THE INTERACTIONS BETWEEN TWO-SEGMENT STRIKING MOTION GENERATED BY PROXIMAL SEGMENT OF UPPER ARM

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The purpose of this study was to examine the kinetical interactions between two segments of the upper arm using the forward dynamics derived from Lagrange's equation of motion, and then clarify the proximal-distal sequence. For the decades, open-linked, multi-segment systems were the important issues to biomechanists. But the more segments have been examined, the more complex the topic has become. Therefore, it is important to examine the effects of joint moment on upper extremities striking motion by simulation of two segments. To facilitate dynamic computation and to simplify the modeling, the upper arm of present study was modeled as a two linked-segment model with upper arm and forearm, in which the forearm and hand were treated as one segment. The summation of results is as follows: When the proximal segment was only given a constant moment (free the distal segment), the whole system displayed a proximal-distal sequence. Furthermore, the distal segment lead to the proximal segment, reaching maximum velocity. The motion presented a periodic fluctuation, and would maintain a straight position indefinitely if the duration of motion were sustained long enough.

KEY WORDS: proximal-distal, forward dynamics, striking

INTRODUCTION: Human movement provides many examples of multi-segment motion, which should be performed by coordinating body segments properly. The motions of multi-segments skills (i.e. striking, throwing and kicking) are generally performed in a proximal-distal sequence, which are often described in terms of the linear velocities of the segment endpoints, joint angular velocities or segment angular velocities (Putnam, 1993). In the example of kicking (simplified as the motion of two segments: thigh and leg), it has been observed that the total movement starts with a forward angular acceleration of the thigh while the lower leg lags behind. Then the thigh decelerates while simultaneously the lower leg accelerates (S∅rensen et. al., 1996; Putnam, 1983, 1993). However, controversies surround the question of whether the thigh is actively decelerated or passively decelerated by joint reaction force from the accelerating lower leg and whether the acceleration of lower leg is enhanced by the decelerating thigh. The results of previous study on the martial high front kick (S∅rensen et. al., 1996) indicated that thigh deceleration was caused by motion-dependant moments arising from lower leg motion and not by active deceleration. They also maintained that lower leg acceleration was not enhanced by thigh deceleration. Considering the striking and throwing motions, the same characteristics of proximal-distal sequence occur. In the fast-unloaded arm striking movements, volleyball spiking is a typical example of impact on an object to create a large linear velocity. The purpose of this study was to examine the effects of joint moment on upper extremities striking motion using two segments simulation.

METHODS: To facilitate dynamic computation and simplifying the modeling, the spiking arm of present study was modeled as a two linked-segment model with upper arm and forearm, in which the forearm and hand were treated as one segment. To examine the kinetical interactions between the two segments, the forward dynamics derived from Lagrange's equation of motion were used.

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{q}_i} - \frac{\partial L}{\partial q_i} = Q_i \qquad (1)$$

Where L is the Lagrange's function which equal to kinetic energy of system minus potential energy: L (Lagrange's function) = T (Kinetic energy) - U(potential energy), $\dot{q}_i$ is the

generalized velocities, q_i is the non-conservative part of generalized coordinates and Q_i is the generalized forces. The free diagram of the model is shown in Figure 1.
Where (x, y) is the coordinate of CM of distal segment, and assumed positioning to middle point of distal segment, α and β are the segment angle of proximal and distal relative to horizontal axis, and the τ_1, τ_2. are the moment applied on proximal and distal segments. So we can derive the equations as following:

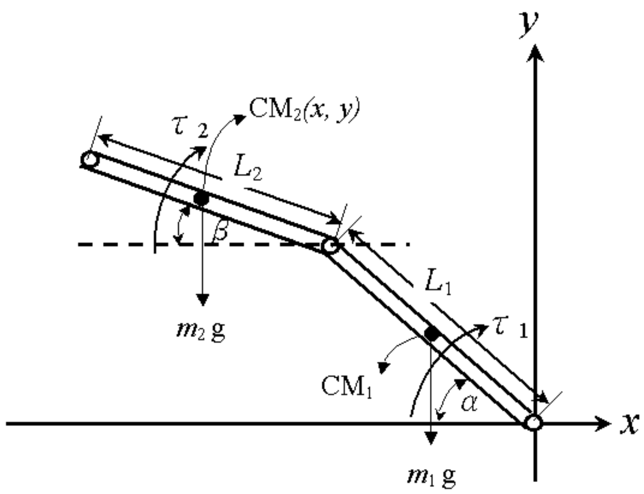

Figure 1 - Free body diagram of upper arm and forearm with moment and gravitational force on the upper extremity.

The (x, y) can be shown as

$$x = -(L_1 \cos\alpha + \frac{1}{2} L_2 \cos\beta)$$
$$y = L_1 \sin\alpha + \frac{1}{2} L_2 \sin\beta \qquad (2)$$

where L_1 and L_2 are the lengths of proximal and distal segment, respectively.

And the resultant velocitie v is

$$v = (\dot{x}^2 + \dot{y}^2)^{\frac{1}{2}} \qquad (3)$$

kinetic and potential energy of the system are

$$T = \frac{1}{2} I_1 \dot{\alpha}^2 + \frac{1}{2} I_2 \dot{\beta}^2 + \frac{1}{2} m_1 (\frac{1}{2} L_1 \dot{\alpha})^2 + \frac{1}{2} m_2 v^2 \qquad (4)$$
$$U = m_1 g \frac{L_1}{2} \sin\alpha + m_2 g (L_1 \sin\alpha + \frac{L_2}{2} \sin\beta) \qquad (5)$$

and the Lagrange function can be shown as:

$$L = T - U$$
$$= \frac{1}{2} I_1 \dot{\alpha}^2 + \frac{1}{2} I_2 \dot{\beta}^2 + \frac{1}{2} m_1 (\frac{1}{2} L_1 \dot{\alpha})^2 + \frac{1}{2} m_2 v_2{}^2 - (m_1 g \frac{L_1}{2} \sin\alpha + m_2 g (L_1 \sin\alpha + \frac{L_2}{2} \sin\beta)) \qquad (6)$$

finally, the Lagrange's equation can be shown as

$$\frac{d}{dt} \frac{\partial L}{\partial \dot{\alpha}} - \frac{\partial L}{\partial \alpha} = \tau_1$$
$$\frac{d}{dt} \frac{\partial L}{\partial \dot{\beta}} - \frac{\partial L}{\partial \beta} = \tau_2 \qquad (7)$$

Combined eq.(6) and (7), a set of two-order differential equations, was derived which belong to nonlinear equations. For the above reasons, numerical solutions were being solved by Mathematica 3.0 software (used the method of finite difference) instead of solved exact algebra solution.

(a) (c)

(b)

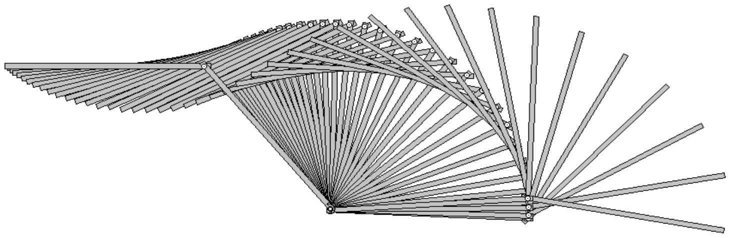

Figure 2 - The trajectory of two-linked motion.

RESULTS AND DISCUSSION: The first part of the results demonstrated that given τ_1 and τ_2 a constant value of 30 Nt-m, and set τ_2 as zero to understand how the motion displayed (the trajectory of the motion be shown in Figure 2). And all the inertia parameters and initial conditions listed as Table 1(these data are given in order to provide the suitable range of the results.)

Table 1 Inertia Parameters and Initial Conditions

Parameters	Proximal	Distal
Length of segments(m)	1	1
Mass(Kg)	0.5	0.5
Inertia of rotation(Kg-m^2)	0.02	0.02
Moment(Nt-m)	30.0	0
Initial angle(rad)	$\pi/4$	0
Initial angular velocity(rad/s)	0	0

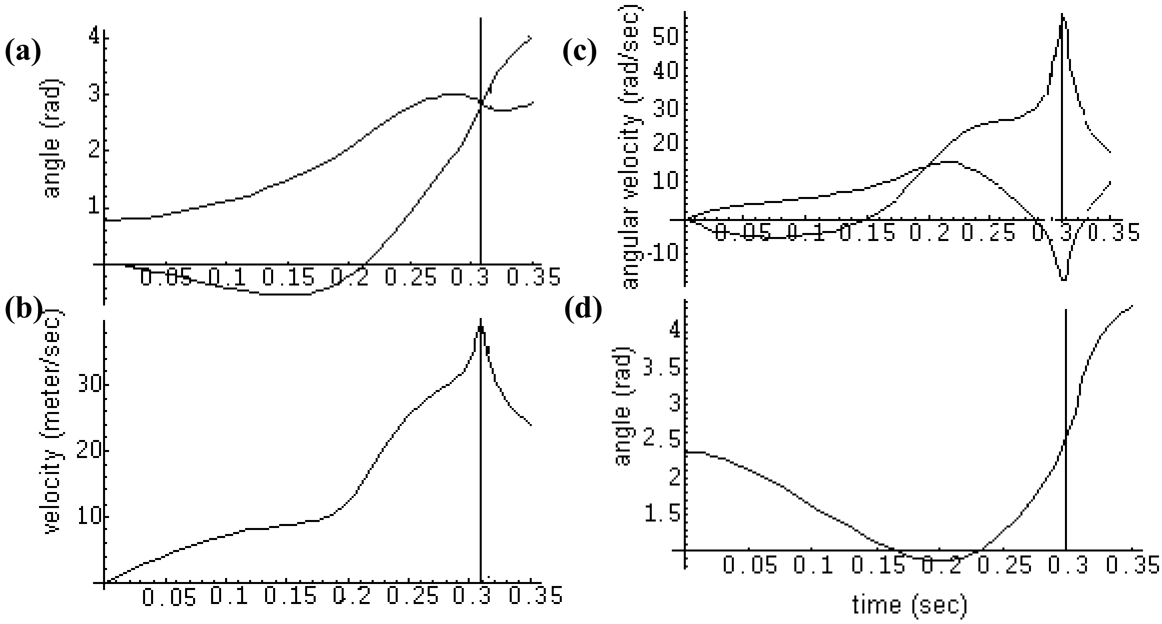

Figure 3 - The selected parametric figures: (a) the segmental angle of two segments; (b) the velocity of CM of distal segment; (c) segmental angular velocity of two segment; (d) joint angle.

The results were shown as the four parametric figures, including segmental angles, the velocities of CM of distal segment, angular velocities of segments and joint angle. The special feature of these results was zero value of moment on the distal segment. It can be shown that the joint of distal segment was free. In previous discussion on this topic, it was thought that the most distal segment of open kinetic chained with free joint, can be generated by so-called “ whip-like” action. However, in the present study, it has been concluded that the appearance of the motion was displayed which is similar to real throwing motion in the situation that only provides a constant moment on proximal segment. The distal segment did not lag behind the proximal segment in whole motion. The results are shown with the common parametric figure together allowing convenient simultaneous comparison. Considering the change of segmental angle (Figure 3a), the lines of two segments have an intersection point, which means that the two segment are in a straight position with the same segmental angle (marked by solid line). In this point, the velocities of CM almost reached the maximum value (Figure 3b). It can be imagined that there are many examples of approximately the same condition in sports activity. The pitcher’s release in baseball, the volleyball player’s attack on the ball with straight upper arm and fore arm. The parameter of angular velocities is also an intuitive way of describing and explaining segment motion. The normal proximal-distal sequential pattern also was demonstrated with these results. In Figure 3c, it was found that the two segments have the same proximal-distal sequence, which means the system starts with forward angular acceleration of the proximal segment while the distal segment lags behind, then the proximal segment decelerates while simultaneously the distal segment accelerates. From the initial condition that was set, the two segments became straight at about 180 degree (Figure 3d.). Something positive occurred when the duration of motion was increased. The joint angle of the two segments presents a periodic fluctuation. This response means that the distal and proximal segments lag behind and lead alternatively. The result also indicated that the amplitude decreased while time lasting (Figure 4). Based on this phenomenon, the two segments continue to be straight if the duration is longer enough.

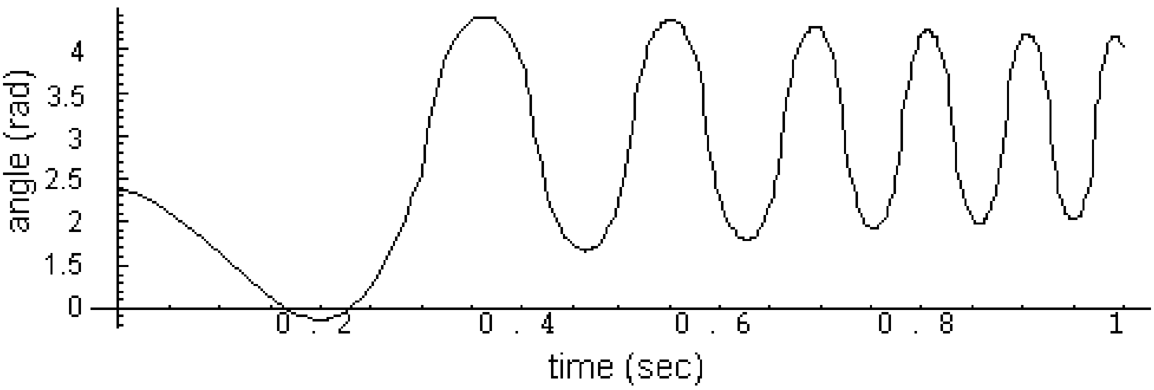

Figure 4 - Joint angle during extending the duration of motion.

CONCLUSION: Open-linked, multi-segment system is the important issue for biomechanists. But when more segment are involved, the more complex analysis should be conducted. In the present study, some new ideas were obtained about two-segment motion by the equations derived from Lagrange’s equation. When the proximal segment was only given a constant moment (free the distal segment), the whole system displayed a proximal-distal sequence. Furthermore, the data has shown that the distal segment leads to proximal segment and then reaches the maximum velocity, and the motion will present a periodic fluctuation and continue straight indefinitely if the duration of motion is long enough.

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