LOWER LIMB KINEMATICS AND FLOW CHARACTERISTICS OF THE WATER POLO 'EGGBEATER' KICK

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INTRODUCTION

In water polo there is a need to raise the upper body above the water by generating a force to counteract the weight force. This force is generated using an 'eggbeater kick.' The water polo 'eggbeater kick' involves a cyclical action of the lower limbs producing upward forces to support players in an elevated position to pass, receive a pass, shoot for goal, or block those of an opponent. Since the pioneering work of Clarys (1974) very little analysis has been conducted on the water polo eggbeater kick. The kick may be used as an explosive action to gain maximum height for a short period for the purpose of passing, shooting for goal, or blocking or intercepting those of an opponent. This is called a 'boost'. Alternatively, the kick may be used to support the body in an elevated position for an extended period of time. This is called a 'hold'.

The purpose of this study was to investigate the lower limb kinematics and flow characteristics of the water polo eggbeater kick performed during 'hold' trials and to identify variables associated with height sustained over several kick cycles.

METHODS

Twelve male water polo players took part in this study. Five were elite at New Zealand National level, two were intermediate in ability and five were novice. Prior to video recording, black plastic 'craft beads' were glued onto white surgical tape strapped onto the subjects feet. These markets were carefully positioned on the underside of the foot at the base of the calcaneous, and on the medial and lateral metatarsal phalangeal joints. These were subsequently digitized to define the plane of each foot. Each subject used an eggbeater kick to 'hold' their elevated position for a period of 30 seconds. The analysis period consisted of at least 1.5 complete cycles of each foot corresponding to the middle of the 30 second period.

Three-dimensional video recording techniques were applied. A 'sputnik' three-dimensional calibration frame was positioned so that half of the calibration markers (16) were below the water surface and half were above the water surface. To record the above water motion two VHS cameras were placed 8 meters from the center of the calibrated space at a height of 1m above the water surface and with their axes at approximately 90 degrees. To record the below water motion two SVHS cameras were positioned behind underwater viewing windows at a depth of approximately 0.5m and approximately 6m from the center of the calibrated space. Their axes were at approximately 90 degrees. All cameras recorded the motion simultaneously at 50Hz.

The body segment endpoints and foot markers were digitized from the video recordings of each camera and input to a DLT direct linear transformation (Abdel-Aziz & Karara, 1971) to determine the three dimensional coordinates. Separate calculations were performed for the above and below water views. A mathematical model was developed and coded into a FORTRAN computer program to determine the variables of interest.

The selection of variables to be analyzed was based on a qualitative model of factors that affect the height sustained. The goal is to sustain a height as great as possible. The height is dependent on the forces that can be generated in the upward direction to raise the body and the weight of the suspended mass acting downward. These forces could not be measured in this study. However, we know that the force generated by each foot is related to the surface area of the foot, the speed of its motion through the water and its coefficients of lift and drag. Players do no have control of the surface area of their feet but they do have control over the speed of the foot. Therefore, the speed of the foot was quantified as well as the direction and path of its motion resulting from the joint actions used. The joint actions were quantified in terms of the joint angle-time profiles and were also displayed as stick figures so that the technique characteristics of each player could be observed.

The coefficients of lift and drag of the feet are not known. However, we know that these vary according to the orientation of the foot with respect to the direction of water flow over the foot. It is expected that good performance is achieved by moving the foot through the water with a path and orientation that produces large forces in the upward direction. It is recognized that these paths and orientations are not achievable throughout the whole movement.

The orientation of the foot was described in terms of 'pitch' and 'sweepback' angles in a similar manner to that commonly used in studies of the hand in swimming (Schleihauf, 1979). Pitch is the angle between the plane of the foot and the direction of water flow. The angle is positive when the water is striking the underside of the foot and negative when striking the top of the foot. The plane of the foot was defined by the three markers attached on the base of the calcaneous, and the medial and lateral metatarsal-phalangeal joints (Figure 1). Sweepback angle describes the direction of flow with respect to the foot. For example, if it is coming across the foot from the side of the big toe the sweepback angle is 0 degrees.

The flow velocity vector for the foot was determined by differentiating the position of the centre of the foot with respect to time. The x, y, and z coordinates of the foot centre were defined as the average of the x, y, and z foot landmark coordinates respectively. Errors in foot centre velocity due to digitizing was within 0.1 $m.s^{-1}$ of the true value. The maximum error in pitch angle was 5 degrees.

RESULTS

The height of the vertex of the head that could be sustained by the players ranged from 0.22 m to 0.42 m. The feet moved in curved paths such that there were substantial contributions from movements in the vertical direction, antero-posterior direction and medio-lateral direction. The elite players' movements were more rounded than the novices. In particular, the elite players had much greater movements in the antero-posterior direction than the novices.

Three foot velocity variables were significantly related to height ($p<0.05$) and together accounted for 89 percent of the variance in height achieved. These were the mean of the squared foot velocity ($r = 0.85$), and the percent contribution of the vertical and antero-posterior components of foot velocity ($r = -0.72$ and $r = 0.72$ respectively). Although there was a considerable contribution by the medio-lateral component to resultant foot velocity, the magnitude of this component was not related to height.

For the group as a whole pitch angles were generally small throughout the kick cycle. The mean maximum pitch angle was 28 degrees (**SD =** 9 degrees) and the mean minimum pitch angle was -13 degrees (**SD =** 8 degrees).

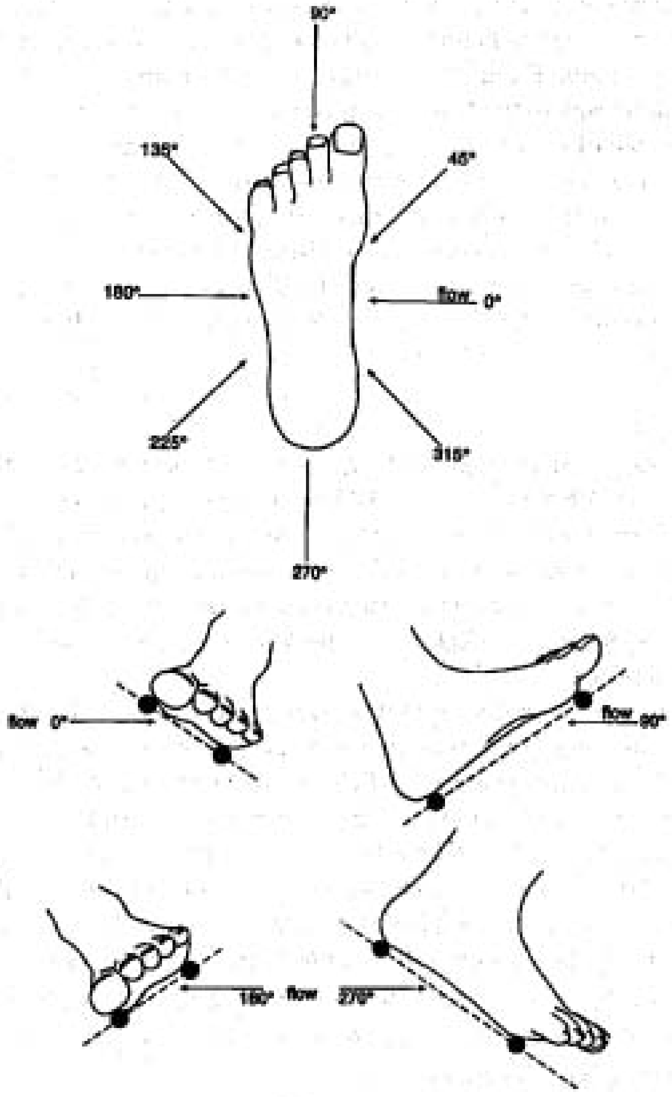

Figure 1. Sweepback angles (top) and the orientation of the foot with a pitch of 35 degrees for sweepback angles of 0/360, 90, 180, 270 degrees (bottom).

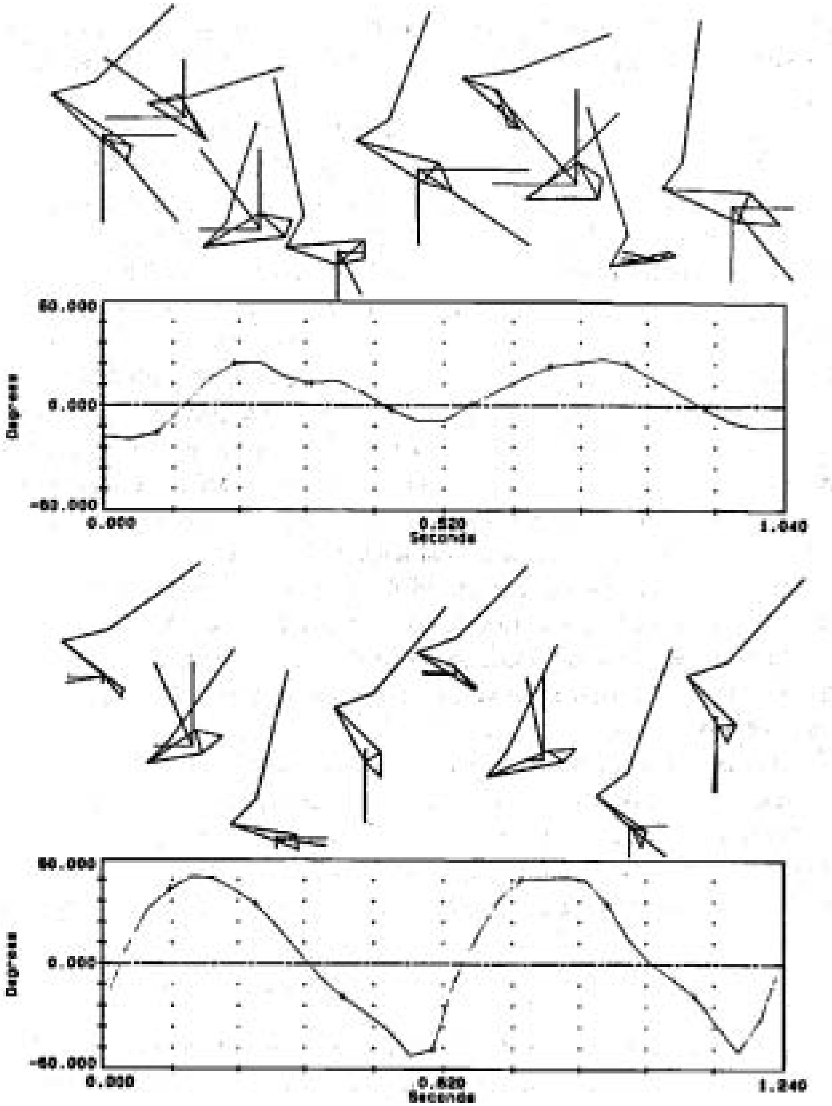

Figure 2. Pitch angles of the left foot of the players who sustained the greatest (top) and least (bottom) height.

Figure 2 shows the pitch angles of the left foot of the players who sustained the greatest and least height. The novice subject had a maximum positive pitch of about 50 degrees and a maximum negative pitch similar in magnitude. By contrast, the elite player used small angles of pitch throughout the cycle. The maximum positive pitch for the elite player was about ***26*** degrees and the maximum negative pitch for any cycle was less than 18 degrees.

The period of negative pitch was about ***0.26s*** for the novice player but considerably shorter for the elite player. The difference in magnitude and duration of negative pitch was related to the the magnitude of antero-posterior motion of the foot during knee flexion. The novice player moved the foot in a predominantly upward direction during knee flexion, thereby causing the flow to strike the top of the foot and producing downward forces. The elite player moved the foot backward during knee flexion. Thus, pitch angles were small and the downward forces were probably small.

Elite players maximized the period of positive pitch by dorsi flexing the feet during their forward motion, plantar flexing the feet during their backward motion, and everting the feet during the period of outward motion.

The flow was across the medial side of the foot, that is between 0 and ***90*** and 0/360 and ***270*** degrees for at least ***66%*** of the cycle time. The short period of flow across the outside of the foot, that is between ***90*** and ***270*** degrees, occurred late in period of knee flexion and early knee extension as the foot moved outward. Because the elite players everted the feet during the period of outward motion, pitch angles were small and positive for most of this period.

At the commencement of knee extension all players had the foot in a laterally rotated position. The foot rotated medially as it moved outward and forward. As a consequence the sweepback angle changed from ***90*** to 0 degrees. The foot continued to rotate medially and moved inward and backward causing the sweepback angle to change from ***01360*** degrees to ***270*** degrees.

CONCLUSION

The results indicated that foot speed is the most important factor contributing to performance in the eggbeater kick. It is also desirable to maximize the relative contribution of the antero-posterior motions and to minimize vertical motions. Players moved the feet in curved paths and orientated the feet to maintain small angles of positive pitch. The fact that players used small angles of pitch and had large horizontal components of foot velocity indicated that lift forces contributed greatly to forces in the upward direction.

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