MORPHOLOGY AND HYDRODYNAMIC RESISTANCE IN YOUNG SWIMMERS

Andrew Lyttle, Nat Benjanuvatra[1], Brian A Blanksby[1] and Bruce C Elliott[1]
Western Australian Institute of Sport
[1]Department of Human Movement and Exercise Science
The University of Western Australia, Perth, Australia

Morphology and hydrodynamic drag were measured of 6 males and 6 females, from each of the 9, 11 and 13 yr age groups. Net forces were examined when towing swimmers while prone streamlined gliding and flutter kicking at 1.3 to 2.5 ms^{-1}. The passive drag force at 1.9, 2.2 and 2.5 ms^{-1} increased with age and anthropometry, but no changes were found at 1.3 and 1.6 ms^{-1}. Stepwise regression revealed passive drag best predicted net active drag at velocities of 1.3, 1.9, 2.2 and 2.5 ms^{-1}. Results supported the Froude number theory that increased height will reduce wave-making drag.

KEY WORDS: hydrodynamic drag, morphology, streamlined gliding, swimming

INTRODUCTION: Swimming is the interaction of propulsive and resistive forces. Understanding the relationship between human morphology and hydrodynamic resistance enables coaches to modify swimming strokes to improve performance. Total drag can be quantified with the body in a fixed position (passive drag), or while in motion (active drag).
Studies of hydrodynamic resistance (both passive and active drag) and body anthropometry have produced varying results (Clarys,1978; Huijing et al.,1988). Generally, research has found that anthropometry influences passive drag, except for body surface area (Chatard et al.,1990; Lyttle et al.,1998). However, the link between morphology and active drag also has yielded contrasting results (Huijing et al.,1988; Kolmogorov et al.,1997). Huijing et al. (1988) found significant correlations between anthropometry and active drag, particularly maximal body cross-sectional area, but others has indicated that swimming mechanics, rather than body dimensions, have a greater influence on active drag.
Toussaint et al. (1990) examined the effects of growth on active drag in swimmers. They used the MAD system to longitudinally measure the change in active drag of children during front crawl swimming at 1.25 ms^{-1} over a 2.5 year period. Despite an 11% increase in height, 37% increase in mass and 16% increase in the body cross-sectional area, no differences were found in active drag at the above velocity. They suggested that the lack of change in active drag was due to a height increase. Theoretically, this reduced the wave drag component of the total drag in accordance with the Froude theory (Toussaint et al.,1990). That is, reduced wave-making resistance appeared to offset any increases in form and frictional drag. However, research has also shown that active drag is affected by swimming technique (Kolmogorov et al.,1997). Thus, changes in the stroke mechanics, skill and streamlining ability could have contributed to the lack of change in total drag found in the swimmers after 2.5 years of training and growth (Touissant et al.,1990). This cross sectional study examined whether drag force was influenced by anthropometry, age, gender and kicking performance.

METHODS: Six males and 6 females aged 9, 11 and 13 years, participated in the study. Height and mass measures were within ±1 standard deviation (SD) from the anthropometric means of Western Australian school children. Selected anthropometric variables were recorded and a maximal 25 m freestyle flutter kick time recorded as a performance measure. Subjects were towed along the surface of a 25 m pool at 1.3, 1.6, 1.9, 2.2 and 2.5 ms^{-1} while performing a prone streamlined glide and freestyle flutter kick at each velocity. Figure 1 outlines the experimental set-up and further details can be found in Lyttle et al. (1999). An underwater video camera, perpendicular to the swimmer’s motion, ensured that the desired body position was maintained throughout the trial.

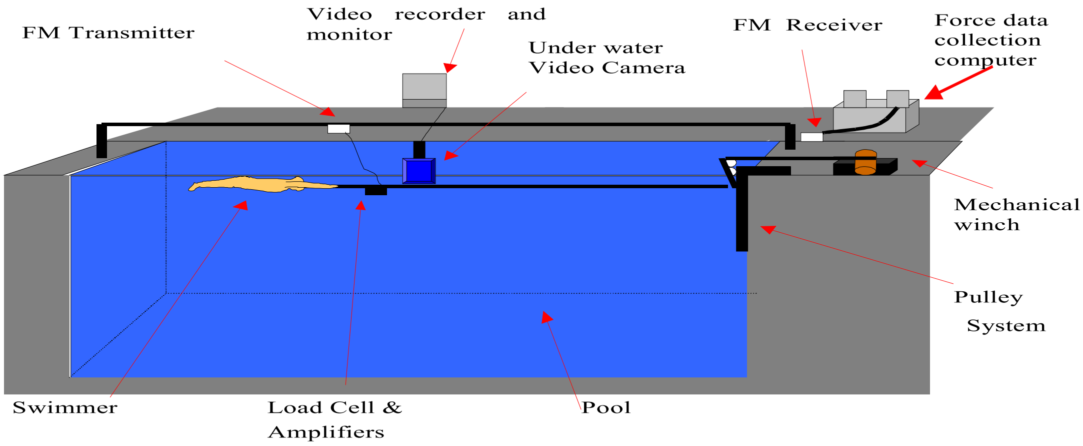

Figure 1 - Schema of the experimental set-up for quantifying net forces.

RESULTS: A MANOVA revealed differences in the selected anthropometric variables between the three age groups (F = 11.877, p<0.01). Males and females were also different across ages (F = 2.516, p=0.04), but the age/gender interaction was not (F = 0.886, p=0.58). A follow-up ANOVA examined each variable for each age group to ascertain the differences between males and females. The only significant gender difference was height for the 11 year olds (girls: mean = 151.48 cm, SD = 3.04; boys: 147.37 cm, SD = 1.49. F = 8.876, p<0.05).
Force Analysis. A four way repeated measures MANOVA examined the differences in the net forces between the towing conditions, age groups and gender. Significant interactions were recorded between age groups and velocity (F = 9.353, p<0.01), and between age groups and towing condition (F = 17.199, p<0.01). However, the three way interaction between velocity, towing condition and age group was not significant (F = 0.929, p=0.454). The repeated measures MANOVA revealed no significant interaction effect for gender and any of the independent variables. However, tests of between-subjects effects revealed gender differences in the net force recorded (F = 7.436, p<0.05). The repeated measure ANOVAs were conducted individually for each of the age groups and towing conditions to identify the age groups with a significant gender difference. Significant differences between gender occurred only in the 11 year age group where the girls created lower net drag forces than the boys in the streamlined glide condition (F = 10.193, p<0.05). Also, repeated measure ANOVAs found no significant interaction between gender and velocity, in the net force of both active and passive towing conditions in all age groups. The net forces from the passive and active conditions were compared via a four way repeated measures MANOVA. This revealed significant differences between the two conditions (F=7.033, p<0.05), as well as a significant velocity and towing condition interaction (F=58.614, p<0.01).
Relationships Between the Net Forces and the Anthropometric Variables. Both height and 25 m flutter kick time correlated significantly with most anthropometric variables and net forces. Partial correlations were constructed with the effects of height and 25 m kick time held constant. Generally, the partial correlations revealed that no common variance was shared at 1.3 ms^{-1} and 1.6 ms^{-1}. However, at higher velocities, body indices and anthropometry correlated significantly with the flutter kick and streamlined glide.
Stepwise multiple regression. Stepwise multiple regression equations were developed to determine the best predictors of the net forces at each of the velocities in both the gliding and kicking conditions of the whole group (N = 36). No regression equations could be computed for passive drag at 1.3 and 1.6 ms^{-1}. Passive drag at the faster velocities best predicted the net forces during the flutter kick.

DISCUSSION: Age differences in net forces for the streamlined glide condition. Lower velocities of 1.3 and 1.6 ms^{-1} revealed similar drag values across the age groups However, as the velocity increased, the 9 year olds recorded significantly lower drag forces than the 11 and the 13 year olds. At 2.2 ms^{-1}, the three age groups differed significantly from one another with the 13 year age group recording the greatest amount of drag.

Toussaint et al. (1990) reported no change in active drag of young swimmers when swimming front crawl at 1.25 ms^{-1} after a 2.5 year period, despite significant height (17 cm) and mass (14.7 kg) increases. They considered that increased height decreased the Froude number and reduced the wave-making drag component. This compensated for any increased frictional and form drag created by a larger body surface and cross sectional areas. No net changes in the drag force implied that the three age groups in the current study should record similar levels of passive drag. This was so at the lower velocities of 1.3 and 1.6 ms^{-1}, but not at the higher velocities.

Passive drag force at 1.9, 2.2 and 2.5 ms^{-1} was significantly and positively correlated with the anthropometric variables except for sum of skinfolds. This agreed with other hydrodynamic studies that showed passive drag was highly influenced by body morphology (Clarys, 1978). Thus, at the higher velocities, differences in passive drag between the three age groups were due to increased body dimensions. However, it remains unclear as to why there was no significant difference at 1.3 and 1.6 ms^{-1}. Frictional drag increases linearly with velocity, form drag increases with the square of the velocity and wave drag varies with the cube of velocity (Rushall et al.,1994). Therefore, 1.3 and 1.6 ms^{-1} might be too slow for body morphology to influence passive drag.

Gender differences in the net force during a streamline glide. There was no gender difference between the passive drag of 9 and 13 year olds, but the mean passive drag of the 11 year old girls was significantly less than that of the 11 year old boys. While the 9 and 13 year old boys and girls were similar in all of the selected anthropometric variables, the 11 year old girls were significantly taller than the 11 year old boys (1.52 & 1.47 m for girls & boys, respectively). As the other anthropometric variables for 11 year olds were similar across gender, the greater height of the girls was associated with reduced wave-making resistance. Similarity in all other anthropometric variables could lead one to assume that the frictional and form drag components also were similar.

Relationship Between Anthropometry and Passive Drag. At 1.3 and 1.6 ms^{-1}, this study agreed with Toussaint et al. (1990) that increased growth did not significantly influence drag. However, at the higher velocities, the increased body size with age also increased drag. Measures of slenderness, such as the ponderal index, H^2/BSA and H^2/X indices correlated significantly ($p<0.05$), but negatively, with passive drag at 1.9, 2.2 and 2.5 ms^{-1}, when height and kick time were held constant. Greater height per unit mass, greater height per unit surface area and greater height per unit body cross-sectional area all corresponded with lower passive drag, and supported the Froude number theory.

Therefore, anthropometric indices could explain how body morphology interacts with passive drag. Furthermore, the ponderal index is associated with the wave making component of drag (Lyttle et al.,1998), while the H^2/BSA and the H^2/X are related to frictional and form drag, respectively (Clarys, 1978). In contrast to these authors, the significant correlations between passive drag and all of the three indices at the three highest velocities suggested similar contributions from wave making, friction and form components of drag.

The Influence of the Flutter Kick on Net Force. The mean kick time for 25 m was significantly and negatively correlated with age and many anthropometric variables. Muscular strength and power of children increases with physical development and enables them to generate greater power. In combination with a better kicking technique, this could enhance kicking performance (Touissant et al.,1990). The kick time of the 9 year olds did not differ significantly from the 11 year olds, but the 13 year olds were faster. Net drag force data show that the 9 and 11 year age groups only benefited from kicking below a velocity of 1.6 ms^{-1} and 1.9 ms^{-1}, respectively. However, the 13 year olds, with better kicking technique and power, benefited at all values below 2.5 ms^{-1}. The lower velocities also equate with reasonable performance times for children of these ages. That is, 38.5 s for 50 m (1.3 ms^{-1})

and 31.3 for 50 m (1.6 ms^{-1}). However, the older swimmers recorded larger passive drag at higher velocities (1.9, 2.2 & 2.5 ms^{-1}) than did the younger age groups.
In conclusion, as the swimmers ages increased, so too did the anthropometric variables and passive drag at velocities exceeding 1.9ms^{-1}. Increased height was only associated with lower passive drag when all other anthropometric variables were similar. This study indicated that active drag during prone flutter kicking is related to passive drag and a number of anthropometric variables. This reinforces the need for streamlining and appropriate choice of timing to recommence kicking after a swimming start or turn.

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