LOWER-EXTREMITY JOINT ANGLES USED DURING THE BREASTSTROKE WHIP KICK AND THE INFLUENCE OF FLEXIBILITY ON THE EFFECTIVENESS OF THE KICK

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The study investigated the range of lower-extremity joint angles exhibited during the execution of the whip kick and the influence of the active range of motion (aROM) of these joints on the effectiveness of the kick. Swimmers of different skill levels were videotaped performing whip kick sprints and standard aROM assessment tests. The obtained three-dimensional coordinates of selected body landmarks were used to determine range of lower-extremity joint angles during the whip kick and the aROM of these joints. The results indicated that while for swimmers with below average flexibility, many joint motions can limit the effectiveness of the whip kick; the external knee rotation was the joint motion most likely to do so. Furthermore, improvements in kicking speed have to be accompanied by improvements in the ankle inversion aROM.

KEY WORDS: whip kick, skill level, range of motion, 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 requires a well-coordinated sequence of motions of the hip, knee, and ankle joints. Experts claim that a good range of motion (ROM) of the lower-extremity joints is essential for a successful whip kick (Wilke & Madsen, 1983; Maglischo, 1993; Counsilman & Counsilman, 1994). The results of previous studies indicated that the faster breaststrokers had greater ROM for external knee rotation, ankle inversion, and plantarflexion than slower swimmers (Vervaecke & Persyn, 1979, Daly et al., 1988), and that swimmers with good ROM were more likely to succeed in swimming a technically correct whip kick (Nimz et al., 1988). Kippenhan (2001) reported that an effective movement direction of the feet during the downsweep was obtained by maintaining a small hip abduction angle (about 30°) and a negligible hip rotation angle while extending the knee joints and increasing the external knee rotation. She furthermore reported that an effective insweep 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 (the more skilled the whip kickers the larger the plantarflexion and inversion angles exhibited). Hip rotation was the most important joint motion for determining the effectiveness of the insweep. However, none of these studies examined in how far active ROM limited the effectiveness of the whip kick, i.e., in how far swimmers reached the limits of their active ROM while executing the whip kick. The purpose of this study was to investigate the range of lower-extremity joint angles exhibited during the execution of the whip kick and the influence of the active ROM of the lower-extremity joints on the effectiveness of the whip kick.

METHODS: Twenty-eight swimmers (18 collegiate varsity swimmers, 10 recreational swimmers) volunteered to participate in the study and signed consent forms. The whip kick of all subjects was in compliance with the rules of the Fédération 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. To determine the range of lower-extremity joint angles (JA_{max}) exhibited during the execution of the whip kick, each subject was asked to swim two 22.9 m breaststroke sprints with the hands and arms supported by a kick board. 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. In addition, each subject was videotaped by two camcorders while performing ROM tests adapted from standard ROM assessment methods (Clarkson & Gilewich, 1989) to determine the active ROMs (aROM) of hip, knee, and ankle joints. Each ROM test was repeated 3 times. For both data collection session, two Styrofoam balls (2.5 cm diameter) were attached to the sides of the subjects' feet at the level of the first and fifth metatarsal-phalangeal joints, so that ankle JA_{max} and aROM could be determined. For each subject, one trial of each test was digitized using a Peak Motion Measurement System (Peak Performance Technologies, Englewood, CO, USA). Sixteen body landmarks were digitized to define a 7-segment model of the lower extremities and the trunk. 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 JA_{max}, aROM, and the difference between JA_{max} and aROM for the following lower-extremity joint motions: hip abduction and adduction, hip flexion and extension, hip internal and external rotation, knee flexion and extension, knee internal and external rotation, dorsiflexion and plantarflexion, and inversion and eversion. The 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.

RESULTS AND DISCUSSION: The aROM and JA_{max} for selected joint motions are shown in Table 1 and 2, respectively. Any time that close to full ROM of a joint motion is used during the kicking action, the possibility exists that the ROM of this joint might prevent a swimmer from succeeding in the whip kick. This may pertain to skill levels as a whole or to individual subjects. For all joint motions, the obtained aROM values agreed well with the 'normal active range of motion' values reported by Clarkson & Gilewich (1989). Significant relationships between aROM and skill level were found for hip extension ($p \leq 0.05$), external knee rotation ($p \leq 0.05$), and ankle inversion ($p \leq 0.05$). However, the significant relationships were primarily due to the markedly smaller aROM values exhibited by the subjects of the weakest skill level (skill level 1). If a near-full ROM of the above-mentioned joint motions was used during the kicking actions, the subjects of skill level 1 were the ones most likely to encounter problems during the execution of the whip kick. Furthermore, large standard deviations were found especially for the aROM of internal and external hip and knee rotation. This meant that the ROM of these joint motions might become a limiting factor to the effectiveness of the kick for individual subjects rather than for a skill level.

Table 1. aROM observed for selected joint motions. Standard deviations are given in parenthesis.

Joint motion	Skill level								Regression Results
	8	7	6	5	4	3	2	1	
Hip extension	12°	10° (8°)	13° (2°)	12° (9°)	4° (4°)	10° (2°)		0° (14°)	$p \leq 0.05$ $r^2 = 0.175$
Int. hip rotation	40°	36° (8°)	29° (14°)	33° (12°)	34° (18°)	35° (1°)	38°	24° (9°)	Not significant
Ext. hip rotation	53°	37° (8°)	44° (11°)	38° (6°)	42° (14°)	33° (1°)	71°	33° (8°)	Not significant
Int. knee rotation	38°	29° (10°)	33° (11°)	25° (9°)	34° (4°)	33° (10°)	33°	33° (13°)	Not significant
Ext. knee rotation	78°	50° (8°)	50° (6°)	37° (15°)	37° (16°)	47° (10°)	51°	38° (8°)	$p \leq 0.05$ $r^2 = 0.154$
Inversion	65°	46° (13°)	54° (4°)	42° (9°)	45° (4°)	42° (9°)	52°	34° (10°)	$p \leq 0.05$ $r^2 = 0.213$
Eversion	15°	11° (9°)	17° (18°)	13° (12°)	8° (3°)	17° (10°)	12°	12° (10°)	Not significant

Hip flexion, abduction, adduction, and external rotation, and knee internal rotation: For the following joint motions the subjects did not use the full ROM while kicking and they therefore should not be a limiting factor for succeeding in the whip kick: hip flexion, hip abduction, hip adduction, hip external rotation, knee internal rotation.

Table 2. JA_{max} observed for selected joint motions. Standard deviations are given in parenthesis.

Joint motion	Skill level								Regression Results
	8	7	6	5	4	3	2	1	
Int. hip rotation	4°	3° (5°)	3° (2°)	-2° (4°)	-2° (3°)	0° (3°)	3°	-3° (4°)	$p \le 0.05$ $r^2 = 0.197$
Ext. knee rotation	43°	39° (5°)	35° (10°)	32° (10°)	24° (10°)	37° (2°)	42°	25° (7°)	$p \le 0.05$ $r^2 = 0.175$
Inversion	57°	51° (12°)	45° (2°)	42° (8°)	45° (8°)	38° (6°)	27°	30° (5°)	$p \le 0.001$ $r^2 = 0.499$
Eversion	-13°	-8° (6°)	-7° (6°)	-4° (5°)	6° (2°)	-2° (8°)	-2°	3° (7°)	$p \le 0.001$ $r^2 = 0.324$

Note: Negative numbers indicate that overall the subjects of this skill level did not exhibit the joint motion during the kicking action, e.g. overall the subjects of skill level 5 did not exhibit internal hip rotation but the smallest mean external hip rotation angle was 2°.

Hip extension, knee flexion and extension, and dorsiflexion: For hip extension, knee flexion and extension, and dorsiflexion all subjects used the full ROM during the kicking action. However, across all skill levels subjects exhibited similar values and no subject exhibited unusually large JA_{max} or aROM values. These joint motions would only be a limiting factor for succeeding in the whip kick, if athletes have a below average aROM.

Internal hip rotation, and ankle eversion: This study did not support the expert opinion that internal hip rotation and ankle eversion are important factors for succeeding in the whip kick (Maglischo 1993; Counsilman 1968). Most subjects used very little internal hip rotation and no subject came close to using the full ROM. Also, most subjects of the more effective skill levels did not use eversion during the kicking action. The eversion JA_{max} displayed by the skilled subjects were smaller than the smallest eversion aROM exhibited by any subject. This indicated that neither internal hip rotation nor eversion should be a limiting factor for succeeding in the whip kick and are, therefore, not as important for the effectiveness of the kick as is often assumed.

External knee rotation: The more skilled the subjects were, the larger the external knee rotation JA_{max} ($p \le 0.05$). Subjects of some weaker skill levels had mean external knee rotation aROMs that were smaller than the mean maximum external knee rotation JA_{max} displayed by most skilled subjects. The skilled subjects exhibited the largest external knee rotation JA_{max} towards the end of the downsweep. Kippenhan (2001) indicated that increasing the external knee rotation during the downsweep was essential for maintaining a more propulsive foot orientation as long as possible. This indicated that the external knee rotation aROM was a factor that could limit the effectiveness of the kicking actions.

Ankle inversion: Significant relationships existed between inversion aROM ($p \le 0.05$), inversion JA_{max} ($p \le 0.001$) and skill level: the more skilled the subjects, the larger the inversion angles. The inversion JA_{max} exhibited by the skilled subjects was larger then the inversion aROM of less skilled subjects. Inversion was used during the insweep for optimal foot orientation and the faster the swimmer the more inversion is necessary to obtain proper foot orientation (Kippenhan, 2001). Thus, even though full ROM was not used by most subjects, inversion aROM might become a limiting factor for swimmers with poor inversion aROM as they improve swimming speed.

CONCLUSIONS: The findings of this study supported the following conclusions: A) No above average aROM values were observed, and with exception for hip extension, external knee rotation, and ankle inversion, no significant relationships were found between skill level and aROM. However, for many joint motions, the values of JA_{max} were close to the values of aROM. Thus, for swimmers with below average flexibility many joint motions may limit the effectiveness of the kick. B) Internal hip rotation and ankle eversion were not as important for the effectiveness of the kick as often assumed. C) External knee rotation was identified as the joint motion most likely to limit the effectiveness of the kick, especially during the downsweep. D) Improvements in the effectiveness of the kick have to be accompanied by improvements in the inversion aROM to enable an optimal orientation of the feet during the insweep.

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