ACTIVATION PATTERN OF TRUNK, THIGH AND LOWER LEG MUCLES DURING UNDERWATER DOLPHIN KICK IN SKILLED FEMALE SWIMMERS

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This study investigated the muscle activation pattern between the agonist and the antagonist muscles in the trunk, thigh and lower leg during underwater dolphin kick. Thirteen female elite swimmers participated in this study and they performed 15 m underwater dolphin kick swimming at maximum effort. The surface electromyography (sEMG) of six muscles were measured and the muscle activation pattern between the agonist and antagonist muscles in the trunk, thigh and lower leg were estimated from the sEMG data. As results, the trunk and the thigh muscles showed a reciprocal activation pattern during one-kick cycle. However, the activation pattern of the lower leg muscles did not show a reciprocal pattern and it was clarified that the lower leg muscles were co-activated during the upward kick phase.

KEY WORDS: Swimming, Electromyography, Co-activation

INTRODUCTION: Underwater dolphin kick is used after starting dive and turns in competitive swimming. Swimmers can maintain higher swimming velocity using underwater dolphin kick after starting dive and turns compared to other strokes (Takeda, Ichikawa, Takagi, & Tsubakimoto, 2009). Therefore, many swimmers besides breaststroke style use underwater dolphin kick in their race in recent years.

Underwater dolphin kick is a cyclic motion which is structured by repetitive kicking motion using both legs simultaneously. Furthermore, the motion of underwater dolphin kick in skilled swimmers include wave motion with a whip-like action (Gavilán, Arellano, & Sanders, 2006). Therefore, skilled swimmers can achieve a quick dolphin kick by the wave motion.

Past studies involving quick cyclic motion such as finger tapping and drumming reported that the reciprocal activation pattern between the agonist and the antagonist muscles was related to achieving higher motion frequency (Heuer, 2007: Fujii, Kudo, Ohtsuki, & Oda, 2009). In contrast, the co-activation between the agonist and the antagonist muscles encumber to conduct a quick cyclic motion. Winter (1990) suggested that an obvious co-contraction is inefficient in dynamic movement because agonist and antagonist muscles fight against each other without producing a net movement. The wave motion of underwater dolphin kick is structured by the flexion and extension in trunk, hip, knee and ankle joints. Therefore, it can be speculated that the activation pattern between the agonist and the antagonist muscles in the trunk, thigh and lower leg during underwater dolphin kick could be a reciprocal pattern in skilled swimmers. However, there is no study focusing on the muscle activation pattern during underwater dolphin kick.

The purpose of this study was to clarify the muscle activation pattern between the agonist and the antagonist muscles in the trunk, thigh and lower leg during underwater dolphin kick in skilled female swimmers.

METHODS: Thirteen female collegiate swimmers (Mean ± SD: Age 20.2 ± 1.7 years, Height 1.63 ± 0.05 m, Mass 55.7 ± 4.7 kg, Athletic career 12.8 ± 3.0 years) participated to this study. Their informed consent was obtained before the experiment. This study was performed under the approval of the research ethics committee of the university. The experiment was conducted in an indoor 50-m pool (Mean ± SD: Water temperature 27.4 ± 0.8 degree). Before the experimental trial, the participants performed a standardized warm-up and were familiarized with the experiment methodologies. After the warm-up and the familiarization session, the participants performed 15-m underwater dolphin kick swimming in maximum effort. The participants were instructed to pass horizontally under 1.0-m water depth during the underwater dolphin kick swimming.

The 2-dimensional motion analysis was conducted according to Shimojo, Sengoku, Miyoshi, Tsubakimoto, & Takagi (2014). Two cameras (High speed 1394 Camera, DKH Inc., Japan) were set on the side of the swimmer and recorded at 100 Hz sampling rate. The twelve landmarks were marked on the right side of the participants and were used to calculate the center of mass according to Ae, Tang & Yokoi (1992). The coordinates of all landmarks were digitized and the digitized coordinates were converted to the global coordinates using the 2-dimensional direct linear transformation method. The five kinematics variables were calculated: 1) Average swimming velocity (horizontal center of mass velocity) ($m \cdot s^{-1}$); 2) Kick frequency (Hz); 3) Kick amplitude (m); 4) Percentage of the downward kick (DK) phase (%); 5) Percentage of the upward kick (UK) phase (%). According to Connaboy, Coleman, Moir, and Sanders (2010), the complete three data obtained from consecutive three kick cycles were used for analysis.

The surface electromyography (sEMG) was measured by using a wireless EMG recorder with 8-channel EMG loggers (Biolog2, S&ME Inc., Japan). The sampling rate of sEMG was set at 1000 Hz. The six muscles (rectus abdominis, RA; erector spinae, ES; rectus femoris, RF; biceps femoris, BF; tibialis anterior, TA; gastrocnemius, GAS) were selected for sEMG measurement. The electrodes were waterproofed by covering them with water resistance tape according to Kobayashi, Kaneoka, Takagi, Sengoku, and Takemura (2015).

The raw EMG were filtered to remove the motion artifacts by using a band-pass filter (10–500 Hz). To estimate the activation pattern in each muscle, the filtered EMG were smoothed using the root mean square (RMS). The RMS curves were calculated on a 50 ms window of data. The RMS curves were normalized by the peak value during three cycles in each muscle. Furthermore, the activation pattern between the agonist and antagonist muscles in the trunk, thigh and lower leg was estimated by the absolute value of the relative-difference signal (RDS) referring to Heuer (2007). In this study, the agonist and antagonist muscles were defined as RA and ES were a pair of trunk muscles, RF and BF were a pair of thigh muscles and TA and GAS were a pair of lower leg muscles. The absolute RDS between the agonist and antagonist muscles in each part were calculated using Equation1:

$$\text{Absolute RDS} = \frac{|\text{Agonist muscle data - Antagonist muscle data}|}{|\text{Agonist muscle data + Antagonist muscle data}|} \quad (1)$$

the data of agonist and antagonist muscles were the normalized RMS data. The absolute RDS represents the magnitude of co-activation, and the value is among 0 to 1. If the absolute RDS is near 0, it can be evaluated that the activation pattern between two muscles is co-activation pattern. If the absolute RDS is near 1, the activation pattern between two muscles is evaluated as reciprocal activation pattern or single activation pattern. To estimate the total activation pattern during one-kick cycle, the average value of the absolute RDS during one-kick cycle was investigated.

The kinematic variables and the EMG variable were presented by the mean and the standard deviation (Mean ± SD). The average absolute RDS were compared between three parts using one-way ANOVA, followed by Tukey's multiple comparison. A p value <.05 was considered statistical significant. Statistical analysis were conducted with SPSS for Windows 22.0 (IBM Inc., USA).

RESULTS: As the results of the kinematic variables, the average swimming velocity was 1.37 ± 0.08 $m \cdot s^{-1}$, the kick frequency was 2.12 ± 0.20 Hz, the kick amplitude was 0.45 ± 0.05 m, the DK phase was 47.2 ± 2.7% and the UK phase was 56.9 ± 2.7%. Figure 1 show the ensemble-averaged curves of the normalized RMS during one-kick cycle. In Figure 1, the trunk and the thigh muscles showed a reciprocal activation pattern. However, the activation pattern of the lower leg muscles did not show a reciprocal pattern. Figure 2 show the ensemble-averaged curves of the absolute RDS during one-kick cycle. In Figure 2, the curves of TA—GAS show different pattern from the curves of RA—ES and RF—BF, and the absolute RDS value of TA—GAS was among 0.4 to 0.6 through UK phase. Table 1 show the result of the average absolute RDS. Significant main effect was observed (F=20.78, p <.05) and there was a significant difference between the three parts in post-hoc test (p <.05).

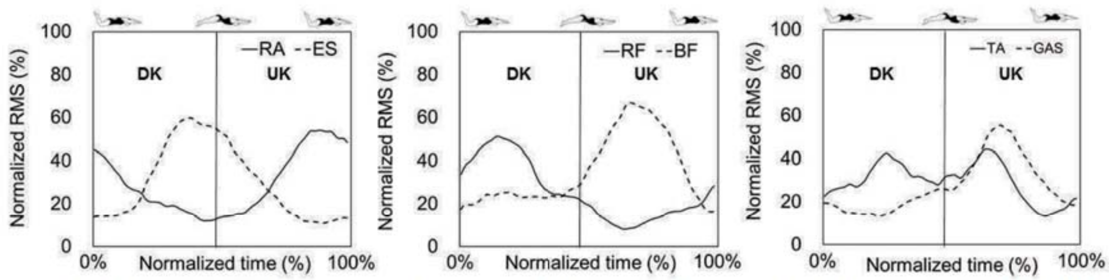

Figure 1: The ensemble-averaged curves of the normalized Root Mean Square (RMS) in each muscle during one-kick cycle.

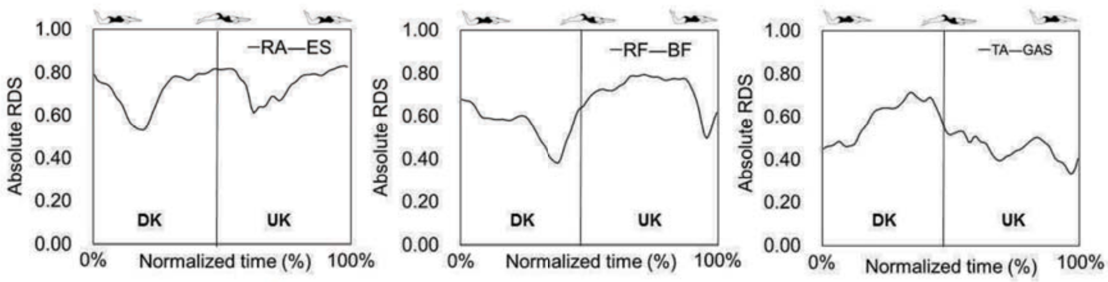

Figure 2: The ensemble-averaged curves of the absolute Relative-Difference Signal (RDS) in each part during one-kick cycle.

Table 1

The results of the average Relative-Difference Signal (RDS) of the each part.

Variables	RA—ES Mean ± SD	RF—BF Mean ± SD	TA—GAS Mean ± SD	*F*-value	*p*-value
Average absolute RDS	0.73 ± 0.06	0.63 ± 0.09[a]	0.53 ± 0.09[a,b]	20.78	$p < .01$

[a] Significant difference from RA—ES

[b] Significant difference from RF—BF

DISCUSSION: The purpose of this study was to clarify the muscle activation pattern between the agonist and the antagonist muscles in the trunk, thigh and lower leg during underwater dolphin kick in female collegiate swimmers. As results, the reciprocal activation pattern in the trunk and the thigh muscles were observed, however, the activation pattern of the lower leg muscles was not reciprocal activation pattern and the lower leg muscles co-activated during UK phase.

Von Loebbecka, Mittal, Fish, and Mark (2009) analyzed the motion of underwater dolphin kick in the Olympic level female swimmers and reported that the average velocity was 1.38 ± 0.12 $m{\cdot}s^{-1}$, the kick frequency was 2.08 ± 0.36 Hz and the kick amplitude was 0.49 ± 0.07 m. The kinematic results of this study were similar with the value of Olympic level female swimmers. Therefore, it was considered that the participants in this study had a high level performance of underwater dolphin kick.

In Figure 1, the reciprocal activation pattern in the trunk muscles (RA and ES) and the thigh muscles (RF and BF) were observed during one-kick cycle. From these results, it was considered that the reciprocal activation of the trunk and the thigh muscles contributed to conducting the flexion–extension movement in the trunk, hip and knee joints. However, the TA curve had two peak during one-kick cycle, and the activation of TA and GAS increased simultaneously during UK phase (Figure 1).

In Figure 2, the magnitude of co-activation between the agonist and antagonist muscles in the trunk and thigh increased at the moment when the two muscle activation switched. In Table 1, the average absolute RDS was significantly higher with the order of the trunk, thigh, and lower leg muscles. In general, muscle co-activation contributes to stopping a quick joint movement (Hagood, Solomonow, Baratta, Zhou, & D'ambrosia, 1990) and stabilizing the joint against to the external force and the instability load (Franklin, So, Kawato, & Milner, 2004;

Milner, 2002). During underwater dolphin kick, the knee joint extended quickly by a whip-like action compared to the trunk joint. Therefore, it was considered that the thigh muscles had to co-activated strongly more than the trunk muscles during the switching of the two muscle activation. The magnitude of co-activation in the lower leg muscles was middle level through UK phase (Figure 2). In underwater dolphin kick, swimmer generate propulsive force during both phases (Sugimoto, Nakashima, Ichikawa, & Nomura, 2006). During UK phase, the foot move upward and push water using by the foot soles. However, the foot soles received the force which caused planter flexion by water drag during UK phase. Lauer, Figueiredo, Vilas-Boas, Fernandes, and Rouard (2013) reported that the elbow muscles during the aquatic phase of the front-crawl stroke co-activated strongly to stabilize the elbow joint to overcome water drag. Similarly, it was considered that the lower leg muscles during UK phase were co-activated to stabilize the ankle to overcome water drag.

CONCLUSION: This study investigated the muscle activation pattern between the agonist and the antagonist muscles in the trunk, thigh and lower leg during underwater dolphin kick in skilled female swimmers. As results, the trunk and thigh muscles were activated reciprocally during one-kick cycle. However, the lower leg muscles were not activated reciprocally and the lower leg muscles co-activated through UK phase.

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