A KINEMATIC ANALYSIS OF THE BREASTROKE KICK

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The study investigated the contribution of the ankle joint in the breaststroke kick using three dimensional kinematic analyses. Methodology included applying reference markers to the right leg using anatomical reference points and then videotaping twelve competitive swimmers performing the breaststroke. A Matlab script was used to calculate relative angles (between the foot and shank), angular and relative angular velocities, and linear velocities. The results of a linear regression at $p<.05$ showed that there was no statistical significance between the foot angular displacement and linear hip velocity, but there was a statistical significance between the local angular velocity and linear hip velocity in the anterior-posterior dimension. The results of the study suggest that the ankle joint and the foot are important contributors to the breaststroke kick.

KEY WORDS: underwater motion analysis, Euler parameters, quaternions.

INTRODUCTION: The purpose of this study was to perform a kinematic analysis of the competitive breaststroke kick. The propulsive phase of the breaststroke kick, specifically ankle joint range of motion, was compared and contrasted between various levels of breaststroke swimmers. Swimming coaches theorize that "better" breaststroke swimmers use more foot motion throughout the breaststroke kick (Maglischo, 1993; Costill et al., 1992). Using a greater range of motion at the ankle joint is consistent with this concept and would enhance the swimmer's performance. While research on the breaststroke kick does exist, most of the studies are more than ten years old and only a few of them focus on the kick, so there is a lack of any detailed research on the ankle movement kick. This study addressed the gap in research and attempts to clarify the importance of the ankle movement in the breaststroke kick. This study proposed that in the breaststroke kick, "better" swimmers (those who have a higher mean linear hip horizontal velocity (V_H) in the breaststroke) use a greater ankle-joint range of motion than swimmers with a slower V_H. When comparing swimmers with different abilities on breaststroke, there would have been significant differences in the beginning and ending positions of the propulsive phase of the breaststroke kick. Existing research on swimming is prevalent for the backstroke, freestyle, and butterfly, but research on the three dimensional kinematics of breaststroke is lacking. Since breaststroke is made up of angular movements, analysis can be complicated, resulting in anecdotal literature, but little three dimensional kinematic data. The significance of the current study is strengthened by changes in the breaststroke technique during the late eighties (Costill et al., 1992; Maglischo, 1993). During this period, the use of the body position became more dynamic with a greater degree of rotation (undulation) about the transverse axis. These innovations led to consistent decreases in breaststroke times, thus more research is key to understanding the difference between “flat” and “modified” techniques (VanTilborgh et al., 1988).

METHODS: Twelve female participants (mean age ± S.D. = 20 ± 1.0 years, mean height ± S.D.= 1.65 ± .06 m, mean weight ± S.D.= 62 ± 5.5 kg, mean U.S.A shoe size S.D.= 8 ±1.0) were selected from a women's swim team of a major regional university, after the approval of Human Subjects committee of the University. The swimmers participated at the NCAA Division I level, with varying levels of competency in the breaststroke. Three Canon ZR45-MCA digital video camcorders were connected with three under water lens units (Sony 1/3 Super HAD CCD sensor, 380 TV lines resolution, 3.6 mm, approx. 92 degree view angle,

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12V battery) made by Under Water Camera Company of America (El Cajon, CA) using three waterproof RCA video cables for video footage collection. Camera 1 was positioned 90º (perpendicular) to the line of motion. It was mounted to a starting block for stability and for a stationary position. Camera 2 was positioned approximately 30º to the line of motion, establishing a front, right view of the participants. Camera 3 was positioned approximately 10 degrees to the line of motion from the anterior side of the movement. The camera field of view was set to achieve the best possible view of the calibration frame and the participants completing the trials. An audio synchronization unit, consisting of a button and cables leading to the audio input of each camcorder, was used to add sound tone to the audio of each tape for later film synchronization. A calibration frame was used to define the volume of data collection for DLT. The frame consisted of a nine marker Qualisys CAB 1000 calibration reference frame. To increase the volume of the calibrated volume, two four by one meter 'T' extensions were added. These were fabricated with 'L' bracket lengths of stainless steel. These extensions added eight markers to the calibration frame, to make sure that enough area was calibrated, so the increased length of the calibrated area was 5.5 meters. Using Qualisys MacReflex motion analysis system the calibration frame was digitized to find the coordinates on land. PEAK Motus 7.2.6 was used to select the better trial for each participant. This was determined by the position of the participant and whether her kick cycle ended up in the field of view of the cameras. A three segment leg model was constructed by digitizing using the Peak system. The digitized information was reconstructed using Direct Linear Transformation with 3.0 mm of error (Abdel-Aziz and Karara, 1971).
The raw coordinate data was exported for use with Matlab^{TM}(Version 6.5.0.R13). Each set of data was run with the constructed Matlab command to calculate the angles, velocities, and accelerations of the center of mass (COM) of each segment. A matlab-script was constructed to establish local coordinate systems for each segment. The script performed calculations for angles (relative and global), angular velocities (relative, local and global), linear velocities of each marker, angular accelerations and linear accelerations of each marker. Microsoft Excel 2000^{TM} also was used to calculate the maximum values, the minimum values, the mean and standard deviation, and the ranges of the angular displacement. The data was smoothed using a modified Butterworth filter for three dimensions using Euler parameters and quaternions (Vrongistinos, et. al 2001).To study the total movement of the ankle three movements were considered for this study: (1) internal/external rotation (z-axis), (2) inversion/eversion (x-axis) and (3) plantar flexion/dorsiflexion (y-axis). Actual anatomical inversion/eversion is a combination of z- and x-axis rotations. The motion analysed was the propulsive phase since it was during this time that propulsion occurs in the kick and the ankle joint uses the greatest range of motion. The propulsive phase of the kick was defined as the beginning of knee extension until the legs completed their adduction. SPSS 11.5 was used to run linear regression analysis between the dependent and independent variables. To address the hypothesis, mean linear hip velocity in the x- anterior posterior dimension (V_H) was the dependent variable, while the independent variable was the relative angular displacement of the foot (RADF) around the x-, y- and z-axes of the coordinate axis of the tibia. A second set of Linear regressions were performed for each trial with V_H as the dependent variable and local angular velocities (x, y, z) of the foot, shank and thigh (LAV_F, LAV_S, LAV_T) relative to the adjacent segments, as the independent variables to find the contribution of each segment.

RESULTS: This study analysed ankle joint range of motion during the breaststroke kick in college-age competitive swimmers. To determine if the use of ankle range of motion was a significant aspect of the kick, angular displacement of the foot was examined along with hip velocity. The hypothesis was that the relative angular displacement of the foot (RADF) relative to the tibia had a significant correlation to the mean linear hip velocity (V_{Hip}). The range of motion of the foot varied considerably from participant to participant. Mean relative angular displacement of the foot on the x-, y-, and z-axes were 119.10 ± 31.35 º, 145.22 ± 36.37 º and 49.88 ± 19.62 º, respectively. The relative angular displacement of the foot on the x-axis ranged from 81.24º to 171.07º, the y-axis ranged from 102.68º to 205.93º, and the z-axis ranged from 28.68º to 92.27º. The maximum ranges of the RADF along all three of the axes were two to three times greater than the minimum ranges. The ankle range of motion was not associated with $V_{H,}$ (*r*=.4 *p*=.23). Linear regression analysis of RADF (x-, y-, z-axis) found no significant correlation with V_H (*r*=.3 *p*=.41). It is noted that the participant with the highest V_H had the least range of motion; whereas the participants with the highest angular displacements had the ninth and sixth highest V_H respectively. All this results suggests that a large range of motion does not necessarily increase the performance of the kick. Analysis of the local angular velocity for the foot (LAV_F), shank (LAV_S) and thigh (LAV_T), resulted in a few dimensions that had a significant correlation with V_H. The mean local angular velocities in the x-, y-, and z- dimensions for each segment were 66.69 º/s ± 53.24 º/s, -64.43 º/s ± 34.96 º/s, and -80.78 º/s ± 24.47 º/s, respectively.

Linear regression was done individually for each trial to see variations between the trials and which segmental velocities contributed the most to hip velocity. Correlations were calculated for each segment's angular velocities x-, y-, and z- dimensions (independent variable) and the V_H (dependent variable). Analysis between LAV_F (x-, y-, z-dimension) and V_H resulted in some significant correlation for two of the trials in the x-dimension, seven of the trials in the y-dimension and four of the trials in the z-dimension. Nine of the twelve trials resulted in significance for at least one dimension of LAV_F. Correlation between LAV_S (x-, y-, z-dimension) and V_H were significant for two trials in the x-dimension, four trials in the y-dimension and four trials in the z-dimension. Correlation between LAV_T (x-, y-, z-dimension) and V_H resulted in significance for three trials in the x-dimension (β=2.249, *p*=.026; β=1.523, *p*=.000; β=1.156, *p*=.000), three trials in the y-dimension (β=1.991, *p*=.005; β=.807, *p*=.026; β=1.595, *p*=.003) and three trials in the z-dimension (β=1.758, *p*=.015; β=.734, *p*=.017; β=1.592, *p*=.019). It is interesting that all of the participants had at least one dimension of local angular velocity with a significant correlation to linear hip velocity in the x-dimension.

Four different approaches were observed based on variations of segment Two participants predominantly used a thigh and foot approach. Three participants used mainly adduction with most of the contribution from the thigh shank. Three others performed the kick from the knee down, using mainly shank and foot velocities, while four participants displayed a more distributed sequence by using significant contributions to velocity from all three segments. This demonstrated that while there was variation in the movements, there also were specific approaches within the group. The angular velocities of the segments were a significant aspect in the performance. All of the participants had at least one dimension (x, y, z) from one of the three segments (foot, shank, thigh) result in a significant correlation between local angular velocity and V_H. Although there was considerable variability (see Figure 1) as to which segment and which dimension was significant, this shows that angular velocity of the segments in general were important to speed regardless of the segment and dimension.

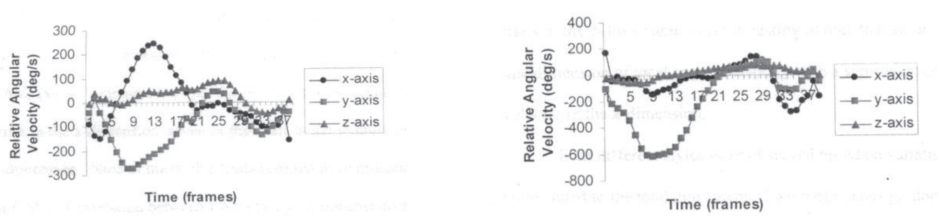

Figure 1: Relative angular velocities of two subjects between foot and thigh. Note similarities on the y-axis in plantar flexion and the variability in other dimensions.

DISCUSSION: The most important implications from this study were the similarities of the movements of the participants. A large use of plantar flexion and inversion is consistent for all the subjects with more variation in the use of internal rotation. Also, continuous movement from one extreme to the other (e.g. full dorsiflexion to full plantar flexion) was apparent in the faster swimmers. This reinforces the idea of using a full sweep with the feet that coaches teach to swimmers. The timing of the ankle movement also has practical implications. The largest ankle movements occurred early in the propulsive phase and the least movement occurred at the end. This was even apparent when looking at the relative velocities and comparing the faster to the slower swimmers. The highest velocities occurred early during plantar flexion for all the participants, while the faster breaststroke swimmers displayed also high inversion velocities in the early phase. Although there was no significant correlation found for the hypothesis, future research may be beneficial to examine a similar hypothesis, but with a larger sample size and more elite level of breaststroke swimmers. Overall, this study contributes to the available data needed to model the breaststroke with few key movements and/or positions of best practices and techniques. The results also contribute to the knowledge applicable to teachers and coaches. It gives more of an insight to the actual segmental movements involved in the breaststroke kick.

The variability of the range of motion was consistent with the observed variation of general swimming techniques. What was surprising was the variability from participant to participant among the faster breaststroke swimmers. Variations in range of motion were expected among the slower non-breaststroke specialists, but at least similarities were expected among the breaststroke specialists. Similar range of flexion, inversion and rotation was expected among the faster breaststroke swimmers, even though the slower swimmers might have a greater degree of variation. This study found no such similarities among the faster participants. In fact, the three participants with the highest V_H had a wide variety of ankle range of motion. In addition, since inversion and internal rotation occurred together as one movement, the measurements of the x- and z-axes both contributed to the inversion of the foot. Complex movements at the ankle such as this make three dimensional analysis difficult, especially to expect findings to show statistically significant results. The current study shows that there was a large degree of variability in the technique and use of the ankle joint in the breaststroke kick. However, these differences in ankle range of motion did not correlate with whether one breaststroke kick was faster or slower. Patterns noticeable with phase diagrams suggest that timing and the use of the range of motion, such as velocity, influence breaststroke kick performance. These patterns were especially apparent for angular movement on the local foot y-axis, placing importance on the use of plantar flexion. Although one of the hypotheses was rejected and the study did not show that there was a statistical correlation between the displacement of the foot and swimming speed, this study does demonstrate the importance of foot speed and the use of the range of motion in the breaststroke kick. The most effective style incorporated the use of a full range of motion among the athletes. More importantly looking individual athletes, there were significant contributions from foot velocity, thus emphasizing the use of the ankle joint.

CONCLUSION: Angular velocity of the foot itself proved to be an important aspect of the breaststroke kick. Nine of the twelve participants showed significant correlation between LAV_F in at least one dimension and V_H. Basically, the greater the foot speed during the early propulsive phase, the greater the hip speed overall.

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