



# The Lyapunov Exponent is Strongly Related to Amputee Preference

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## INTRODUCTION

Currently, there are no objective prosthesis prescription criteria (Hofstad 2004), likely due to the large discrepancy between objective biomechanical data and subjective patient perception (Hafner 2002). For an objective biomechanical measure to be a strong prescriptive measure, it needs to relate to the clinical gold standard of subjective patient perception and be universal enough to be applied to all subgroups of amputees. A review by Hafner et al (2002) concluded that a lack of significant relation between patient perception and biomechanics may be "beyond the detection of conventional equipment or methodologies". This seems to imply that a biomechanical measure sensitive enough to detect patient perception has not been implemented in amputee research. For this reason, the Lyapunov exponent (LyE) was implemented to assess amputee gait. The LyE has recently been used to discriminate pathological gait (Myers 2009). Unlike common biomechanics measures, the LyE measures the consistency in the gait pattern over multiple strides, i.e. the natural fluctuations that occur between strides (Myers 2009). To determine whether the LyE is sensitive enough to detect clinically significant differences in amputee performance, the LyE values of the leg joints (bilateral ankle, knee, and hip) were correlated with patient preference of the prostheses.

## METHODS

**Subjects:** 6 transtibial amputees (age: 53.5 ± 18.0 yrs; ht: 178.2 ± 8.8 cm; wt: 96.5 ± 21.0 kg; yrs since amputation: 5.8 ± 3.6 yrs)

**Procedures:** Subjects walked on a treadmill at their self-selected velocity for 3 minutes with their prescribed (Rx) and an alternate prosthesis (Ax; SACH Foot, The Ohio Willow Wood Company, Mt. Sterling, OH) while movements were recorded with an 8 camera system (60 Hz; Motion Analysis Corp., Santa Rosa, CA). The prostheses were aligned by certified prosthetists and the order of presentation was randomized. Following walking, subjects indicated the degree of preference on a 20 cm line (extreme right corresponded to complete preference of Rx and extreme left to Ax). Distance on the line was then converted to a percentage from left to right.

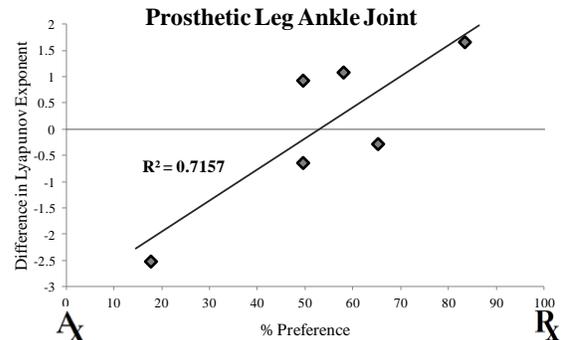
**Data Analysis:** Joint angle time series were analyzed for LyE (Myers 2009). The difference in LyE between prostheses was tested for significant correlation with preference through the Pearson correlation coefficient.

## RESULTS

The difference in LyE at the ankle joint for the prescribed prosthesis and the alternate prosthesis was significantly correlated to the degree of

Pearson's r	Sound Leg			Amputated Leg		
	Ankle	Knee	Hip	Ankle	Knee	Hip
	0.155	-0.591	0.440	0.846	-0.089	0.110
p-value	0.769	0.217	0.382	<b>0.034*</b>	0.867	0.835

**Table 1:** Pearson's r value for difference of ankle, knee, and hip joint angle time series LyE correlated to preference difference between prescribed and alternate prosthesis. Significant correlations are bolded.



**Figure 1:** Linear fit and  $R^2$  value for sound leg ankle joint for transtibial amputees. Data indicates LyE heavily influences amputee prosthesis preference.

preference between the prostheses for the amputee (Table 1, Figure 1).

## DISCUSSION

Nearly 72% of what affects a transtibial amputee's perception of their prosthesis can be attributed to the LyE of the prosthetic ankle joint. This work is clinically significant as it begins to establish a universal objective biomechanical measure that could be implemented for outcomes and prescription. Recently it has been found that amputees have a preferred "roll-over shape" (Klodd 2010). However, this was the result of a comparison of group sums of rankings, which is not as strong as statistically relating two measures. Future work should relate LyE to "roll-over shape". Finally, future work will determine which joint LyE dominates preference in amputees beyond transtibial level as well as designing a clinically friendly device to begin measuring LyE in the clinic.

## CONCLUSION

The LyE is a clinically significant objective biomechanical measure for amputee gait that is highly related to patient perception.

## REFERENCES

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