INTRODUCTION

Being able to rise and stand from a seated position is a basic, yet biomechanically demanding, activity of daily living [1]. However, due to weakened muscles or diseased joints, more than 2 million Americans over the age of 64 have difficulty accomplishing a sit-to-stand (STS) transfer independently, which can significantly limit mobility and independence [2, 3]. Several studies have determined joint torques and muscle activations associated with a STS transfer for various initial seating conditions by using traditional gait analysis techniques or rigid body models [2, 4, 5]. However, individual muscle forces in the STS transfer have yet to be fully explored. Understanding individual muscle function potentially informs rehabilitation strategies for patients with weakened muscles to improve performance with the STS transfer. As a first step toward that goal, the purpose of this study was to examine individual muscle forces in STS transfer in a young, healthy population.

METHODS

Seven healthy subjects (5 male and 2 female, Age: 22.7 ± 2.9 years) provided IRB-approved written consent. Subjects completed three trials of STS transfer, rising from a 55.2 cm position with their arms crossed over their chest while motion data was collected at 150 Hz using an 8-camera Vicon MX-F40 system and the Point-Cluster Technique (PCT) [6]. Ground reaction forces were obtained from two force plates sampled at 600 Hz, one placed under each of the subject’s feet; no part of the chair touched the force plates. Bilateral surface EMG data was collected on the gluteus maximus, gluteus medius, rectus femoris, vastus lateralis, biceps femoris, tibialis anterior, medial gastrocnemius, and soleus using a 1500 Hz, 16-channel device.

Muscle-driven simulations of STS transfer were created for each subject’s trial in OpenSim 2.4 [7]. A generic lower limb musculoskeletal model was scaled to each subject’s anthropometry. Inverse kinematics was implemented with a least-squares approach to reproduce the STS transfer motion in the scaled model with minimal difference between the experimental marker locations and the model’s virtual marker locations. The joint forces and torques for each STS trial were determined through inverse dynamics and further resolved into individual muscle forces using static optimization (STO) [8].

The simulated muscle activations from STO were compared to the subject’s experimental EMG after normalizing the EMG by peak activations in the simulation.

The data were sufficiently consistent between trials to use one trial per subject for analysis. We divided each STS trial into 3 phases: forward leaning (Phase 1), momentum transfer (Phase 2), and extension (Phase 3) [9]. The forward leaning phase begins when lumbar extension increases by .5 degrees from its initial value when the subject is at rest. The momentum transfer phase begins when hip flexion angle reaches its maximum value. The momentum transfer phase ends and the extension phase begins when the ankle reaches its maximum dorsiflexion value. The extension phase ends when the subject reaches their maximum hip extension value [9].

We investigated the gluteal muscles, quadriceps (vasti and rectus femoris), hamstrings, sartorius, gastrocnemius, soleus, and tibialis anterior, averaged the individual muscle forces across
subjects and examined them across the three phases. After noticing that subjects had a tendency to lean sideways or have valgus knee positioning during the STS transfer, we further investigated the inter-limb differences in maximum muscle forces per phase.

**RESULTS AND DISCUSSION**

The quadriceps, hamstrings, soleus, and gastrocnemius generate a large amount of force during the STS transfer (Figure 1). In Phase 1, the quadriceps and hamstrings reach their peak values. In Phase 2, the forces in these muscles decrease while the force generated by the soleus increases. The soleus force continues to increase in Phase 3 as a standing position is attained. At the end of Phase 3, the gastrocnemius generates the greatest force of the muscles examined.

There were notable differences between the dominant and non-dominant leg average maximum muscle forces across subjects. Values are reported for muscles displaying a difference greater than 20% (Table 1). Some muscles, such as the soleus, also had negative percent differences between the dominant and non-dominant leg, implying that certain muscles generated a greater force in the non-dominant leg during the STS transfer.

Our kinematic, kinetic, and EMG data compared favorably to those reported by other studies [4, 10], and we built upon those previous studies by estimating forces in individual muscles. It was expected that the quadriceps and hamstrings would play a large role in the STS transfer. However, the crossover between the forces in the quadriceps and hamstrings with the soleus in Phase 2 as well as the relatively large asymmetry between limbs in this healthy population were unexpected.

**CONCLUSIONS**

Understanding individual muscle forces as well as symmetry of muscle forces between legs during STS transfer in healthy subjects is the first step to analyzing muscle function and weakness in subjects with conditions such as osteoarthritis. These results set the stage for future work to investigate how unilateral and bilateral weakness affects a person’s ability to perform the STS transfer and potentially inform rehabilitation strategies that could improve patients’ functional performance with this task.

**REFERENCES**


![Figure 1: Selected muscle forces during STS transfer.](image)

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