The effect of the bilateral asymmetry of muscle strength on the jumping height of the counter movement jump: a computer simulation study

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SUMMARY
The purpose of this study was to examine the effect of bilateral asymmetry of muscle strength on the jumping performance (maximal jumping height) of counter movement jump. Computer simulation technique was conducted. Two kinds of 3D human lower limb musculoskeletal models (model-symmetry and model-asymmetry) were developed. The total muscle strength of the two models was set to be identical. Bilateral muscle strength was equal in the model-symmetry simulation, while the model-asymmetry simulation was set with a 10 percent bilateral strength asymmetry. The counter movement jumps were successfully generated, producing jumping heights of 0.416 m for model-symmetry, and 0.419 m for model-asymmetry. The small difference in height (0.7%) indicated that bilateral asymmetry by itself does not have a significant effect on jumping performance.

INTRODUCTION
In humans, fluctuating bilateral asymmetry – small, random differences normally distributed across a mean of zero – is reported to be commonplace [1]. Also, most people have a dominant hand and leg with which they perform daily tasks or sports. Newton et al. reported that the isokinetic knee extension/flexion peak torque exerted by the dominant leg was significantly higher than that exerted by the non-dominant leg [2].

The relationship between bilateral asymmetry of lower extremity muscles and injuries is an interesting topic in various kinds of sports and has been investigated by many researchers. Similarly, the relationship between bilateral asymmetry of lower extremity muscles and performance is also an interesting one. However, little is known about the performance benefits.

Therefore, the purpose of this study was to examine the effect of the bilateral asymmetry of muscle strength on the jumping performance (maximal jumping height) of the counter movement jump.

METHODS
Two kinds of a three-dimensional human lower limb musculoskeletal model (model-symmetry and model-asymmetry) were developed using DADS-3D (LMS International, Leuven, Belgium). These models consisted of three sub-models (skeletal model, muscle model and neuromuscular dynamics) [3]. These human models were driven only by the contractile element of the muscle model through neural input signals. The muscle strength of the model-symmetry was set to a bilateral symmetry. That of the model-asymmetry was set to a bilateral asymmetry of 10 percent between the strong and weak leg. The total muscle strength of the model-symmetry and the model-asymmetry was set to be identical. The other elements of the two models were identical. An approach of forward dynamics was used to simulate counter movement jumps. Neural input signal profiles to generate maximal jumping height were searched using the optimization technique [4]. After optimization, the jumping kinematics and kinetics of the model-symmetry and the model-asymmetry were compared.

RESULTS AND DISCUSSION
The counter movement jumps of the model-symmetry and model-asymmetry were successfully generated through the optimization process (Figure 1, 2). The jumping height of the model-symmetry and model-asymmetry was 0.416 and 0.419 m, respectively. The difference was very small (0.7%). These results indicated that bilateral asymmetry by itself does not have a significant effect on jumping performance.

![Figure 1: The counter movement jumping kinematics (sagittal view, right side) simulated with the model-symmetry (upper figure) and model-asymmetry (lower figure).](image-url)
The total muscle work of the model-symmetry and model-asymmetry was 492.4 J and 496.5 J, respectively. The difference in the total work between the model-symmetry and model-asymmetry was 1.0%. The total work of the right (strong) leg of the model-asymmetry (257.7 J) exhibited the highest value, followed by the right and left leg of the model-symmetry (246.2 J) and the left (weak) leg of the model-asymmetry (238.8 J). This order also corresponded to the order of the muscle strength of the leg. It can be said that the strong leg compensated for the muscle strength deficit of the weak leg.

During the counter movement phase, the center of mass moved to the right (strong) side. Then, during the next propulsion phase, the center of mass shifted to the left (weak) side (Figure 3). The vertical ground reaction forces during the model-symmetry and model-asymmetry jumps have similar profiles (Figure 4). However, some small differences were observed during the propulsion phase of the jump. The vertical ground reaction force of the right (strong) leg of the model-asymmetry exhibited the highest value, followed by the right and left leg of the model-symmetry and the left (weak) leg of the model-asymmetry. This order corresponded to the order of the muscle strength of the leg. These results indicated that lateral movement of the body distributed the load proportional to the muscle strength of each leg.

CONCLUSIONS
The effect of the 10% bilateral asymmetry of the muscle strength on the jumping height was very small, because, in the model-asymmetry, the strong leg compensated for the muscle strength deficit of the weak leg by lateral movement of the body, which distributed the load proportional to the muscle strength of each leg.

REFERENCES