THE EFFECT OF COP ERRORS ON JOINT MOMENTS AT DIFFERENT GAIT VELOCITIES

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INTRODUCTION

In the bottom-up method of inverse dynamics (ID), errors in the location of the center of pressure (5 and 10 mm) on joint moment uncertainties at different gait velocities (1.0, 1.5, and 2.0 m/s). Joint moments of five healthy young adults were calculated by inverse dynamics using the bottom-up approach. Results indicated that there is a linear relationship between errors in center of pressure and absolute joint moment uncertainties. The absolute moment peak uncertainties expressed on the anatomic reference frames decreased from distal to proximal joints, except for the abduction moments. There was an increase in moment uncertainty (up to 0.04 Nm/kg for the 10 mm error in the center of pressure) from the lower to higher gait velocity, although not for hip or knee abduction. Finally, depending on the plane of movement and the joint, relative uncertainties experienced variation between 5 and 31%, and the knee joint moments were the most affected.

SUMMARY

The aim of this study was to investigate the effect of errors in the location of the center of pressure (5 and 10 mm) on joint moment uncertainties at different gait velocities (1.0, 1.5, and 2.0 m/s). Joint moments of five healthy young adults were calculated by inverse dynamics using the bottom-up approach. Results indicated that there is a linear relationship between errors in center of pressure and absolute joint moment uncertainties. The absolute moment peak uncertainties expressed on the anatomic reference frames decreased from distal to proximal joints, except for the abduction moments. There was an increase in moment uncertainty (up to 0.04 Nm/kg for the 10 mm error in the center of pressure) from the lower to higher gait velocity, although not for hip or knee abduction. Finally, depending on the plane of movement and the joint, relative uncertainties experienced variation between 5 and 31%, and the knee joint moments were the most affected.

METHODS

Five healthy male subjects (23.2±2.7yr; 74.6±8.0kg, and 1.78±0.01m) participated in this experiment, which was approved by the local research Ethics Committee. The subjects were instructed to walk at different velocities (slow = 1.0; natural = 1.5, and fast = 2.0 m/s, 5% variation tolerance). The kinematic and ground reaction force data were filtered using a Butterworth filter, with cut-off frequencies defined by residual analysis.

RESULTS AND DISCUSSION

The overall results showed that CoP shifting caused a decrease in ΔM (particularly for medial/lateral rotation or inversion/eversion and flexion/extension) from distal to proximal joints, and an increase in ΔM with an increase of gait velocity. However, relative ΔMs were not the highest in the most distal joint on fast gait (Table 1). The linear dependency between CoP shifting (5 and 10 mm) and ΔM, already observed in the literature [3, 5], was confirmed to be independent of movement plane and gait velocity in this study. The explanation for that result lies in the linear dependency between ΔM and moment arm errors, and the propagation of the ΔM from distal to proximal segments. Because of the significant changes in the M components, the choice of different reference systems [7, 15] (global or local) may alter ΔM/M, especially for M components about the longitudinal axes of the segments.
By observing the $\Delta M/M$, it was possible to identify that knee M peaks were the most affected by CoP shifting, as it was observed in 2D analysis [5]. This was because, for this joint, the instants of M and $\Delta M$ peak occurrence are rather coincident (between 20–30% of the stance phase) and the absolute difference of their magnitudes are smaller. Consequently, the $\Delta M/M$ were more critical at peaks medial/lateral (or inversion/eversion) and adductor/abductor M, and at slow gait, for which M magnitudes are smaller. Given the linearity between $\Delta$CoP and $\Delta M$, the uncertainties can be reported as uncertainties per unit of error in the CoP location. At the instants of peak M, maximum uncertainty values of 0.012 Nm/kg/mm (slow gait), 0.014 Nm/kg/mm (natural gait), and 0.015 Nm/kg/mm (fast gait) were found, consistently increasing from proximal to distal. Errors in the CoP location in the range of 5–10 mm are likely in typical gait analysis applications [5]. In particular, due to limitations in the equipment, CoP errors can be more than 3 mm for strain gauge force plates embedded in the ground [16], or up to 20 mm for those mounted on treadmills [17] and for piezoelectric force plates [18]. Consequently, for instance, extension $\Delta M$ in the knee of up to 0.20 Nm/kg can occur, corresponding to 28% of the peak extension M in this joint observed at the natural gait velocity, and 62 and 22% at the slow and fast gait velocities, respectively.

Improvements in the body motion reconstruction based on optimization techniques [19], alternative ID schemes [4, 20] and the use of correction algorithms [18] may improve estimations of the CoP location with respect to the lower limb or mitigate the problem. We emphasize that our results are relevant in clinical assessments, as the expected magnitude of the $\Delta M$ resulting from errors in the CoP location has been established for different walking velocities.

**CONCLUSIONS**

The uncertainties in joint moment peaks, calculated by 3D bottom-up inverse dynamics, decreases from distal to proximal segments at the transverse and sagittal planes in any gait velocity when expressed in LRS-a. Those uncertainties were directly proportional to gait velocity, except for the knee and hip abductor peaks. Knee joint moments were the most affected by the shift in center of pressure, because of higher similarity between the patterns of the moment and uncertainty magnitudes. The uncertainties were especially critical for medial/lateral (or inversion/eversion) and adductor/abductor moments at slow gait.

**REFERENCES**


**Table 1:** Means and standard deviations of moment peaks (M) without perturbation and uncertainties ($\Delta M/M$) caused by CoP shifting (delta = 10 mm), and relative uncertainty ($\Delta M/M$) at different gait velocities (V) [slow (s), natural (n) and fast (f)].

<table>
<thead>
<tr>
<th>Variable</th>
<th>V</th>
<th>Ankle</th>
<th>Knee</th>
<th>Hip</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>inversion</td>
<td>abduction</td>
<td>extension</td>
</tr>
<tr>
<td>$\Delta M/M$</td>
<td>s</td>
<td>0.20</td>
<td>0.22</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>0.26</td>
<td>0.11</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>f</td>
<td>0.27</td>
<td>0.11</td>
<td>0.08</td>
</tr>
</tbody>
</table>

*Note:* The lowest relative $\Delta M$ occurred in the hip, particularly in extensor peak (5 to 7%) at all velocities, and the highest uncertainties were found in all knee moments, especially during slow gait (29 to 31%).