INTRODUCTION

Deep brain stimulation (DBS) of subthalamic nucleus (STN) has been used to mitigate cardinal symptoms of Parkinson’s disease (PD) such as tremor, rigidity, and bradykinesia. Mixed results have been found as to whether DBS leads to improved or sustained gait performance [1]. Recently, Vallabhajosula et al. [2] have examined 18 PD patients with bilateral STN-DBS implants. Using traditional gait analysis parameters, they found that only overground gait speed was significantly different between test conditions when the stimulator was switched OFF or ON. New gait analysis methods have recently been developed with the intention of providing greater quantitative insight into the complex and coupled nature of human movement. Specifically, these methods characterize regions or periods of deviation in joint movement and symmetry [3,4], quantify the complexity & variability of cyclic shapes (i.e., phase space portraits) [5], and identify coupling of multiple joint movements [6]. In the current study, we apply these new gait analysis methods to the PD gait data of Vallabhajosula et al. to assess whether these methods can provide better insight into detecting changes in gait behavior as a consequence of STN-DBS.

METHODS

Eighteen individuals with idiopathic PD, who had bilateral STN-DBS at least six months, prior to testing were recruited for participation (3 females, 15 males, mean age 62±9 years, mean duration of disease 13±4 years, Hoehn & Yahr score 2 or greater when off medication). Antiparkinsonian medication and DBS stimulation was inactivated 12 hours prior to data collection. After familiarization with the treadmill, participants walked for three minutes at their self-selected comfortable pace. The DBS stimulators were then turned on and after a short rest, participants again walked on the treadmill for three minutes. The protocol was approved by the university’s institutional review board and informed consent was received for each participant. Kinematics of walking were captured using a motion capture system (Vicon Nexus, Oxford, UK; 120Hz). Ankle, knee, and hip flexion/extension angular positions and velocities were determined for a 20 gait cycle window over each walking trial. This window was examined after at least the first 25 gait cycles of walking. To provide comparison of PD gait in both OFF and ON DBS conditions, these data were compared to previously collected gait data from 20 healthy young male control subjects (23 ± 2 years) that walked on a treadmill at their self-selected speed for three minutes. Gait kinematics were captured on a motion capture system (Vicon, Workstation 460, Oxford, UK; 120 Hz) [5].

Regions of Deviation analysis [3,4] was used to examine changes in movement behavior over the gait cycle due to DBS use. This method compared the test conditions (ON vs. OFF, ON vs. healthy control, and OFF vs. healthy control) and examined differences in joint angular position as a function of gait cycle for individual joints or symmetry between bilateral joint pairs. For each comparison, individual joint or symmetry, t-tests (α =0.05) were conducted for three parameters: peak value, peak timing, and integral of absolute difference values over full gait cycle.

To examine changes in the complexity & variability of phase portrait shapes of joint position vs. velocity, the method of DiBerardino et al. [5] was
used. This technique quantifies the complexity of the phase portrait shape by determining the maximum number of Fourier harmonics necessary to reproduce the near-elliptical phase portrait shape with 99.9% accuracy. Inter-cycle variability was determined by examining the movement (drift and swept area) of the phase portrait centroid over the 20 cycles. Paired t-tests (α =0.05) were used to test for difference in complexity and variability measures between ON and OFF DBS.

Condition Signature analysis [6] was used to examine coupling between 12 joint movements (bilateral ankle, knee and hip angular positions and velocities). Temporal cross-correlation compared the timing and shape of these time-series gait parameters. This method utilized changes in maximum cross-correlation (maxCC) value and phase shift at maxCC between ipsilateral and contralateral joint parameter pairs to examine coupling and coordination patterns between conditions (ON vs. OFF, ON vs. healthy control, and OFF vs. control). For each condition, paired t-tests (α =0.05) were used to compare differences in maxCC or phase shift of each joint parameter pairing. These comparisons created 132 parameter coupling cells within a condition signature diagram.

In this report, preliminary results from six subjects (1 female, 5 males, mean age 63±10 years, mean duration of disease 11±3 years) are presented.

RESULTS AND DISCUSSION
Similar to previous reports evaluating only spatiotemporal gait variables, none of these analysis methods found any significant difference due to STN-DBS use, i.e., there were no significant differences in lower limb joint movements with respect to either healthy normal control behavior nor between the two stimulator settings for the PD group.

Regions of Deviation analysis found that there were no significant differences in symmetry and individual joint regions of deviation between ON vs. OFF, ON vs. healthy control, or OFF vs. control. Further, the use of STN-DBS did not significantly change the complexity & variability of lower extremity joint variables (Table 1). Finally, there were only seven significant changes out of 132 joint couplings between ON and OFF-DBS conditions. In the comparison with healthy controls, the condition signatures for ON and OFF-DBS conditions had 25 and 26 significant changes in joint couplings, respectively. The results from these analyses indicate that joint movement, symmetry, and coupling characteristics during gait of the PD group were similar under both conditions.

CONCLUSIONS
These results suggest that STN-DBS intervention does not necessarily affect continuous gait behavior among persons with PD. Analysis of the remaining 12 subjects is necessary to substantiate these preliminary observations.

REFERENCES
2. VallabhaJosula, S. et al. (in preparation)

ACKNOWLEDGEMENTS
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Table 1: Mean (and standard deviation) values of complexity and variability measures for lower extremity joint variables

<table>
<thead>
<tr>
<th>Joint</th>
<th>Angle</th>
<th>Complexity [# harmonics]</th>
<th>Area</th>
<th>Drift</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>OFF-DBS</td>
<td>ON-DBS</td>
<td>OFF-DBS</td>
</tr>
<tr>
<td>Hip</td>
<td>Left</td>
<td>166 (25)</td>
<td>176 (39)</td>
<td>0.0188 (0.0138)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>165 (14)</td>
<td>164 (12)</td>
<td>0.0163 (0.0123)</td>
</tr>
<tr>
<td>Knee</td>
<td>Left</td>
<td>181 (23)</td>
<td>173 (33)</td>
<td>0.0146 (0.0050)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>171 (28)</td>
<td>165 (16)</td>
<td>0.0161 (0.0095)</td>
</tr>
<tr>
<td>Ankle</td>
<td>Left</td>
<td>241 (15)</td>
<td>231 (25)</td>
<td>0.0139 (0.0141)</td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td>248 (25)</td>
<td>233 (24)</td>
<td>0.0134 (0.0159)</td>
</tr>
</tbody>
</table>