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COMPARISON OF SUPINE AND PRONE ORIENTATION IN SWIMMING

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The purpose of this study was to identify the differences in drag characteristics exhibited by a human form towed in a prone and a supine position below the water surface. Drag curves were established for both orientations over 13 velocities and 7 depths. From the results of a two way repeated measures ANOVA it was evident that while there is no practical difference between the two orientations at the greater depths, as depth decreases there is greater increase in drag force exhibited in the supine condition. There was a significantly greater drag force across all velocities (especially at those greater than 1.2ms^{-1}) for the supine condition. These differences were up to 20N or approximately 40%. From these results it is recommended that athletes utilise a greater depth when kicking in a supine orientation in order to limit the influence of greater surface interactions and the associated increase in drag force.

KEY WORDS: drag

INTRODUCTION: With the increased popularity of swimmers using a significant amount of underwater travel during swimming races (up to 30m of every 50m in a short course 25m pool) there is a need to understand the hydrodynamics of this underwater swimming. There have been previous analyses examining the influence of velocity, depth, body shape and orientation on the drag forces experienced by athletes. (B. Bixler & Pease, 2006; B Bixler, Pease, & Fairhurst, 2007; A. D. Lyttle, Blanksby, Elliott, & Lloyd, 2000; 1998; 1999; Vennell, Pease, & Wilson, 2006). However, one aspect which has not been as fully examined is the influence of a prone vs a supine position at varying depths.

There have been a few early studies which have examined the effects of towing a person prone and supine at the surface (DuBois-Reymond, 1905; Karpovich, 1933; Liljestrand & Stenstrom, 1919) with conflicting results. It has also been found in fish based research (Blake & Chan, 2007) that there are significant differences in the resistive forces for a catfish swimming upside down as opposed to when it swims with the dorsal surface facing up. This was somewhat expected due to the significantly different shapes on the dorsal and ventral surfaces of the fish and therefore the different flow fields surrounding the fish. This is also an issue in human swimmers due to the different shapes of the dorsal and ventral surfaces.

While the majority of competitive swimming is conducted in a prone orientation, with only backstroke being swum while supine, it is important that any differences between the two orientations in terms of drag characteristics for human swimming also be determined as accurately as possible. Various strategies adopted by competitive swimmers, some of whom believe that supine underwater streamlining is faster than prone and some who believe the opposite. In order to assess the differences in drag forces between the two orientations and provide useful information for the athletes and coaches the current study was undertaken.

METHODS: All testing was conducted in the aquatic treadmill or 'flume' at the University of Otago, as described by Britton, Rogers, and Reimann (1998). In order to achieve the desired control over position of the body relative to the water flow as well as consistency between conditions, it was necessary to utilise an anatomically accurate mannequin rather than a live subject. The mannequin used was the same as that described in previous research (B. Bixler & Pease, 2006; B Bixler et al., 2007; Pease & Vennell, 2010; Vennell et al., 2006).

The mounting structure used to support the mannequin during prone testing was the same as that described by Pease and Vennell (2010) and allowed the support of the mannequin through a vertical spar through the mannequin's back.

Due to structure of the mannequin it was necessary to utilise a different support structure for the supine testing. The structure utilised for supine towing was the same as that described in Vennell et al. (2006) and is similar to that in used in the prone testing but adds a horizontal rod extending downstream from the vertical spar and which affixes to the fingertips of the mannequin. In order to obtain the optimal drag-velocity curves for the mannequin, data was collected for 13 velocities: 0, 0.34, 0.55, 0.75, 0.95, 1.16, 1.36, 1.57, 1.77, 1.94, 2.15, 2.36, and 2.55 ms^{-1} respectively at tow depths of 0.2 – 0.8 m at 0.1m increments. Decomposition into the component forms of drag was then undertaken as per the methods described in Pease and Vennell (2010).

In order to test the difference in the drag values between the supine towing and prone mounted conditions means for each depth and velocity were compared using a two way repeated measures ANOVA. Paired t-tests of samples of unequal variances were also then performed to determine where any significant differences were found.

RESULTS: The results of the ANOVA showed a significant effect between towing condition of p=.018 across all depths and velocities. Due to the high level consistency and low variance of the data virtually all differences between testing conditions were found to be statistically significant. However, particularly at the greater depths, these differences are unlikely to have any practical significance due to the differences in the mounting structures. As noted, and accounted for in the analyses with samples of unequal variances, there was a difference in the variances of the two towing conditions. The greater variance for the prone mounted condition is likely due to the greater transmission of forces provided for by the more rigid mounting structure. For the supine towing condition some of forces may have been slightly damped due to the ability of the mannequin, and a small portion of the horizontal towing rod, to move freely during data collection.

In order to more clearly compare the two testing conditions the following figures depict the data in graphical form for each towing depth across all velocities. As shown in Figure A (prone) and Figure B (supine), the total drag magnitudes for the supine towed condition were greater than those determined during the prone mounted tests. However, this is largely due to the change in the angle of attack as flow velocity increased near the surface. From the data it is evident that at depth (0.7-0.8m) there is no practical difference between the two conditions despite statistical significance being demonstrated. This is not surprising due to the fact that at depths of this magnitude there is expected to be little or no surface interaction effects and therefore little or no measurable wave drag. As depth decreases there is a concurrent increase in the difference between the conditions. These differences appear to be arising from the changes in attack angle of the supine towed mannequin as lift forces increase as the mannequin is towed closer to the water surface. This change in angle of attack is on the order of up to four degrees.

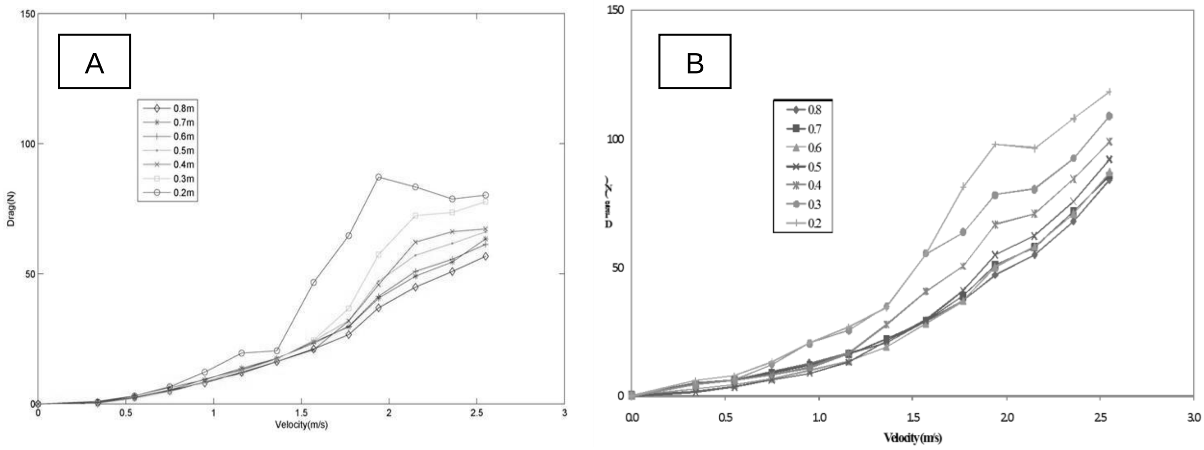

Figure 1 Total drag for all depths and velocities for a) prone orientation b) supine orientation

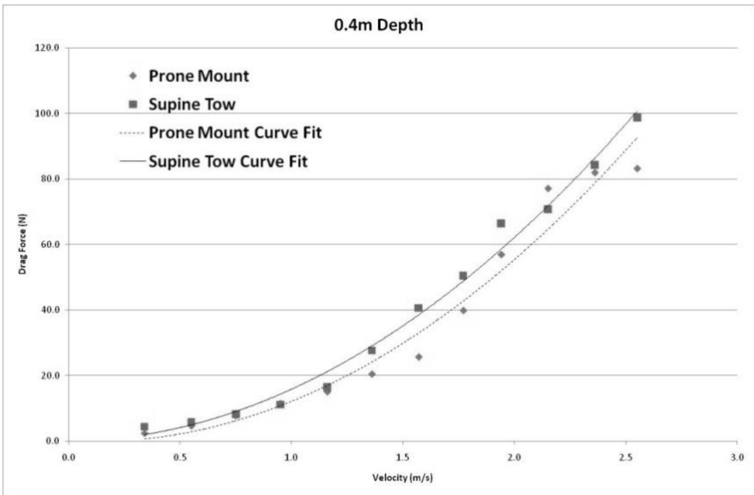

Figure 2 Comparison of the prone and supine drag curves across all velocities at 0.4m depth

DISCUSSION: From this study it was found that body orientation (prone or supine) in a deep, ie greater than 0.7m, fully submerged condition has little or no influence on the total drag force experienced by a body as water flows around it. This is not a surprising result and also provides further evidence of the lack of surface interactions at these depths and confirms the findings of previous studies (A.D. Lyttle et al., 1998; Vennell et al., 2006; Webb, Sims, & Schultz, 1991) who all found little or no wave drag contributions below a depth of at least 0.6m.

However, as hypothesized, as depth decreases differences begin to emerge. The most substantial differences appear at a depth of 0.4m as shown in Figure 2. At this point, for the supine towing method, the changes in angle of attack are minimal so most of the differences identified should be largely due to the differences in flow field and the resulting drag forces between the two orientations. By examining the shape of the mannequin it is evident that the shape of the ventral surface of the mannequin is more irregular than the dorsal surface due to the anterior projection of the head of the mannequin. Due to this surface irregularity it is likely that there is an earlier flow separation thereby causing an increase in the disturbed flow away from the mannequin's body. This disturbed flow is then interacting with the free surface and generating wave drag earlier than seems to be the case with the prone position. This is supported by additional CFD analysis which was conducted on the mannequin form for a fully submerged condition as part of the study by Bixler et al.(2007). This CFD analysis was undertaken in order to lend additional evidence to the characteristics of the flow field. Even though the CFD is still on an estimate of the field it is encouraging that findings were consistent with the experimental findings of the current study.

While not examined in the current study the fact that athletes tend to put increased effort on the down beat (ventrally directed) portion of the dolphin kick (hip flexion, knee extension), when supine the mass of fluid flow deflected towards the surface would tend to be greater than when in a prone position where the main deflection is downward away from the free surface.

CONCLUSION: From the results, which point to an increased resistance to movement when supine, it would be advisable for athletes to travel slightly deeper when travelling on their backs. Not only would this limit the influence of the surface effects interacting with the deflected fluid flow, but it would also limit the wave generating effects of the more powerful kicking action normally utilised when performing the underwater dolphin kick action. .

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