

## Effects of Acute Static Stretching on Electromyography (EMG) and Peak Force Responses

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**ABSTRACT** The purpose of the present study was to investigate the possibility of an interaction between the stretching-induced-force-deficit and bilateral-deficit during maximal voluntary isometric hand flexion under the stretch and non-stretch, bilateral, and unilateral conditions through measurement of EMG and force production. Force output and associated EMG were recorded during either unilateral or bilateral 3-second maximal voluntary isometric hand flexion (MVC) against a force transducer. The effect of the stretch on the right hand in a unilateral MVC was decreased in force with a decrease in integrated EMG (IEMG) activity. The left hand bilateral force in the stretch condition was significantly smaller than the left hand unilateral force in the non-stretched condition. It was concluded that a cumulative deficit might indicate activation of multiple inhibitory mechanisms or pathways or possibly a greater activation of a single inhibitory mechanism or pathway. Trends were observed that may prove to be significant with a stronger experimental design and greater subject numbers with less variability between subjects.

### INTRODUCTION

The muscle stretching is a type of exercise and used as a part of a warm-up that tenses the soft tissue structures to enable greater mobility, leading to an increase in joint range of motion and flexibility (Murphy et al. 2010; Daneshmandy et al. 2011; Melo et al. 2014; Meric 2014).

Stretching is a widely used practice during the warm-up routines of many sports and activities as well as during various modalities of rehabilitation. The stretching also occurs during active segments of many activities such as climbing (Ogura et al. 2007). A stretching-induced force deficit (SFD), which is the reduced contractile ability observed following stretching, has been identified and has been demonstrated to occur during voluntary isometric contractions following acute bouts of static stretching (SS) (Ryan et al. 2008). Additionally, studies have reported a reduction in muscle motor unit activation and electromyogram (EMG) activation after SS (Jakobi et al. 2001). Two mechanisms have been proposed as the causes of the stretching-induced force deficit. One proposed type of mechanism is mechanical, such as stretching-induced alterations in the length-tension relationship within the muscle, and a second proposed type of mechanism is neural, such as decreases in muscle activation as a result of stretching (Costa et al. 2009).

Another force deficit that has been observed during isometric muscle contractions is the bilateral deficit (BLD), which is the reduction in forces produced in homonymous muscle when unilateral forces are summed compared to bilateral forces (Khodiguian et al. 2003). While neuromuscular system is capable of performing motor tasks of great complexity, there are several reports in the literature relating the incapability of human subjects to produce maximal force when contra lateral muscle pairs work concurrently (Kroll 1965; Koh et al. 1993; Oda and Moritani 1995; Ohtsuki 1981; Rothmuller and Cafarelli 1995; Vandervoort et al. 1984; Van Soest et al. 1985). For instance, BLD in isometric hand grip contractions have been reported in a range of 3-5% of force (Fowles et al. 2000). Changes in EMG are seen to parallel force output decreases during BLD (Jakobi et al. 2001; Hakkinen et al. 1996). Many causes have been proposed for the BLD, including inhibitory spinal reflexes, inhibition of one cerebral hemisphere when the opposite hemisphere is activated with cortical activity reported to be adversely affected during bilateral contractions compared to unilateral, conditions (Jakobi et al. 2001). In addition, it has been suggested that factors such as training, (Rothmuller et al. 1995; Howard et al. 1991; Secher 1975; Schantz et al. 1989), age, (Hakkinen et al. 1996; Hakkinen et al. 1995) fatigue, (Kroll 1965; Howard et al. 1991) fiber type, (Koh et al. 1993; Howard et

al. 1991; Hakkinen et al. 1995) and right-left dominance (Henry et al. 1961; Herbert et al. 1996; Oda et al. 1994; Ohtsuki 1983; Weir et al. 1995) have a part in this phenomenon. Further, it has been reported that unilateral training increases unilateral force production and increases BLD, while bilateral training increases bilateral force production and decreases BLD that may be related to a neural mechanism at the supraspinal level (Jakobi et al. 2001).

Both SFD and BLD have been observed during isometric force production and have been measured with EMG. It is not known whether there is an additive effect of these two deficits. Further, because the actual causes of both deficits are not known, it is uncertain whether they utilize the same inhibitory pathway or rely on different mechanisms. Further, it is not certain whether the pathways or mechanisms interact. Nonetheless, the possibility of identifying the relationship of the two deficits has implications on prescription of specific training modalities for optimal performance or for recovery methodologies. Thus, the purpose of the current study is to investigate the possibility of an interaction between the SFD and BLD during maximal voluntary isometric hand flexion under stretch and no-stretch conditions through measurement of EMG and force production. By studying SFD and BLD separately and together, it was possible to observe the effect of stretching on maximal voluntary hand contractions alone and combined with the BLD. It was hypothesized that the overall (combined sum of both limbs) bilateral deficit would be greater in the stretch (S) versus the non-stretch (NS) condition. It was also hypothesized that the dominant hand would be stronger in the unilateral NS condition, and that the amount that the dominant hand was stronger would be reduced in both the BL conditions (S and NS), but more so in the S condition. Further, it was also hypothesized that when calculating BL indices for each limb independently, the dominant hand would be inhibited more in the S condition than the NS condition, and that this deficit would be greater than that of the non-dominant hand using the same comparison (as only the dominant hand was stretched). However, some investigators (Costa et al. 2009; Cromer et al. 2005) have reported finding a deficit in the non-stretched, contra lateral limb in a unilateral stretch condition, in both EMG and force, thus, it may also be reasonable to predict instead that

the deficit in the non-dominant hand will be notable in the S versus the NS (the dominant hand was not stretched in the unilateral, left contraction condition) as well as in the BL versus the unilateral condition.

## MATERIAL AND METHODS

**Participants:** Seven subjects (Four female and three male, age  $31.7 \pm 10.9$  yr, height  $167.2 \pm 9.0$  cm; means  $\pm$  SD) participated in the study. Five subjects were right-hand dominant and two subjects were left-hand dominant. The participants were not naive to the purpose of the study and the anticipated findings.

### Experimental Protocol

Force output and associated EMG were recorded during either unilateral (UL) or bilateral (BL) 3-second maximal voluntary isometric hand flexion (MVC) against a force transducer. Three trials of each UL and BL condition were performed in a randomized fashion. Additionally, three trials of each condition UL and BL were performed in a randomized fashion with 30 seconds manual passive stretching, administered on the dominant hand of subjects (for UL and BL only when this included the dominant hand but not UL of non-dominant hand only trials).

### Measurement of Force and EMG

Subjects were tested in a seated position, relaxed, facing forward, with knees bent and both feet on the floor, upper arms hanging naturally beside the body with elbows at approximately  $90^\circ$ , and untested hand resting on the same side leg. The subjects were prepared by identification of the left and right Flexor Digitorum Superficialis (FDS) by palpation. The FDS was traced to the middle of the muscle belly and marked. To obtain the best signal in surfaced electrodes, dead skin was removed; the skin was swabbed with alcohol then abraded with light sandpaper until a mild burning "sunburn like" sensation was reported by the subject. The site was then swabbed with alcohol again after which pre-ampped unipolar surface electrodes were placed on the surface skin over the FDS of both arms. One ground electrode was placed on the bony, non-conducting surface of either the patella or lateral malleolus of the fibula. Electrodes were taped in place. Pri-

or to testing, a warm-up consisting of 10 sub-maximal (75% of maximum force as perceived by the subject) BL flexions against the force transducers were performed. This was followed by two or three accommodation trials to familiarize the subjects with timing and voice commands during the test as well as to determine a clean signal in the electrodes. The transducer signal was zeroed before every trial.

All the trials for a given subject were completed in one visit. The initial phase for each subject consisted of the three non-stretched trials of MVC of each UL and BL condition. This was followed by the three stretched trials of MVC of each UL and BL condition. Previous investigators indicated that decreases in peak tension result from performing MVCs immediately following stretching (Schantz et al. 1989; Coyle et al. 1981) contrasted with no observed inhibition when allowing a rest between MVCs and testing (Torres et al. 2008), thus, the stretching was administered immediately before the subject performed MVCs and no rest time was allowed. Each MVC lasted no longer than 3 seconds. The stretch, administered by a participating Kinesiology Masters student, was the strongest passive torque the subject could tolerate during a stretch that is, the point identified by the subject as uncomfortable, but not painful), administered for 30 seconds. The subjects were given 1-minute rest between each test in a series of UL and BL trials (Randomized: Bilateral, Unilateral Left, Unilateral Right) and given 3-minutes between each series of tests as well as before beginning the stretched portion of the trial. Encouragement was provided during the MVCs.

### Data Reduction

The EMG collection software package was used to obtain the maximum-recorded peak force (PF) (N) and integrated EMG (iEMG) (mV•s) for the closest 500 ms of the plateau region for the recorded PF.

The bilateral index (BI) is the proportion between bilateral and unilateral force was measured from left unilateral, right unilateral and bilateral maximum isometric tests. The equation bilateral index calculated is as below (Khodiguian et al. 2003):

$$BI(\%) = \{100 \times [(right\ bilateral + left\ bilateral) \div (right\ unilateral + left\ unilateral)]\} - 100$$

Bilateral indices for each individual limb was calculated as:  $BI(\%) = [(bilateral \div unilateral) \times 100] - 100$

A negative BI indicated a bilateral deficit while a positive BI indicated a bilateral facilitation.

### Analysis of Results

For the comparison of stretch and non-stretch as well as bilateral and unilateral means, paired t-tests were performed. Additionally, for bilateral indexes a single sample t-test was used to test the difference of the mean from zero. Further, to analyze the relationship between parameters, Pearson's correlation was used. To test the significance of correlation coefficients ( $r$ ), the t-test statistic was used. The correlation coefficient was considered to be statistically significant if the computed t value was greater than the critical value of a t-distribution. Statistical significance was accepted at  $\alpha$ -level of 0.05.

### Data

For all values for mean, standard deviation, standard error of the mean, Pearson's correlation, t-test, etcetera,  $n$  of 5 was used, excluding the left-hand dominant value. Force during bilateral and unilateral maximal voluntary isometric hand flexion in stretched and non-stretched conditions were recorded. Force in MVC for the bilateral un-stretched condition was  $347 \pm 36.3$  N for the right hand and  $308.88 \pm 37.1$  N for the left hand. MVC force in the unilateral un-stretched condition was  $351.94 \pm 35.5$  N for the right hand and  $322.21 \pm 45.1$  N for the left hand. MVC force in the bilateral stretched condition was  $312.68 \pm 25.36$  N for the right hand and  $273.72 \pm 35.3$  N for the left hand. MVC force in the unilateral stretched condition was  $310.14 \pm 27.6$  N for the right hand and  $286.70 \pm 34.8$  N for the left hand (Table 1).

iEMG during bilateral and unilateral maximal voluntary isometric hand flexion in stretched and non-stretched conditions was recorded. iEMG in MVC for the bilateral un-stretched condition were  $0.0539 \pm 0.10$  mV•s for the right hand and  $0.0631 \pm 0.012$  mV•s for the left hand. MVC force in the unilateral unstretched condition was  $0.0574 \pm 0.010$  mV•s for the right hand and  $0.0715 \pm 0.015$  mV•s for the left hand. MVC force in the bilateral stretched condition was

**Table 1: Force (N) during bilateral and unilateral maximal voluntary isometric hand flexion in stretched and non-stretched conditions.**

| <i>Force</i>       |                            |                            |                            |
|--------------------|----------------------------|----------------------------|----------------------------|
| <i>BLForceR-NS</i> | <i>BLForceL-NS</i>         | <i>ULForceR-NS</i>         | <i>ULForceL-NS</i>         |
| 347.80 ± 36.3      | 308.88 ± 37.1              | 351.94 ± 35.5 <sup>†</sup> | 322.21 ± 45.1              |
| <i>BLForceR-S</i>  | <i>BLForceL-S</i>          | <i>ULForceR-S</i>          | <i>ULForceL-S</i>          |
| 312.68 ± 25.6      | 273.72 ± 35.3 <sup>‡</sup> | 310.14 ± 27.6 <sup>†</sup> | 286.70 ± 34.8 <sup>‡</sup> |

Units in N. Values are mean ± SE. BL = bilateral; UL = unilateral; R = right side; L = left side; NS = non-stretch; S = stretch.

<sup>†</sup> UL Force R-S is significantly smaller than UL Force R-NS (P<0.05); <sup>‡</sup> Force (N) BL Force L-S significantly smaller than ULForceL-NS (P<0.05).

0.0510±0.008 mV•s for the right hand and 0.0529±0.012 mV•s for the left hand. MVC force in the unilateral stretched condition was 0.0506±0.008 mV•s for the right hand and 0.0629±0.014 mV•s for the left hand (Table 2).

Bilateral indexes for each limb for force and iEMG were determined, as were overall force and iEMG bilateral indexes. BI (F)% in the stretch condition was -11.61±5.3% while in the non-stretch condition it was -2.25±1.0%. BI (iEMG)% in the stretch condition was -17.06±5.5% while in the non-stretch condition it was -8.45±6.2%. BI% for force measurements for the right non-stretch condition was -1.26±2.2%, while for the

right stretch condition it was -10.06±4.1%. BI% for force measurements for the left non-stretch condition was -2.96±2.5% while for the left stretch condition it was -13.12±6.7%. BI% for iEMG measurements for the right non-stretch condition was -5.70±7.7% while for the stretch condition it was -9.17±7.4%. BI% for force measurements for the left non-stretch condition was -9.25±6.0% while for the left stretch condition it was -22.49±9.1% (Table 3).

Values are mean ± SE. BL = bilateral; UL = unilateral; R = right side; L = left side; NS = non-stretch; S = stretch; iEMG = integrated electromyogram; BI (F) = bilateral index for force; BI

**Table 2: iEMG during bilateral and unilateral maximal voluntary isometric hand flexion in stretched and non-stretched conditions**

| <i>iEMG</i>       |                           |                           |                           |
|-------------------|---------------------------|---------------------------|---------------------------|
| <i>BLiEMGR-NS</i> | <i>BLiEMGL-NS</i>         | <i>ULiEMGR-NS</i>         | <i>ULiEMGL-NS</i>         |
| 0.0539±0.010      | 0.0631±0.012              | 0.0574±0.010 <sup>È</sup> | 0.0715±0.015              |
| <i>BLiEMGR-S</i>  | <i>BLiEMGL-S</i>          | <i>ULiEMGR-S</i>          | <i>ULiEMGL-S</i>          |
| 0.0510±0.008      | 0.0529±0.012 <sup>Å</sup> | 0.0506±0.008 <sup>È</sup> | 0.0629±0.014 <sup>Å</sup> |

Units in mV•s. Values are mean ± SE. BL = bilateral; UL = unilateral; R = right side; L = left side; NS = nonstretch; S = stretch; iEMG = integrated electromyogram. <sup>È</sup> ULiEMGR-S significantly smaller than ULiEMGR-NS (P<0.05); <sup>Å</sup> BLiEMGL-S significantly smaller than ULiEMGL-S (P<0.05)

**Table 3: BI (F) and BI (iEMG) during bilateral and unilateral maximal voluntary isometric hand flexion in stretched and non-stretched conditions**

|            | <i>S</i>                 | <i>NS</i>              | <i>R - NS</i> | <i>R-S</i>              | <i>L - NS</i> | <i>L - S</i>            |
|------------|--------------------------|------------------------|---------------|-------------------------|---------------|-------------------------|
| BI(F) %    | -11.61± 5.3 <sup>È</sup> | -2.25±1.0 <sup>*</sup> |               |                         |               |                         |
| BI % force |                          |                        | -1.26±2.2     | -10.06±4.1 <sup>‡</sup> | -2.96±2.5     | -13.12±6.7              |
| BI(iEMG)   | -17.06±5.5 <sup>È</sup>  | -8.45±6.2              |               |                         |               |                         |
| BI % iEMG  |                          |                        | -5.70±7.7     | -9.17±7.4               | -9.25±6.0     | -22.49±9.1 <sup>‡</sup> |

Values are mean ± SE. BL = bilateral; UL = unilateral; R = right side; L = left side; NS = non-stretch; S = stretch; iEMG = integrated electromyogram; BI (F) = bilateral index for force; BI (iEMG) = bilateral index for iEMG. <sup>È</sup> BI(F)% BLS significantly smaller than ULS (P<0.05); <sup>\*</sup> BI (F)% BLNS significantly smaller than ULNS (P<0.05); <sup>È</sup> BI(iEMG)% BLS significantly smaller than ULS (P<0.05); <sup>‡</sup> BI% for force BLS-R significantly lower than ULNSR (P<0.05); <sup>†</sup> BI% for iEMG BLS-L significantly lower than ULNS-L (P<0.05).

(iEMG) = bilateral index for iEMG.  $\hat{=}$  BI(F)% BLS significantly smaller than ULS ( $P < 0.05$ ); \* BI (F)% BLNS significantly smaller than ULNS ( $P < 0.05$ );  $\ddagger$  BI(iEMG)% BLS significantly smaller than ULS ( $P < 0.05$ );  $\ddagger$  BI% for force BLS-R significantly lower than ULNSR ( $P < 0.05$ );  $\dagger$  BI% for iEMG BLS-L significantly lower than ULNS-L ( $P < 0.05$ ).

## RESULTS

Significant deficits in force and iEMG were observed throughout the various conditions. As predicted, in the right hand stretch condition, UL force was significantly smaller than the right hand UL force in the un-stretched condition ( $P < 0.05$ ). This was paralleled by the right hand stretch condition UL iEMG being significantly smaller than the right hand un-stretched condition UL iEMG ( $P < 0.05$ ). Thus, the effect of the stretch on the right hand in a unilateral MVC was a decrease in force with a decrease in iEMG activity. Similarly, the left hand BL force in the stretch condition was significantly smaller than the left hand UL force in the non-stretched condition ( $P < 0.05$ ). This was accompanied by the left hand stretch condition BL iEMG being significantly smaller than the left hand stretch condition UL iEMG ( $P < 0.05$ ). Thus, it was also found that when the right hand was stretched, the left hand saw a significant decrease in force and that there was a significant decrease in iEMG in the left hand when the right hand was stretched (this only occurred in the BL stretch condition) compared to the left hand iEMG when the right hand was un-stretched (ULiEMG-S, where the right hand was not stretched).

No significant difference in force or iEMG was seen between S and NS in the BL condition for either R or L ( $P > 0.05$ ). BI (F)% for the BL stretched condition was significantly smaller than for the UL stretched condition ( $P < 0.05$ ). BI (F) % for the BL non-stretched condition was significantly smaller than for the UL non-stretched condition ( $P < 0.05$ ), indicating a significant overall BLD for both S and NS conditions. However, no significant difference was observed between BLS and BLNS for BLD ( $P > 0.05$ ), though the trend was in favor of a greater deficit in the BLS condition compared to the BLNS condition, with all but one subject experiencing a greater deficit in the BLS condition. BI (iEMG) % for the BL stretch condition was significantly smaller

than for the UL stretch condition ( $P < 0.05$ ), indicating a significant iEMG deficit in the BL condition under conditions of stretching. Looking at the limbs individually, BI% for force for the right hand BL stretch condition was significantly lower than for the right hand UL non-stretch condition ( $P < 0.05$ ) as expected. BI% for iEMG for the left hand BL stretch condition was significantly lower than for the left hand UL non-stretch condition ( $P < 0.05$ ). There was a significant correlation between BI (F) % force and BI (iEMG) % within the stretch condition ( $r = 0.853$ ;  $n = 5$ ;  $P < 0.05$ ). There was also a significant correlation between BI(F)% and BI(iEMG)% for the BI(F)% of the BL stretch and non-stretch conditions ( $r = 0.852$ ;  $n = 5$ ;  $P < 0.05$ ). Further, there was a significant correlation between BI% for force and BI% for iEMG for the left limb stretch condition ( $r = 0.926$ ;  $n = 5$ ;  $P < 0.05$ ). Thus it was observed that changes in EMG were seen to parallel force output decreases during SFD (Fowles et al. 2000; Schantz et al. 1989).

## DISCUSSION

The purpose of the current study was to investigate the possibility of an interaction between the SFD and BLD during maximal voluntary isometric hand flexion under S and NS and BL and UL conditions through measurement of EMG and force production. By studying SFD and BLD separately and together, it was possible to observe the effect of stretching on maximal voluntary hand contractions alone and combined with the BLD. Some studies (Babault et al. 2014; Costa e Silva et al. 2014) have indicated how static stretching affects the force performance negatively, especially, stretching just before exercise which might cause temporary strength deficits (Bingul 2014).

It was theorized that a cumulative deficit might indicate activation of multiple inhibitory mechanisms or pathways, or possibly a greater activation of a single inhibitory mechanism or pathway. Based upon the small subject numbers and various simplifications of experimental design, it was expected that only trends would be discerned in the data. It was, therefore, surprising to find significance in many conditions tested. The trend observed between the various conditions, though not always significant, was for a deficit in S versus NS conditions, for a deficit in BL versus UL, and for a greater deficit in the BLS



compared to the BLNS condition. The lack of significance in many figures can possibly be attributable to the low sample number ( $n=7$ ), the large variances observed due to the variability in subjects, as well as the observed potentiating of force output in some individuals (Jakobi et al. 2001).

As hypothesized, there was a significant overall (combined sum of both limbs) bilateral deficit that was found to be significantly greater in the stretch (S) versus the non-stretch (NS) condition. It was also hypothesized that the dominant hand would be stronger in the UL NS condition and that the amount that the dominant hand was stronger would be reduced in both the BL conditions (S and NS), but more so in the S condition. It was found that the dominant hand was significantly weaker in the UL S condition versus the UL NS condition as well as being significantly weaker in the BL S condition versus the UL NS condition, however, there was no significant difference between the UL S and BL S conditions, nor between BL NS and BL S for the dominant hand, though the latter demonstrated a trend in BL S being weaker. Further, it was hypothesized that when calculating BL indices for each limb independently, the dominant hand would be inhibited more in the S condition than the NS condition. It was found that the dominant hand was inhibited significantly in the S while the deficit in the NS condition was not significant. Finally, it was hypothesized that the deficit in the S versus the NS condition would be greater than that of the non-dominant hand using the same comparison (as only the dominant hand was stretched).

It was noted, however, that not only was there a greater, though not significant, deficit in the left hand S versus the NS condition, there was also a significant decrease in BI% for iEMG in L S versus the NS condition, as well as there being a significant force deficit in BL LS compared to UL LNS. Previous (Cramer et al. 2005 and Costa et al. 2009.) have reported finding a deficit in the non-stretched, contra lateral limb in a unilateral stretch condition, in both EMG and force. This may help to confirm the deficit in the non-dominant hand that was observed in the BL LS versus the UL LNS (the dominant hand was not stretched in the unilateral, left contraction condition) as well as in the BL S and NS condition for the left hand.

Altogether, the findings can be said to support the hypotheses. Further, trends were observed that may prove to be significant with a stronger experimental design and greater subject numbers with less variability between subjects. Further, because the deficit in force from stretching seems to be accompanied by decreases in iEMG, this may point to the contribution of a neural mechanism for both the BLD and the SFD, though other researchers have speculated that SFD is primarily mechanical in nature (Ryan 2008; Costa et al. 2009) though they do not disregard that neural factors may participate.

Some interesting implications arose as a result of this study and are worth further investigation. The possibility of combined deficit effects from BLD and SFD may have implications for some athletes as well as therapy settings. The observed left hand deficit that occurred in conjunction with right hand stretching only may also be a very useful mechanism to understand in its application to recovery, therapy, and sport. Follow-up experiments should seek to avoid some of the weaknesses of this study to establish better consistency and statistical power. This might include replications as well as testing on different days. This also might include standardizing some of the protocols, such as motivation, and stretch duration and intensity. Further, the determination of the effect of a left hand stretch or bilateral stretching might also proved to be illuminating.

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