INTERNAL ROTATION OF THE UPPER ARM : THE MISSING LINK IN THE KINEMATIC CHAIN

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INTRODUCTION

Many situations in sport demand that maximum speed be produced at the end of the most distal segment in a chain of movements. An essential aspect of this proximal-to-distal speed summation, is that movement of each segment is exploited in order that maximum speed is generated from the "kinematic chain". The summation of speed principle states that to maximise the speed at the distal end of a linked system, the movement should start with the more proximal and progress to the more distal segments, such that each segment starts its motion at the instant of greatest speed of the preceding segment and reaches a maximum speed greater than that of its predecessor (Bunn, 1972).

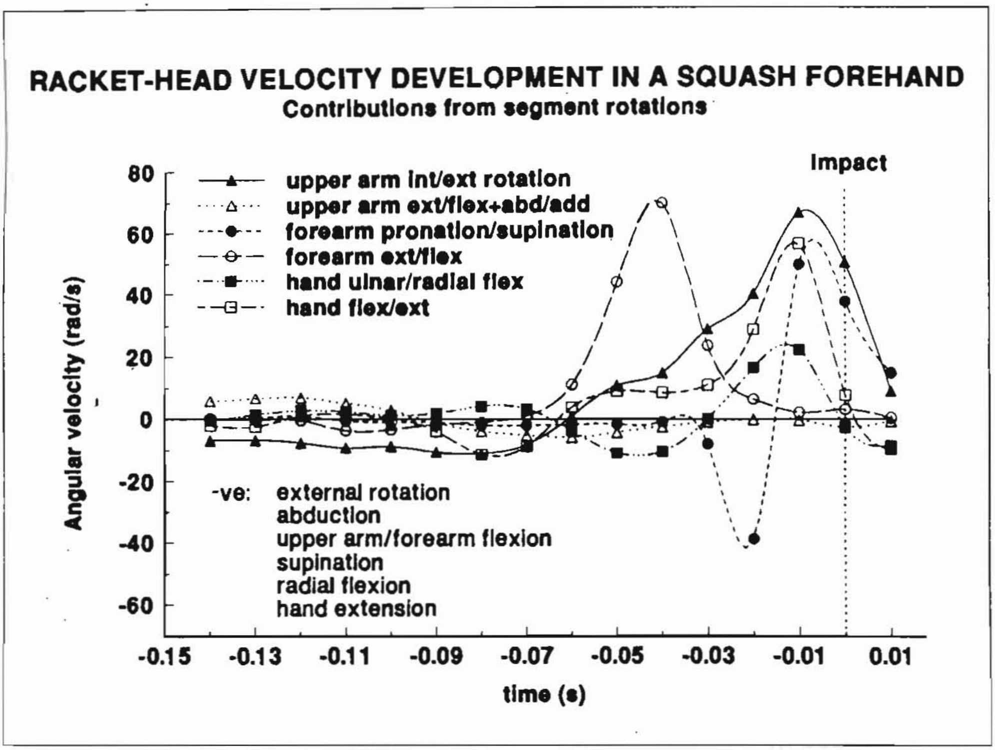
Research studies have reported linear velocities of segment endpoints, joint angular velocities and/or segment angular velocities in two-dimensional or three-dimensional formats to either support or refute this principle. Putnam (1993) in reviewing the logic of using the different means of describing the summation principle emphasised that motion about all the degrees of freedom for each joint must be considered in any thorough analysis of movement sequencing.

Recent developments in computer software (Feltner and Dapena,1989;Sakurai et al.,1993 ; Sprigings et al.,1994) have permitted segment rotations about all their degrees of freedom to be calculated and their role in velocity generation with respect to an endpoint such as a racket to be established. The influence on final speed and sequence timing of long axis rotational movements (e.g., internal/external rotation of upper arm; pronation/supination of forearm) can therefore be ascertained. This paper will present published and original data that clearly show that internal rotation of the upper arm must be considered in any discussion of upper limb sequencing. It plays a major role in speed development of the distal end of the chain, while occurring very late in the forward swing phase of trunk and upper limb movements prior to release or impact.

DISCUSSION

The role with respect to the generation of distal endpoint speed and timing of internal rotation, with respect to the sequencing of other upper limb segments, will be discussed for three racket skills (tennis and squash forehands and tennis serve). The role of timing of internal rotation will also be discussed for two throwing skills (quarterback throw in American football and the baseball pitch).

In the high speed squash forehand drive, trunk and upper limb segments must coordinate within a 200 ms forward swing phase if a high racket speed is to be attained (Woo and Chapman,1991; Elliott, Marshall and Noffal, 1996). In the study by Elliott and colleagues, which analysed the forehand actions of high performance male and female players, the mean peak internal rotation angular velocity (77 rad s^{-1}) was reduced to 47 rad s^{-1} at impact. This internal rotation, which was a primary source of racket speed at impact (approximately 46% : Sprigings et al.,1992; Elliott et al.,1996),was focussed over a 50 ms period prior to impact and peaked together with hand flexion approximately 10 ms prior to impact (see Figure 1)



In the tennis forehand internal rotation of the upper arm at the shoulder joint was a primary source (approximately 40%) in the production of racket speed at impact (Sprigings et al.,1991; Takahashi Elliott and Noffal in preparation). The peak angular velocity of 16.6 rad s^{-1}, that reduced to 15.3 rad s^{-1} at impact, occurred very late in the forward swing sequence (approximately 10 ms prior to impact) together with palmar and ulnar flexion of the hand. This sequencing was generally common across flat, topspin and topspin lob forehand groundstrokes.

Internal rotation of the upper arm was shown to be the most important contributor (54%) to forward speed of the racket at impact in the tennis service (Elliott, Marshall and Noffal,1995). The mean peak angular velocity of 36.5 rad s^{-1} was recorded 0.005 s prior to impact. From a proximal-to-distal sequencing perspective this rotation coincided with palmar flexion and occurred later than other movements about the shoulder and elbow joints.

Internal rotation of the upper arm has been shown to be an important feature of overarm throwing skills, although the actual contribution to performance has not been quantified. In the quarterback throw in American football peak torque for internal shoulder rotation was recorded close to the position of maximum external rotation during the preparatory phase of the throw (Rash and Shapiro,1995). The elastic energy stored during this eccentric muscle action is at least in part used to assist muscles to produce the high levels of internal rotation during the acceleration phase of the throw. As in previously discussed high velocity striking movements, internal rotation angular velocity of the upper arm occurred relatively late in the forward swing phase of motion and peaked after ball release.

In baseball pitching internal rotation at the shoulder as part of the kinematic chain occurred very late (approximately 30 ms prior to release) in the forward swing motion (Feltner and Dapena,1986; Sakurai et al.,1993). The peak angular velocity of internal rotation also coincided approximately with ball release.

CONCLUSION

The proximal-to-distal sequencing of the kinematic chain for selected striking and throwing skills does not hold up under close scrutiny if movements produced by upper limb segments are analysed. While segment endpoints do increase in linear speed (shoulder-elbow-wrist-distal end of phalanges) an analysis of segment movements about all their degrees of freedom shows that internal rotation of the upper arm does not fit the above sequencing format. It is a primary generator of endpoint speed in striking and throwing skills and occurs very late in the movement sequence.

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