly forceful fast-twitch units. However, exceptions to this principle have been reported (13, 15, 21, 22).

For eccentric muscle actions, Nardone and Schieppati (22) reported velocity-related derecruitment of slow motor units with selective activation of fast motor units during voluntary lengthening of the triceps surae. If this velocity-related selective recruitment also occurs in the vastus lateralis, it is possible that in the present study the muscle sounds at the slow knee angular velocity were produced primarily by slow-twitch fibers and at the fast knee angular velocity by fast-twitch fibers. If this were the case, the muscle sounds from the slow-twitch fibers, which are generally located deep within the muscle (18), may have been damped by the surrounding tissues (27), resulting in reduced MMG amplitude. At the fast knee angular velocity, however, the muscle sounds from the more superficially located fast-twitch fibers (18) may not have been damped to the same degree and, therefore, the MMG amplitude was greater.

- **Movement of limb.** It is possible that in the present study the increase in MMG amplitude with increased knee angular velocity may have been due to the movement of the limb itself. Barry and Cole (2) have suggested, while working with isolated frog muscle in solution, that movement of the interstitial fluid where the muscle belly expands and recedes during contraction may result in a hydrodynamic “sloshing,” which could contribute to an increased MMG amplitude ob-
served as velocity of movement increases. If this also occurs in vivo, because the knee angular velocity increased in the present study, there may have been a greater overall disturbance of the intracellular and extracellular fluid mediums. The sounds produced from the movement of the fluid may have caused an increase in the MMG amplitude.

Additional factors that may affect MMG amplitude. A number of factors such as muscle stiffness, mass, length, the viscosity of the muscle and surrounding medium, and the mechanical properties of the tissue between the muscle and surface of the skin can affect the amplitude of the MMG signal (3, 23). Little is known, however, about the influences of these factors on MMG responses to dynamic muscle actions. This is particularly true regarding their potential contributions to the velocity-related increase in MMG amplitude during eccentric isokinetic muscle actions found in the present study.

Conclusion

In conclusion, the results of the present study indicated a velocity-related dissociation between MMG amplitude and peak torque during maximal eccentric isokinetic muscle actions. These findings may provide a basis for the study of the physiological changes that occur during eccentric muscle actions at different velocities. Further studies are needed to determine the reason for the velocity-related increase in MMG amplitude during eccentric muscle actions.

Address for reprint requests: D. B. Smith, MABL 137, Univ. of Nebraska at Lincoln, Lincoln, NE 68588-0229.

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