FORCE AND ELECTROMYOGRAPHIC (EMG) RELATIONSHIPS OF LEG EXTENSORS DURING ERGOMETER CONTRACTIONS

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The purpose of this study was to examine the force/EMG relationship during dynamic muscle contractions. Three ergometers (isokinetic dynamometer, adapted leg-only ergometer, standard rowing ergometer) were modified with strain gauges and potentiometers to measure force and displacement. Surface electrodes were used to record EMG of rectus femoris (RF) and vastus lateralis (VL) muscles. Trained rowers (n=11) performed leg extensions at randomly selected target forces under each condition. There was a strong positive linear correlation between force and EMG amplitude (RF, VL) under constant velocity conditions (r^2 =.866, .871). Although diminished in strength, this relationship was maintained under leg-only and standard ergometer conditions. The findings support the use of force/EMG analysis during rowing performance.

KEY WORDS: force, electromyography, rowing ergometry.

INTRODUCTION: The relationship between force output and EMG activity is a useful indicator of neuromuscular function during performance tasks. It is well known that during isometric contractions force and EMG amplitude are well correlated (Basmajian, 1974). Furthermore, for isokinetic concentric contractions, the strength of the force/EMG relationship is reduced (Christensen et al. 1995). In most performance situations, contractions are less controlled, involving multiple muscle contributions, changes in muscle length and varying contraction velocities. The purpose of this study was to compare the force/EMG responses during leg extension exercise under three conditions where muscle length, shortening velocity and contribution to force output, were under different levels of control. These conditions were isokinetic, dynamic leg extension only and dynamic leg extension plus upper body assistance.

METHODS: Trained male rowers (n=11) with a minimum of two seasons training experience, aged 28.2 ± 9.9 (mean ± SD) years, consented to participate in the study and performed contractions on each of the three ergometers during separate visits to the laboratory. Leg extensions were performed on three ergometers. A Cybex 6000 isokinetic dynamometer (T_{cyb}) was modified to export analogue torque and angular displacement data. An adapted leg-only rowing ergometer (T_{adap}) fitted with a strain gauge between the stock (rigidly attached to the seat) and ergometer chain was used to measure linear propulsive force of leg extensors and a potentiometer used to measure linear displacement of the stock. Transmission of force was achieved by means of a harness, positioned around the subject's lower back and firmly attached to the stock. A standard Concept II rowing ergometer (T_{stan}) was modified by addition of a strain gauge and potentiometer to measure handle force and displacement respectively. EMG activity was recorded from the right VL and RF muscles, using bipolar surface electrodes (10mm diameter, Ag/AgCl, Medi Trace) placed over prepared sites. Impedance between the electrodes was < 10 kohms. For all contractions EMG data were sampled at 2000Hz for a 660 data point window (0.3 seconds). The raw EMG signal was band-pass filtered (below 5 & above 300hz) and linearly smoothed (20 samples). EMG data was averaged by taking the root mean squared (rms) of the data window. A computerized data acquisition system (Amlab scientific equipment) was used for data collection. Prior to each testing session subjects completed a 5 min. non-fatiguing warm-up on a standard rowing ergometer. Maximal voluntary contraction (MVC) force was measured as the average force achieved during three initial maximal efforts with 60 s recovery between contractions. Subjects then matched contractions to a target force (20, 40, 60 or 80% MVC). Each target force was repeated three times in a random order with visual feedback of both target force and actual force output. Protocols were identical for each ergometer except that subjects were asked to maintain a movement velocity and duty cycle for T_{adap} and T_{stan}, similar to that in T_{cyb} (200 ° s^{-1}, 2 s). Force and rmsEMG were normalized to respective MVC values on the same ergometer and common linear variance scores (r^2) between force and rmsEMG for RF and VL muscles were calculated. Subject scores were meaned for each ergometer type and muscle then compared for significant difference to zero using a One-Sample T-Test. Comparison of force/rmsEMG relationships between ergometer types and muscles were examined using a 3 (ergometer type: T_{cyb}, T_{adap}, T_{stan}) x 2 (muscle: RF, VL) fully repeated measures Analysis of Variance.

RESULTS:

A positive linear relationship was found between leg extensor force and rmsEMG signal amplitude in VL and RF for all ergometer types (Fig.1, Table1). However there was a noticeable effect of ergometer type on this relationship, with the strength of the force/rmsEMG relationship being significantly diminished for both T_{adap} ($p=.012$) and T_{stan} ($p=.018$) when compared with T_{cyb}. There was a clear increase in variability of the force/rmsEMG association when forces were greater than 80% MVC with a resultant loss in linearity of the relationship. On frequent occasions, particularly at near-maximal effort, normalized EMG amplitude was greater than demonstrated at the pre-test MVC without a concomitant increase in force. Comparison of the force/rmsEMG relationship between the two leg extensor muscles revealed similar correlation scores ($p< .05$) for both VL and RF (Table 1) which in T_{stan} , was marginally stronger for VL than RF.

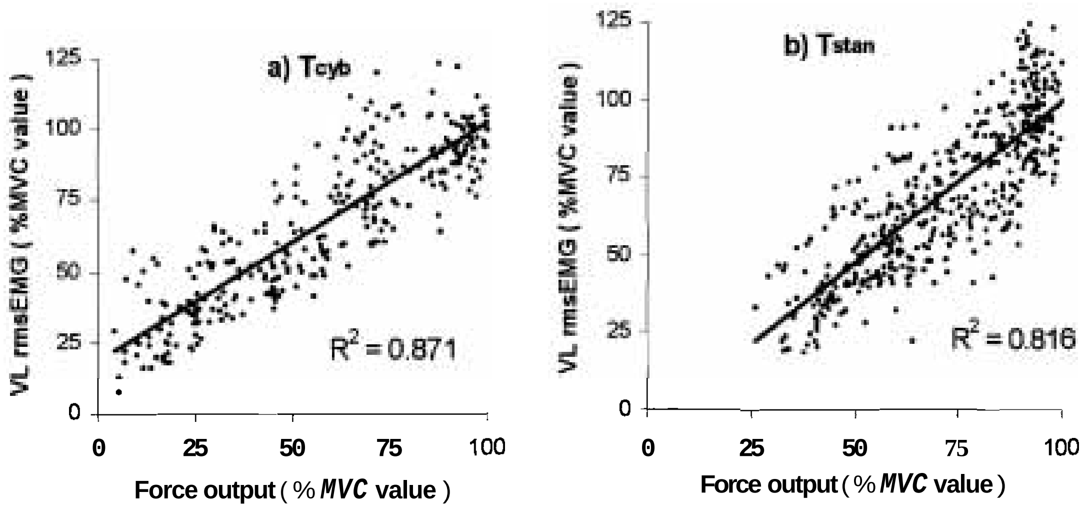

Figure 1- Relationship between normalized force and rmsEMG from vastus lateralis (VL) muscle during a) T_{cyb} isokinetic dynamometer leg extensions and b) T_{stan} standard ergometer leg extensions.

TABLE 1 Force and rmsEMG relationship for different ergometer types (T_{cyb}, T_{adap}, T_{stan}) and muscles (RF, VL). Mean ± SD correlation scores (r^2) for 11 subjects. Significance * = ($p <.05$).

	T_{cyb}	T_{adap}	T_{stan}
RF	.866 (.048)*	.720 (.181)*	.748 (.088)*
VL	.871 (.052)*	.684 (.135)*	.816 (.113)*

DISCUSSION: In agreement with Esposito et al. (1996), the current study found that an increase in force resulted in a corresponding predictable increase in rmsEMG, particularly when contractions were below 80% MVC. Importantly this relationship was maintained in T_{adap} & T_{stan} despite the fact that confounding factors such as multiple muscle contributon, changing muscle length and contraction velocity, were associated with these conditions. The increased variability of the force/rmsEMG association at high force levels has been attributed to the presence of agonist co-contraction, the possible effect of fatigue (Yang & Winter, 1983) and inefficient central nervous control (De Luca, 1997). Methodological factors that effect EMG, including electrode positioning and variations in skin impedance, were minimized or controlled in the current study and were similar between ergometer types and therefore it is unlikely these were a source of variance. The reduction in force/rmsEMG relationship observed when subjects were tested on T_{adap} and T_{stan} compared to T_{cyb}, are likely due to the fact that in the latter condition, the addition of synergistic muscle groups to leg extensor force output (eg. hip-flexors) was restricted. In T_{adap}, the hip-flexors may have also assisted to increase force output. Furthermore, since both feet were strapped into the foot-chocks allowing plantar flexion, some action of the calf muscles may also have contributed to the force measured. The pattern of movement performed in T_{stan} allowed complete coordinated synergistic muscle activation of plantar flexors, leg extensors, hip extensors, back extensors and arm flexors, thus closely representing the on-water rowing action (Wilson et a1.1988). Despite multiple muscle contributions in T_{stan}, force and quadriceps rmsEMG were significantly related. It was interesting that the force/rmsEMG correlations were better for T_{stan} than T_{adap}, although the difference did not prove statistically significant. This could be related to the fact that subjects were able to achieve more consistent contractions in the former, due to greater familiarity with the pattern of movement in T_{stan} compared to T_{adap}.
Changes in muscle length affect the area of muscle sampled (Mannion & Dolan, 1995; De Luca, 1997) and in T_{cyb} this factor was controlled (0 -100° of knee extension) and remained consistent between contractions and subjects. ROM in T_{adap} and T_{stan} varied between subjects, depending on each subject's biomechanical limitations and performance, and may therefore have been a source of variance. However, muscle length changes within subject, were the same in T_{stan} and T_{adap}. The effect of muscle length on the EMG signal was further minimized by the fact that the data sampling "window " was consistent within each subject and condition. Change in contraction velocity and related conduction. velocity affects the EMG signal, the stationarity of the signal and the force output (Arendt-Nielson & Mills, 1988). The contraction velocity during T_{cyb} was constant but in T_{adap} and T_{stan}, leg extension accelerated or decelerated during each contraction, more closely replicating the rowing movement. The movement was least controlled in T_{adap} and this was reflected in the strength of the force/EMG relationships. In the current trials the EMG signal was recorded from the right leg, but in T_{adap} and T_{stan} bilateral forces were measured which may have affected the force/EMG relationship differently than the unilateral leg forces measured in T_{cyb} (Vandervoort et al.,1984). The force/rmsEMG associations were similar for both muscles for each ergometer, except for T_{stan}, where a marginally stronger although not significant different relationship was shown for VL compared to RF, suggesting a greater reliability on VL during rowing ergometry. Although Wilson et al. (1998) showed that RF and VL were active under ergometer conditions, their data did not compare force/EMG relationships between muscles.

CONCLUSIONS: The force/rmsEMG relationship during leg extensor contractions under constant velocity conditions, although diminished in strength, was maintained under leg-only and standard rowing ergometer conditions. This supports the use of quadriceps EMG analysis in relation to biomechanical parameters during rowing performance.

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