DETERMINATION OF TORQUES AT UPPER LIMB JOINTS DURING JUMPING IN BADMINTON SMASH VIA KANE'S METHOD

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The paper discusses determination of torque forces at the upper limb joints, namely shoulder, elbow and wrist, using 2-dimensional Kane's mathematical model of a three-link system, comprises of upper arm, lower arm and hand-racket segments. A planar three-link kinematic chain model is developed and the inverse dynamic method is applied. Kinematic data from 2 professional badminton players in a Thomas Cup's Tournament are taken as input in the dynamics equation and torques calculated. The result shows that the elbow joint produced the highest value of torque during contact while performing the jumping smash activity.

KEYWORDS: upper limb joints; Kane's method; inverse dynamic; torques; badminton smash

INTRODUCTION:

Badminton is one of the most popular sports in the world. It is the fastest racquet sport in the world with the shuttlecock speeds reaching over 260 km/h (Lee et al., 2005). Smash is known as the most powerful strokes because of its speed and steep trajectory, which contributes to a winning point. Smash is also defined as the most common killing shot, which accounted for 53.9 % of the distribution of the killing shot (Tong & Hong, 2000). According to Rambely et al. (2005b), jumping while performing a smash is the most popular technique chosen by world top ranking badminton players. When a player performs a smash, arm movement pattern plays an important role in the execution of the stroke. The pattern involved an overarm pattern, which is flexion of the elbow and medial rotation of the humerus during the forward or force-producing phase. Biomechanical analysis of badminton smash has revealed that during this phase there is a powerful inward rotation of the arm, followed by inward rotation of the forearm and lastly a flexion of the hand. However, the rotational movements of an arm while performing the stroke is not quantified by researchers. Therefore, the objective of the paper is to determine the unknown torques that caused the rotational movement of the upper limb joints using Kane's method.

METHODS:

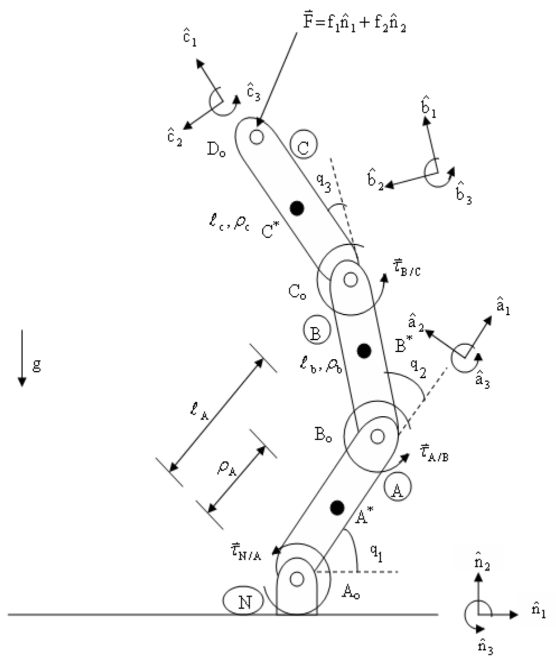
Video data were collected on badminton games during the men's singles and doubles semi-final and final events of the Thomas/Uber Cup 2000 competition held in Kuala Lumpur, Malaysia, from 11 May to 21 May 2000. World class male badminton players (n = 2) with average of 1.80 meters and 80 kilograms were taken as subjects in this study. There were eight trials involved for a subject and each trial consisted of, on average, 60 frames starting from the action of getting ready to the landing position after the smashing stroke. The recording system consisted of six sets of 50 Hz shuttered CCTV cameras (WV-CP450/WV-CP454 Panasonic) with color S-video, genlock and 6x zoom capabilities, 6 time-code generators (Norita SR-50), six 9-system portable colour televisions (CA688 Fumiyama), and six Peak-computerized and controlled VCR (NV-SD570AM Panasonic). For calibration, the cameras captured a reference structure (calibration frame) with 25 markers of known coordinates in space encompassing the whole court. The cameras were directly genlocked for video to provide shutter synchronization and identical frame rates.

Multiple cameras were used during the video capture. The videotapes were edited using an industrial standard NTSC Panasonic AG-7350 VCR and an IBM-compatible personal computer. The Peak Motus 2000 software was used to digitize the trials.

Body segment parameters from the Dempster model were used but adjusted to include the shuttlecock and the badminton racket (rear and bottom) (Dempster, 1955). In each video image, 25 control points, 21 anatomical landmarks representing the endpoints of 24

segments, one point for centre of mass, two points on the racket (top and rear), and one point for the shuttlecock were digitized manually. Subsequent to digitizing, the raw data were smoothed using the Butterworth digital filter with the cut-off frequency of 3 Hz of Peak Motus system.
Calculations were done to determine the torques of the joints using the model developed by Ariff and Rambely (2007) and data obtained from digitizing of captured images.

MODEL:
A 2-dimensional biomechanics model for three-link kinematic chain of an arm was constructed using Kane's method in a sagittal plane (Figure 1). Kane's method is a vector-based approach which used vector cross and dot products to determine velocities and acceleration rather than calculus (Yamaguchi, 2001). It creates auxiliary quantities called partial angular velocities and partial velocities, and uses them to form dot product with the forces and torques acting from external and inertial forces. The dot products form quantities called the generalized active forces and the generalized inertia forces, which are the simplified forms of the forces and moments used to write the dynamic equation of motion (Yamaguchi, 2001).



Notation :

○ = joints
● = centre of mass
(A) = segment A (shoulder-elbow)
(B) = segment B (elbow-wrist)
(C) = segment C (wrist-racquet)
A*, B*, C* = centre of mass of segments A, B and C respectively
$\hat{n}_1, \hat{n}_2, \hat{n}_3, \hat{a}_1, \hat{a}_2, \hat{a}_3, \hat{b}_1, \hat{b}_2, \hat{b}_3, \hat{c}_1, \hat{c}_2, \hat{c}_3$ = mutually orthogonal unit vector
ρ_A, ρ_B, ρ_C = distances of centre of mass from their proximal ends
ℓ_A, ℓ_B, ℓ_C = length of segments
$\vec{\tau}_{N/A}$, $\vec{\tau}_{A/B}$, $\vec{\tau}_{B/C}$ = torques of each joints
$\vec{F} = f_1 \hat{n}_1 + f_2 \hat{n}_2$ = endpoint force of arbitrary direction and magnitude

Figure 1. Planar three-link kinematic chain of an arm with an endpoint

The dynamics equations obtained is represented in vector form,

$$\mathbf{I}\ddot{\vec{\mathbf{Q}}} = \vec{\mathbf{G}} + \vec{\mathbf{E}} + \vec{\mathbf{T}},$$

where **I**: inertia matrix, $\ddot{\vec{\mathbf{Q}}}$: angular acceleration vectors, $\vec{\mathbf{G}}$: vector of moments from gravitational force, $\vec{\mathbf{E}}$: vector of moments from external forces, and, $\vec{\mathbf{T}}$: vector of applied torques.

RESULT AND DISCUSSION:
The torque of the joints is obtained from the model developed and kinematic data obtained from world-class badminton players. In order to describe the movements, four significant events are identified, which represent the events while a player performs a jumping smash activity. The events identified are the planting of foot, taking off, contact and landing. These four significant events occur in the five phases during the execution of the smash; described

by Rambely et al.(2005a). i.e. the getting into position, back swing, forward swing, contact and follow-through phases

The first event identified is the planting of foot, which occurs in the getting into position phase. Then a player will lower down his body before the taking off event. The player will then push himself upward and jump. During this airborne phase, the arm segment is in the force producing phase and at contact, the racket touches the shuttlecock. Then the player is in a follow through phase and his body moves downward and he lands.

Table 1 shows the value of torques obtained at each joint while the subject is performing the jumping smash stroke and Figure 2 illustrates the changes of torques on the joints in each position. This information helps to describe the movement of the subject while performing the smash stroke.

Table 1 Torques of the joints produced for the arm segment at the specific joint

Joint (Nm)	Planting of foot (Frame 7)	Take off (Frame 18)	Contact (Frame 24)	Landing (Frame 28)
Shoulder	-8.20E+04	-1.06E+06	4.35E+05	-1.59E+06
Elbow	-7.98E+04	-3.63E+05	5.99E+05	-8.52E+05
Wrist	-3.54E+02	-3.60E+03	3.16E+03	-2.90E+03

During the execution of smash, the extension movement of the elbow reaches its maximum about 0.02s and ceases before impact. The wrist starts its dorsiflexion (flexion) from palmar flexion (extension) and reaches its maximum position 0.05 s before contact. The shoulder is in its extension movement in the force producing phase and reaches its maximum before contact. After impact the value of torque at the shoulder joint ceases and it continues in the follow through phase.

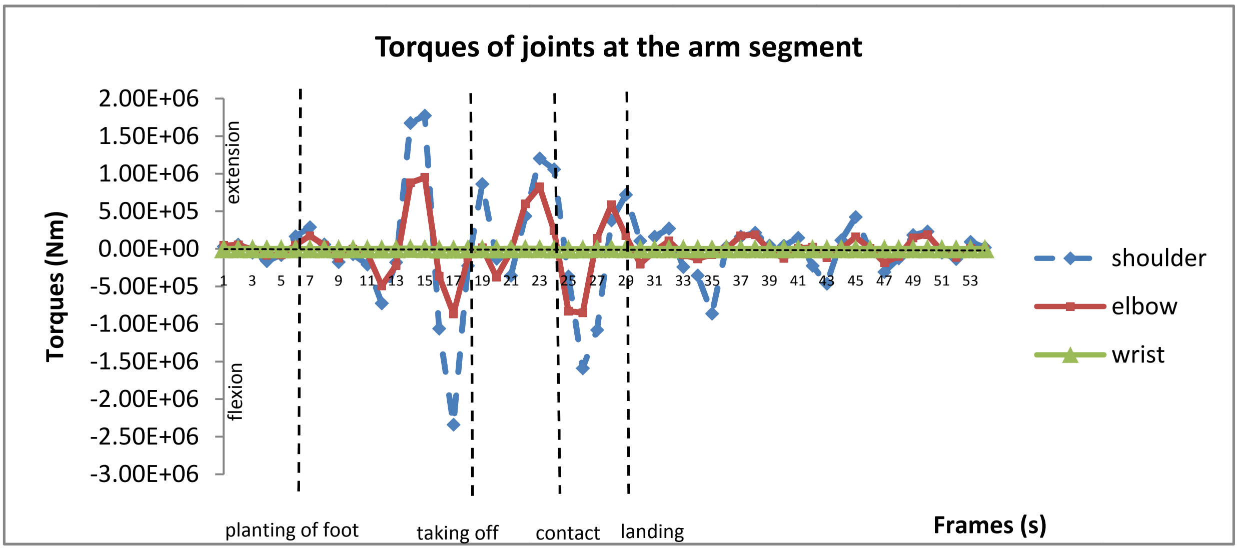


Figure 2: Torques of joints at each segment from planting of foot (7), taking-off (18), contact during airborne (24) and landing events (28)

Through the value of torques showed in Table 1, there are changes in the value of torque as movements change. When the player is in the position of planting his foot, forces to make next movement are generated by lowering his body to generate the upward vertical component of force. The force gained is transferred from the ground to the lower limb and transferred sequentially to the trunk. As the trunk rotates, the force is transmitted to the shoulder, which is the proximal limb. When the force at the proximal limb achieves its maximum, the distal limb (hand and racket segment) starts to accelerate. This will continue until the racket makes contact with the shuttlecock. At this point, the value of torque for elbow joint is greater than that of the shoulder joint which is 5.99E+05 Nm and 4.35E+05 Nm respectively. The greater value of torque at the elbow joint contributes to the speed of the racket. During this force-producing phase, the arm has full force to execute the smash stroke. Hence the transfer of force from the racket to the shuttlecock accelerates the shuttlecock in the opposite direction. Finally, in the follow through phase, the value of torques at each joint decrease as the player lands on the ground.

CONCLUSION:

The arm segments are in extension position during the force producing phase and achieve their maximum before contact with the shuttlecock. The force on the upper limb gained from the lower limb during take-off is transferred from the shoulder joint to the elbow joint at contact. The torque of the elbow joint shows the highest value at this point and thus contributes the most to the speed of the racket, hence accelerates the shuttlecock.

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