

# BIOMECHANICS OF CANOEING AND KAYAKING

Ralph Mann

Biomechanics Laboratory

University of Kentucky; Seaton Building; Lexington; Kentucky; 40506

Jay T. Kearney

University of Kentucky

Lexington, Kentucky

The strokes used in Olympic-style flatwater racing represent a refinement of attempts to generate a maximum amount of power in the kayak and canoe. The conditions under which Olympic events are contested-flatwater at distances of 500 or 1,000 meters-have led to the emphasis of these "pure power" type of strokes.

The stroke used in the Olympic-style kayak is very similar to the stroke used in any kayak. However, the high-kneeling Olympic canoe stroke is notably different from that employed in most canoes. Since 1978, both of these strokes have been biomechanically investigated to determine the basic motor patterns, as well as provide feedback to the involved performers.\* Performers have included world champions and United States and Canadian national team members. In all cases, the film data were collected under race or simulated race conditions. Measurements taken from the film or subsequently calculated have included displacement, velocity, and acceleration of numerous joint centers, the boat, and the body center of gravity (Kearney, 1979; Mann, 1980).

For purposes of analysis the stroke draw segments (wrist, elbow, shoulder) were defined as those of the bottom arm (closest to the water) while the thrust segments were those of the top arm.

## The Kayak Stroke

The critical movement patterns in the kayak stroke are the movements in the direction of travel, which is horizontal motion in the paddler's sagittal plane (Figure 1). From the air phase of the stroke, the paddler moves to paddle entry (Position 1) by a combination of negative (downward) vertical displacement of the draw segments and positive (forward) horizontal displacement of the thrust segments. From entry (Position 1) through the shaft vertical position (Position 2) until just prior to water-paddle disassociation (Position 3) the primary movement of both the draw and thrust segments is horizontal. As position 3 is approached, however, there is an increase in emphasis on vertical displacement of the draw wrist and elbow. Thus, the movement emphasis during water contact begins with vertical, then becomes horizontal during the majority of the phase, then again shifts to vertical.

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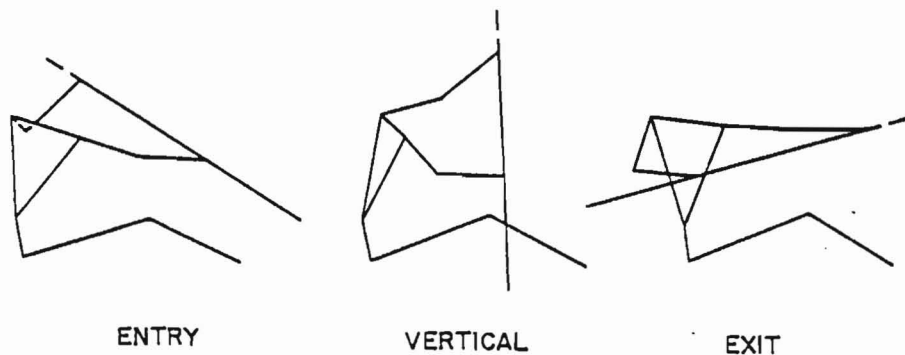


Figure 1. Specific reference positions utilized to describe the kayak stroke. Paddle-water contact (Position 1) is shown as ENTRY, paddle shaft vertical position (Position 2) is identified as VERTICAL, paddle-water disassociation (Position 3) is designated as EXIT, and the paddle-air phase occurs as the performer moves from EXIT toward ENTRY on the opposite side.

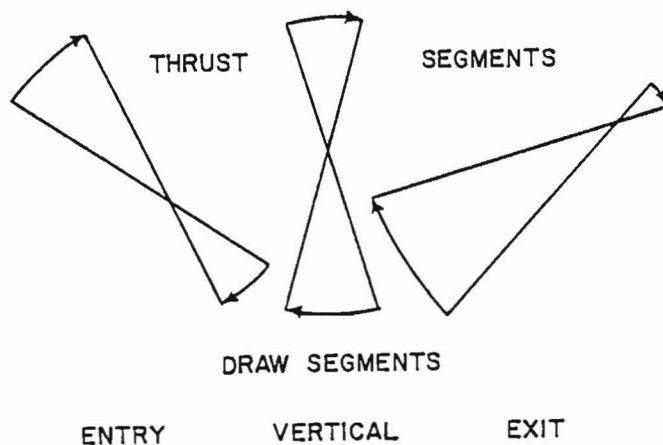


Figure 2. The relative displacement of the paddle pivot point from near the draw segments at ENTRY (Position 1) to near the thrust segments as VERTICAL (Position 2) and EXIT (Position 3) are achieved. The example is taken from an actual stroke with each position shown rotating an equal number of degrees.

Regarding the absolute (external reference) horizontal velocity of the thrust and draw wrists, the kayak, and the body center of gravity (CG) during paddle-water contact, the maximum velocity of the thrust segments precedes the minimum velocity of the draw segments. Referencing these actions to the relative velocity of the boat, maximum thrust segment velocity indicates the upper portion of the paddle is being moved much faster than the boat and performer, while the minimum draw segment velocity occurs when the lower blade is virtually fixed in the water and the boat and paddler are being pulled by. As shown in Figure 2, this relative movement pattern indicates that, at paddle entry, the paddle pivot point is located near the draw wrist, with the majority of the angular rotation being produced by the thrust segments. As the stroke progresses, the pivot point is shifted up the paddle as the draw segments achieve dominance in horizontal displacement. Since it is generally recognized that the maximum absolute horizontal acceleration of the boat occurs at and around the vertical paddle position, the most effective stroke would be one that rapidly achieves this position, then extends it as long as possible. The push action of the thrust segments, followed by the pull action of the draw segments coupled with rotation of the trunk, accomplishes this goal. As shown in Figure 2, the achievement of maximum thrust segment velocity immediately following paddle entry places the paddle pivot point near the draw wrist. This type of rotation rapidly moves the paddle toward the vertical power position. Subsequent to achieving this power position, the pivot point is shifted toward the top of the paddle as the draw segments reach minimum absolute velocity. This action, coupled with trunk rotation, extends the time the paddle remains at and around the vertical position, thus maximizing the most effective portion of the stroke. The assumption that the most effective phase of the stroke is around Position 2 is validated by the fact that the maximum horizontal boat acceleration occurs at this time.

The typical kayak and body CG absolute horizontal velocity patterns indicate that the boat decelerates as the the body CG shifts forward prior to paddle entry. This action-reaction is followed by a period of boat horizontal acceleration beginning immediately prior to and continuing through Position 2. Peak boat horizontal velocity is achieved about half-way between Position 2 and Position 3. From this point through paddle exit, the boat decreases its horizontal velocity. Throughout paddle-water contact, the body CG remains at a fairly constant velocity, allowing the boat to move under the body. These results further support the critical role the motion around the vertical paddle position plays in propelling the performer and kayak.

The absolute horizontal movement patterns of the joint centers of both upper limbs demonstrates that: (1) in both the thrust and draw segments the velocity patterns of the wrist and elbow are very similar; (2) the velocity patterns of both shoulders are similar to, but of a lower magnitude than their respective wrist and elbow; (3) peak thrust wrist and elbow velocities occur between Position 1 and 2 while minimum draw wrist, elbow, and shoulder velocities were obtained between Position 2 and Position 3; and (4) peak thrust shoulder velocity is delayed to occur at approximately the same time as the maximum velocity of the draw segments. This indicates that the thrust wrist and elbow are the major joints involved in the push

action as paddle entry is achieved. The involvement of the thrust shoulder is however, delayed to correspond with the action of the draw joints. This indicates that, while the thrust arm is accomplishing the push, the pull or power position involves not only the draw arm but the powerful trunk rotators as well.

The angular position of the paddle at the entry and exit positions make it a poor force producer in the horizontal direction. The rapid paddle rotation produced by the thrust segments at entry allows the paddler to generate some effective force during the initial portion of paddle-water contact, however, the final portion of paddle-water contact does not have this advantage and therefore should be terminated as quickly as possible to avoid dragging the paddle. Thus, as the paddle passes the vertical position, the absolute vertical acceleration of the draw wrist and elbow increases to allow for rapid paddle exit. In addition, the performer rotates the paddle along the long axis to decrease the projected area and, therefore, the force necessary to pull it from the water.

Finally, during the initial and final portions of paddle-water contact, while the wrist and elbow are accelerating vertically, there is minimal vertical acceleration of the draw shoulder. To accomplish this, the performer must transfer as much of the body mass as is necessary onto the paddle to oppose the reactive vertical force between Position 1 and Position 2. Then, from Position 2 to Position 3, the vertical force is reversed since the performer is attempting to pull the blade from the water. If this shifting of body mass can be coordinated with cyclical variations in vertical force, the performer will minimize the lateral rotation of the boat and, consequently, reduce additional drag.

### The Canoe Stroke

As in the kayak stroke, the critical movement patterns in the canoe stroke occur in the direction of travel, which is horizontal motion in the paddler's sagittal plane (Figure 3). From the air phase of the stroke, the paddler moves to paddle entry (Position 1) by a combination of negative (downward) vertical displacement and positive (forward) horizontal displacement of both the draw and thrust segments. Just prior to water entry, the draw segments action is dominated by vertical displacement, while the thrust segment emphasis becomes more horizontal in nature. From entry (position 1) through the shaft vertical position (Position 2) until just prior to paddle exit (Position 3) the primary movement of both the draw and thrust segments is a combination of horizontal and vertical displacement. As position 3 is approached, however, an increase of vertical emphasis in both groups of segments is produced.

As in the kayak stroke, the absolute maximum horizontal velocity of the thrust segments precedes the minimum horizontal velocity of the draw segments. This is where the similarities, however, come to an end. The maximum draw segment horizontal velocity occurs at paddle entry, which brings the canoe paddle to the vertical position very early in the stroke. This action is quickly followed by the minimum horizontal velocity of the draw segments. Halfway through the paddle-water contact, the horizontal velocities of the thrust and draw segments rapidly approach equality,

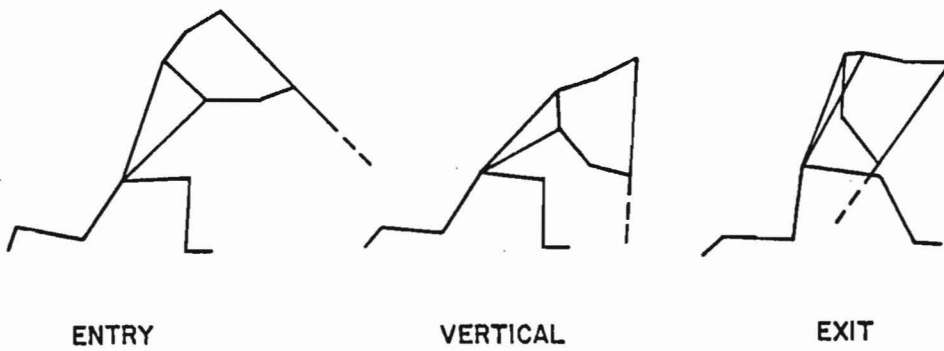


Figure 3. Specific reference positions utilized to describe the canoe stroke. Paddle-water contact (Position 1) is shown as ENTRY, paddle shaft vertical position (Position 2) is identified as VERTICAL, paddle-water disassociation (Position 3) is designed as EXIT, and the paddle-air phase occurs as the performer moves from EXIT toward ENTRY on the opposite side.

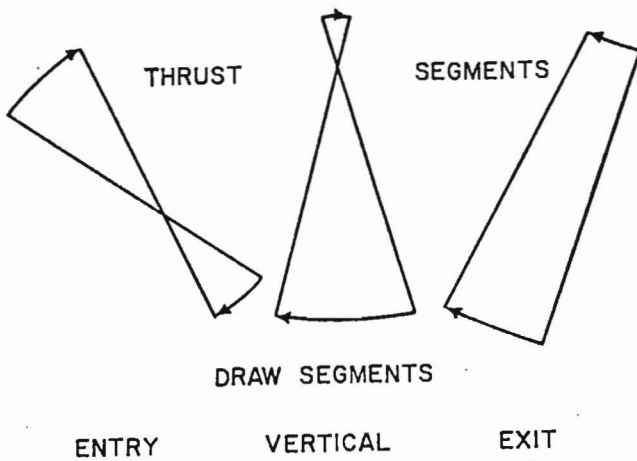


Figure 4. The relative displacement of the paddle pivot point from near the draw segments at ENTRY (Position 1) to near the thrust segments as VERTICAL (Position 2) is achieved. As EXIT (Position 3) is approached, trunk extension, not rotation, is used to produce most of the paddle movement.

quickly decreasing the rotation of the paddle (see Figure 4). Thus, by the time the stroke has progressed to this point, the benefit derived from rotating the paddle while in contact with the water has been virtually completed.

Although the obvious contributions of the thrust and draw segments has been completed by the time the paddle-water contact phase has progressed just past the halfway point, the ability of the performer to alter the motion of the system has not ended. Due to the fact that the canoe position is a high-kneeling situation, it allows major involvement of the trunk and legs. During the initial portion of paddle-water contact, the trunk is flexed, producing the extreme vertical displacement in the thrust and draw segments not found in the kayak stroke. Then, once the thrust and draw segments have essentially completed their contribution, the trunk is quickly extended, moving the body forward with respect to the boat. Once the trunk has completed its contribution, there is a period of paddle-water contact that is detrimental to horizontal velocity. This continuation of the stroke is necessary, however, since steering must be accomplished prior to paddle exit.

The typical canoe and body CG absolute velocity patterns indicate that the boat decelerates as the body CG shifts forward prior to paddle entry. This action-reaction is followed by a period of boat horizontal acceleration beginning immediately prior to entry (Position 1) and continuing to Position 2. Peak boat horizontal velocity is achieved around Position 2 and maintained until the steering action slows the boat. At entry, the body CG decelerates as trunk flexion shifts the body back. After Position 2 is achieved, trunk extension accelerates the body CG forward. As with boat velocity, some body CG velocity is lost during steering. The relatively large body CG change in horizontal velocity, in comparison to the kayak stroke, is again produced by the high-kneeling position in the canoe stroke, which allows more total body movement in relationship to the boat.

Finally, due to the large vertical movements caused by trunk flexion in the initial portion of paddle-water contact, it is critical that the performer transfer this vertical force to the paddle and not the boat. Since the exit action is not as vigorous due to the need for steering, the vertical forces are not as great a problem.

### Conclusions

The research into the kayak stroke has identified the activity as a bilateral paddling action dedicated to using the paddle-water contact phase to efficiently maintain horizontal velocity. This is accomplished by quickly rotating the paddle to the vertical position using the thrust segments, then using the draw segments and trunk (rotation) to get the most out of the "power phase" of the action. The paddle-water contact phase of the canoe stroke is similarly used to maintain horizontal velocity, however, due to the high-kneeling position and unilateral characteristics of the event, the mechanics are somewhat altered from the canoe stroke. As in the kayak stroke, the thrust segment followed by draw segment horizontal action quickly brings the paddle vertical and efficiently used the "power position" of the stroke. Once this action has been completed, the trunk is extended to continue to produce horizontal velocity. Due to the unilateral nature of the canoe stroke, detrimental paddle-water contact must be extended to accomplish steering.

## REFERENCES

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