INTRODUCTION

The presence of persistent correlations in human gait has been shown in both treadmill and overground running [1,2]. There are reasons why treadmill and overground gait might elicit different movement patterns, but in the case of walking, reported differences in stride timing persistence are equivocal [3,4]. Further, even if results of walking studies were not equivocal, differences between walking and running gait make extrapolation of such results difficult. Not only is running more physiologically strenuous than walking, but there also may be task execution challenges that are only manifest when higher intensities are performed on the treadmill. Therefore, because there has not yet been a direct comparison of running modes, the purpose of this study was to compare nonlinear gait timing dynamics of paced treadmill and overground running at different speeds.

METHODS

10 trained runners ran for 8 min on an indoor running track at preferred pace (PP). They then completed paced treadmill and track trials at 80%, 100%, and 120% PP for 8 min each. Pacing for track running was accomplished using lights around the track that were lit in sequence to 0.1 km·h⁻¹ precision. The treadmill and track sessions were done on separate days and in random order. The order of speeds was also random.

Foot contact was identified using telemetric 3-D accelerometers mounted on the top of the running shoe (316-10G, Noraxon, Phoenix, AZ; mass ~ 20 g each). Stride time series were generated from the peak vertical accelerations in each stride cycle.

We applied detrended fluctuation analysis (DFA), power spectral density analysis (PSD), and multiscale entropy (MSE) analysis [5]. DFA and PSD have a close theoretical relationship and quantify the strength of serial correlations in a data set. MSE quantifies system entropy and complexity. We tested for significant differences due to condition and speed using ANOVA. All analyses were performed in Matlab (R2009a, Mathworks, Natick, MA), except MSE, which was performed in a Cygwin environment.

RESULTS AND DISCUSSION

Treadmill exhibited a higher DFA and lower PSD scaling exponent (Table 1). Treadmill also demonstrated lower sample entropy (S_E) across all scaling factors, with a significant difference between running at 100% and 120% PP (Fig. 1).

Figure 1: MSE for treadmill and overground running. *significant difference at this particular speed and condition (p<0.05), †significantly different between adjacent speeds for that condition (p<0.05).

The effect of condition and speed on the full MSE output is displayed in Fig. 2, showing significant differences between treadmill and overground for 80% and 120% PP, but not 100% PP.
This suggests that factors other than mere running speed may contribute to constraint. Alton et al. suggested that on the treadmill, individuals may feel a greater sense of urgency to move their swing limb forward as the supporting limb is carried backward on the belt, perhaps leading to altered afferent feedback [6]. The agreement between afferent feedback and visual input may also influence operant constraints. This relationship is "normal" in overground conditions, but with treadmill, there may be a conflict between the forward speed seen by the eye and the speed sensed by the legs and feet [7]. The above mechanisms may modify the underlying persistent gait rhythm.

CONCLUSIONS

Treadmill running leads to reduced serial correlations and more regular timing compared to overground running. These dynamics are indicative of higher constraint and therefore a tighter control of stride timing. The underlying rhythm is likely influenced by task and environmental constraints, which may arise from interactions between mechanical, afferent, and visual phenomena. That these changes may be more pronounced during faster running suggests that factors from the task and environment combine to elicit especially constrained behavior.

REFERENCES

7. Srinivasan, M. *Chaos* 19, 026112.

Table 1: Effect of condition and speed on DFA and PSD scaling exponents. Values are mean ± SD.

<table>
<thead>
<tr>
<th></th>
<th>Treadmill</th>
<th>Track</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80% PP</td>
<td>PP</td>
</tr>
<tr>
<td><strong>DFA α</strong>*</td>
<td>0.96 ± 0.08</td>
<td>0.93 ± 0.07</td>
</tr>
<tr>
<td><strong>PSD β</strong>*</td>
<td>0.69 ± 0.17</td>
<td>0.63 ± 0.15</td>
</tr>
</tbody>
</table>

*significant difference between conditions (p<0.05)