The Effect of Neural Drive on Bilateral and Unilateral Isometric Knee Extensions

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ABSTRACT

The bilateral limb deficit (BLD) phenomenon is the difference in the maximal or near maximal force generating capacity of muscles when a muscle is contracted alone or in unison with another muscle. While the BLD has been shown to occur in various muscle groups and movement patterns, surprisingly the source of the BLD remains unknown.

The interpolated twitch technique is a widely used measure of voluntary activation of muscle. It involves interjecting a maximal electrical stimulus onto contracting muscle to determine if all the motoneurons have been recruited or if some are not firing impulses at the optimal frequency for force generation. Minimal studies have used twitch interpolation to examine the BLD and the results have been equivocal.

This work examines the contribution of neural mechanisms during bilateral and unilateral isometric knee extension contractions to determine if neural drive is compromised during bilateral contractions. Preliminary results are presented.

INTRODUCTION

The ability to efficiently move our limbs to accomplish normal tasks is a complex process that is yet to be completely understood. The level of complexity increases as we lose this ability either through injury, disorder or a decline by normal aging. The way our limbs work together, 'interlimb coordination', is an area that has become critical in our understanding of the neuromuscular system. This, in turn, has a direct impact on how everyday movements are completed. The Bilateral Limb Deficit (BLD) is the difference in the maximal or near maximal force generating capacity of muscles when a muscle is contracted alone or in unison with another muscle. While there has been a great deal of speculation, the cause of the deficit remains unknown. The purposes of this study were to determine if the BLD is present in untrained adults, to determine if the Bilateral Limb Ratio (BLR) is affected by the index used in the calculation, and to determine if voluntary activation is compromised with simultaneous homonymous limbs contracting. The results obtained may help to elucidate the origin of the deficit.

Background

Neural drive refers to the contribution of the central nervous system to the contractions as opposed to the localized contributions of the muscle itself. This work will consist of two parts. Only two studies have used twitch interpolation techniques to examine bilateral and unilateral strength differences [Herbert and Gandevia, 1996, and Jakobi and Caffarelli, 1998] and of these only one looked at lower limbs.

Jakobi and Cafarelli (1998) used twitch interpolation to look at isometric contractions from the knee extensors of untrained young male subjects to see if the BLD is associated with a decreased activation of the quadriceps, increased activation of the antagonist muscle, or an alteration in motor unit firing rates. They found no significant limitation in neuromuscular control between bilateral and unilateral isometric contractions of the knee extensor muscles in young male subjects. They also found that the ability to voluntarily activate the quadriceps is not altered in a bilateral contraction compared with a unilateral contraction.

Herbert and Gandevia (1996) used twitch interpolation to examine maximal voluntary contractions of the right thumb adductor muscles and the BLD. They found that the activation level of the thumb adductors contracted bilaterally was slightly less than during thumb alone contractions. If the BLD were, in fact, a function of impaired drive, one would expect some decrement in the voluntary activation level.

METHODS

Subjects

Nine subjects (3 female, 6 male, mean age = 27.1 ± 4.8 years, mean height = 173.9 ± 8.5, mean weight = 73.5 ± 12.0) voluntarily participated in this study. None of the subjects were instructed as to whether the bilateral forces should be equivalent, greater than or less than the unilateral forces. All subjects were familiarized with the testing apparatus in a practice session before the test session.

Instrumentation

A custom-built force chair was used to collect data. The subject was asked to sit in the chair and was strapped in via Velcro straps. The ankle was secured to a force transducer (Precision Transducers Ltd., Auckland) and the force data was sampled at 1250 Hz and displayed and analysed using data acquisition software (Windaq version 1.51). The knee angle was set to approximately 85 degrees of knee flexion (0 degrees equals full extension) and the hip angle was approximately set to 90 degrees.

Subjects were first familiarized with the twitch interpolation technique. During this session the subject's supramaximal twitch was determined, that is the stimulus at which no further motor units are recruited. This was obtained by placing stimulating carbon rubber electrodes (Empi, 2" X 4") over the quadriceps muscle and using an isolated constant current stimulator(Digitimer stimulator model DS7A, Hertfordshire, England) to interject rectangular pulse stimuli (square wave pulse, width, 200 µS; maximum voltage, 400 V) onto the quadriceps with gradually increasing current until there was no longer any increase in the force. The supramaximal twitch current ranged from 125 mA to a maximum of 400 mA across subjects.

Disposable silver-silver-chloride surface electrodes (Duotrode, bipolar configuration) were placed on the vastus lateralis of the right and left legs to record surface myoelectric signals (MES) to measure the voluntary force. The electrodes were connected to a high performance electromyography/processor system (Moroz Biomeasurement Systems 4P-AX, Hamilton, ON, Canada). The signal was low and high pass filtered at 15 and 700 Hz, amplified, full wave rectified and smoothed (20 ms time constant).

Protocol

Once the subject was comfortable with the procedure, testing began. The test consisted of twelve 5-second maximal voluntary contractions (MVCs), two sets of each of the following conditions: bilateral (BL), unilateral right (ULR) and unilateral left (ULL) without stimulation and bilateral, unilateral right and unilateral left with stimulation. During the stimulation trials, two supramaximal twitches were elicited on top of the subject's MVC and another twitch was elicited after the contraction when the subject was relaxed. Voluntary activation was calculated as in previous studies (Herbert and Gandevia, Jakobi and Cafarelli) as:

$$\left(1 - \frac{\text{superimposed twitch}}{\text{control twitch}}\right) \times 100 \qquad \text{(Equation 1)}$$

where the superimposed twitch was the best of two twitches elicited over the maximal voluntary contraction. The control twitch was the twitch elicited immediately after the contraction.

The Bilateral Limb Ratio (BLR) was calculated as in previous studies (Ohtsuki, 1983):

$$\text{BLR} = \left(\frac{\text{BLR} + \text{BLL}}{\text{ULR} + \text{ULL}}\right) \times 100 \qquad \text{(Equation 2)}$$

The BLR was calculated in three ways, using the peak force data from the custom-built force chair, the root mean square value of the myoelectric signal (MES), and the median frequency of the MES.

Statistical Analysis

Paired *t* tests (2 tailed) were used to determine if there were differences between total unilateral and bilateral force and MES activity and between the bilateral and unilateral voluntary activation levels. The 0.05 level was chosen to indicate statistical significance for individual tests.

RESULTS

Force Data

Three subjects showed a total unilateral force greater than their bilateral force, or a BLD. The differences in the total unilateral and total bilateral forces across subjects are shown in Figure 1.

Myoelectric Signal (MES) Data

No significant differences were found between unilateral summed MES Root Mean Square (RMS) values compared to bilateral MES RMS values. There was no significant difference between the median frequencies of unilateral left and bilateral left (BLL) contractions. There was, however, a difference between the median frequencies of the unilateral and bilateral right leg (BLR) contractions (Table 1).

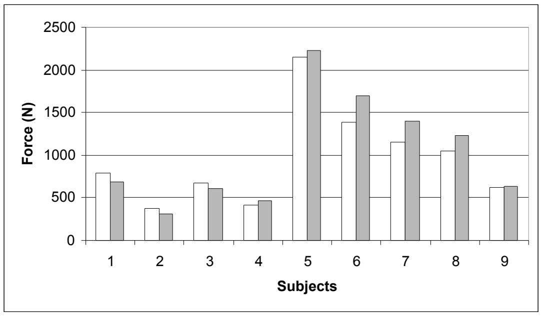

Figure 1: Total unilateral (UL_{total}, unshaded bars) and bilateral (BL_{total}, shaded bars) maximal forces. There were no statistically significant differences between the two.

	ULR	BLR	ULL	BLL
MES RMS (mV)	0.45 ± 0.30	0.47 ± 0.32	0.26 ± 0.10	0.41 ± 0.24
MES F_{median} (Hz)	57.34 ± 6.73*	55.59 ± 6.15*	59.19 ± 7.13	60.15 ± 9.85

Table 1: Myoelectric signal data for bilateral and unilateral contractions. * Only the median frequency showed differences between unilateral and bilateral conditions ($p<0.05$).

Bilateral Limb Ratios

Individual subjects data showed that three subjects showed a deficit in peak force and MES RMS. The BLR calculated using median frequency showed a deficit in eight of nine subjects. The mean values of the BLR calculated using the three different indices are shown in Table 2. The BLRs calculated across subjects are shown in Figure 2.

Index	BLR (%)
Peak Force (N)	104.02 ± 14.56
MES RMS (mV)	115.27 ± 25.26
MES F_{median} (Hz)	94.92 ± 4.81

Table 2: Mean values of BLR using three different indices. BLR from median frequency showed a deficit across all subjects. BLR from peak force and RMS showed deficit across the same three subjects.

Voluntary Activation

There were no significant differences in the voluntary activation levels between bilateral and unilateral contractions. The mean values of the voluntary activation levels are shown in Table 3. A typical recording a subject's force data with the superimposed and control twitches and MES signal is illustrated in Figure 3.

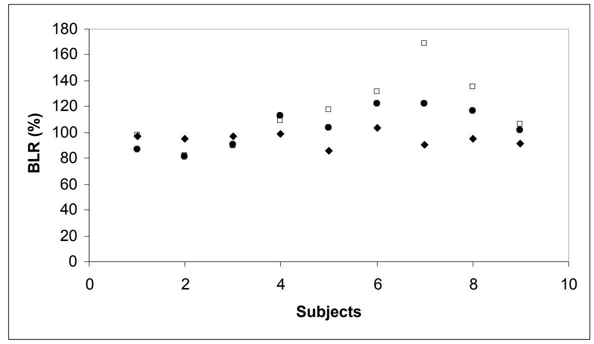

Figure 2: BLR values across subjects (• =BLR_{force}, = BLR_{RMS} and = $BLR_{median\ f}$.)

	BLR	ULR	BLL	ULL
Voluntary Activation (%)	82.61 ± 11.48	81.75 ± 6.64	77.62 ± 13.45	81.79 ± 9.13

Table 3: Mean values of voluntary activation levels for bilateral and unilateral conditions.

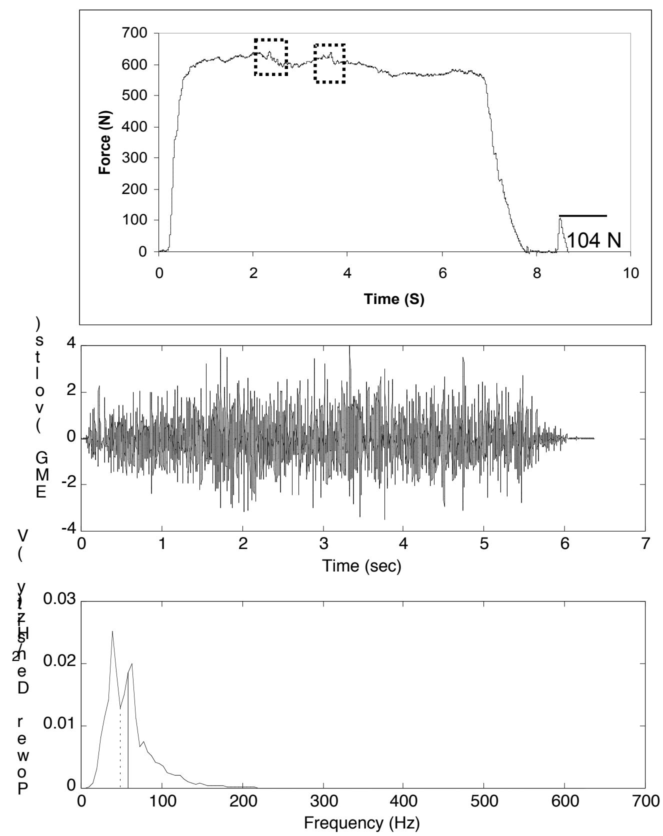

Figure 3: Sample of one subject's force data with superimposed twitch (--), RMS and power spectrum.

DISCUSSION

This study found that some subjects exhibit the bilateral deficit while in others a bilateral facilitation (BLR > 100%) occurs. However, the sample size to date for this work is relatively small. Further testing is required to determine if the 6 subjects that did not exhibit the deficit are the norm or outliers.

It was also found that, depending on the index used in the BLR calculation, the presence of the deficit may be more apparent. Specifically, it was found that when median frequency is used in the BLR calculation, there is greater amount of deficit classifications. As expected, the BLR calculated using the MES RMS value resulted in similar results as the BLR calculated using peak force. The BLR calculated using median frequency, however, indicated a deficit in 8 of 9 subjects. Koh, et. al. (1993) calculated the BLR using average MES and median frequency. In this study the mean BLR MF was 94.92 ± 4.81 which is similar to the value reported by previous studies of 96.4% (Koh, et. al., 1993). It is questionable, however, if the median frequency is a good index to use in the BLR calculation. It has been shown that the sensitivity of the median frequency to reflect muscle fiber recruitment is affected by muscle fiber type homogeneity (Pinciviero, et. al., 2001).

Koh, et. al. (1993) did not find significant differences in bilateral and unilateral MES parameters. In this study no differences were found between the unilateral and bilateral MES RMS values, but a difference was found between the median frequency of the right leg contracting unilaterally rather than bilaterally. The higher median frequency in the unilateral contraction may indicate a higher proportion of fast twitch fibers, which have faster conduction velocities. This difference was quite small and may simply be due to the limited sample size.

It was found that voluntary activation does not alter with bilateral contractions compared to total unilateral contractions. This would suggest that neural drive does not affect bilateral contractions. The voluntary activation levels found in this study were lower than those reported by Jakobi and Caffarelli (1998). They found an average of approximately 90% activation of the right quadriceps was possible in both bilateral and unilateral contractions. Other studies of the quadriceps femoris during knee extension have reported activation levels more similar to the ones reported here. Babault, et. al. (2002) reported activation levels of 87.9% ± 5.1 % for isometric knee extensions. In this study the femoral nerve was directly stimulated. An earlier study by Babault, et. al. (2001) found activation levels of 95.2% for isometric contractions of the quadriceps femoris. Kawakami, et. al. (2001) reported a mean voluntary activation of 86.0% (± 5.3) in the quadriceps femoris during knee extension from untrained individuals.

CONCLUSION

This study found that the BLD is exhibited in some subjects, while others exhibit a bilateral facilitation. It was found that neural drive is not compromised in bilateral contractions compared to unilateral contractions. It was also found that the index used to calculate the BLR can affect the determination of presence of the deficit and more work needs to be done to determine if MES parameters are valid indices to be used in the calculation.

REFERENCES

Babault, N., Pousson, M., Ballay, Y., Van Hoecke, J. (2001). Activation of human quadriceps femoris during isometric, concentric, and eccentric contractions. *Journal of Applied Physiology, 91,* 2628 – 2634.

Babult, N., Pousson, M., Michaut, A., Ballay, Y., Van Hoecke, J. (2002). EMG activity and voluntary activation during knee-extensor concentric torque generation. *European Journal of Applied Physiology, 86*, 541 – 547.

Jakobi & Cafarelli (1998). Neuromuscular drive and force production are not altered during bilateral contractions*. Journal of Applied Physiology, 84(1)*, 200-206.

Herbert, R. D. & Gandevia, S. C. (1996). Muscle activation in unilateral and bilateral efforts assessed by motor nerve and cortical stimulation. *Journal of Applied Physiology, 80*, 1351-1356.

Kawakami, Y., Akima, H., Kubo, K., Muraoka, Y., Hasegawa, H., Kouzaki, M., Imai, M., Suzuki, Y., Gunji, A., Kanehisa, H. and Fukunga, T. (2001) Changes in muscle size, architecture, and neural activation after 20 days of bed rest with and without resistance exercise. *European Journal of Applied Physiology, 84*, 7 – 12.

Koh, T., Grabiner, M., & Clough, C. (1993). Bilateral deficit is larger for step than for ramp isometric contractions. *Journal of Applied Physiology, 74,* 1200-1205.

Pincivero, D., Campy, R., Salfetnikov, Y., Bright, A., and Coelho, A. (2001). Influence of contraction intensity, muscle, and gender on median frequency of the quadriceps femoris. *Journal of Applied Physiology, 90*, 804 – 810.

Ohtsuki, T. (1983). Decrease in human voluntary isometric arm strength induced by simultaneous bilateral exertion. *Behavioural Brain Research, 7*, 165-178.