CENTER FOR RESEARCH IN HUMAN MOVEMENT VARIABILITY

# ACL Reconstruction Results in Alterations to Force Control Variability During Multidirectional Force Production

Amelia S. Lanier[1,2], Brian A. Knarr[1,2], Nicholas Stergiou[1], Thomas S. Buchanan[2]
[1]University of Nebraska at Omaha, Omaha, NE; [2]University of Delaware, Newark, DE

## INTRODUCTION

- Anterior cruciate ligament (ACL) rupture is a common sports related injury & most patients will undergo reconstructive surgery. Within the first year after surgery 25% of patients will re-tear their ACL.
- Most of those injured attempt to return to sports which include running and cutting tasks.
- Understanding alterations to multidirectional ground reaction force (mGRF) production in healthy and ACL reconstructed (ACL-r) patients can lend insight to the high instance of re-injury post surgery.
- Recently, research using nonlinear techniques, such as the Lyapunov exponent (LyE), has been able to capture subtle time varying changes that linear variability measures cannot quantify. LyE quantifies the structure of variability present in a dynamic system.
- Recent studies using this measure to quantify changes to variability in knee flexion during gait found significant increases in LyE measured after ACL injury and reconstruction when compared to uninjured subjects indicating alterations to the structure of kinematic variability [1, 2].
- Alterations to variability during multidirectional force production has yet to be evaluated.
- Therefore, the purpose of this study was to understand the ability of those with ACL reconstruction to produce specific mGRFs.

We hypothesized that:
- LyE values would be greater after ACL reconstruction when compared to healthy uninjured controls.
- LyE values measured during the medial/lateral (ML) task would be greater compared to the anterior/posterior (AP) task.

## METHODS

18 subjects:
- All active in 50 hrs/yr of Level I & II sports
- 8 (2 males) had no history of knee injury
- 10 (3 male) ACL-r subjects
  - Cadaveric Allograft
  - Hamstrings Allograft

*Force Control Task*
- Required subjects to control a cursor via force production at each foot with the aid of real time visual feedback. Custom written Labview code was used to provide feedback. (Fig.1)
- Subjects stood barefoot on 2 force plates (OR-6, AMTI, Watertown, MA, USA), a force plate for each foot.
- Anterior/Posterior(AP) and Medial/Lateral(ML) shear forces generated by a single limb controlled the cursor's movement on the screen. (Fig. 1)
- Subjects were instructed to as accurately as possible align the blue cursor with each yellow cursor to the beat of a 60 bpm metronome.
- Yellow cursors denote 50% maximal force in the respective direction.
- Subjects completed two tasks, AP & ML, with each limb.
- Ground reaction force data was collected from both limbs for all tests at 1000 Hz.

*Data Analysis*
- Force profiles from each test were used to calculate the maximum Lyapunov Exponent (LyE).
- LyE calculations include 3 steps:
  - Time lag ($\tau$) calculation via Average Mutual Information
  - Embedding dimension ($m$) calculation via Global False Nearest Neighbor
  - Distance calculation
- $\tau$ and $m$ transform the force profiles into state space.
- Once in state space, the Wolf algorithm [3] was used to calculate ML LyE & AP LyE for each limb.

## RESULTS

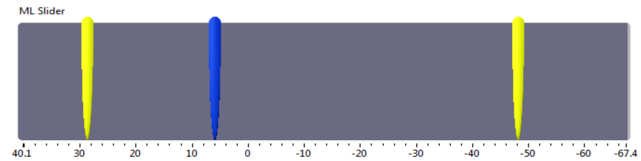


FIGURE 1: Depiction of visual feedback provided to subjects for the ML direction. The blue cursor responds to ML forces generated on a single plate. The yellow cursors denote ±50% of the subjects maximal force production in the ML direction.

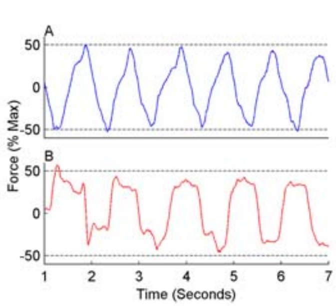


FIGURE 2. Representative force profile from a healthy subject (A) and an ACL reconstructed subject (B). Goals are indicated with a dashed line.

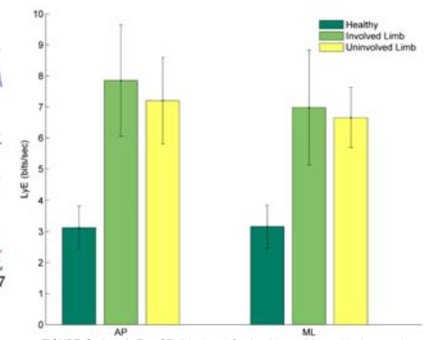


FIGURE 3: Avg. LyE ± SE (bits/sec) for healthy subjects (dark green) and ACL-reconstructed subjects (Involved Limb in light green; Uninvolved limb in yellow).

ACL-reconstructed subjects exhibited greater Lyapunov exponents (LyE), when compared to healthy uninjured subjects (Fig. 3).
- LyE calculated for both the involved and uninvolved limbs was greater than that of healthy uninjured subjects.

ACL-reconstructed subjects showed no difference in LyE when comparing:
- Limbs (Involved vs. Uninvolved)
- Directions (AP vs. ML)

## CONCLUSIONS

The maximum Lyapunov exponent was higher in ACL-reconstructed subjects compared to healthy controls indicating alterations to force control variability.

We found no differences in maximum Lyanpunov exponent when comparing the AP & ML directions in both healthy and ACL-reconstructed subjects…
- this is surprising as the musculature supporting AP loads provide more potential for control (i.e., greater strength) than that supporting ML loads.

We found no differences in maximum Lyapunov exponent between limbs in ACL-reconstructed subjects…
- which may indicate an upper level neuromuscular deficit and additionally contribute to the increased likelihood of contralateral limb re-injury [4].

In the context of the optimality of variability proposition, changes to the structure of variability, as seen by increased LyE values in those with ACL reconstruction, may put patients at an increased risk for subsequent injury especially as they return to sports requiring running and cutting activities.

REFERENCES

1. Stergiou, N. *Clin Biomech*, 2004, 19, 957-63, June.
2. Moraiti, C. *Gait & Posture,* 2010, 32, 169-75, April.
3. Wolf, A. *Physica*, 1985, 16, 285-317, October.
4. Paterno, M. *Clin J Sports Med,* 2012, 22, 116-21, March

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