REFINEMENTS OF MOMENT-BASED COST FUNCTIONS IMPROVE PREDICTION OF EXPERIMENTAL MOMENT PROFILES IN CYCLING

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INTRODUCTION

Many cycling simulations (e.g., Gonzalez & Hull, 1989; Kautz & Hull, 1995) have employed joint moment-based computer models. A common cost function in simulations is based on the sum of squares of ankle, knee, and hip moments (e.g., Kautz & Hull, 1995; Redfield & Hull, 1986). In its simplest form absolute joint moments are used with equal weighting of concentric and eccentric contributions and equal contributions of the three joints. Potential refinements include using net joint moments expressed relative to maximum flexion and extension moment capacities, representing eccentric effort as some fraction of concentric effort, and weighting contributions from the ankle, knee, and hip differently (e.g., Kautz (1992) doubled the relative cost of the knee in cycling simulations). Our purpose was to evaluate the effect of these three refinements on the accuracy of predicting experimentally-derived lower extremity moments for 250 W cycling at 90 rpm. We predicted each of these refinements would result in more accurate lower extremity moment profiles.

METHODS

The leg-bicycle system was modeled as a planar five bar-linkage for each leg. The three degree of freedom (DOF) model was reduced to a one DOF system by constraining the ankle motion to follow experimentally collected data. The problem was formulated using a dynamic forward optimization framework that minimized a given cost function for the system task and constraints. Joint moments were parameterized using 12 discrete nodes; values between nodes were calculated through interpolation. The optimization problem was solved using a standard non-linear optimization routine. Four cost functions were used:

CF1: $$\int_0^{t_f}\left(M_h^{\,2}+M_k^{\,2}+M_a^{\,2}\right)dt$$

CF1 used absolute moment amplitudes, provided no distinction between concentric and eccentric contributions, and equally weighted effort at the hip, knee, and ankle. It served as the nominal condition to which other cost functions were compared.

CF2: $$\int_0^{t_f}\left(\%M_h^{\,2}+\%M_k^{\,2}+\%M_a^{\,2}\right)dt$$

CF2 expressed moments as a percentage of maximum isometric moment capacity.

CF3: $$\int_0^{t_f}\left(M_h^{\,*2}+M_k^{\,*2}+M_a^{\,*2}\right)dt$$

CF3 weighted eccentric contributions at 1/3 those of concentric contributions.

CF4: $$\int_0^{t_f}\left(M_h^{\,2}+2M_k^{\,2}+M_a^{\,2}\right)dt$$

CF4 doubled the importance of knee contributions as suggested by Kautz (1992). A final model (ALL) incorporated all three modifications to examine their collective effect. Optimized joint moment histories for all cost functions were compared to experimental cycling joint moments from Kautz and Hull (1995). Root mean square error (RMSE) between experimental and simulated results were calculated for each cost function at each joint and averaged across joints.

RESULTS

ALL matched experimental hip joint moment most accurately, although each of the cost functions underestimated maximum hip extension moments (Figure 1a). CF2 predicted experimental knee joint moment most accurately (Figure 1b). Each of the other cost functions underestimated the knee extensor moment. The ankle moment was simulated effectively by all cost functions (Figure 1c), but was matched most closely by ALL. The mean RMSE between experimental results and simulation outputs using individual cost functions was the lowest for CF2, followed by CF4, CF3 and CF1 (Table 1). The difference between CF3 and CF1, however, was negligible. ALL showed the biggest reduction in RMSE.

DISCUSSION

A moment-based cost function expressing moments relative to maximum capabilities (CF2); which recognizes that moment generating capacity is not equal across the ankle, knee, and hip; improved prediction of experimental moment profiles substantially relative to the nominal case (CF1). Increasing the importance of the knee moment (CF4) made the second largest improvement in prediction of experimental profiles. This result suggests the relative importance of the knee musculature during the cycling task. Reducing the importance of eccentric contributions (CF3) had little effect on model predictive ability. This is presumably linked to the limited eccentric effort reflected in the cycling task. Overall, results indicate more physiologically sound cost functions improve the accuracy of prediction of experimental results.

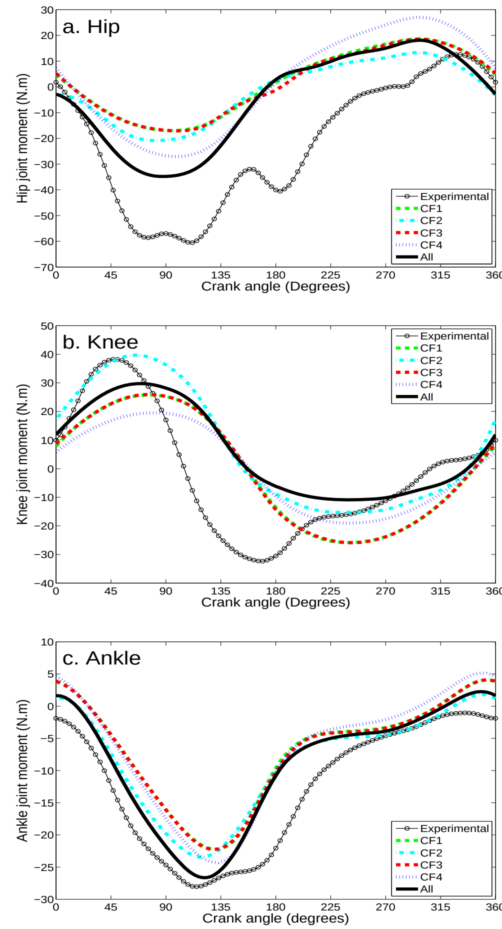

Figure 1. Experimental and simulated joint moments at the hip (a), knee (b), and ankle (c).

	CF1	CF2	CF3	CF4	ALL
RMSE	**17.3**	**16.1**	**17.1**	**16.5**	**14.3**
% change	-	6.7%	1.1%	4.6%	17.3%

Table 1. Mean RMSE across all joints for different cost functions and percent change relative to original cost function (CF1).

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