LOWER LIMB FORCE PRODUCTION AND BILATERAL FORCE ASYMMETRIES ARE BASED ON SENSE OF EFFORT

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INTRODUCTION

Humans control force production in their limbs by using an internal model of musculoskeletal mechanics to calculate appropriate neural signals (Wolpert & Ghahramani 2000). Subjects produce less force during an isometric force matching task when one limb is fatigued (Carson et al. 2002), presumably because they have not updated their internal model. Carson et al. (2002) also found that upper limb force production after fatigue scales with maximum voluntary strength. This suggests that individuals use a sense of effort (Gandevia & McCloskey 1977), rather than proprioceptive feedback, to gauge upper limb force production.

We have adopted the isometric force matching task used by Carson et al. (2002) to study normal force asymmetry in the lower limbs of humans. The goal of this study was to determine if force asymmetry during bilateral force production results from a neural mechanism related to sense of effort. We hypothesized that subjects attempting to produce equal forces in their lower limbs would generate equal percentages of their bilateral maximum voluntary strength rather than equal absolute limb forces. If true, this could provide critical insight into the neural origins of lower limb force asymmetry during movement.

METHODS

Ten healthy subjects performed isometric lower limb extensions on a leg press exercise machine (Figure 1). We recorded individual limb forces from a dual force platform and muscle activity from electromyography electrodes. We assessed subjects' isometric strength with three trials each of bilateral, left limb, and right limb maximum voluntary contractions (MVC) in a randomized order with three minutes rest between trials. Lower limb MVC values were determined as the peak force measured within the three trials of each condition. We identified the stronger limb as the limb that produced the higher peak force during the bilateral MVC condition.

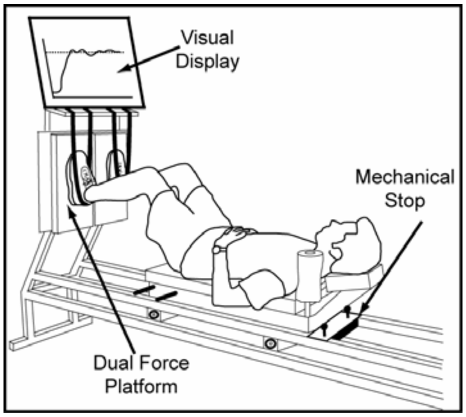

Figure 1. Leg press exercise machine.

After a ten minute rest period, we assessed subjects' ability to match forces in their lower limbs with nine force matching trials. Subjects were asked to exert a force using the stronger limb equal to 20, 40, or 60% of the peak force recorded from the weaker limb during the bilateral MVC condition. Subjects received visual feedback of the target force level and the stronger limb force. When subjects reached the target force level in the stronger limb, they began applying force with the weaker limb. Subjects verbally signaled to the experimenter once they believed they had matched forces in both lower limbs. No

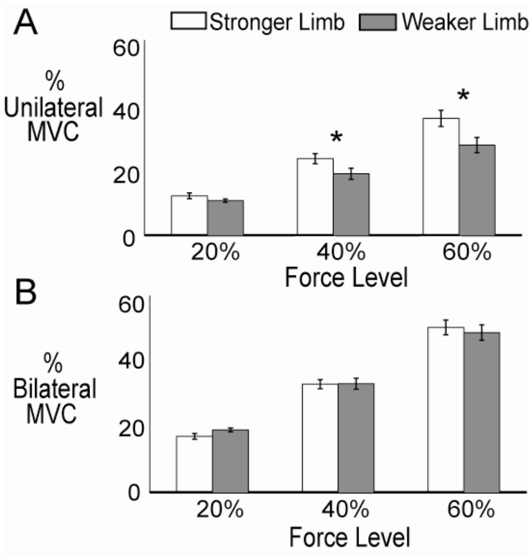

Figure 2. Average forces for all subjects during three different levels of force matching. Force levels were 20%, 40%, and 60% of the maximum force recorded at the weaker limb during the bilateral MVC condition. A) Forces normalized to unilateral MVC for each limb show significant differences for 40% and 60% force levels. B) Forces normalized to bilateral MVC shows no differences between limbs. Error bars are standard error of the mean.

feedback was given about weaker limb force. Subjects performed three trials at each of the three force levels in a randomized order. Subjects were unaware of the study's purpose and which limb produced more force during the bilateral MVC condition.

For all force matching trials, we calculated the average force applied by each limb for three seconds after subjects indicated they believed the forces were equal. We normalized foot forces to a) each limb's unilateral MVC and b) to each limb's bilateral MVC. We used a repeated measures ANOVA and Tukey-Kramer Honestly Significant Difference (HSD) post-hoc tests to determine if there were differences between limbs and force levels.

RESULTS AND DISCUSSION

MVC trials showed significant differences in peak force between limbs and conditions (ANOVA, $p < 0.001$). Subjects produced average peak forces of 1143 N ± 130 N (mean ± s.e.m.) and 904 N ± 111 N for their stronger and weaker limbs during bilateral MVC trials, respectively (interlimb difference $p < 0.05$). Subjects produced average peak forces of 1625 N ± 180 N and 1582 N ± 157 N for their stronger and weaker limbs during unilateral MVC trials, respectively (interlimb difference $p > 0.05$). All subjects demonstrated a decrease in the peak force generated during the bilateral MVC trials when compared to the unilateral MVC trials for each limb ($p < 0.05$).

During the force matching trials, subjects consistently produced less force in their weaker limb during both the 40% and 60% force matching levels as a percentage of their unilateral MVC force ($p < 0.05$) (Figure 2A). However, normalizing force magnitudes by bilateral MVC forces revealed no significant differences between limbs at all three force matching levels (ANOVA, $p=0.8506$) (Figure 2B).

CONCLUSIONS

These results indicate that normal limb force asymmetry during bilateral activation has a neural origin. Regardless of whether humans produce maximal or submaximal forces, limb force asymmetry results from an uneven neural drive to the lower limbs. Our findings have implications for bilateral asymmetries during movement in healthy and neurologically impaired populations such as individuals with post-stroke hemiparesis.

REFERENCES

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