EXPERIMENTAL EVALUATION OF MODEL-BASED LOWER EXTREMITY INDUCED ACCELERATIONS

Betsy V. Hunter[1], Darryl G. Thelen[2], and Yasin Y. Dhaher[1]

[1]Northwestern University, Evanston, IL, USA
[2]University of Wisconsin-Madison, Madison, WI, USA
E-mail: b-hunter@northwestern.edu

INTRODUCTION

Following neurological pathologies such as stroke, impaired motor control may result in detrimental gait abnormalities. Hence, there is increasing interest in establishing rehabilitation interventions to improve locomotion (Daley, 2004; Johnson et al. 2004). These treatments, outcomes of which are highly variable, are primarily based on an anatomical perception of muscle function and may not incorporate effects of dynamic coupling. In order to target three-dimensional multi-joint abnormalities, improvement of these intervention strategies will likely require integration of a more extensive definition of muscle function.

In recent years, Induced Acceleration Analysis (IAA) has been used to provide a direct correlation between a system's kinetics and kinematics. Using IAA with musculoskeletal modeling, an individual muscle's contribution to the movement of multiple joints can instantly be determined. However, IAA-based simulation techniques lack substantial experimental validation of muscle-specific results. Therefore the goal of this study is to determine if model-based predictions of muscle contributions would emulate observed functions under a **well-controlled experimental paradigm**. We hypothesize that three-dimensional acceleration directions obtained in gait simulations will be observed experimentally under identical conditions. We propose that findings will facilitate the interpretation of dynamic muscle function in cross-planar movements that occur following stroke.

METHODS

The experimental framework uses individual muscle stimulation of the biceps femoris (BF), rectus femoris (RF) and vastus lateralis (VL) to isolate each muscle's contribution to movement. Ten healthy subjects were positioned in four static multi-joint configurations ranging from toe-off to heel strike of gait (figure 1). Series elastic elements placed between the orthosis and the limb allowed for small movements while counterbalancing gravity. As each muscle was delivered a 60ms pulse train, spring forces and limb movements were recorded. Joint angles were differentiated twice to obtain experimentally observed accelerations.

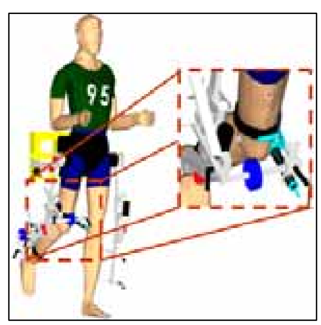

Figure 1: Experimental setup with limb in static posture. Series elastic elements allow for stimulation induced joint movements.

The experiment was simulated using a three segment, two-dof model. Inputs included muscle force (representing the stimulation) and external forces applied to the femur and tibia (measured spring forces). The resulting induced accelerations at the hip and knee were calculated.

RESULTS

The simulations predicted all three muscles to accelerate the hip into extension, the RF and VL to knee extension, and BF to knee flexion in the first 3 configurations and knee extension near heel strike. As shown in figure 2, most subjects were consistent in the acceleration direction predicted by the model (averaging hip and knee: 65%, 81%, 83% of subjects for BF, RF and VL, respectively).

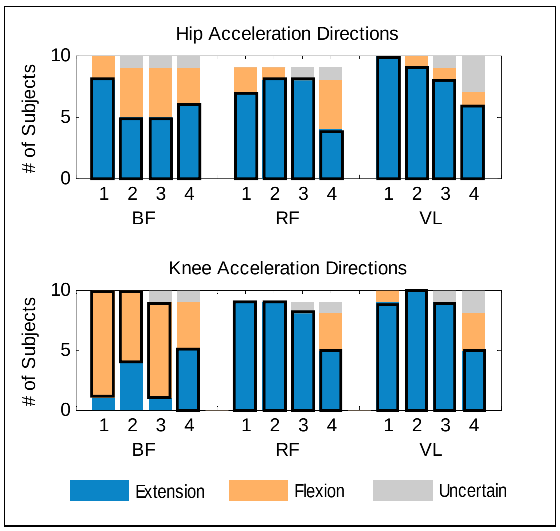

Figure 2: Subject distribution of hip and knee sagittal acceleration directions for each muscle in four postures. Regions outlined in black indicate directions predicted by model.

In the frontal plane, our simulations predicted BF and VL to accelerate the hip into adduction and RF in abduction. In preliminary three-dimensional experiments, the majority of acceleration directions are consistent with model predictions. On average, frontal plane accelerations are 1/2, 2/3 and 1/6 the size of sagittal plane accelerations for BF, RF, and VL, respectively.

DISCUSSION/CONCLUSIONS

Muscle stimulation has been shown to be an effective strategy for observing individual muscle behavior. The non-intuitive behaviors observed in RF (hip extension) and BF (knee flexion) are contrary to what their anatomical structure suggests and indicate that biarticular muscles can indeed accelerate joints in the opposite direction of their static torque generation capability (Zajac, 1993). Additionally, the hip movement observed following VL stimulation indicates that uniarticular muscles can produce movement of distant joints due to system dynamics (Zajac, 1993).

Preliminary data of three-dimensional muscle induced accelerations indicate that dynamic out-of-plane contributions of these muscles are larger than perceived by static moment arm values (3/10 and 1/4 the size of sagittal plane accelerations for BF and RF, respectively). Therefore, sagittal plane muscles groups targeted in current rehabilitation interventions may have a significant and unanticipated contribution to frontal plane movement and thus may hinder the success of these intervention strategies.

REFERENCES

Daly et al. (2004). *JRRD*, **41,** 807-820.
Johnson et al. (2004). *Arch Phys Med Rehabil*. **85,** 902-909.
Zajac, F.E (1993). *J. Biomech.*, **26,** 109-124.

ACKNOWLEDGEMENTS

We would like to acknowledge Winsean Lin for his assistance in data collection. Research is supported by NIDRR Field Initiated # H133A990008 and NSF Graduate Research Fellowship.