COPD PATIENTS EXHIBIT SIMILAR JOINT ANGLE VARIABILITY COMPARED TO OLDER, HEALTHY CONTROL SUBJECTS

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INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a syndrome characterized by expiratory airflow limitation; however, the effects of the disease reach further than just the respiratory system. For example many patients report muscle fatigue as the main limiting factor to activity as opposed to dyspnea, indicating muscular limitations [1]. Another possible limitation may be gait; however, an investigation of biomechanics of gait in COPD patients revealed only moderate changes to their ankle mechanics as compared to healthy controls [2]. Moreover, COPD patients walk with a more periodic step length and step width at their preferred walking speed than healthy controls [3]. COPD patients walk with greater mediolateral variability than healthy controls and this walking variability was associated with functional capacity [4]. Therefore, it is feasible that variability measures of gait may be more sensitive to discriminating gait dysfunction in patients with COPD versus healthy controls.

Variability is an inherent characteristic in all physiological systems and the level of variability has two extremes. On one end of the spectrum, a highly variable, yet irregular system is uncoordinated; whereas a highly regular, invariable system is unable to adapt to perturbations. According the optimal movement variability theory, a healthy system is a highly variable system, in which the fluctuations have deterministic properties [5]. A diseased physiological system is characterized by a level of variability away from the optimal level, either too variable and irregular or too periodic. Thus, healthy physiological systems present a moderate level of predictability (i.e. regularity) and a high level of complexity.

Therefore, our aim was to compare the joint angle variability in patients with COPD to healthy, older control subjects using the Lyapunov exponent. It was hypothesized that patients with COPD would exhibit an increase in variability of the ankle joints compared to healthy controls as deficits in ankle mechanics in patients with COPD have been determined previously [2].

METHODS

A total of nine healthy controls (70.2±7.1 yrs; 176.9±8.7 cm; 80.1±17.0 kg) and nine patients with COPD (66.3±9.3 yrs; 176.2±14.3 cm; 101.8±36.5 kg) participated in this study. A spirometry test revealing a FEV1/FVC >0.7 categorized the subjects into the COPD group. Both groups reported no lower extremity injuries or pathologies that would alter normal gait. The groups were speed matched (post hoc) to attenuate speed as a factor (COPD = 0.88±0.21 m/s; Control = 1.00±.27 m/s).

Subjects walked for four minutes at a self-selected speed on a treadmill while three dimensional marker trajectories were recorded (MAC, Santa Rosa, CA; 60Hz). The kinematic data were tracked in Cortex (MAC, Santa Rosa, CA) and were unfiltered, providing the true fluctuations over time. Visual 3D (C-Motion, Germantown, MD) was used to calculate the joint angles. Using Wolf’s algorithm [5], the Lyapunov exponent of the ankle, knee, and hip joints was calculated in MatLab (MathWorks, Natick, MA). The Lyapunov exponent was calculated from 14400 frames of continuous joint angle data. The lag and embedding dimension used for each subject’s Lyapunov exponent calculation was specific to each individual. Lag ranged from 9-53 in the COPD group and 8-30 in the control group, while the embedding dimension ranged from 5-9 in the COPD group and 5-8 in the control group. Group mean Lyapunov
exponent values for each joint were compared using an independent t-test.

RESULTS AND DISCUSSION

Contrary to our hypothesis, the Lyapunov exponent for the ankle angle was not different between the two groups (p=0.99; Table 1). In fact, no significant differences were found between the groups at any joint (knee: p=0.40; hip: p=0.35). The ankle angle demonstrated the greatest Lyapunov exponent value across all three joints. The Lyapunov exponent quantifies the rate at which an attractor is diverging. A larger Lyapunov exponent value indicates larger stride-to-stride fluctuation in the joint angles, while a smaller Lyapunov exponent value represents a more organized and consistent system. As can been seen in Figure 1, although there were no significant differences in the group means, a few patients with COPD did demonstrate a less consistent attractor. It is feasible that some patients with COPD have greater variation in movement and some have less, this is consistent with heterogeneity and the presentation of phenotypes in the patient population.

Although not significant, it is interesting to note that the patients with COPD exhibited decreased knee and hip Lyapunov exponent values as compared to the controls. A smaller number would indicate that the attractor is diverging at a slower rate and possibly maintaining a more consistent pattern. This would indicate an altered organization of the neuromuscular system compared to older healthy control, with the possibility of the knee and hip compensating for the ankle.

CONCLUSIONS

These results do not support our hypothesis that COPD patients would exhibit an increase in ankle joint angle variability compared to older, healthy controls. Although COPD patients alter gait in the mediolateral direction [4], these results suggest that it does not affect joint angles in the anteroposterior plane. Although no significant differences were found in this study, further investigation into the effects of COPD on gait variability should be done due to variability’s association with functional capacity.

![Figure 1](image)

**Figure 1:** Top: The relative phase of the right ankle joint for a representative COPD subject. Bottom: The relative phase of the right ankle joint for a representative healthy control subject.

REFERENCES


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Table 1: Calculated Lyapunov exponent values for both groups and all three joints.

<table>
<thead>
<tr>
<th>Joint Angle (LyE)</th>
<th>Joint</th>
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<tbody>
<tr>
<td></td>
<td>Ankle (bits/sec)</td>
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<tr>
<td><strong>Patients with COPD (n = 9)</strong></td>
<td>1.798 ± 0.91</td>
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<tr>
<td><strong>Older, Healthy Controls (n = 9)</strong></td>
<td>1.793 ± 0.73</td>
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