AN ANALYSIS OF UNCERTAINTIES IN INVERSE DYNAMICS SOLUTIONS FOR GAIT

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INTRODUCTION

Inverse dynamics is a powerful tool for analysis of human movement [1], but is subject to error from various sources; these include estimates of segmental properties [2], skin artifacts [3], inaccuracies in center of pressure (COP) locations [4], and inherent noise in instrumentation. Previous studies have focused on the effect of only one or two error sources [2, 3, 4]. The combined effect of all sources of error on the calculated joint torques has not been investigated. A comprehensive analysis can provide a thorough understanding of uncertainties in inverse dynamics solutions. It can also lead to more effective error controls and improved algorithms for error correction such as the variance-weighted least-squares method [5].

This study seeks to provide a comprehensive analysis of most sources of error in inverse dynamics and their effects on computed lower extremity joint torques during gait.

METHODS

A three-segment linkage (foot, shank and thigh) represented the human leg, and served as the basis for Newton-Euler equations incorporating ground reaction force measurements (bottom up). An inverse dynamics solution was then computed for the joint torques at the ankle, knee and hip.

The magnitudes of the uncertainties in the leg joint torques are determined using an error analysis method [6]

$$E = \sqrt{\left(\frac{d\tau}{dx_1}\Delta x_1\right)^2 + \left(\frac{d\tau}{dx_2}\Delta x_2\right)^2 + \ldots\ldots + \left(\frac{d\tau}{dx_n}\Delta x_n\right)^2} \qquad (1)$$

where τ is the torque at a given joint, and Δx_i are estimated inaccuracies associated with the input variables in the equation of motion of interest. The uncertainty, E, is a statistical representation of the possible 3σ-error in the torque value. The magnitudes of the inaccuracies (Δx_i) were derived from literature data [2, 3, 4] and our own experimental studies. Since the reported values for Δx_i varied across the studies, and because different systems and methods where used to determine input parameters to the equations of motion, two sets of Δx_i where used to represent the range of values: Set 1 (small Δx_i) and Set 2 (large Δx_i).

Five males and five females (weight: 75.98±14.74 kg; height: 1.69±0.06 m) walked at their normal speed, with the right foot landing on a force plate (AMTI) while motion capture system (Vicon) recorded their movements. These measurements, the estimated segment parameters, and Δx_i where then input into Equation 1 to estimate the uncertainties in each joint torque.

RESULTS AND DISCUSSION

The magnitudes of the uncertainties changed over time (Fig. 1) and show temporal resemblance to the vertical ground reaction force profiles during stance, but not at all to the torque profiles. Similar trends where observed for both sets of Δx_i. The values of estimated uncertainties relative to peak joint torque for the ankle, knee and hip are: 4 %, 29 %, 56 %, respectively, when using Set 1, and are 7 %, 70 % and 140 %, respectively, for Set 2. This suggests that the difference between the inverse dynamics results and the true joint torque at knee and hip can be substantial.

The main contributors to the uncertainty in the joint torques are the inaccuracies in the segment angles, the distance from the COP to the ankle center of rotation, and the foot mass (Fig. 2). Other studies have suggested that inaccuracy in the joint torques is closely related to the quality of the acceleration estimation [7]. Our findings, however, indicate such is not the case for the leg joint torques at least during normal gait.

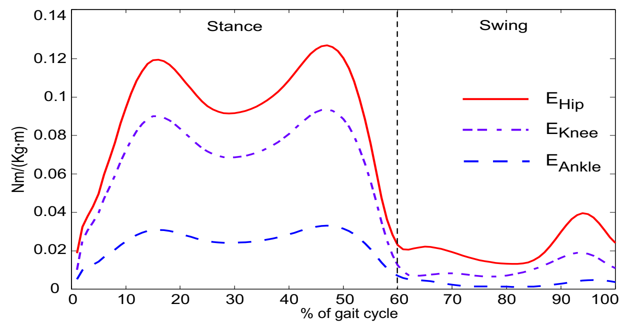

Figure 1: Estimated uncertainties (Set 1) in calculated joints torques during a gait cycle (normalize by weight and height).

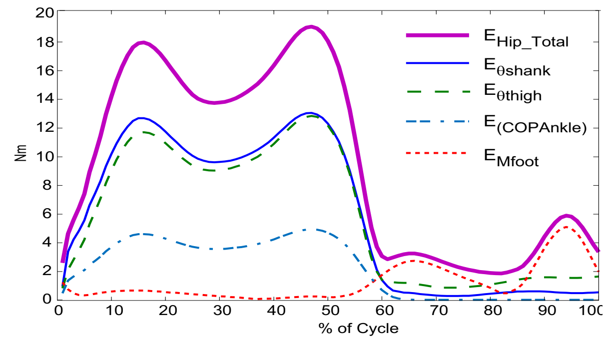

Figure 2: Main contributors for estimated uncertainty in hip joint torque for a 1.8 m and 80 kg subject in one cycle (Set 1).

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