Biomechanical Analysis of Undulatory Underwater Swimming Across Different Levels of Swimmers

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Summary

This study analyzes biomechanical differences in dolphin kick performance across swimmers of various age groups (elementary, junior high, high school, and university). Key factors such as propulsion speed, kinematic parameters, muscle activation, joint strength, and ankle flexibility were examined. Results show that older swimmers exhibited superior body control, strength, and propulsion efficiency. Higher-level swimmers demonstrated faster kick frequency, more effective body wave motion, and better coordination, with hip strength and trunk stability being critical to performance. The findings highlight the importance of both physical development and technical mastery in optimizing dolphin kick performance, with age and training experience playing significant roles.

Introduction

Dolphin kick plays a crucial role in swimming competitions during starts and turns, as underwater propulsion reduces drag and increases speed. Besides technical execution, the strength and flexibility of relevant muscle groups significantly impact performance. Given the varying levels of physical maturity among swimmers of different age groups, their mastery of technique and physical fitness development may differ. However, research on this topic remains limited.

This study aims to investigate the biomechanical differences in underwater dolphin kicking among swimmers of different levels. Specifically, it examines variations in propulsion speed, kinematic parameters of limb movements, muscle activation levels, maximum strength of relevant muscle groups, and ankle flexibility.

Methods

Competitive swimmers in freestyle, backstroke, and butterfly from elementary, junior high, high school, and university teams who met the national competition standards for their respective age groups were recruited. Data was collected from 10 swimmers at each school level. Dolphin kick motion was recorded and analyzed using waterproof inertial measurement units (IMUs) and a waterproof wireless electromyography (EMG) system. A custom-built piezoelectric signal device synchronized with underwater cameras assisted in motion analysis. Maximum strength of the trunk, hip, knee, and ankle joints was measured using an isokinetic dynamometer, while ankle flexibility was assessed with a goniometer. One-way ANOVA was used to compare biomechanical parameters across different swimmer levels.

Results and Discussion

1. Impact of Age and Physiological Factors on Dolphin Kick Performance:

- Older swimmers (university, high school) exhibited better height, weight, and propulsion efficiency, supporting previous studies suggesting that a lean body type reduces drag and enhances kick amplitude.
- High school swimmers showed superior ankle dorsiflexion, indicating a connection between ankle flexibility and training experience.

2. Variations in Dolphin Kick Kinematic Parameters:

- Kick Efficiency and Frequency: University swimmers demonstrated faster kick frequency, likely linked to improved muscle strength and coordination. High school swimmers had higher maximum hip flexion angular velocity than elementary swimmers, indicating greater driving force during the kick.
- Trunk and Pelvic Movement: University and high school swimmers exhibited greater trunk angular velocity and pelvic upward and downward acceleration compared to elementary swimmers, indicating more effective use of body wave motion to enhance propulsion.

3. Strength and Kick Performance:

- Hip, Knee, and Core Strength: Older swimmers showed superior hip strength in both slow and fast extension/flexion, contributing to better propulsion. Core strength, particularly in the university group, was key to body stability and better Dolphin kick performance.
- Muscle Activation and Motion Control: The rectus abdominis muscle showed more activity during the kick phase in middle school swimmers, while higher-level swimmers (university, high school) relied on more efficient movement patterns, reducing reliance on abdominal contractions.

Conclusions

Overall, older age group swimmers outperformed younger groups in Dolphin kick technique, body control, and muscle strength. The acceleration and angular velocity of the pelvis and hip joints, along with kick frequency and angular velocity, were identified as key factors influencing propulsion. Higher-level swimmers demonstrated faster Dolphin kick speeds, more stable body wave motion, and better kick coordination, validating the importance of technical skill and physical development for optimizing Dolphin kick performance.