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Full Length Article

Effect of increased kick frequency on propelling efficiency and muscular co-activation during underwater dolphin kick

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ABSTRACT

In this study, we investigated the effects of increased kick frequency on the propelling efficiency and the muscular co-activation during underwater dolphin kick. Participants included eight female collegiate swimmers. The participants performed seven 15-m underwater dolphin kick swimming trials at different kick frequencies, which is 85, 90, 95, 100, 105, 110, and 115% of their maximum effort. The Froude (propelling) efficiency of the dolphin kick was calculated from the kinematic analysis. The surface electromyography was measured from six muscles (rectus abdominis, erector spinae, rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius). From the EMG data, the co-active phase during one cycle in the trunk, thigh, and leg was evaluated. Our results show that the Froude efficiency decreased at the supra-maximum kick frequency (e.g. 100%F: 0.72 ± 0.03 vs. 115%F: 0.70 ± 0.03, $p < .05$). The co-active phase in the trunk, thigh, and leg increased with increasing the kick frequency (e.g. 85%F vs. 115%F, $p < 0.05$). Furthermore, it was observed that there was a negative relationship between the trunk co-active phase and the Froude efficiency ($r = -0.527$, $p < 0.05$). Therefore, both the propelling efficiency and the muscular activation pattern became inefficient when the swimmer increased their kick frequency above their maximum effort.

1. Introduction

Underwater dolphin kick is used after diving starts and turns in competitive swimming, and the technique can help maintain the high swimming velocity obtained by pushing off the start block or wall. Several studies have reported that the swimming velocity during the underwater phase is related to the total performance of the start and the turn phases (Guimaraes & Hay, 1985; Veiga, Mallo, Navandar, & Navarro, 2014; Zatsiorsky, Bulgakova, & Chaplinsky, 1979). Therefore, improvements in the performance of the underwater dolphin kick can reduce times at the start or turns and improve overall performance.

Several previous studies reported relationships between kinematic parameters and swimming performance during underwater dolphin kick. Arellano, Pardillo, and Gavilán (2002) reported that the average swimming velocity and kick frequency during underwater dolphin kick in international-level swimmers is significantly higher than those of junior swimmers, and concluded that the higher swimming velocity results from a higher kick frequency. Furthermore, Cohen, Cleary, and Mason (2012) used a computational simulation of the underwater dolphin kick to demonstrate that the mean of the net stream wise forces increases linearly with kick

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frequency. Therefore, higher kick frequency relates to higher underwater dolphin kick velocity.

Propelling efficiency is also important for higher dolphin kick performance. Froude efficiency is used to evaluate the propelling efficiency of the underwater dolphin kick (Hochstein & Blickhan, 2011; Shimojo, Sengoku, Miyoshi, Tsubakimoto, & Takagi, 2014; Zamparo, Vicentini, Scattolini, Rigamonti, & Bonifazi, 2012). Froude efficiency is determined by the relationship between the backward progressing undulatory wave velocity and the average forward speed of the swimmer. Zamparo et al. (2012) reported that the velocity and the acceleration in the first 5 m and the following 10 m after a turn correlate positively to the Froude efficiency of the underwater dolphin kick. Therefore, higher swimming velocity is related to not only higher kick frequency, but also higher propelling efficiency. Accordingly, if swimmers attempt to improve the swimming velocity during the underwater dolphin kick, they should increase the kick frequency and improve the propelling efficiency.

Shimojo et al. (2014) investigated changes in the average swimming velocity and the Froude efficiency during the underwater dolphin kick when swimmers increased the kick frequency from 85 to 115% of their maximum effort using metronome sounds, and reported that the average swimming velocities did not change and the Froude efficiency decreased at the supra-maximum (105–115%) kick frequency trials compared to their maximum effort trial (100%). These results contradicted their hypothesis, which predicted the average swimming velocity to increase. In addition, these results indicated that the swimmers could not increase the swimming velocity without maintaining the propelling efficiency as the swimmers increase their kick frequency. Zamparo, Pendergast, Termin, and Minetti (2002) noted that the value of Froude efficiency reflects the ability of the swimmer to impart useful kinetic energy to the water and that this ability depends on the frequency of the movement (for a given speed, the lower the movement frequency the larger the Froude efficiency). Therefore, the excess kinetic energy increased according to dolphin kick frequency above the maximum effort.

Electromyography (EMG) has been used to assess muscle inputs (Rouard, 2011) and can indirectly evaluate muscle contraction forces, which contributes to kinetic energy. Therefore, EMG measurement can estimate the increment of the kinetic energy during the underwater dolphin kick. Furthermore, flexor and extensor muscles in the trunk, thigh, and leg are required to contract alternately during dolphin kicking (McLeod, 2010). In other cyclical movements requiring reciprocal activation between agonist and antagonist muscles, co-activation between the muscles assumes an inefficient muscular activation pattern (Fujii, Kudo, Ohtsuki, & Oda, 2009; Heuer, 2007; Matsuda et al., 2016). Winter (2009) suggested that an obvious co-contraction is inefficient in a dynamic movement because agonist and antagonist muscles fight against each other without producing a net movement. Therefore, evaluation of co-contraction can be used to detect inefficiencies in movement during the underwater dolphin kick.

The purpose of this study was to clarify the effect of increased kick frequency on the Froude efficiency and the muscular activation patterns in the trunk, thigh, and leg during the underwater dolphin kick. We hypothesized that when the kick frequency increases above the maximum effort frequency, the Froude efficiency decreases, as described by Shimojo et al. (2014), and, correspondingly, the magnitude of muscular activation increases and the muscular co-activation between the agonist and the antagonist muscles also increases. If the muscular co-activation becomes an index of inefficiencies in movement during the underwater dolphin kick, it may be related to the swimming velocity or the propelling efficiency. Therefore, we also investigated the relationships between the average swimming velocity or the Froude efficiency and the muscular activation pattern, and hypothesized that the average swimming velocity decreases and the propelling efficiency deteriorates when the co-active time between the flexor and extensor muscles increases.

2. Methods

2.1. Participants

Eight female competitive swimmers (mean ± standard deviation (SD): age, 20.9 ± 1.9 years; height, 1.63 ± 0.06 m; weight, 54.9 ± 5.3 kg) participated in the study. All participants practiced 8 times every week with a collegiate swimming team, and the mean of the International Swimming Federation (FINA) points of their best record for their individual special event was 817.6 ± 18.2 points. The participants were made fully aware of the risks, benefits, and stresses of the study and their informed consent was obtained. This study was performed with the approval of the research ethics committee of the university.

2.2. Experimental settings

Experimental trials were conducted in a 50 m indoor pool. The mean water temperature was 27.2 ± 0.8 °C for all of the experiments. Two cameras (high-speed camera 1394, DKH Inc., Japan) filmed the sagittal swimmer's motion and recorded through underwater windows at a 100 Hz sampling rate (Fig. 1).

For 2-dimensional (2-D) analysis, twelve points were marked with wireless LED markers (Kirameki, Nobby Tech Inc., Japan) on the right side of all participants. The twelve anatomical landmarks were selected to calculate the center of mass (CM) position according to the body segment parameters for Japanese athletes (Ae, Tang, & Yokoi, 1992), and included the tragus, superior margin of the sternum, lateral epicondyle of the femur, lateral malleolus, calcaneus, epiphysis of fifth metatarsal (toe), acromion, lateral epicondyle of the humerus, styloid process, fifth distal phalanx, greater trochanter, and the lower end of the tenth rib. The procedure proposed by Shimojo et al. (2014) was used to estimate the head position from the tragus position because the head position is generally hidden by the arm during the underwater dolphin kick.

Surface EMG was measured using a wireless recorder with an 8-channel EMG logger (Biolog2, S & ME Inc., Japan). The EMG data were recorded at a sampling frequency of 1000 Hz with 16-bit analogue to digital conversion. Six muscles (rectus abdominis [RA],