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ABSTRACT

Although the sport of karate has been somewhat neglected by scientists, the following two isolated biomechanical studies exist in literature: (1) tracings of a karate chop in two planes were presented, but no data was given concerning the rates of movement of the limb segments, and (2) pre- and postimpact phenomena of five subjects were studied, and hand velocities and forces at impact were reported. This study attempts to provide additional data for the biomechanical analysis of the karate chop. An initial subjective analysis of five subjects using film taken at 200 frames per second identified three fundamentally different patterns of movement. Films were also taken to analyze the kinetic aspects of the study; they show the various components contributing to the accelerometer output. The various unknowns can also be calculated from film giving an interesting comparison of direct and indirect methods of estimating acceleration. The study uses the technique of accelometry to illustrate the differences in using preferred and nonpreferred hands to break boards. The accelometer recorded considerable differences during this experiment, and this technique may prove to be a useful teaching device which can provide immediate feedback. The study incorporates electromyographic results with kinematic and kinetic data to provide further insight into the movement to be obtained. Although the study is primarily concerned with preimpact phenomena, it also makes very approximate estimates of the forces existing at impact. (BD)

A Biomechanical Analysis of the Karate Chop

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The sport of karate has been somewhat neglected by sport scientists, who have directed their attention chiefly towards traumatology and conditioning of the hand. Two isolated biomechanical studies do exist in the literature. Plagenhoef (1971) presented tracings of a karate chop in two planes but gave no data concerning the rates of movement of the limb segments. He indicated the need to strike the blocks at right angles and estimated that a force in the region of 875 lbs. was necessary to break the specimen used. Vos and Binkhorst (1966) used stroboscopic and strain gauge techniques to study pre and post impact phenomena on five subjects breaking both bricks and blocks. Treating the problem in a linear manner, hand velocities from 28-31 mph were found in experienced subjects and forces at impact from 28-132 lbf were reported, although it is unclear exactly what these forces represent.

Hirate (1971) reports studies by Kato of three subjects in which the maximum speeds in straight thrusts (presumably by the hand) reached 8.1 m/sec in the skilled and 5.3 m/sec in the unskilled performers. Speeds at impact were considerably less than these maxima and estimates of the forces at impact ranged

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from 171-700 Kg. In related studies on overarm throwing, Toyoshima et al. (1974) reported angular velocities for the forearm of 31 radians per second in normal throwing and 16 radians per second in forearm only throwing. These investigators also commented on the whiplike action of the upper limb.

In the present experiments an initial subjective analysis of five experienced subjects identified three fundamentally different patterns of movement. These can be characterized as shown in the first slide (Figure 1) by the posture at the top of the backswing and the subsequent movements. Style 1 is basically a punch - the movement from the posture shown being adduction at the shoulder and elbow extension. Style 2 is a combination of horizontal flexion and adduction at the shoulder together with elbow extension. Style 3 involves only extension at both shoulder and elbow joints, the movement being principally limited to the sagittal plane. This last style represents the simplest case as far as two dimensional analysis is concerned and all subsequent kinematic analysis is concerned with the subject who executed the movement in this manner.

This subject was a first degree black belt who had three years experience in breaking boards. The instrumentation for this study is shown in the following clip of experimental film taken at 200 frames per second. Markers were placed over approximate joint centers and Beckman surface electrodes were applied over biceps, triceps, latissimus dorsi on the right side and overlying the external obliques on the left side. A linear accelerometer was mounted on the wrist with the sensitive axis normal to the long axis of the forearm. After two practice trials data were collected from successful breaks of two or three boards. A synchronization light enabled the EMG and accelerometer data to be matched in time with displacement data reduced from film using a motion analyzer.

Segment angles to the vertical are shown in the next slide (Figure 2) which begins just before the top of the backswing, as the upper arm is approaching its maximum deviation. The time base is shown as the number of milliseconds before contact, and thus, once the downswing is initiated, the movement is complete in 150 msec. The orientation of the trunk in space remained relatively fixed until the second half of the movement when forward lean was initiated. To emphasize the coordinated movement at the shoulder and elbow, the joint angles are plotted against each other on an angle-angle diagram (Cavanagh and Grieve, 1973) in the next slide (Figure 3). The diagram starts in the upper left hand corner, when the shoulder and elbow are both flexed. Movement down the graph, parallel to the y axis indicated shoulder extension and no movement at the elbow while simultaneous movement of both joints would be represented by a diagonal line. It is clear from the diagram that upper limb movement during the karate chop is characterized by a sequential rather than simultaneous extension at the two joints. In trial 3 the elbow was actually flexing as shoulder extension was underway. Typically shoulder extension was at least 70% complete before elbow extension began.

Joint angular velocities were calculated from the displacement time data by numerical differentiation. A least squares quadratic equation was fitted to five adjacent data points and the derivative of the smoothed curve at the central data point taken as an estimate of velocity at that point. The sequential pattern of movement is further emphasized by the angular velocity data shown in the next slide (Figure 4). From the top of the back swing, at zero shoulder angular velocity, a peak of nine radians/second occurs during shoulder extension. At this time the elbow joint has not begun to extend, the peak velocity of 25 radians per second at the elbow occurring 70 milliseconds later just prior to impact. This is a quantitative representation of the "whiplike" action mentioned by other investigators.

Turning now to the kinetic aspects of the study, the next slide (Figure 5) shows the various components contributing to the accelerometer output. The x and y components of acceleration of the point of attachment and the gravitational component will all be resolved along the sensitive axis of the accelerometer giving the final output as indicated on the slide (Figure 5). Besides allowing us to understand the accelerometer output, the various unknowns in this expression can also be calculated from film giving an interesting comparison of direct and indirect methods of estimating acceleration.

A typical acceleration time curve starting from the rest position is shown in part A of the next slide (Figure 6). The first positive peak occurs early in the backswing as the forearm is raised in preparation: the records typically then show two negative peaks separated in time by approximately 100-200 milliseconds. The first peak occurs at the limit of shoulder flexion and is responsible for the initiation of the downswing; the second peak is the result of activity in the elbow extensors. A peak linear acceleration of the region of seven g's is seen to occur shortly before contact. The similarity of the accelerometer records within four trials of a different subject is apparent from part B (Figure 6). No clear trend relating peak acceleration to the number of boards broken was evident.

An interesting application of the technique of accelerometry is illustrated in parts C and D of this slide (Figure 6). This subject attempted to break boards with both preferred and nonpreferred hands and considerable differences were discernable from the accelerometer recordings. While the two negative peaks identified earlier were present in both records those in the nonpreferred hand were separated by a time interval some 30 percent greater. This difference suggests the lack of coordination that would be expected from the nonpreferred arm. The technique may prove to be an extremely useful teaching device providing immediate feedback in an important aspect of the skill.

A question of some importance in biomechanics is the validity of force and acceleration data derived by double differentiation from the high speed cinematography. As mentioned earlier this study provides an opportunity for both direct and indirect estimates of acceleration to be compared. Using the nine point technique described by Lanczos (1956), the equivalent quantity to the accelerometer output was calculated from film data, and the resulting comparisons are shown in the next slide (Figure 7). The discrepancies both in amplitude and phase are seen to be considerable casting further doubt on the process of double differentiation.

Incorporating the electromyographic results with the kinematic and kinetic data enables further insight into the movement to be obtained. A semiquantitative representation of the EMG's is shown in the next slide (Figure 8) where two levels of activity in the triceps and external obliques are shown, to distinguish the activity of these muscles from the relatively steady level of activity of the other muscles studied. A sequence of muscle activity is clearly seen with trunk, shoulder and elbow muscles exhibiting consecutive activity. It is interesting to note that activity in biceps brachii is present almost 50 msec before contact. This activity, in anticipation of impact, is a demonstration of the lag between electrical activity and the development of tension.

Although this study is concerned with pre-impact phenomena, with certain assumptions, very approximate estimates of the forces existing at impact can be made. Treating the problem as rotation of the forearm and hand about an elbow joint fixed in space, as shown in the next slide, (Figure 9) the Impulse-Momentum relationship can be used. If the force-time pattern at impact is considered to be a square pulse of height $\bar{F}$ and width ΔT the angular impulse is $\bar{F} l \Delta T$ where l is the forearm length. The change in angular momentum is $I_E \omega_o$ since ω_1 is zero. Equating these two values results in an expression for the average force during impact. The time of contact was definitely less than 1 interframe interval which was 5 msec. so using reasonable anthropometric data and taking the time of contact to be first four and then two milliseconds, estimates of 270 lbf and 540 lbf respectively are obtained for $\bar{F}$. These are considerably greater than the values obtained by Vos and Binkhorst and should be further verified by suitable direct measurement.

This initial study has provided data for the rather limited case of the "planar" karate chop. Clearly three dimensional cinematographic techniques are needed for the analysis of other styles of chop. In addition, direct measurement of the forces at impact would provide valuable information and it is hoped that such data would help the understanding of the seemingly incredible skills of the karate exponent.

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