A COMPARISON OF UNDERWATER GLIDING AND KICKING TECHNIQUES

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Net forces created when towing swimmers through water were examined for gliding and undelwater kicking. Sixteen experienced male swimmers of similar body shape were towed through water via a motorised winch and pulley system. A load cell measured net force (propulsive force - drag force) at velocities of 1.6, 1.9, 2.2, 2.5 and 3.1 ms^{-1}, respectively. At each velocity swimmers performed a prone streamline glide; lateral streamline glide; prone freestyle kick; prone dolphin kick; and lateral dolphin kick. A 2-way repeated measures ANOVA revealed significant differences between the gliding and kicking conditions at different velocities. Results suggest that there is an optimal velocity at which to begin undelwater kicking in order to prevent energy loss from excessive active drag.

KEY WORDS: hydrodynamic drag, streamlined gliding, undelwater kicking, swimming,

INTRODUCTION: Resistance (Hydrodynamic drag) experienced by swimmers moving through water is of interest to coaches and sport scientists. Minimising resistance may be more efficient than the usual practice of solely increasing propulsive effort. Knowledge of hydrodynamic drag forces incurred during underwater gliding and kicking enables technique changes which reduce deleterious drag.
Resistance in water has been measured by towing subjects at various velocities to quantify body drag in prone positions (passive drag) or while moving (active drag) (Jiskoot and Clarys, 1975; Clarys, 1979; Lyttle et al., in press). Lyttle et al. found significantly less passive drag at 0.4 m underwater than at shallower depths, which was in agreement with previous fluid dynamic studies (Hertel, 1966; Larsen et al., 1981).
Despite investigations of the active drag during different swimming strokes, there is little information on the hydrodynamic characteristics of underwater kicking. Coaches have also promoted a lateral streamline glide and lateral dolphin kick in competition over the traditional prone positions. Despite this, there is no evidence of any advantages of this method. Therefore, the net force created by different underwater kicking techniques and the optimal timing of the kick during the stroke resumption phase of the turn is unknown. This study sought to establish the appropriate velocity for initiating underwater kicking, as well as the most efficient gliding position and kicking technique.

METHODS: Sixteen adult male, experienced swimmers acted as subjects. All were of similar body shape, mass and height to minimise the variation in drag resulting from differences in body form (Clarys, 1979). A comparison between the experienced swimmers used in the current study and elite swimmers from the 1991 World swimming championships showed no significant differences between the two groups for any of the anthropometric variables measured (Mazza et al., 1994).
Subjects were towed along the length of a 25 m pool at a depth of 0.5 m underwater at each of five different velocities (1.6; 1.9; 2.2; 2.5; & 3.1 ms^{-1}). These velocities were controlled using a variable-control, motorised winch, which could accurately and consistently maintain a set velocity. The velocity range used covers the practical velocities experienced by club and elite level swimmers during the push-off and glide following a turn. At each velocity, the subjects performed a prone streamline glide, lateral streamline glide, prone freestyle kick, prone dolphin kick and lateral dolphin kick. All kicking trials were performed at maximal effort. Figure 1 outlines the experimental set-up used during testing. Further detail on the experimental set-up can be found in the paper by Lyttle et al.

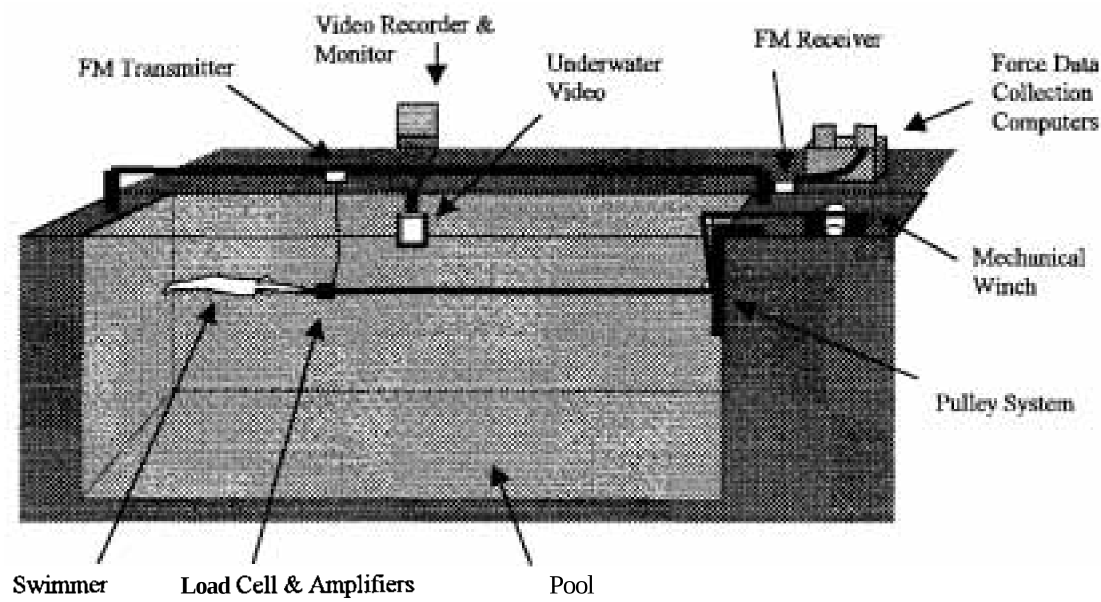

Figure 1 - Testing set-up for quantifying net force.

During each trial net force was recorded using a uni-directional load cell. For the kicking trials this represented the total propulsive force produced during the kicks minus the active drag force resisting towing. During the prone and lateral streamline trials the net force consisted solely of the negative passive drag forces. Therefore, it is beneficial for the swimmer to have a smaller net force during the kicking trials than that recorded during the streamline glide positions at any given velocity.

Depth was controlled using a two-pulley system fixed to the pool wall. The lower pulley permitted the towing force vector to be horizontal at the required 0.5 m depth. This depth was chosen as previous findings have revealed no significant differences between passive drag at 0.4 and 0.6 m deep (Lyttle et al., in press). Given the deviation of the feet from the midline when kicking underwater (approximately $\pm$ 0.1 m), the 0.5 m depth reduced the possibility that changes in net force resulted from movement at different depths. Depth was defined by using the mid-line of the frontal plane when the swimmer was in the prone streamline, freestyle and dolphin kicking positions; and the mid-line of the sagittal plane in the lateral streamline and dolphin kicking positions. An underwater video camera was positioned perpendicular to the swimmer's line of motion to ensure the desired body position throughout the towing trial. Following each towing trial, swimmers were provided with feedback from the video image and the trial was repeated if the swimmer was outside 0.05 m of the set depth, or in inappropriate body position.

A 2-way repeated measures ANOVA was used to analyse the data with the net force as the criterion measure. The towing conditions (gliding and kicking) and towing velocities were the independent variables. With a significant towing condition/velocity interaction evident, separate 1-way repeated measures ANOVAS were run on the towing condition for each towing velocity. Tukey's Post-Hoc comparisons were then used to determine which differences between towing conditions were significant.

RESULTS: The means and standard deviations (SD) for the net forces at each of the velocities and towing conditions are listed in Table 1, and presented graphically in Figure 2. The 2-way repeated measures ANOVA revealed significant velocity-by-towing condition interactions. Further 1-way repeated measures ANOVAs on each velocity revealed significant differences between the towing conditions for each velocity with the exception of 2.5 ms^{-1}.

Table 1 Means and SD for the Net Force (N) Recorded at Each Velocity and Towing Condition.

Velocity	Prone Streamline Glide	Lateral Streamline Glide	Prone Freestyle Kick	Prone Dolphin Kick	Side Dolphin Kick
1.6 ms^{-1}	- 43.3 ± 6.1	- 45.5 ± 7.3	-24.22 12.1	- 21.3 ± 12.6	- 24.9 ± 11.9
1.9 ms^{-1}	- 64.3 ± 6.7	- 67.5 ± 7.1	- 52.4 ± 15.3	- 48.3 ± 14.8	-53.1 ± 15.9
2.2 ms^{-1}	- 92.9 ± 8.5	- 98.3 ± 9.5	- 88.7 ± 18.6	- 87.0 ± 18.3	- 89.9 ± 17.7
2.5 ms^{-1}	- 123.1 ± 12.7	- 127.52 10.9	- 125.6 ± 22.7	- 122.1520.0	- 128.9 ± 19.8
3.1 ms^{-1}	- 182.5 ± 16.0	- 188.7 ± 16.6	- 195.3 ± 22.5	- 192.7 ± 22.0	- 194.3 ± 22.8

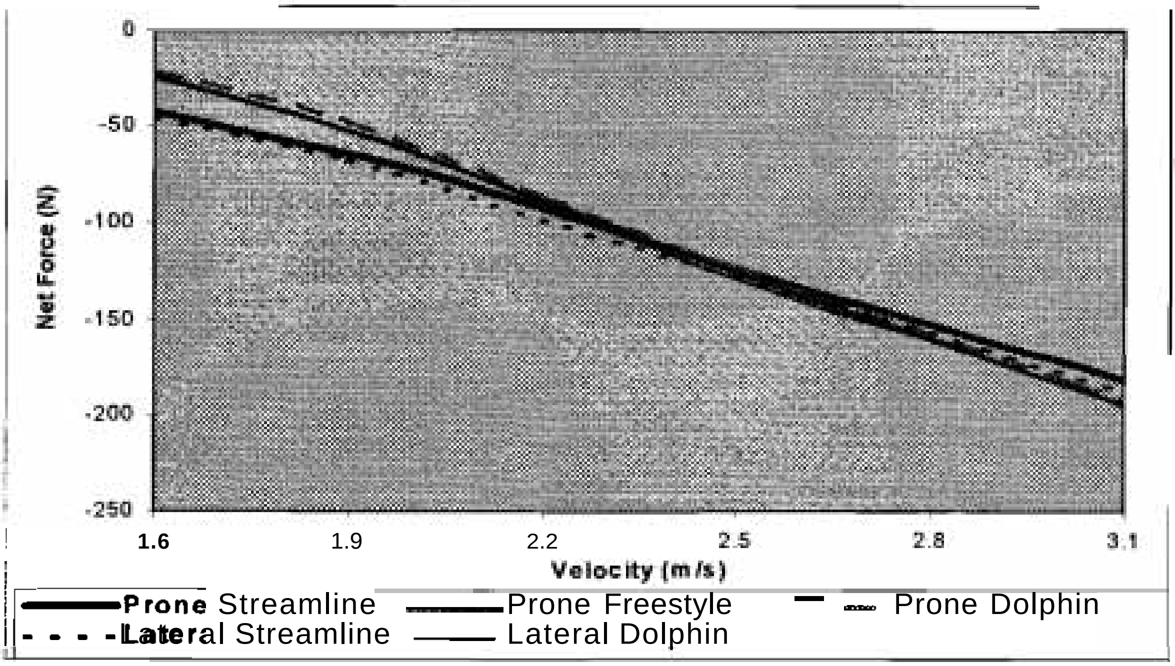

Figure 2 - Average net force for each velocity and towing condition.

At the 1.6 ms^{-1} and 1.9 ms^{-1} velocities, post-hoc comparisons revealed no significant differences between the three kicking conditions or between the two streamline positions. The streamline positions however recorded significantly higher net force than the kicking conditions. For the 2.2 ms^{-1} velocity, there was also no significant difference between the three kicking conditions or between the two streamline positions. However, for this velocity the prone streamline position was not significantly different from the kicking conditions, indicating that there is no advantage for the swimmers in kicking at this velocity. The lateral streamline position again recorded significantly higher net forces than the kicking conditions. As the 2.5 ms^{-1} velocity failed to demonstrate a significant difference between any of the towing conditions in the l-way ANOVA, no post-hoc comparisons were performed. The final velocity of 3.1 ms^{-1} demonstrated a reversal in trends. Again, no significant differences were found between the three kicking conditions or between the two streamline positions. However, at this velocity, the prone streamline position demonstrated significantly lower net forces than the kicking positions which indicate that kicking at this velocity would be detrimental to the swimmer. The lateral streamline position recorded no significant differences in net force than those recorded for the kicking conditions.

DISCUSSION: Choosing the correct time for resuming kicking after a turn as well as the relative merits of the different gliding and kicking styles, have not been determined previously despite the practical significance for swimmers. Optimising the glide and underwater kicking phases can reduce turn times and energy loss by decreasing drag. As the wall push-off and glide of experienced swimmers generally produces velocities similar to those used in this study, the net force results can indicate when swimmers should initiate underwater kicking. Information on the relative strength of swimmers' kicking styles and their streamlining ability also need to be investigated as this will influence their gliding and underwater kicking strategy.

The preferred kicking resumption velocity can be determined from the towing testing by identifying the highest velocity at which the kicking positions produce less net force than streamline positions. This infers that the swimmer creates more propulsive force while kicking than the active drag force created by deviating from the streamline glide position. An equal or greater negative net force recorded during kicking than in the streamline glide position at the same velocity indicates that the swimmer is creating more active drag than propulsion, leading to wasted energy and/or decelerating the swimmer. It should also be noted that at no velocity did a positive net force occur, which would have indicated that the swimmer was accelerating as a result of underwater kicking.

This study found that most swimmers followed a similar trend in both the proficiency of the kicking styles and also in the streamline positions. Results indicated that swimmers should start underwater kicking at between 1.9 ms^{-1} and 2.2 ms^{-1} as this was the maximum velocity which produced a significant reduction in net force in the kicking conditions compared with the streamline positions. It was also found that no significant difference was evident between the prone freestyle kick, prone dolphin kick or the lateral dolphin kick at any of the velocities. Hence, neither kick resulted in a significant advantage over the other. In addition, no significant difference was found between the prone and lateral streamline glides at any velocity, although the lateral streamline position tended to consistently record higher negative net forces at each velocity.

CONCLUSION: An optimal outbound turning technique incorporates maximising the distance achieved from the wall push-off by minimising the deceleration rate caused by the drag force. By initiating the underwater kick too early in the glide, there will be an increase in active drag which slows the swimmer. By leaving the underwater kicking too long in the glide phase, the swimmer will waste energy having to accelerate the body up to free swimming speed. Hence, an efficient streamlined glide and correct timing of the underwater kick will result in a reduced total turn time.

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