EFFECT OF DIFFERENT TRACK START POSITIONS ON HORIZONTAL TAKE-OFF VELOCITY OF WHOLE-BODY CENTER OF MASS IN SWIMMING: A SIMUALTION STUDY

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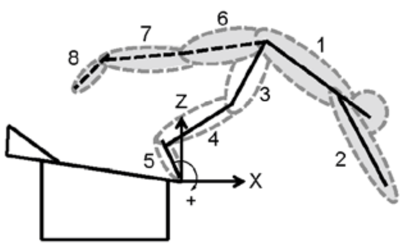
The objective of this study was to investigate the effects of different track start positions on horizontal take-off velocity of the whole-body center of mass (COM) in swimming. The whole body was modeled as linked rigid-body segments to simulate the track start performance, and a simulation was performed with two different track start positions, with the COM positioned at the rear and low level (RL), and at the front and high level (FH). The results demonstrated that the horizontal take-off velocity was faster for the RL than the FH. The hip joint moments were larger for the RL than the FH on both front and rear legs. Therefore, the COM positioned at the rear and lower level for the track start would contribute to a greater hip joint moment generation, producing a greater horizontal velocity of the COM at take-off.

KEY WORDS: starting performance, joint moment, swimming simulation

INTRODUCTION: The track start is one of the commonly used block start techniques in swimming, where one foot is placed at the front of the platform surface while the other foot is placed towards the rear of the platform surface. Among a number of different block start techniques, a preference for the track start has recently emerged amongst international level swimmers, which reduces the potential for a false start by providing increased stability through a larger base of support (Barlow et al., 2014). In competitive swimming, a fast start with a greater horizontal velocity at take-off is important for competitive success (García-Ramos et al., 2015), and it has been reported that a track start position would affect such take-off velocity (Barlow et al., 2014). For instance, rear-weighted track start generated a greater horizontal velocity at take-off than front-weighted (Barlow et al., 2014). It has also been shown that a difference in starting position affects start performance, inducing changes in the lower leg joint angles (Otsuka et al., 2015) and the whole-body center of mass (COM) position in sprinting (Harland and Steele, 1997), which requires track start similar to swimming. Therefore, the changes in the lower leg joint angles and the COM induced by different starting positions would affect the starting performance in competitive swimming. The objective of this study was, therefore, to investigate the effects of different track start positions on horizontal take-off velocity of the COM by a computational simulation, controlling the initial track start positions.

METHODS: The whole body was modeled as linked eight rigid-body segments to simulate track start performance (Fig1). The mass and length of each segment was calculated based on a subject with the age of 23 years, height of 169.8cm, and body mass of 68kg. Inertial parameters were calculated via anthropometric reference (Ae et al., 1992).



1: Head-Trunk Segment
2: Synchronized Arms Segment
3: Front Thigh Segment
4: Front Shank Segment
5: Front Foot Segment
6: Rear Thigh Segment
7: Rear Shank Segment
8: Rear Foot Segment

Figure1: Eight rigid-body segment human model

The equation of motion for this model was given as:

$$\ddot{q} = M^{-1}(C + G + F + T) \quad \text{......................................(1)}$$

where q, M, C, G, F and T represent the generalized coordinate vector, inertia matrix, Coriolis and centrifugal force vector, gravitational force vector, external force vector such as ground reaction forces between the foot and starting block, and joint moment vector, respectively. The joint moment was assumed to be the product of the maximum isometric force as a function of joint angle, joint angular velocity and joint activation level. The optimization algorithm was to find the optimal period for activation that the horizontal velocity of the COM at take-off was maximized by the downhill simplex method (Nelder and Mead, 1965). A simulation of track start was performed with two different track start positions, with the COM positioned at the rear and low level (RL), and at the front and high level (FH). The present model was validated through a simulation of a vertical jump, by comparing with the previously reported values (Cheng, 2008). It was confirmed that the results of the simulated COM height and lower limb joint moment patterns with our model were similar to their results, where they used a similar model with five rigid-body segments (Right and left legs were not independent).

RESULTS: The horizontal velocity of the COM at take-off for RL was about 3.17% faster than FH position (Table1 and Fig2). The peak hip joint moments for RL were about 15.92% and 31.88 % larger than FH position on the front and rear leg, respectively (Table1). The hip joint angles on the front and rear leg were also different between the positions (Table1).

Table1: Simulated kinematic and kinetic variables for RL and FH positioned track starts

	RL	FH
Horizontal COM position at simulation start (m)	-0.22	-0.18
Vertical COM position at simulation start (m)	0.61	0.64
Horizontal velocity of the COM at takeoff (m/s)	3.69	3.57
Hip angle at simulation start (deg)		
Front leg	-138.56	-132.94
Rear leg	-131.23	-118.11
Hip angle at M_{peak} (deg)		
Front leg	-84.62	-10.29
Rear leg	-81.56	-47.96
Peak hip extensor moment (Nm)		
Front leg	164.30	141.73
Rear leg	256.46	194.46

Positive and negative values for hip joint angle and moment indicate extension and flexion, respectively. M_{peak} indicates the timing of peak hip moment.

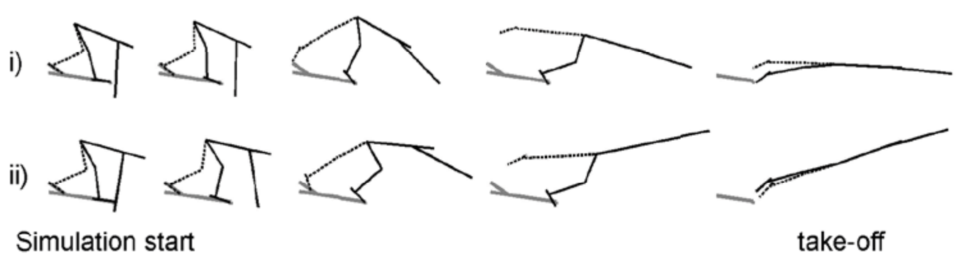


Figure2: Stick diagrams of simulated track starts for i): RL and ii): FH.

DISCUSSION: The objective of this study was to investigate the effects of different track start positions on horizontal take-off velocity of the COM. The horizontal velocity of the COM at take-off was found to be faster for the RL than the FH. Furthermore, the hip joint moments were found to be larger for the RL than the FH on both front and rear legs. Thus, the COM positioned at rear and lower level for the track start would contribute to a greater hip joint moment generation, producing a greater horizontal velocity of the COM at take-off. The horizontal velocity of the COM at take-off was greater for the RL, which is in agreement with a previous finding (Barlow et al., 2014). They reported that increasing horizontal distance between the hip and the forward edge of the platform produced a greater take-off horizontal velocity. The hip joint angle for the RL could be the reason for such a fast start. The hip joint angles differed between the different track start positions, and the hip joint moments were greater for the RL. Joint moment could be influenced by joint angle, because of the length-tension relationship (Harland and Steele, 1997). The joint angle has its optimal angle for the greatest joint moment generation, and the hip joint angle for the RL seems to be closer to that optimal angle, producing a greater joint moment as observed. It has also been reported that a greater hip joint moment resulted in an increased vertical take-off velocity during a vertical jump (Cheng, 2008). The greater horizontal take-off velocity observed for the RL in this study also result from a greater hip joint moment. A greater hip joint moment could be generated when the COM is positioned at the rear and lower level, which would help to increase horizontal take-off velocity.

CONCLUSION: The COM positioned at the rear and lower level for the track start would contribute to a greater hip joint moment generation, producing a greater horizontal velocity of the COM at take-off.

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