Task Dynamics and Movement Control

Barry Wilson and Ian Howick
Kinesiology, School of Physical Education
University of Otago
Dunedin, New Zealand

INTRODUCTION

The human potential for movement is a function of the neural and musculoskeletal systems of the body and the physical laws and principles of motion which govern all aspects of motion. Given this complex environment, theories which indicate how movement is controlled are many and varied and depend on the field of study as well as the perspective of the investigator. Most theories which indicate how movement is controlled are concerned with the timing of actions since coordinated movement may be considered as a correctly timed sequence of actions.

Biomechanists have made numerous statements about timing and sequencing of segment action in movement. Bunn (1955) stated that strong muscles should begin actions where maximal forces are required with the weaker muscles continuing the motion. Bum also gives principles related to timing of actions, each force should be started at the point of greatest velocity but least acceleration of the preceding force...successive movement would start when the movement of the preceding member was approximately at the end of extension. Dyson (1973) stated that for movements to maximise impulse, all parts of the body should commence their accelerations simultaneously. He observed that in practice the stronger but slower muscles initiate the movement with the weaker, lighter and faster extremities completing the movement, ideally with all forces acting together.

A number or authors advocate a summation of speed principle when describing the movement pattern of the body segments. Bum (1972) states that when the movement of several segments of the body are involved in developing maximal speed, the speed of each segment should be faster than that of its predecessor and in the same direction, and should start at the moment of the greatest speed of the preceding segment. Putnam (1980) stated that the summation of speed principle was supported by studies of the punt kick but did not hold for the data of a gymnastic dismount. In the latter study the summation of speed principle may have been inappropriate because the movement was not to generate maximum speed.

A summation of force principle has also been proposed in an attempt to explain movement patterns. Bunn (1972) stated that the total effective force will be the sum of the forces of each member of the body if applied in a single direction and in a proper sequence. Hopper (1973) presented a theoretical model based on springs of varying stiffness representing muscles to support his argument for muscle groups producing large forces acting First with smaller groups adding their contribution later in the motion. Implicit in both the summation of speed and summation of force principles is appropriate timing of the segment actions.

Because the purpose of a movement task appears to dictate the manner of the movement, theories of movement have been put forward for several fundamental classes of movement (Bunn 1955, Hochmuth, and Marhold 1978). Hochmuth describes the development of his biomechanical principles as occurring in the early 1960's. These are described as useful for assessing the efficiency of sports motor dynamics. Hochmuth and Marhold, (1978) on the basis of a theoretical model suggests patterns of acceleration forces which may be labelled simultaneous for motions where the path of the acceleration is constrained, and sequential for when the greatest final velocity shall be reached.

A unifying concept was provided by Kreighbaum and Barthels, who in 1981 presented the Kinetic Link Theory, a description and explanation of segment timing for movements where the goal is maximum velocity. This theory postulates that such movements exhibit a proximal to distal sequence of timing of segment actions. Their explanation is in terms of principles of summation of velocity and momentum transfer. They also postulate a continuum in the timing pattern for movement for speed. The continuum proposed ranges from sequencing of proximal to distal segment actions, to simultaneous actions as the load and/or accuracy requirement is increased. While intuitively appealing due to its simplicity, Kreighbaum and Barthels (1981) presentation of the Kinetic Link Theory is not convincing due to the imprecise use of mechanical terms, and the loose application of mechanical principles such as momentum conservation to systems which cannot be considered to be conservative.

Very few experimental studies have been designed to test the Kinetic Link Theory. Several investigators have studied segment timing and interactions without testing the theory (Neal and Wilson 1985, Putnam 1988). Other authors have made use of the theory in interpreting the results of their research (Milburn 1982, Hudson 1986). Studies have shown sequential timing patterns in high speed, low load tasks such as throwing, kicking (Putnam, 1983) and striking (Milburn 1982), and simultaneous patterns in high load, low speed tasks such as jumping (Hudson, 1986). Neal (1988) concluded that subjects exhibit different patterns and do not change their movement pattern in response to increased load in an overarm throwing task.

In spite of these studies, the question remains as to whether the Kinetic Link Theory is valid as an explanation of segment timing and coordination. A further limitation of the Kinetic Link Theory is that it does not appear to provide an explanation of order effects which appear in the whiplike action in throwing and kicking for maximal speed or distance.

The timing patterns of movement have been studied in detail within the field of motor control. Timing has been operationally defied as external timing, the time relationship between the movement of some external object and the movement of the body, and relative or internal timing, the time in which various phases of the movement are completed by the body or its segments. Invariant relative timing is believed to be a feature exhibited by movements which have an underlying motor program (Schmidt, 1975). In a movement exhibiting variant relative timing the topology is scaled as required by the particular task by varying such parameters as the amplitudes of muscle forces and torques required. Evidence for a concept of invariant relative timing is widespread. That is not so clear is the task definition and constraints of movements which do and do not exhibit invariant relative timing.

Bernstein (1967) proposed a concept of motor equivalence, with groups of different muscles supposedly capable of producing the same topology of a movement. Kelso's work in the 1980's can be considered to support this notion. Kelso refers to ensembles of loosely coupled non-linear limit cycle oscillators. Such ensembles are constrained to move with set frequencies determined by the inertial characteristics of the components of the ensemble. Saltzman and Kelso (1987) present 'action units' defined in terms of a task dynamic framework. Task dynamics implies an invariant control structure that is specified according to the dynamic requirements of a movement task. Coordinated structures or 'action units' are controlled by relationships among the systems dynamic variables. Variables such as stiffness damping, mass and inertia. This approach considers the spatio-temporal structure to arise in a self organized way from interactions among the dynamics of the system supporting movement, external objects and forces, and the task objective (Higgins, 1985; Kelso, and Schoner 1988).

Statement of Purpose

The purpose of this study was to investigate segment timing and sequencing, the basis of coordination and movement. Specifically to investigate the validity of the Kinetic Link Theory as an explanation of segment timing in throwing movements at varying speeds and with different masses.

The first and second experiments were designed to determine if increased inertial loading changed the timing of segment action towards simultaneous action on the sequential - simultaneous timing continuum. The second experiment was designed to determine if increasing speed of movement was associated with segment timing on the sequential side of the sequential-simultaneous timing continuum.

METHODOLOGY

Subjects

Seven volunteer subjects were used in the studies. The nature of the experimental procedure and the aims of the experiment were explained to each subject, and all subjects signed a formal consent document. The subjects used were physical education faculty students or technical staff. Each subject participated in at least one and no more than three experimental sessions of approximately 10 minutes duration.

Apparatus

A Flextrac/ExpertVision (FEV) video motion analysis system (Motion Analysis Corporation, Santa Rosa, California), was used to obtain a two dimensional kinematic description in the horizontal movement plane. The system consists of a high speed video camera, video recording and playback apparatus, and a computer system which digitises the video data and allows a wide variety of further processing. The video camera used was a NAC (NAC Inc., Minato-ku, Tokyo, Japan), high speed video camera (model V-14B), equipped with Angeniux 12-120mm zoom lens set at 17mm. The validity of linear measurements provided by the FEV system has been shown to be equal to that provided by more traditional cinematographic techniques (Smith, Dillman, and Risenhoover, 1988).

Subjects were seated at a horizontal bench over which movements were performed. The bench top consisted of smooth varnished chipboard, and was 0.93 metres above the floor. The chair seat was 0.45 metres above the floor. This resulted in the bench surface being just below the armpit height of the subjects.

Experiment one:

Movements were performed with different masses (0.026, 0.998, 1.999, 2.889 and 3.998 kg.), held in the hand with the mass in contact, with the table top. The masses were nylon covered bags, cylindrical in shape, 7 cm in diameter and 18 cm in length. The coefficient of static friction between the table and masses was measured to be about 0.2.

Experiments two and three:

Modifications were made to the apparatus and task requirements to remove the effect of friction between the mass and bench, and to avoid having to decelerate the rapidly moving mass. Masses were suspended 2 cm above the table by an overhead cord of length 3.7 m. The suspension point was directly above the mid range of the movement. The task was changed to one of throwing the suspended mass at a target zone of width 0.53 m at the far end of the bench. The target apparatus prevented the mass swinging back and hitting the subject.

In all experiments video data was collected at 200 frames/sec using the video camera placed vertically 3.4 metres above the table. Retro-reflective markers on the shoulder, elbow, wrist joints, and the third knuckle of the hand defined segment endpoints. A light placed behind the camera and adjustment of the camera aperture was used to obtain a high contrast between the markers and the dark background of the video image.

Procedure

The subject was seated at the table, and the retro-reflective markers were affixed to the arm at segment endpoints. The subject was then given verbal instructions about the movements to be performed. The starting position involved the subject being seated at the bench, with their chest against its front edge. The left arm held the side of the bench with sufficient force to hold the chest against the bench and thus restrict shoulder movement. The mass was held in the right hand and subjects were instructed to start each movement with the mass touching a marker placed on the bench adjacent to the left shoulder.

Experiment one:

The task was described as having to move the mass as fast as possible in the direction of the experimenter (i.e. along the bench) immediately after the sound of the buzzer. The subjects were also instructed to keep the mass in contact with the bench and maintain hold of it throughout the movement. Several practice trials were given prior to recording, using the 1 kg mass until the above requirements were fulfilled. Five trials at each of the five mass conditions were then recorded, with a short rest between each condition. The five mass conditions were presented in the order: 1, 4, 0, 3, 2 kg. Data were collected for three subjects.

Experiment two:

The procedure in experiment two was identical to that followed in experiment one except for the changed task requirement and apparatus. The task was described as throwing the suspended mass at the target as fast as possible. Data were collected for one subject.

Experiment three:

Experiment three involved the subject voluntarily producing the range of different speeds while throwing a constant mass of 2 kg. In order to produce this range of speeds, four different speed conditions were adopted. These were described to the subject as (1) "An easy swing (one quarter maximum)" (2)"Medium speed (one half maximum)" (3) "A hard swing (three quarter maximum)" (4) "As hard as possible (maximum speed)". Prior to recording, two trials at each speed condition were given in the order (2), (3), (4), (1), to provide practice and warm up. Twenty four trials (six at each speed condition) were then recorded. These were presented in a random order. Data were collected for four subjects.

Immediately subsequent to each testing session, the required subject anthropometric data for predicting the segment inertial characteristics was obtained using an anthropometer and tape measure. Segment masses and principle moments of inertia were predicted using Hanavan anthropometric variables (Hanavan, 1964, Jensen and Wilson, 1988).

Data Reduction and Dependent Measures

The data analysis consisted of four stages:

(1) Automated digitisation of segment endpoint markers on the video image and calculation of marker paths. Following the experimental sessions, 1 second of video data from each trial was digitised at 200 samples/second. This sampling rate was chosen as optimal for the digitising system and speed of movement being digitised (it is desirable that objects move between 2 and 15 pixels per digitised frame, FEV reference manual, 1986, p196). An event marking tone placed on the video tape coincidental with the buzzer sound was used to start the FEV digitisation process. FEV user programmes were developed to analyze the data and provide descriptive statistics of the desired dependent measures.

(2) Calculation of angular and linear kinematics. The angular kinematics of the three segments were calculated. Velocities and accelerations were

calculated by differentiation of smoothed angular displacement data. The FEV "Tukey Window" digital smoothing routine with a window of 11 data points was used. In addition, certain linear kinematics were calculated. These consisted of the resultant hand linear speed, and the magnitude of the resultant hand linear acceleration. These were calculated from path data which had been smoothed with a Tukey Window of 11 data points.

(3) Extraction of the dependent measures of the movements

a. Timing. The time of the start of the movement was defined as the time at which the magnitude of the hand linear acceleration reached one metre/sec^2. This appeared to pick a time close to the start of movement with a good degree of consistency and accuracy. The timing of the actions of the three segments was measured by picking the time of their peak angular velocities (PAV) in relation to the start of the movement. The time of achievement of the task goal (maximum linear hand speed) relative to the start of the movement was measured. The time from the start of the movement to this event was taken as the 'movement time' for the purposes of calculating the relative timing of the other events.

b. Magnitudes of segment actions and task achievement. The magnitude of the PAV for the three segments and the peak linear hand velocity achieved were calculated.

c, Spatial characteristics: The length of path traversed by the hand from the start of the movement to the time of achievement of peak linear hand speed was also calculated.

(4) Data Analysis. Descriptive statistics were calculated within the FEV system. In order to calculate inferential statistics for the data, the data for all dependent measures was transferred to a Microvax system, and BMDP 2V software was used to carry out repeated measures analyses of variance (ANOVAs). Use was also made of Macintosh Statworks 512$^+$ software to do regression analysis for some variables.

RESULTS AND DISCUSSION

Times to peak angular velocity for the upper arm, forearm and hand as functions of mass in the hand are shown for three subjects in Figure 1. Time to PAV for the upper arm was achieved before the PAV for the forearm which in turn occurred before the PAV for the hand except under the lightest mass condition. This illustrates that the timing of segment actions conformed to the general principle of proximal to distal timing of segment action in movement for maximal speed.

Time to reach peak hand speed and the times to PAVs for the hand and forearm increased markedly as the mass in the hand was increased. Time to reach PAV for the upper arm was relatively unchanged as the mass in the hand was increased. Loading the distal segment had the most marked influence on the time to PAV of the distal segments. The timing difference between the PAV for the upper arm and forearm and hand became more accentuated with increasing the mass in the hand. Thus, contrary to the Kinetic Link Theory, there was evidence of a shift from simultaneous to sequential timing as load was increased in movement for maximal speed.

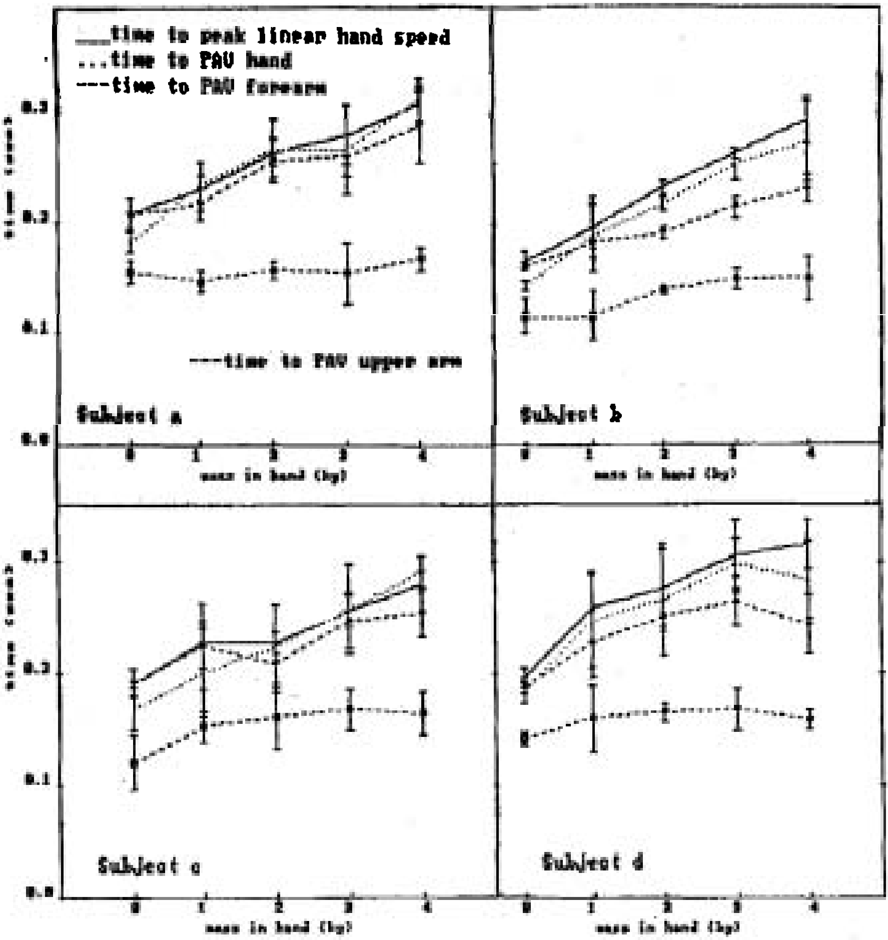
The second study determined that using a load that was released at the end of the movement did not influence the time to PAV in the movement being studied. (Figure 1: a, b and c were derived from experiment one data and Figure 1 d was derived from experiment 2 data).

In the third study the target speed of the throwingtask wasvaried. Times to PAV relative to total movement time for the upper arm, forearm and hand as functions of movement speed achieved are shown in Figure 2 for four subjects. When movement kinematics (target movement speed), was increased with mass in the hand a constant, peak hand speed increased and total movement time decreased. These curves tend to diverge in relative time at increasing movement speeds. Thus, the hypothesis that movement at maximal speed would exhibit more sequential timing than the low speed movement was supported for this median load condition. Further data is being collected for other load conditions.

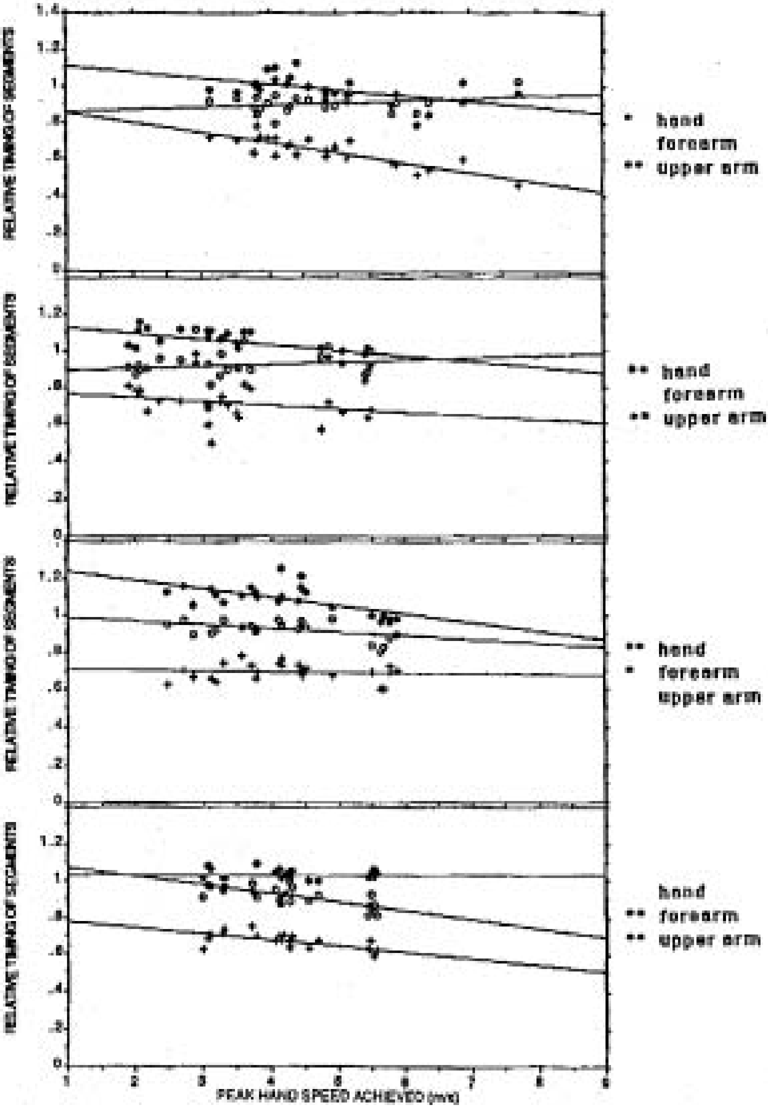
The data from experiment 1 were then expressed in the same form as that of experiment 3, as shown in Figure 3. With movement kinematics dynamically constrained by increasing the mass held in the hand, peak hand speed was decreased and total movement time increased. Linear regression lines are shown for relative time versus peak speed for each segment. In 6 of the 12 curves PAVs occur later in relative time at increasing movement speeds with no significant slope for the 4 curves and negative slopes for two curves. Thus, movement at the high speed exhibits more simultaneous timing than the low speed movement when the kinematics are dynamically constrained, the opposite effect was illustrated when the movement speed was under volitional control.

Thus in all experiments relative timing was shown to change with increasing movement speed. There was no evidence of a shift from sequential to simultaneous timing as load increased. Movement at maximal speed was more sequential in timing than movement at low speed which supports the Kinetic Link Theory of a timing continuum. However, when the movement was dynamically constrained by load, high speed movements became more simultaneous than low speed movements which does not support the Kinetic Link Theory.

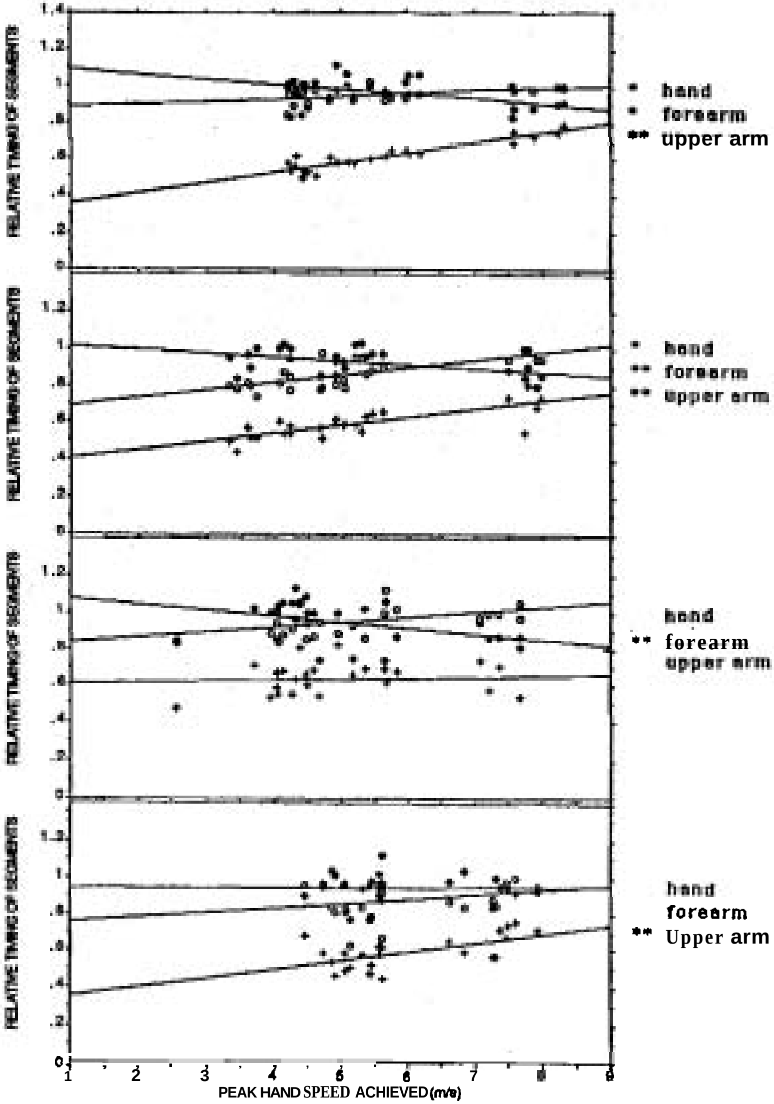
The date, conditions of speed and load have been varied for the throwing task while spatial constraints on the movement have been held constant. The influence of spatial constraints on the movement, such as start and end position or accuracy of the task, on segment timing and sequencing have yet to be investigated



___time to peak linear hand speed
...time to PAU hand
---time to PAU forearm
---time to PAU upper arm
Subject a
Subject b
Subject c
Subject d
0.0
0.1
0.2
0.3
0
1
2
3
4
mass in hand (kg)



RELATIVE TIMING OF SEGMENTS
1.4
1.2
1
.8
.6
.4
.2
0
* hand
forearm
** upper arm
** hand
forearm
** upper arm
** hand
* forearm
upper arm
hand
** forearm
** upper arm
1
2
3
4
5
6
7
8
9
PEAK HAND SPEED ACHIEVED (m/s)


RELATIVE TIMING OF SEGMENTS
hand
forearm
upper arm
hand
forearm
upper arm
hand
forearm
upper arm
hand
forearm
Upper arm
PEAK HAND SPEED ACHIEVED (m/s)

REFERENCES

Bernstein, N.A. 1967. The coordination and regulation of movement. Oxford Pergamon Press. p. 132.

Bunn, J.W. 1955. Scientific principles of coaching (First Edition) Englewood Cliffs, Prentice-Hall.

Bunn, J.W. 1972 Scientific principles of coaching. Englewood Cliffs, Prentice-Hall.

Dyson, G.H.G. 1977. The Mechanics of Athletics. (Ed. 7) London: Hodder and Stoughton.

Hanavan, E.P. 1964. A mathematical model of the human body. Technical Report, Aerospace Medical Research Laboratory TR-64-102, Wright-Patterson Air Force Base, Ohio.

Hochmuth, G. and Marhold, G., 1978. The further development of biomechanical principles. In: Asmussen, E. and Jorgensen, K. (eds). Biomechanics VI-B. University Park Press Baltimore. pp 93-106.

Hopper, B.J. 1973. The mechanics of human movement. New York, American Elsevier.

Higgins, S., 1985. Movement as an emergent form: its structural limits. *Human Movement Science* 4, 119-148.

Hudson, J. L., 1986. Coordination of segments in the vertical jump. *Med. Sci. Sports Exerc.* 18 (2), 242-251.

Jensen, R.K. and Wilson, B.D., 1988. Prediction of segment masses and principle moments of inertia using Hanavan anthropometric variables. ***Journal* of *Biomechanics*** (in press).

Kelso, J.A.S. and G. Schoner, 1988. Self-organisation of coordinative movement patterns. ***Human Movement Science*** 7, 27-46.

Kreighbaum, E. and K.M. Barthels, 1981. Biomechanics: A Qualitative Approach for Studying Human Movement. Minneapolis: Burgess. pp 377-413.

Milburn. P.D. 1982 Summation of segmental velocities in the golf swing. *Med. Sci. Sports Exer.* 14 (1), 60-64.

Neal, RJ., 1988. The influence of load on movement patterns. Unpublished doctoral **dissertation,** University of Queensland, Brisbane.
Neal, R.J. and Wilson, B.D. 1985 3D kinematics and kinetics of the golf swing *Int. J.* of Sports Biomechanics, 1; 221-232.

Putnam, C.A., 1980. Segment Interaction in selected two-segment motions. Unpublished doctoral dissertation, University of Iowa, Iowa City.
Putnam, C.A., 1983. Interaction between segments during a **kicking** motion. In; Matsui, H. and Kobayashi, K. (eds), Biomechanics VIII-B. Champaign, Illinois: Human Kinetics Publishers. pp 688-694.
Putnam, C.A., 1988. Personal communication.

Saltzman, E. and Kelso, J.A.S., 1987. Skilled actions: a task dynamic approach Psychological Review., **94(1),** 84-106.
Schmidt, R.A. 1975, A schema theory of discrete motor skill learning. Psychology Review, 82; **225-260.**
Smith, S.L. Dillman, C.J. and Risenhoover, S.G. 1988. Validation of an automatic system. Med. Sci. Sports *Exerc.* 20 (2); S75.