KINETIC ANALYSIS OF START MOTION ON STARTING BLOCK IN COMPETITIVE SWIMMING

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The aim of this study was to investigate kinetic features of start motion with use of an instrumented starting block. This is the first study that quantified joint torques of the whole body during start motion. Six male swimmers dived from the instrumented starting block, which contains force plates and sensors. Four high-speed cameras were used to obtain kinematics data of the swimmers. Inverse dynamics calculation was carried out with use of the kinetics and kinematics data. The results showed that 1) the large pulling up forces exerted by both hands were generated by extension torques of the shoulder joints, 2) the rear side lower limb joints exerted large extension torque to obtain horizontal reaction force, and 3) the knee joint of the front side lower limb exerted large flexion torque to maintain the large vertical reaction force until 60% normalized start motion time.

KEY WORDS: reaction force, joint torque, kinetic analysis, competitive swimming start motion

INTRODUCTION: Swimmers dive into a pool from starting block in competitive swimming except for the case of backstroke. Since drag force that swimmers receive from above water is considerably smaller than that from below water, swimmers achieve the fastest velocity in this start phase during the race events. Maglischo (2003) reported that the start times, defined as the duration from start signal to the instance when the head of swimmer reaches 15m distance point, accounts for approximately 5% and 25% of the times in 100 m and 25 m races, respectively. This study indicates that an improvement of start skill can reduce race time by a minimum of 0.10 sec. Since the time difference, such as 0.01 sec, would change the results of race in competitive swimming, start motion is one of the important factors that determine the outcome of race.
Previous studies on swimming start motion investigated the kinematic parameters of swimmers; such as, take-off velocity, take-off angle, joint angle and angular velocity, through video analysis (Robert et al., 2008; Alptekin, 2014; Ozeki et al., 2012; Takeda et al., 2012). The horizontal component of the take-off velocity, which is the most important factor of the parameters, is generated by the forces exerted by the upper and lower limb joints. However, previous studies on kinetics of start motion measured non-concurrently the forces exerted by upper and lower limbs (Mason et al., 2007; Slawson et al., 2012a, 2012b; Honda et al., 2012). Few study calculated the lower limb joint torques. Furthermore, no study calculated the upper limb joint torques during the starting motion.
The aim of this study was to investigate the kinetic features of the individual joints of the upper and lower limbs with use of an instrumented starting block, which enables us to measure the force exerted by each limb of the upper and lower limbs.

METHODS: Six male swimmers (age: 20.0 ± 0.9 yrs, height: 171.9 ± 4.3 m, weight: 66.1 ± 5.8 kg, FINA point: 684 ± 26.6) participated in this study. All participants had qualified to get in the Japan National Championships in swimming. After enough warm-up, the participants with 25 target points marked on their body practiced three dive starts with maximum effort from an instrumented starting block (Fig. 1).
The starting block contains 1) force plate (9253B11, Kistler Co., 1000Hz) for measurement of front foot reaction force, 2) force plate (TF-2050-W, TEC Gihan Co., 1000Hz) for measurement of rear foot reaction force, and 3) two tri-axial force sensors for measurements of the individual hand forces (TL3B04, TEC Gihan Co., 500Hz). The start motion was captured with four high-

speed video cameras (B-cam system, DKH Co., sampling frequency: 100Hz, exposure time: 1/500sec). Three dimensional coordinate data of motion were obtained by a DLT method (FramDIAS IV , DKH Inc., Japan). The high-speed cameras and the instrumented starting block were synchronized electrically with use of Start System (Electronic Start System. Model SS2, Colorado Time System). The individual joint torques were calculated from inverse dynamics computation with use of the kinematics data and the kinetics data. Since the flexion/extension axes of the ankle, knee and elbow joints were defined as the normal axes of the planes constructed with neighboring longitudinal axes of the segments, the joint torques were calculated while the neighboring longitudinal axes could construct the planes. The results of the kinetic data were normalized by the period of the start motion, from the start signal to the front foot take-off, as 0 to 100%.

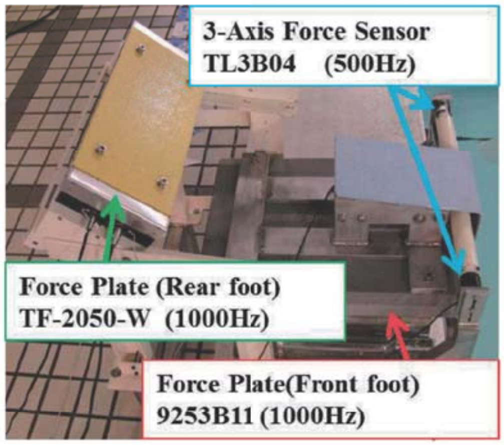

Figure 1: Instrumented starting block

RESULTS AND DISCUSSION: Figure 2 shows the mean time-curves of the reaction force exerted by each hand and foot during the start motion. The left and right figures show respectively the horizontal anterior/posterior and vertical components of the reaction forces. The dashed and dotted lines in the figures indicate the instances of hand take-off and rear foot take-off, respectively.

The anterior/posterior horizontal reaction force of the rear foot began with the magnitude of 100N until 20% normalized time, then increased until 65% with peak value of 600N, and then decreased toward the instance of the rear foot take-off. The horizontal reaction force of the front foot began with -150N until 30%, then increased until 90% with peak of 500N, and then decreased toward the front foot take-off. In contrast, the horizontal reaction forces exerted by the both hands showed small values throughout the griping handle phase. Both feet exerted horizontal forces that cancel with each other from start signal to 25% normalized time.

The vertical reaction force exerted by the front foot began with the magnitude of 600N until 30%, then decreased until 50% with lowest peak of 400N, and then increased until 75% with peak value of 800N, and decreased toward the instance of the front foot take-off. The vertical reaction force exerted by the rear foot began with 200N until 20%, then increased until 55% with peak value of 600N, and then decreased toward the instance of the rear foot take-off. The vertical force of each hand began with -50N until 20%, then decreased until 50% with negative peak of 300N, and then increased until the hand take-off.

Swimmers exerted countervailing horizontal forces from start signal to 25% with front and rear feet, and countervailing vertical forces from 20% to 70% with both hands and both feet (Fig. 2). These countervailing forces would induce pre-tension of muscles to exert large joint torques. Moreover, the vertical countervailing forces would induce coupling force which enables the swimmer to rotate its body forward quickly. Although Maglischo (2003) suggested that a powerful arm pull is unnecessary for swimmers to get their body in motion, our results in this study are inconsistent with his suggestion.

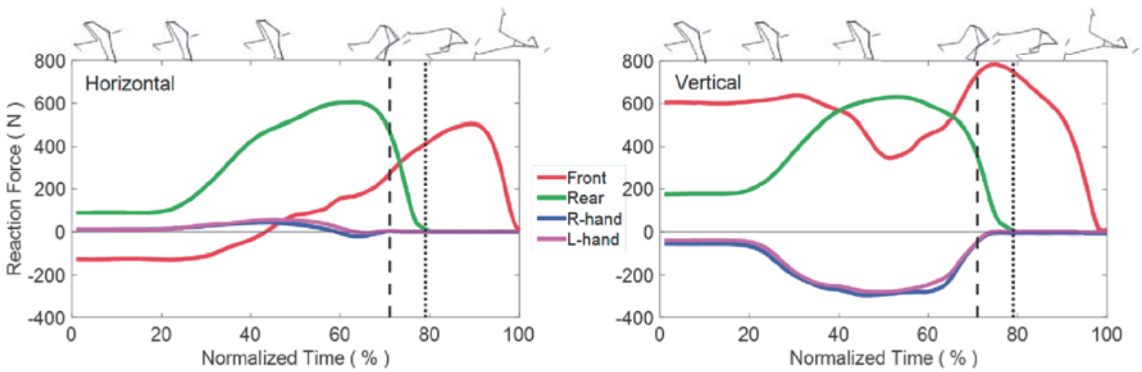

Figure 2: Mean time-curves of the reaction force of each limb during start motion (Front: front foot, Rear: rear foot, R-hand: right hand, L-hand: left hand; vertical dashed line: the instance of hands take-off; vertical dotted line; the instance of rear foot take-off).

Figure 3 shows the mean time-curves of the flexion/extension joint torques of the upper and lower limbs, where the joint torques of the upper limbs were plotted until the hands take-off; the hip and knee joint torques of the lower limbs were plotted while the longitudinal axes of the shank and thigh segments can construct a stable common plane.

The extension torques at the hip and knee joints and plantar flexion torque at the ankle joint of the rear side lower limb generated the reaction force. We found that the reaction force exerted by the rear foot from 20% to 50% normalized time is generated mainly by the extension torques at the hip and knee joints, and then by the ankle plantar flexion torque. In contrast with the kinetics of the rear side lower limb, the knee joint of the front side lower limb exerted flexion torque. The main role of this flexion torque would be the maintenance of the large vertical reaction force until 60% normalized time. The extension torques at the hip and knee joints and plantar flexion torque at the ankle joint of the front side lower limb after 70% normalized time generated the large horizontal reaction force that contributes to obtaining large take-off velocity. The large extension torques at the shoulder joints of the upper limbs, which increased after 20% and then reached their peak values around at 65% normalized time, contributed to the quick anterior inclination of the upper body. Since few studies reported joint torques during starting motion, the results of this study provide us with beneficial information for understanding the mechanism of start motion.

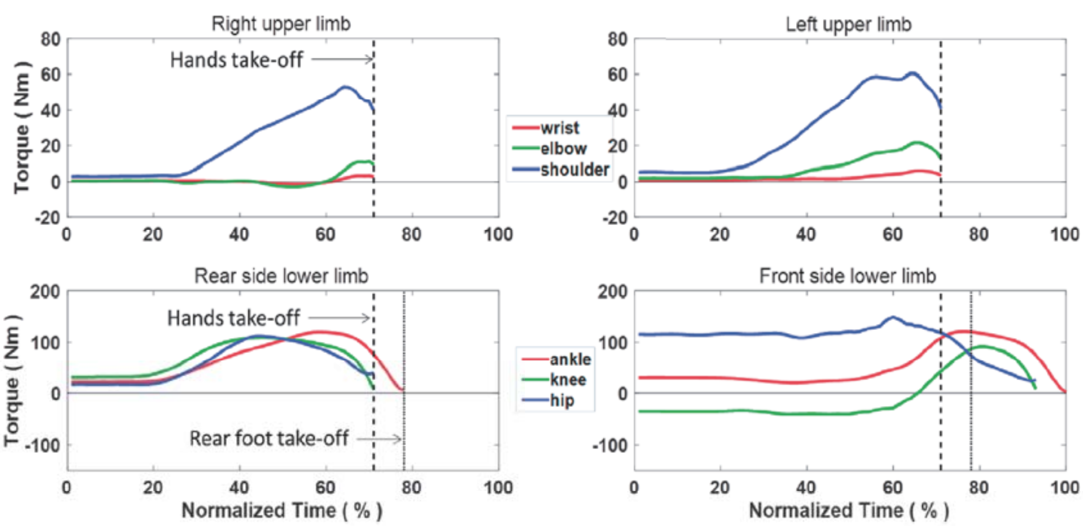

Figure 3: Mean time-curves of flexion/extension torques of both arms and legs joints during start motion. Positive values show extension, plantar flexion, and palmar flexion torques.

CONCLUSION: The aim of this study was to calculate kinetics of the upper and lower limb joints during start motion with use of an instrumented starting block. The results are summarized as follows:

(1) The extension torques at the shoulder joints generated the large negative vertical reaction force, which was cancelled with the increasing positive force exerted by the rear side foot.
(2) The extension torques at the hip and knee joints and plantar flexion torque at the ankle joint of the rear side lower limb generated the reaction force.
(3) In contrast with the kinetics of the rear side lower limb, the knee joint of the front side lower limb exerted flexion torque. The main role of this flexion torque would be the maintenance of the large vertical reaction force until 60% normalized start motion time.
(4) The extension torques at the hip and knee joints and plantar flexion torque at the ankle joint of the front side lower limb after 70% normalized time generated the large horizontal reaction force that contributes to obtaining large take-off velocity.

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