JOINT COORDINATION VARIABILITY DURING OVERGROUND AND TREADMILL RUNNING

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INTRODUCTION

Using a treadmill to monitor locomotion is extremely convenient for sport and exercise research (Nigg et al., 1995). A problem exists if kinematic, kinetic, and metabolic or other variables, for example, are not uniform between treadmill and overground locomotion. As Nigg et al. (1995) suggested discussion about the degree of similarity between overground and treadmill running is inconsistent throughout the literature. For example, Schache et al. (2001), in their study of the three-dimensional kinematics of the lumbo-pelvic-hip complex, found subtle but significant differences in the sagittal plane movement of the hip joint. However, Williams (1985) concluded that the only significant differences in kinematics present between overground and treadmill running were at speeds greater than 5 m.s⁻¹.

Variability is inherent within and between all biological systems (Newell and Corcos, 1993). Given the huge number of degrees of freedom in the body, with its 10² joints, 10³ muscles, 10⁵ cell types and 10⁶ neurones and neural connections (Kelso, 1995), it would seem that some degree of variability should be expected in all movements. Furthermore, as opposed to the traditional view that variability is error, variability is now seen as functional in many disciplines (Newell and Corcos, 1993; Hamill et al., 1999). Hamill et al. (1999) reported two separate experiments: one compared the effect of the quadriceps angle on coordination variability, whilst the other examined the relationship between coordination variability and patellofemoral pain. Variability in the coordination between body segments was seen in all groups, in both experiments. The former experiment was conducted overground and the latter was conducted on a treadmill. Through visual inspection of the data (comparing the ‘healthy’ individuals in each study) there is evidence of decreased coordination variability during treadmill running. There is also evidence in the literature of differences in the amount of variability in angular kinematics between the two forms of locomotion. For example, Dingwell et al. (2001) compared sagittal plane ankle, knee and hip angles collected during overground and treadmill walking. The results demonstrated significantly lower variability in the treadmill condition. Additionally, Nelson et al. (1972) reported reduced variability in the horizontal and vertical velocities of the centre of mass during treadmill as opposed to overground running.

The aim of this study was to assess any differences in the variability of lower extremity coordination between overground and treadmill running. It was hypothesised that there would be significantly lower variability in lower extremity coordination in the treadmill condition than the overground condition.

METHODS

The procedures were approved by the University’s Ethics Committee and eight males (mean (± SD) mass = 72.1 ± 10.2 kg; height = 1.76 ± 0.07 m; age 26.9 ± 4.7 years) gave written informed consent before data collection began. Premoulded, Velcro backed thermoplastic shells, equipped with four 25 mm retro-reflective markers, were attached to the participant’s left shank and thigh using the ‘optimal’ technique described by Manal et al. (2000). Additionally, eight further retro-reflective markers were attached to the participant’s pelvis and left foot at relevant anatomical landmarks.

All kinematic data were collected using an eight camera motion capture system (Motion Analysis Corporation, Santa Rosa, CA, USA), sampling at 120 Hz. In the overground condition, participants were required to complete 10 ‘good’ running trials at 3.83 m.s⁻¹ (±5%). A trial was accepted if the whole of the participant’s left foot struck the force platform (Type 9281CA Kistler, Winterthur, Switzerland) collecting at 1200 Hz, without any obvious alterations to their running gait. During the treadmill trials, participants were required to run at 3.83 m.s⁻¹ on a Kistler Gaitway treadmill (Kistler, Winterthur, Switzerland) with built in force platforms collecting at 1200 Hz, for one minute. At the end of the minute, 15 s of kinematic data containing at least 11 strides were collected. In both conditions, the vertical component of the ground reaction force was used to determine foot contact events (thresholds of 50 N and 20 N were used to determine foot-contact and toe-off respectively). In order to define a full stride during the overground trials, the toe-off preceding the stance phase on the force platform was determined using a custom written algorithm based on the vertical displacement and velocity of the toe marker. The three-dimensional coordinate data were filtered using a fourth order low-pass Butterworth filter, with separate cut-off frequencies determined using the residual analysis method (Winter, 1990). Three-dimensional Joint Coordinate System angles (Grood and Suntay, 1983) were calculated at the ankle, knee and hip joints throughout each stride cycle using MAREy Software (Cavanagh et al., 2001) written for MATLAB (Natick, MA, USA).

Similarly to Hamill et al. (1999), coordination variability was quantified by calculating the standard deviation in continuous relative phase (CRP) between body segments. However, phase angles were calculated within a range of 0° ≤ ϕ ≤ 360° and between trial standard deviations were calculated using circular statistics; each CRP profile was interpolated to 100 data points using a cubic spline procedure to allow the calculation of between trial standard deviations. In addition to calculating the average standard deviation across the entire stride cycle, average CRP standard deviations were also calculated within specific intervals of the stride. This procedure was repeated for each
of the following inter-joint couplings: hip flexion/knee flexion, hip flexion/ankle dorsiflexion and knee flexion/ankle inversion. A series of two-factor (condition, interval) analyses of variance (ANOVA), with repeated measures on both factors were performed for each joint coupling to assess differences between overground and treadmill running. The alpha level of significance was adapted using the Bonferroni technique to reduce the risk of a type I statistical error ($\alpha = 0.05/3 = 0.017$). Where significant main effects for the condition factor were observed, simple effects tests were used post-hoc to determine where the differences lay.

RESULTS

Table 1: Average (± SD) CRP variability for the three joint couplings over the entire stride and different intervals of the stride in both the overground (OG) and treadmill (TM) conditions

<table>
<thead>
<tr>
<th>Average CRP Variability (°)</th>
<th>Stride</th>
<th>Swing</th>
<th>0-25% Stance</th>
<th>26-50% Stance</th>
<th>51-75% Stance</th>
<th>76-100% Stance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Flexion/Knee Flexion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OG</td>
<td>9.8 ± 3.9</td>
<td>5.6 ± 1.6</td>
<td>21.3 ± 12.6</td>
<td>15.1 ± 9.1</td>
<td>22.1 ± 16.7</td>
<td>8.5 ± 7.2</td>
</tr>
<tr>
<td>TM</td>
<td>5.4 ± 1.0</td>
<td>4.4 ± 0.9</td>
<td>10.0 ± 4.4</td>
<td>4.3 ± 1.2</td>
<td>4.3 ± 1.3</td>
<td>3.4 ± 0.9</td>
</tr>
<tr>
<td>Hip Flexion/Ankle Dorsiflexion</td>
<td>13.4 ± 3.7</td>
<td>12.6 ± 4.1</td>
<td>25.0 ± 12.3</td>
<td>15.1 ± 9.2</td>
<td>7.4 ± 4.2</td>
<td>12.8 ± 6.9</td>
</tr>
<tr>
<td>TM</td>
<td>8.4 ± 2.0</td>
<td>9.0 ± 2.4</td>
<td>13.9 ± 3.2</td>
<td>4.3 ± 1.2</td>
<td>3.3 ± 1.2</td>
<td>5.0 ± 1.9</td>
</tr>
<tr>
<td>Knee Flexion/Ankle Inversion</td>
<td>26.0 ± 9.3</td>
<td>26.5 ± 10.4</td>
<td>14.9 ± 4.9</td>
<td>27.2 ± 12.5</td>
<td>27.9 ± 16.9</td>
<td>30.3 ± 18.7</td>
</tr>
<tr>
<td>TM</td>
<td>19.0 ± 8.6</td>
<td>22.4 ± 12.0</td>
<td>7.1 ± 1.6</td>
<td>9.2 ± 3.4</td>
<td>9.7 ± 3.7</td>
<td>18.7 ± 13.2</td>
</tr>
</tbody>
</table>

* Significant difference between conditions

DISCUSSION

Significantly reduced coordination variability was observed in the treadmill condition, over the entire stride as well as various phases of the stride cycle, for two of the three joint couplings studied. Although no statistically significant differences between the two forms of locomotion were seen for the hip flexion/knee flexion coupling, the pattern of increased coordination variability during overground running can be seen in all couplings during each phase of the stride (Table 1).

The decreased variability in lower extremity coordination during treadmill running seen in this study is consistent with previous literature examining kinematic variability of sagittal plane hip, knee, and ankle joint angles during overground and treadmill walking (Dingwell et al., 2001). Significantly smaller joint angle standard deviations were reported in the treadmill condition compared to the overground condition at the ankle and knee joint.

Coordination variability has been suggested to provide an adaptive mechanism to potential external perturbations such as uneven ground (Holt et al., 1995). The present study lends some support to this hypothesis because reduced coordination variability was apparent in the treadmill condition and it is likely that less threat of an external perturbation is perceived whilst running on a treadmill. However, Dingwell et al. (2001) highlighted concerns with using the magnitude of variations across strides as an indicator of stability. Standard deviation, which was used in the present study, gives only a measure of the magnitude of the variability with no regard to its structure, meaning that conclusions with regard to the stability of movement should be made with caution. It should be noted that the non-linear methods available for the analysis of the structure of variability were beyond the scope of this study because they require that the strides analysed are consecutive; this was not the case in the overground condition.

In their study, Dingwell et al. (2001) suggested that a possible reason for decreased kinematic variability was the treadmill belt imposing an artificially constant speed, externally driving the participant's feet throughout the stance phase of each stride cycle. This argument may explain the differences observed between the two forms of locomotion in this study. An interesting point is that the two joint couplings that exhibited significant differences between the treadmill and overground conditions involved the ankle, the most distal joint of the lower extremity. This result seems intuitive as the ankle is closest to the belt that is constraining the movement in the treadmill condition and therefore has
the least potential for variability during treadmill running. This is again consistent with the results of Dingwell et al. (2001) who reported that differences between overground and treadmill walking systematically became 'more significant' from the proximal to the distal joints.

Within the scope and limitations of this study, the results highlighted significant differences in coordination variability between overground and treadmill running. Specifically, treadmill running was associated with significant reductions in coordination variability in the hip flexion/ankle dorsiflexion and knee flexion/ankle inversion couplings over the entire stride and during various phases of the stride cycle. Caution should, therefore, be applied when comparing results from studies using overground and treadmill analysis. Also, performing studies of joint coordination variability on a motorised treadmill may mask differences between experimental groups.

REFERENCES