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Water Depth Requirements of Competitive Racing Starts

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Abstract

The purpose of the study was to measure the water depth required of 30 collegiate swimmers using the pike and flat starts from both 15 inch and 30 inch starting blocks. Time to reach maximum depth and angle of entry was also measured. All data were collected from films taken at 100 frames per second and projected onto a Numonic digitizer for frame-by-frame analysis.

Subjects required significantly greater water depth when using the pike start. It was recommended that starting blocks used by competitive swimmers be placed over a minimum 4.5 foot depth, and coaches not permit swimmers to enter the water at that depth until they demonstrate mastery of starting techniques over at least 6 feet of water. In pools where blocks cannot be placed over 4.5 feet of water they should be lowered to below a 15 inch height or eliminated entirely.

The above recommendations are for experienced competitive swimmers. Recreational swimmers should use starting blocks only when at least 10 feet of water is below them.

Introduction

Several swimming authorities (1,2,3) have warned against using the pike or scoop start in water of 3.5 or 4.0 foot depth as catastrophic head and neck injuries, they report, have resulted from doing this. None of the warnings, however, were based on published research of competitive swimmers performing the pike start from starting blocks.

The purpose of this study was to measure the depth of plunge of collegiate swimmers using two different starting techniques from two starting block heights. Calculations of the time to reach maximum depth as well as the angle of entry into the water were also made.

Current NCAA rules governing scholastic and collegiate swimming recommend a minimum water depth of 4 feet with maximum permissible starting block (platform) height of 30 inches above the surface.

Methods

Twelve female and eighteen male competitive swimmers were filmed through an underwater window in 12.5 feet of water. Each swimmer performed two pike (scoop) and two conventional (flat) starts from both 15 inch and 30 inch starting blocks, for a total of eight competitive starts. The order in which the start-heights were performed was systematically varied among the subjects. Then the sixteen millimeter movie films, taken at 100 frames per second were studied frame-by-frame by projection onto a Numonic digitizer to determine:

1. Maximum depth of subjects head.
2. Time to reach maximum depth.
3. Angle of entry of head, neck, and torso.

The depth data, considered to be the primary focus of the study, were further analyzed to determine: (1) differences in depth requirement of the two starting techniques from the two heights, and (2) if a swimmer’s height and weight influenced the depth of plunge. The starting technique and block height data were analyzed by one-way analysis of variance in order to make the desired comparisons. The influence of height and weight was determined by analysis of covariance.

Findings

1. There was no significant difference in water depth requirements between males and females at any of the dive technique block height combinations.
2. With subjects combined (male, female), the pike start required significantly greater water depth than the conventional start at both 15 inch and 30 inch start-
ing block heights. The pike technique at a 15 inch height resulted in a greater depth of plunge than did the conventional start at 30 inches (see Tables 1 and 2).

3. Subject’s height was significant in influencing the depth of the dive as taller subjects required a greater depth.

4. The covariate weight had only a negligible effect and was not significant in determining water depth requirements in this homogeneous group of swimmers.

Discussion

On the basis of the above findings, the depth requirement was the least with the 15 inch-conventional start and increased progressively with 30 inch-conventional, 15 inch-pike and 30 inch-pike starts. The obvious conclusion is that when one dives into pools of 3.5 or 4 foot depths the above order represents the degree of increased risks of striking the bottom with possible catastrophic injury.

It is recognized that the subjects in this study were tested in 12.5 feet of water and this may have caused some to be less cautious than if diving into shallower water. It is assumed, however, that this possible influence on the depth of the plunge had an equal effect on both methods of starting. Furthermore, when one considers the short time interval of 0.5 seconds or less to reach maximum depth, one must recognize that a distracting thought in a shallow water situation could result in dire consequences.

The extent of instruction and prior experience by the subjects performing the two starting techniques is not known; it was assumed that collegiate swimmers were familiar with both techniques. Prior to testing, subjects were instructed in both techniques and were given a minimum of two practice starts with each technique.

Recommendations

1. Whenever possible, move starting blocks to the deep end of a pool.

2. For skilled collegiate swimmers using 30 inch blocks, the minimum water depth should be increased to 4.5 feet. The additional depth will provide an increased margin of safety in terms of both depth of dive and time to react.

3. In situations where recommendations 1 and 2 cannot be met, the starting blocks should be lowered to below 15 inches or eliminated entirely.

4. Coaches who teach any new or unfamiliar methods of starting to swimmers should do so at a depth of at least 6 feet. Swimmers should be permitted to practice the start in shallower water (4.5 feet/minimum) only after demonstrated mastery.

5. Coaches should educate swimmers of the dangers in-

| TABLE 1 |
| DEPTH, TIME TO DEPTH AND ANGLE OF ENTRY DATA FOR MALE SUBJECTS, N=18 |

<table>
<thead>
<tr>
<th></th>
<th>15 inch block</th>
<th>15 inch block</th>
<th>30 inch block</th>
<th>30 inch block</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional Start</td>
<td>Pike Start</td>
<td>Conventional Start</td>
<td>Pike Start</td>
</tr>
<tr>
<td>MAX DEPTH, AVG:</td>
<td>1.83 FT</td>
<td>2.37 FT</td>
<td>2.23 FT</td>
<td>2.56 FT</td>
</tr>
<tr>
<td>TIME TO MAX DEPTH, AVG:</td>
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<td>.43 SEC</td>
<td>.38 SEC</td>
<td>.39 SEC</td>
</tr>
<tr>
<td>ANGLE OF ENTRY, AVG:</td>
<td>24º</td>
<td>31º</td>
<td>29º</td>
<td>34º</td>
</tr>
</tbody>
</table>

| TABLE 2 |
| DEPTH, TIME TO DEPTH AND ANGLE OF ENTRY DATA FOR FEMALE SUBJECTS, N=12 |

<table>
<thead>
<tr>
<th></th>
<th>15 inch block</th>
<th>15 inch block</th>
<th>30 inch block</th>
<th>30 inch block</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional Start</td>
<td>Pike Start</td>
<td>Conventional Start</td>
<td>Pike Start</td>
</tr>
<tr>
<td>MAX DEPTH, AVG:</td>
<td>1.56 FT</td>
<td>2.16 FT</td>
<td>1.67 FT</td>
<td>2.31 FT</td>
</tr>
<tr>
<td>TIME TO MAX DEPTH, AVG:</td>
<td>.33 SEC</td>
<td>.41 SEC</td>
<td>.31 SEC</td>
<td>.39 SEC</td>
</tr>
<tr>
<td>ANGLE OF ENTRY, AVG:</td>
<td>20º</td>
<td>35º</td>
<td>23º</td>
<td>31º</td>
</tr>
</tbody>
</table>
herent in diving from starting blocks; entry on a false start must not be altered from one's normally prudent technique.

6. When non-skilled or recreational swimmers are using a pool, starting blocks should be removed or made inoperable unless they are located over at least 10 feet of water.

References


Interpreting Statistical Analyses in Swimming Research

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Abstract

In order to interpret much of the current swimming research, a basic knowledge of statistics is required. This knowledge also permits the reader to question the validity of experimental results and accept or reject the authors’ conclusions about the experiment. The descriptive statistics of mean, standard deviation, and range are discussed. Correlation is covered under the heading of descriptive statistics because it describes the possible relationship between two of the variables. Regression is presented with consideration given to the limitations of its results being inferred to other populations of subjects. The analysis of variance and t tests are covered primarily with regard to interpretation of results of the experiment and without consideration of the inference space. It is the intent of this article to educate the readers of JSR in the area of statistics and not necessarily to criticize the methodology of its contributors.

Introduction

The purpose of this article is to inform the readers of The Journal of Swimming Research (JSR) about the uses of statistical methodology in research. The intent is primarily educational, as it is assumed that the methodological correctness has already been determined by the editorial board.

Descriptive statistics are used in any quantitative type of research (1, 3, 5, 6, 8). The mean (\(\bar{X}\)), standard deviation (SD), and range are examples of commonly-used descriptive statistics. The correlation coefficient (r) is a measure of linear association between two variables. It is not an indicator of a cause and effect relationship between the two variables. Coaches intuitively look for correlations that relate to success. One of the most common correlations coaches use intuitively is percentage of workouts attended and the amount of improvement made by their swimmer.

The Standard error (Se) caption appears in tables summarizing results from regression (3) and analysis of variance (7). When (Se) appears in conjunction with analysis of variance, it represents the standard error of the mean. When (Se) appears with regression analysis, it represents the standard error of prediction.

Analysis of variance (ANOVA) and the t-test (t) are statistical tools that allow a researcher to determine whether experimental differences between groups of subjects occurred as a result of the experimental procedures or by chance (13). An ANOVA is used when two or more groups participate in an experiment and the (t) is used when only two groups are involved in an experiment (2, 4). Variations of these tests can also be used to test differences between performance scores of one group of subjects measured on two occasions (t) or more than two occasions (ANOVA).

When statistics are used and interpreted correctly, they can be of value to coaches and researchers alike. Statistics allow a more objective view into the relationships between performance and factors eliciting variations in performance.

Descriptive Statistics

The \(\bar{X}\), SD and range were the most common descriptive statistics appearing in JSR (1, 3, 7, 8, 12). The \(\bar{X}\) is the arithmetic average. Coaches consistently use this statistic for evaluating their swimming program. For instance, the average time for a swimming set such as 10 × 100 yards freestyle may be kept in the coaches’ or swimmers’ log book. The SD is a measure of dispersion. It tells how far a score is from the \(\bar{X}\). If a group of scores is normally distributed then 68.26% of the scores will lie within +1 and −1 SD from the \(\bar{X}\), 95% of the scores lie within +2 and −2 SD from the \(\bar{X}\), and 99.5% of the scores will lie within +3 and −3 SD from the \(\bar{X}\). For
example, Manning et al. (7) reported a \( \bar{X} \) post test heart rate score of 190.71 beats per minute and a SD of 7.70. If these scores were normally distributed, 68.26% of the subjects had heart rates ranging from 183.01 and 198.41 beats per minute. These scores might appear in the narrative portion of the article as \( \bar{X} = 190.71 \) or \( \pm 7.70 \). The range, reported in (1, 12) is found by subtracting the lowest score from the highest score plus 1. As its name implies, it describes the range of scores in the experiment. It is the simplest measure of dispersion and gives the reader some idea about the breadth of scores in the experiment. Taking the example of 10 \( \times \) 100 yards freestyle for a group of swimmers, the slowest time might be 56.5 seconds and the fastest time might be 46.5 seconds. The range would be 11. In the narrative portion of the text, the range of scores would be reported as “scores (times) ranged from 46.5 to 56.5” showing the fastest and slowest time. These are types of standard error (SE) recently reported in JSR (3, 7). Both are denoted by letters SE. When the results of a regression analysis are presented, the SE stands for the standard error of prediction. It may also be presented as SE.x (13). For example, if an experiment had been repeated many times with different groups of subjects sampled from the same population (i.e., the population might be 11-12 year old male swimmers), there would be a mean error found when trying to predict a dependent or (y) variable from the score of an independent or (x) variable. The SE is an estimate of the SD of this error. This estimate is needed because researchers generally cannot repeat their experiments enough times to determine this error. When the SE appears in a table that summarizes the results of ANOVA, it represents the standard error of the mean which could also be symbolized as SE. If a large number of equal-sized groups were sampled from a population and scores for a given criteria were collected, their mean scores would have a normal distribution. The SE, when calculated, would be an estimate of the SD of these scores had this procedure been followed. Again, this estimate is needed because researchers cannot repeat their experiment many times. In summary, the SD is a measure of dispersion showing how far a score is from the \( \bar{X} \) and the SE is an estimate of the standard deviation of a sampling distribution.

The Pearsonian r or Pearson Product-Moment Correlation (r) is used to describe the degree of linear relationship between two variables (2). The values of r range from +1 indicating a perfect positive correlation or relationship to −1 indicating a perfect negative correlation or relationship. A positive relationship often seen in coaching, although not perfect, might be the relationship between improvement in swimming performance and workout attendance. Values in between such as .7 or −.5 describe some intermediate relationship between two variables is seen in Figure 1. The regression line shows a correlation of .84 between swimming velocity and power production.

Stager et al. (9) presented a correlation matrix of the linear relationships between elapsed time for swimming 100 yards freestyle and several indices of body composition. The asterisk beside some of the coefficients indicates these relationships did not occur by chance. The footnote, by the asterisk, indicates the probability that a relationship of this magnitude will occur by chance. In this case, “p < .001” indicates the relationship will occur by chance 1 out of 1000 times.

Another way to look at a correlation coefficient is to calculate the coefficient of determination (13) which is the value of \( r \) squared. For example, Costill et al. (3) reported an \( r \) of .84 between sprint velocity for 22.86 meters and power scores generated while swimming tethered to a Biokinetic dynamometer. The value of the coefficient of determination would be .7056 (not reported). This means that 70.56% of the total variation in sprint velocity scores can be accounted for by the power scores. If there are a lot of scores used in an experiment, a low correlation coefficient may be significant. The \( r \) squared value tells the reader the actual percentage of variation accounted for by the independent variable. While the correlations reported by Stager et al. were statistically significant, the \( r \) square values were not particularly high. For instance, there was a significant correlation between lean body mass and time for 100 yards freestyle (−.26). This means that if lean body mass were higher in subjects, their time for 100 yards freestyle was faster. The coefficient of determination of .0676 indicating that lean body mass only accounted for 6.76% of the variation in times for 100 yards freestyle.

![Figure 1](image)

Figure 1. The relationship between tethered, biokinetic front crawl swimming power and maximal sprinting velocity, as measured during a 22.86 m (25 yd) swim. (From Costill et al. 1986)
yards free style. Other factors such as strength, experience, conditioning, and technique are probably more important for predicting time for the 100 yards freestyle. The correlation between % body fat and time for 100 yards freestyle was low (.18). Percent body fat related to performance in 100 yards freestyle only by chance. Also, this coefficient of determination would not be significant.

Regression

For the purposes of this article, regression can be considered a cousin to correlation. In the preceding section, the Pearsonian r was shown to describe the relationship between power scores and sprint velocity. The power scores and sprint velocity were both measured by the researcher with the idea that at a later time one would only have to measure the power scores in order to predict how fast the subject could swim—the sprint velocity being the dependent variable or variable of interest (y) and the power score being the independent variable (x). After measuring both variables, the regression equation was generated and shown in (3) Figure 1. The y variable is sprint velocity and the x variable is power production. The value of .007 is average change in swimming time per unit change in the power score. The value 1.575 is the intercept or the point where the regression line intersects the y axis. The prediction equation will hold true for the group of swimmers which were tested, and for the range of values which were measured. If a significant F ratio were reported (see next section), the prediction would hold true for other swimmers in the same population. So, if a group of 10 and under age group swimmers or another dissimilar group were tested, the prediction may not hold. Bradley et al. (1) reported the prediction equation for estimating residual volumes did not accurately estimate residual volumes for elite swimmers. This was because the subjects used to generate this prediction equation were not elite swimmers but from some other population. The final outcome of relying on this equation would have been an inaccurate assessment of the body composition of swimmers at an elite training camp. Regression as well as other statistical tools can be misleading. Therefore, their limitations must be fully understood by the reader in order to avoid problems similar to those described by Bradley et al. (1).

Analysis of Variance

The ANOVA procedure is commonly employed to measure differences between two or more groups of subjects after they have been subjected to some experimental procedure. The ANOVA can also be used to compare performances of one group on two or more occasions. This is called a repeated measures ANOVA. Manning et al. (6) used a repeated measures ANOVA to determine differences in power measurements for a group of swimmers, on three different occasions. The results were reported as an F ratio. The asterisk by the reported F ratios indicates the variation between tests was greater than the variation between the subjects for each test. Had this been an F ratio for a regular ANOVA, testing differences between three groups, it would have indicated than the variation between the three groups of subjects, on the test criterion, was greater than the variation within the groups of subjects on the test criterion. So, a significant F ratio reported by Manning et al. (7) indicated that the differences between the scores for each occasion were greater than the differences between the scores of the subjects on each of the occasions when the measurements were made. The footnote at the bottom of the table indicates the probability level for the test (p < .05), meaning that the differences of these magnitudes occurred by chance only 5 times out of 100. An F ratio does not indicate where differences occurred. A post hoc test is employed to test for differences between all possible combinations of groups. For instance, Manning et al. (7) also reported significant differences (F = 4.20, p < .05) for revolutions completed, on a bicycle ergometer, on 3 different occasions. The post hoc tests should have reported if the differences occurred between 9 weeks prior and just prior, 9 weeks prior and post, and just prior and post. Generally, these results are reported in the narrative portion of the article (7). Results of post hoc tests can also be reported in tabular form, particularly if there are 5 or more groups or tests (see Table 1 for an example).

| 120 | 100 | 80 | 70 | 40 | 10 |

TABLE 1

Example of how results of post hoc ANOVA tests may be presented. Values connected by lines are not significantly different.

The t Test

The t test is often used when there are two groups being tested (independent t) or when one group is tested on two occasions (dependent t). The results are reported in the form of a t ratio, which is essentially same as the F ratio. The P value or probability is reported in exactly the same manner as previously discussed. In the case of the t test, a post hoc test is not necessary since there are only two groups. Although the ANOVA and t are essentially the same test, a t is more commonly used for 2 groups. Using multiple t tests to test differences between more than two groups is inappropriate, the reason being that as the number of tests on the same set of data increases, the probability that differences will be found increases only as a result of increasing the number of tests.
The ANOVA and method of calculating the post hoc tests prevents this from happening. The Bonferroni correction factor (13) is sometimes seen in the literature. It is used when multiple t-tests are employed in the post hoc procedures or in a priori procedures which are beyond the scope of this article.

Discussion and Conclusions

Examples of scientific fields which have contributed to our present knowledge about human performance are physiology, exercise physiology, biomechanics, and certain areas within the discipline of psychology. Current literature published in these fields often requires the use of statistical analyses to document or support the conclusions of the authors. This has been demonstrated in JSR. In order to evaluate the authors' conclusions, a rudimentary knowledge of statistics is necessary. However, for the reader/coach to effectively evaluate the findings of research, a greater understanding of statistics is generally required. For example, two authors may draw different conclusions from similar experiments. The seed of the controversy may be in the way the data were analyzed. If one has to draw conclusions from conflicting results, then knowledge of statistics could be useful. When interpreting results of statistical analyses, it is important to keep in mind that statistical significance is not necessarily practical significance. These statistical tests will find very small differences to be statistically significant if there are a large number of subjects. It is up to the reader to determine if these differences are of practical significance if one is going to employ procedures recommended by an author. Another factor to consider when deciding whether to employ the results of research in a training program is were the subjects in the experiment from the same population as your swimmers. If the subjects in an experimental procedure were 10 and under girls, it is unlikely the results would be the same if you were coaching collegiate males. Winer (13) provides a discussion on inferring the results of statistical tests.

Many coaches keep very consistent and accurate records of their swimmers' weight training and swimming workouts. These records can be a valuable tool for a coach when planning or drawing conclusions from previously-completed training. However, it is necessary for these records to be correctly analyzed. For example, two groups are tested for 100 yards freestyle; Group A groups averaged 54 seconds and had a fastest time of 49.5. Group G averaged 55 seconds and had a fastest time of 54.2. Which group had a better performance? Since extreme (very large or very small) scores have a big influence on the X score, determining which group had the best performance would be inaccurate if one were to only look at the X differences. The ANOVA procedure or t could be used since they take into account the amount of variation within each group, thereby eliminating judgment error on the coaches part as to which group had the best performance. One word of warning on using ANOVA and t tests is that if the times within each group did not have any variation (everyone swimming had identical time), then these testing procedures cannot be used. Statistical test procedures are relatively simple and once an understanding of their meaning is acquired, very inexpensive computer programs perform the calculations. Simple statistical analyses can help eliminate some of the error in a coaches decision making process as well as help in the understanding of current research in the area of human performance.

References

A Biomechanical Analysis of the 1984 U.S. Olympic Swimming Team: The Distance Freestylers

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Joseph Higgins,
Richard Hinricks,
David Luedtke,
Robert E. Schlehauf and
Anne Thayer

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Abstract

Six distance freestyle swimmers from the 1984 U.S. Olympic Swimming Team were filmed while swimming at their Olympic qualifying paces. The films were subjected to a 3-D biomechanical analysis to determine such aspects as stroke patterns, hand velocity patterns, and the application of propulsive force. The data indicated that there were four phases in the underwater armstroke where a considerable amount of propulsion could be generated. However, none of the subjects in this study used more than two of those phases to advantage. The discussion centered on why these swimmers did not or could not take full advantage of the propulsive potential available in all four phases of the armstroke.

Introduction

The propulsive efficiency of competitive swimmers has been a matter of considerable interest for many decades (Alley, 1952; Plagenhoff, 1971; Báthelys & Adrian, 1974; Schlehauf, 1978; Schlehauf et al., 1985). In 1974 Robert E. Schlehauf introduced a method for estimating the instantaneous propulsive force that is generated by swimmers as they stroke down the pool. This method is based on using vector analysis to solve for the resultant and propulsive forces when the velocity, direction, and angle of attack of the hand and arm are known.

Schlehauf’s method was used to study the propulsive effectiveness of selected members of the 1984 U.S. Olympic Swimming Team while they attended a Pre-Games training camp in Mission Viejo, California during July, 1984. The project was funded by United States Swimming with the permission of the athletes and coaching staff. The Sports Medicine Committee of United States Swimming selected the authors to conduct the investigation. The purpose of this paper is to present the results concerning selected distance freestyle members of the team.

Methods and Procedures

Six distance freestylers were filmed, three women and two men. Each athlete was asked to push off the wall and swim 25 meters at their Olympic qualifying pace. Times were recorded to insure that the paces were correct and the swimmers were asked to repeat the swims when the paces were slower or faster than they should have been. This procedure was followed for each event in which the swimmers qualified.

The locations of certain body parts were marked with shiny black tape or small battery operated lights. The points marked were the tip of the middle finger, the base of the index finger and the little finger and the wrist.

Two 16mm LoCam movie cameras were used in the filming process. They were placed in water-tight plexiglass housings and placed in the pool in fixed positions so that the athletes swam through the field of view. One camera was placed on the bottom of the pool to record underneath views. The other was placed at the end of the pool approximately 30 centimeters underwater to record front views. The cameras were activated
simultaneously by a common switch. They were operating at 66 frames per second.

Once the film was processed it was digitized using a Numonics digitizer and an Eiki 16mm projector. Every frame was digitized for one complete underwater arm-stroke of both the right and left arms.

The digitized information was then analyzed by means of a computer program that had been written by Robert E. Schlehauf. This program calculated stroke patterns, hand velocities and angles of attack of the hands from front, side and underneath views. The stroke patterns were determined from the paths traced by the middle fingers of the swimmers’ hands. Hand velocities were calculated from movements of the middle finger. The three markings on the fingers and the marking on the wrist were used to calculate the angle of attack of the hand. This information was combined with directional and velocity computations to determine the total force produced by the swimmer’s arm-stroke and that portion of the force that was propulsive.

Results

An analysis of the data revealed that there were four distinct propulsive phases during the underwater arm-stroke. These phases are illustrated by a female subject’s right arm-stroke in Figure 1. That figure depicts stroke patterns drawn from both front and side views. The side view is on the left and the front view is on the right. The front view is drawn as a mirror image so that the reader can trace the movements by following the pattern with his or her right hand. A line graph of the propulsive force produced during the arm-stroke is also shown.

The stroke patterns show clearly that all stroking movements are three-dimensional in nature. For example, it can be seen from the side view that, between frames 10 and 30, the swimmer in Figure 1 is moving her hand downward and forward. The front view reveals that her hand is traveling somewhat inward between frames 10 and 20 and outward between frames 20 and 30.

Descriptions of the four propulsive phases follow. Although the three-dimensional nature of each phase will be described, the term used to identify each phase will be based on the predominant direction that the hand is moving.

A. Downsweep. This phase takes place between frames 20 and 30 in Figure 1. It begins midway through the long downward sweep after entry, when the swimmer’s hand also begins traveling outward. It ends when the swimmer’s hand begins sweeping inward at frame 30.

B. Insweep. This phase occurs between frames 30 and 40. It begins as the hand sweeps inward under the body and ends when the swimmer begins sweeping outward and upward.

C. Outsweep. This phase is shown between frames 40 and 50 in Figure 1. It begins when the swimmer’s hand sweeps outward from underneath her body and ends when her hand is moving in a primarily upward direction toward the surface. The swimmer in Figure 1 tends to blend this portion of the arm-stroke with the final phase, the upswing such that they are really one continuous outward and upward motion rather than two distinct sweeps. Other subjects in this study had a much more distinct outward sweep during this phase. One such subject is depicted in Figure 2. Notice that, between frames 42 and 56, his hand is moving almost entirely outward rather than outward and upward.

Two of the six subjects in this study used a style similar to the one depicted in Figure 1 on both their right and...
left armstrokes. One swimmer used the style shown in Figure 2 exclusively. The remaining subjects used a combination of these two styles. That is, they tended to combine the out sweep and up sweep into one motion during either the right or left arm stroke while using a very distinct outward sweep during the opposite arm stroke.

D. Upsweep. This particular phase of the arm stroke is most prominent between frames 50 and 60 in Figure 1 and between frames 60 and 70 in Figure 2. It begins when the hand is moving upward, backward and slightly outward and ends when the motion of the hand becomes upward and forward. The swimmer in Figure 1 is using the up sweep very effectively because her hand is moving backward as well as upward throughout the sweep. You can see, in the graph below her stroke patterns, that she is maintaining a fairly large amount of propulsive force during this phase. On the other hand, the swimmer in Figure 2 has a rapid drop-off in propulsive force because his hand is moving upward and forward during the up sweep.

It is interesting that each of the distance swimmers in this study were able to generate large propulsive peaks, (3 kgs or more), during only one or two of the four sweeping movements. The swimmer in Figure 1 has a propulsive peak during the out sweep, another during the up sweep. The swimmer in Figure 2 achieves his propulsive peaks during the insweep and out sweep.

The right arm stroke patterns and propulsive force data for three of the four remaining athletes are shown in Figures 3, 4, and 5. The male swimmer in Figure 3 achieves his major propulsive peaks during the down sweep (frames 30-40) and up sweep (frames 54-64). The female swimmer in Figures 4 achieves her major propulsive peaks during the out sweep (frames 30-40) and the up sweep (frames 40-50) that follows. The female swimmer in Figure 5 has only one propulsive peak, during the insweep (frames 30-40).

Another interesting aspect of this investigation was that the subjects tended to favor either lateral or vertical stroking motions. Those swimmer who gained most of their propulsion when their hands were moving in primarily vertical directions were not very effective when they were sweeping their hands in lateral directions. Conversely, the laterally-oriented swimmers were not very effective when they were sweeping their hands vertically.

This tendency to favor either lateral or vertical stroking motions is illustrated by the swimmers in Figures 1 through 5. Notice the small propulsive peak during the insweep (frames 36-40) for the vertically-oriented swimmer in Figure 1. This swimmer minimizes the inward sweep.
so that she can get on to the more productive upsweep portion of her armstroke. The male swimmer in Figure 3 is vertically oriented. His major propulsive peaks occur during the downsweep (frames 30-40) and upsweep (frames 56-66). He is only minimally effective during the insweep (frames 40-30). The female swimmer in Figure 4 has practically no insweep and achieves almost all of her propulsion during the outsweep (frames 32-38) and the upsweep (frames 44-54). Although this swimmer might be interpreted as using a combination of lateral and vertical stroking motions, her front stroke pattern indicates that she combines the outsweep and upsweep into one long motion which is predominantly vertical in nature.

The laterally-oriented swimmers in Figures 2 and 5 are only minimally effective during the downsweep and upsweep portions of their armstrokes. The male swimmer in Figure 2 is most effective during the insweep (frames 30-40) and outsweep (50-58). He is less effective on the downsweep (frames 20-30) and not at all effective on the upsweep (frames 60-70). The female swimmer in Figure 5 is most effective during the insweep (frames 30-40). She is not very effective at all during the downsweep (frames 20-30) and upsweep portions of her armstroke (frames 40-60).

Discussion

Why did the distance swimmers in this study utilize only one or two propulsive phases of their armstroke when four were available to them? Figures 6 and 7 depict hypothetical male and female swimmers, respectively, who combine the most effective sweeps of the subjects in this study. The strokes of the three male distance swimmers are combined in Figure 6 while the strokes of the female swimmers are combined in Figure 7.

These fictional swimmers could attain large propulsive peaks during the downsweep and maintain approximately that same peak until their hands near the surface of the water. It is obvious that a competitive swimmer who could combine the best propulsive characteristics of the world class swimmers in this study would establish World Records in the freestyle events that defy credulity. A swimmer who could utilize all four sweeps to advantage should be able to generate a large amount of propulsive force for a little over .5 of a second during an underwater stroke that requires approximately .8 of a second to complete.

It is surprising that none of the distance swimmers in this group were able to maintain a propulsive peak for longer than .15 seconds and most were only able to do this twice during each stroke. One possible explanation for this result is that it might be too fatiguing to try for major propulsive peaks in all four phases of the armstroke. Perhaps swimmers utilize their energy more efficiently by working hard only during the most effective portions of their underwater armstrokes while minimizing those sweeps where they are least effective.

Another possible explanation is that swimmers may not be able to maintain propulsive peaks for more than .15 of a second before accelerating the water beyond their ability to maintain pressure against it. Figure 8 shows the hand velocity of one of the subjects superimposed over the propulsive force that he is producing during the various phases of his armstroke. The propulsive peaks occur during periods when the hand is accelerating which is in agreement with the information presented by Counsilman and wasilak in 1982. Notice that there is a deceleration between peaks (see frames 36-42). This deceleration occurs when the swimmer’s hand is changing directions from an inward sweeping to an outward sweeping motion. Perhaps, as Counsilman (1977) has theorized, this deceleration is necessary in order to find relatively slow moving water that can be accelerated in the new direction. On the other hand, it may be a result of the normal
slowing that must take place in order to change directions.

Regardless of the reason, the swimmers in this study tended to emphasize only two of the four sweeping mo-

Figure 8. A comparison of changes in hand velocity and propulsive force for a male distance swimmer.

tions available to them. An interesting question for future research would be to determine if swimmers can be taught to use all four phases of the stroke effectively. If it is possible to do so, swimmers of the future might be considerably faster than contemporary athletes. On the other hand, swimmers who are taught to emphasize all four propulsive phases of the stroke may only be able to generate four minor propulsive peaks which, when combined, do not equal the magnitude of the two major peaks.

Summary

There seems to be four phases of the freestyle arm-stroke where a considerable amount of propulsive force can be generated. These phases are: the downsweep, insweep, outsweep and upsweep. No swimmer in this study was able to generate large propulsive peaks in more than two of those phases. This may be because it is not possible to generate the hand velocities and/or force required to maintain propulsive peaks during all four phases. Therefore, the world-class swimmers in this study may have intuitively learned to use the two sweeps that were most effective for them while minimizing the effort expended in the remaining two stroke phases. It is interesting to speculate as to whether swimmers of the future should concentrate on learning to use all four phases of the underwater armstroke or whether they should elect to use only the two sweeps that are most effective for them.

References

A quarterly publication for applied swimming science and research.

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