INFLUENCE OF LOWER EXTREMITY JOINT MOTIONS ON THE EFFECTIVENESS OF THE KICK IN BREASTSTROKE SWIMMING

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The study investigated how characteristics of an effective whip kick were influenced by movements of the feet relative to the hip and by the lower-extremity joint angles during the whip kick execution. Breaststroke swimmers of different skill levels were videotaped performing whip kick sprints. The obtained three-dimensional coordinates of selected body landmarks were used to determine the lower extremity joint angles and other pertinent characteristics of the whip kick. The results indicate that an effective downsweep is characterized by a small hip abduction angle, a negligible external hip rotation, partial hip extension, and increasing internal knee rotation. An effective insweep is characterized by negligible hip rotation, and ankle plantarflexion and inversion that were fine-tuned to the orientation of the other joints and the overall movement velocity.

KEY WORDS: whip kick, skill level, leg joint motions, videography

INTRODUCTION: It is recognized that the breaststroke kick, especially the whip kick, makes a major contribution to the forward propulsion in breaststroke (Reischle, 1988; Mason et al., 1989; Kippenhan, 1991). The whip kick is considered to be the most propulsive kick of the four competitive strokes (Yeater et al., 1980), if executed correctly. However, breaststroke is also considered a technically difficult stroke (Colwin. 1992; Counsilman & Counsilman, 1994). The difficulties are generally associated with the whip kick, which consists of a complicated sequence of motions of the hip, knee, and ankle joints. One problem commonly encountered is a kick that seems to be executed correctly but the swimmer gets little propulsion from the kicking action. Based on the movements of the feet and the body, the whip kick is generally subdivided into four phases or sweeps: (1) recovery (2) downsweep, (3) insweep, and (4) glide (Maglischo, 1993). Of these four phases, the downsweep and insweep have proven to be the most important phases with regard to the effectiveness of the kick (Kippenhan, 2001). It has been shown that during the downsweep the most distinguishing kinematic characteristic of an effective kick is the movement direction of the feet relative to a pool-fixed reference system (Kippenhan, 2001). The less skilled the swimmer, the more the downsweep is dominated by movements in the outward direction. In more skilled swimmers, movements in a downward direction tend to dominate the kicking motion. In addition, in more skilled swimmers the movement direction of the feet is well suited for generating favorable angles of attack (Kippenhan, 2001). It has also been shown that during the insweep the most distinguishing kinematic characteristic is the orientation of the feet relative to a pool-fixed reference system. In the skilled swimmers, the feet were oriented such that (1) the toes pointed toward the bottom of the pool, (2) the soles faced in the movement direction of the feet, and (3) the toes were not pointed against the movement direction of the feet. Therefore, the foot orientations of the skilled swimmers were better suited to generate favorable angles of attack than were those of their less skilled counterparts (Kippenhan, 2001). However, swimmers do not perceive the movements and orientations of their limbs relative to a pool-fixed reference system, but a trunk-fixed reference system. The purpose of this study was to investigate how the distinguishing kinematic characteristics of an effective whip kick were influenced by the movements of the feet relative to the hip and by the angles of the lower-extremity joints during the execution of the whip kick.

METHODS: Twenty-nine swimmers (18 collegiate varsity swimmers, 11 recreational swimmers) volunteered to participate in the study. The whip kick of all subjects was in compliance with the rules of the Federation Internationale de Natation Amateur (FINA). The kicking effectiveness or skill level (1 = very ineffective, 8 = very effective) of each subject was determined subjectively by two experienced swim coaches with no prior knowledge of the swimmer's skill level. Each subject was asked to swim two 22.9 m breaststroke sprints with the hands and arms supported by a kick board. Two Styrofoam balls (2.5 cm diameter) were attached to the sides of the feet at the level of the first and fifth metatarsal-phalangeal joints, so the orientations of the soles of the feet could be determined. Panasonic camcorders fixed to two custom-made panning periscope systems (Yanai et al., 1996) were used to record the above and below water motions of the swimmers at 60 Hz. For each subject, one trial was digitized using a Peak Motion Measurement System (Peak Performance Technologies, Englewood, CO, USA). Sixteen body bndmarks were digitized to define a 7-segment model of the lower extremities and the trunk, including the orientations of the soles of the feet. The obtained 2D coordinate data were smoothed using a Butterworth filter with a cutoff frequency of 6 Hz, based on a Fourier analysis of the raw data, and used as input to custom-made software to determine the corresponding 3D coordinates (Yanai et al., 1996). The 3D coordinates were used to compute the following variables: (1) movement direction of the ankle relative to a hip-fixed reference system, (2) hip joint angles (abductionladduction, flexionlextension, internallexternal rotation), (3) knee joint angles (flexionlextension, internallexternal rotation), (4) ankle joint angles (dorsiflexion/plantarflexion, inversionleversion). (5) angles of attack (pitch and sweepback angle), (6) movement velocity of the center of gravity relative to a pool-fixed reference system. All obtained angle and velocity data were smoothed again using a Butterworth filter with a cut-off frequency of 6 Hz. Linear regression analysis with a level of significance of 0.05 was used to test for significant relationships between skill levels and the dependent variable of interest at selected instants throughout the different phases (0%, 20%, 50%, 80%, and 100% of each phase).

RESULTS AND DISCUSSION:

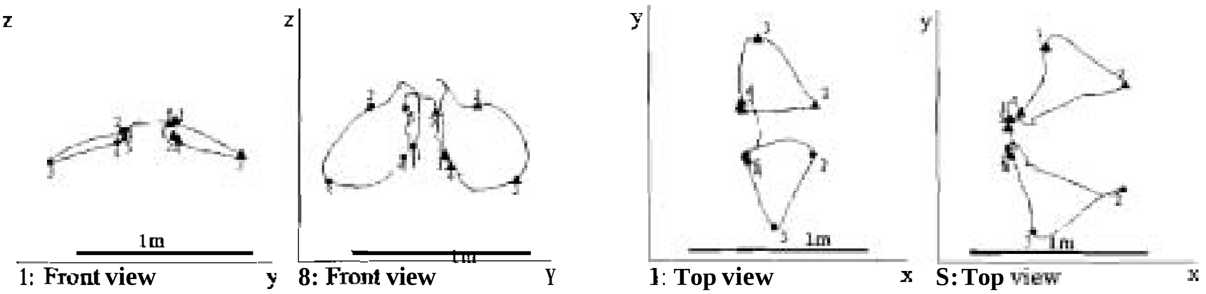

Figure **1 –** Movement pattern of the ankle relative to the hip for **a** subject of skill level **1** and 8 **(1-2** recovery, **2-3** downsweep, **3-4 insweep, 4-5** glide, swimming direction: left to right).

Recovery. The purpose of the recovery is to bring the legs and feet into a position from which a swimmer can generate forces that propel the body forward (catch position). For most variables, large standard deviations within the different skill levels resulted in few significant relationships between skill level and the dependent variables being found. Apparently, it is more important *that* the catch position is obtained than how it is obtained. However, differences among skill levels could be seen in the catch position. The more skilled the swimmers, the less external hip rotation ($p \leq 0.005$), the less internal knee rotation ($p \leq 0.05$), and the more ankle inversion ($p \leq 0.05$) they exhibited. These observations do not support the general consensus in the coaching literature about the joint angles at the catch position. In addition, the more skilled the swimmers, the further apart their ankle joints were in the catch position ($p \leq 0.001$). For the swimmers of the weaker skill levels, the ankle joints were less than shoulder width apart, while for the swimmers of the stronger skill levels the joint ankles were up to 0.30 m further apart than shoulder width. It should be noted that for all skill levels the knee joints were on the average more than shoulder width apart.

Downsweep. Statistical analysis showed that the less skilled the swimmers, the more the movement direction of the feet relative to the hip-fixed reference system was dominated by the outward direction ($p \leq 0.001$), and the more skilled the subjects, the more important were the overall downward ($p \leq 0.005$) and backward movements ($p \leq 0.001$) of the ankle joints (Figure 1). The movement of the ankle joint relative to the hip joint is determined by the movements of the knee joint relative to the hip joint and of the ankle joint relative to the knee joint. The movement of the knee joint relative to the hip joint is influenced by hip flexionlextension and hip abductionladduction. Significant relationships could only be found between skill level and hip abduction, indicating that the more skilled the swimmers, the smaller the hip abduction angle they maintained ($p \leq 0.001$). While the swimmers of the higher skill levels almost maintained their hip abduction angle, the swimmers of the lower skill levels increased the hip abduction angle throughout the course of the downsweep. The movement of the ankle joint relative to the knee joint is influenced by knee flexionlextension and hip internallexternal rotation. Significant relationships could only be found for the hip rotation, indicating that more skilled subjects maintained the smallest external hip rotation angles ($p \leq 0.005$). This showed that the differences found in hip abduction and external hip rotation are primarily responsible for the observed differences in the overall movement direction of the ankle joints. The larger the hip abduction and external hip rotation angles, the larger the movement of the ankle in an outward direction when the knees are being extended, as shown by the less skilled subjects. Knee rotation and ankle joint angles are used to fine-tune the foot orientations. The foot orientations are influenced by an intricate combination of all lower extremity joint angles. Discussions in the literature about the angles of attack (Schleihauf, 1979; Firby, 1975) indicate that whenever possible the medial side of the foot should be the leading edge with the sole of the foot pitched in movement direction and against swimming direction. However, differences with regard to the effectiveness of the downsweep were primarily caused by the movement direction of the feet. Thus, athletes should primarily focus on achieving the proper movement direction, and only once proper movement direction has been achieved should the focus change to the foot orientation.

Insweep. For the insweep, no significant relationships between skill levels and the overall movement direction of the feet relative to the hips could be found. For all skill levels the inward direction was the dominant movement direction. This observation held true for selected instants throughout the insweep (Figure 1). With a knee flexion angle of less then 15" for the majority of the insweep, the movement direction of the feet relative to the hips was primarily influenced by hip and knee flexionlextension and by hip abductionladduction. Little to no changes in hip and knee flexion angles could be observed during the first 80% of the insweep, while all swimmers showed similar decreases in hip abduction angle. This suggests that the movement direction is primarily driven by hip adduction. However, statistical analysis indicated that, on the average, the more skilled the subject the smaller a hip abduction angle they maintained ($p \leq 0.001$) throughout the insweep. It was noted that the lower skill levels did not adduct at the hip to the same extent as the higher skill levels, and started flexing the knees toward the end of the insweep. In addition, these skill levels also tended to exhibit no glide. It appears that the less skilled swimmers abort the insweep phase early and rush into the recovery. While hip and knee flexionlextension and hip abductionladduction are primarily used to influence the movement direction of the feet, the remaining joint angles are used to fine-tune the foot orientation to obtain more favorable angles of attack. The combination of joint angles used depends on all lower extremity joint angles as well as the movement velocity of the center of gravity. For a favorable sweepback angle, the medial edge of the foot should be the leading edge with the toes pointing toward the bottom of the pool. Due to the small knee flexion values observed during this phase, it is primarily the hip rotation and ankle flexion that are responsible for determining the leading edge of the foot. Statistical analysis indicated, that the less skilled the swimmers, the larger the external rotation value observed ($p \leq 0.001$), and thus the less it was suited for generating a favorable sweepback angle. Statistical analysis furthermore indicated that the more skilled swimmers exhibited more plantartlexion ($p \leq 0.05$). However, to obtain a favorable foot orientation the ankle flexion needs to correspond to the hip flexion value. The larger the hip flexion value (as exhibited by the more skilled swimmers) the more plantarflexion is needed to obtain a favorable foot orientation. The angle of pitch is dependent on the movement velocity of the center of gravity. The faster the movement velocity, the more the soles of the feet need to be facing each other (Kippenhan, 2001), thus the more ankle inversion is needed to obtain a favorable angle of pitch. Significant relationships between skill level and ankle inversion indicated that the more skilled the subjects, and thus the faster the movement velocity, the larger was the ankle inversion angle observed ($p \leq 0.001$).

Glide. No major changes in joint angles could be observed for the glide phase. It was previously suggested that the glide could be looked at as the follow-through of the insweep, to bring the movements of the insweep to a conclusion and that its existence is important for the proper timing between arm and leg motions in the breaststroke (Kippenhan, 2001). As such, the existence of the glide is of importance other than to maintain as streamlined a position as possible.

CONCLUSIONS: The findings of this study supported the following conclusions:

1. A leg'position at the end of the downsweep with an average hip flexion angle of 55°, an average hip abduction angle of 30" and almost negligible hip and knee rotation was important to obtain an optimum starting position for the ensuing downsweep.
2. An effective movement direction of the feet during the downsweep was obtained by maintaining a small hip abduction angle (knees about shoulder width apart) and a negligible hip rotation angle while extending the knee joints and partially extending the hip joints. The more skilled swimmers exhibited a hip flexion angle of about 25" at the end of the downsweep.
3. The downsweep was more effective when a foot orientation with the toes pointing outward was maintained as long as possible by increasing the external knee rotation in the course of the downsweep.
4. The foot orientation during the insweep was primarily modified with hip rotation, ankle plantarflexion and inversion. An effective kick was characterized by little, if any, external hip rotation, while the plantarflexion and inversion angles were adjusted to hip and knee flexion angle and the movement velocity of the center of gravity, respectively. Of the above-mentioned joint motions, the hip rotation was the most important joint motion for determining the effectiveness of the insweep.
5. The insweep should be brought to a full completion by keeping the knees extended until the legs are fully adducted.

REFERENCES:

Colwin, C.M. (1992). Swimming into the *21st* century. Champaign, IL: Leisure Press.

Counsilman, J.E., & Counsilman, B.E. (1994). The new science of swimming. Englewood Cliffs, NJ: Prentice Hall.

Firby, H. (1975). Howard *Firby* on Swimming. London: Pelham Books.

Kippenhan, B.C. (1991). *Überprüfung* der *Geschwindigkeit-Zeit-Verlaufe* bei D-Kader SchwimmerInnen *mittels* der *Sensor-Video-PC-Kopplung.* Ruprecht-Karls-Universitat Heidelberg, Germany: Unpublished thesis.

Kippenhan, B.C. (2001, May). Distinguishing kinematic parameters of an effective kick in breaststroke swimming. Paper presented at the annual meeting of the American College in Sports Medicine, Baltimore, MD.

Maglischo, E.W. (1993). Swimming even faster. Mountain View, CA: Mayfield.

Mason, B.R., Patton, S.G., & Newton, A.P. (1989). Propulsion in breaststroke swimming. In W.E. Morrison (Ed.), Proceedings of the VII International Symposium on Biomechanics in *Sport* (pp. 257-267). Melbourne, Australia: Footscray Institute of Technology.

Reischle, K. (1988). Biomechanik des Schwimmens. Bockenem, Germany: Fahnemann.

Schleihauf, R.E. (1979). A hydrodynamic analysis of swimming propulsion. In J. Terauds & E.W. Bedingfield (Eds.), Swimming 111 (pp. 70-109). Baltimore: University Park Press.

Yanai T., Hay, J.G., & Gerot, J.T. (1996). Three-dimensional videography of swimming with panning periscopes. Journal of Biomechanics. **29,** 673-678.

Yeater, R.A., Martin, R.B., White, M.K., & Gilson, K.H. (1980). Tethered swimming forces in the crawl, breast and back strokes and their relationship to competitive performance. Journal of Biomechanics, **14,** 527-537.