Propulsion in Breaststroke Swimming

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INTRODUCTION

It is a biomechanical principle that if two athletes have identical average velocities, the athlete with greater fluctuations in velocity would tend to be more inefficient than the athlete with less velocity variation. This principle holds true in the case of the intra stroke velocity fluctuations of swimmers.

It is also a biomechanical principle that the acceleration pattern of an athlete is directly related to the external forces acting on the athlete. Only external forces are able to change the velocity of the athlete. The intra stroke acceleration profile of a swimmer indicates where the swimmer utilises effective propulsive actions to propel himself or herself forward through the water and where the swimmer uses effective streamlining to reduce drag as the body moves through the water.

It is important that the centre of gravity (COG) of the swimmer is used to determine the velocity and acceleration profile of the swimmer. The movement pattern of the COG reflects the true movement pattern of the whole swimmer. However, it is almost impossible to obtain accurate velocity and acceleration information about the COG of the body directly from a transducer. This, on the other hand, would not be too difficult to achieve using a single point on the body. 'The COG information is only readily obtainable by digitising the image of the swimmer's anatomical landmarks from film and computing the location of the COG, a frame at a time, before calculating the velocity and acceleration parameters. As this procedure is very time consuming, the research investigated whether velocity and acceleration parameters associated with the hip movement could be reliably substituted for the COG parameters without losing too much accuracy.

The major aim of the research project was to obtain information about the intra stroke velocity and acceleration profiles of elite breaststroke swimmers. A knowledge of such profiles for a number of swimmers would provide an improved understanding of the biomechanics of the swimming stroke. The next stage of the project was to identify if this information could be used to evaluate the technique efficiency of swimmers involved in the study so that any disclosed inefficiencies could be eliminated.

METHOD

Elite international and national calibre breaststroke swimmers were filmed using a high speed 16 mm camera operating at 100 frames per second. One of the female subjects in the study was from the D.D.R. and held the world record for the 100 metres breaststroke at the time of data collection. All swimmers were asked to swim their regular competitive distance at competition pace. The high speed filming was done as they swam the last two laps in a 25 metre pool. The filming was performed at right angles to the swimmers' movement plane from behind a viewing window which extended both above and below the level of the water line. The camera was located three lanes distant from the swimmer just beneath water level and was panned to obtain a large image size of the swimmer over approximately three full swim cycles or strokes in each direction. During the second swim cycle filmed, the axis of the camera lens moved through an angle of 90 degrees to the plane of movement. A periscope attachment on the camera permitted a split image to be filmed which provided simultaneous pictures of the swimmers's body parts both above and below the water on each frame of the film. Two sets of markers, located both above and below the swimmer, permitted information obtained from either above or below water level to be adjusted so as to rectify for the difficulties associated with the complex filming procedures. Such difficulties arose as a result of the differences in the size and displacement of those parts of the image which were out of the water compared to the parts which were in the water. This was caused by the different refractive induces of light in air and water. Another difficulty resolved by using the markers was that adjustment could be made to the varying displacement measurements which arose because of the changing camera angles to the plane of motion that resulted from using a panned camera.

The start of the stroke was considered to be the first observable action of the hands in an outward direction following arm recovery. This particular aspect of the stroke is referred to by coaches as the commencement of the 'catch'. The body segmental endpoints for each swimmer were digitised in every frame over an entire stroke length, together with 20 extra frames before and after the stroke. The extra 40 frames were digitised to provide the necessary information to permit an accurate data smoothing process at the beginning and end of the stroke. The particular stroke selected for analysis usually occurred when the camera filmed at right angles to the plane of movement. In all, 22 points were digitised in each frame to represent the swimmers' body. Another four points were digitised, which were the reference markers, so that the computer could correct the displacement of the body's segmental endppoints to adjust for the filming environment. The adjusted two dimensional data, representing the relativelocation of the swimmer's body landmarks, was smoothed using a digital filtering technique after any obvious errors in digitising were corrected. The displacement of the swimmer's COG in the horizontal plane was computed for each frame digitised. The velocity of the swimmer was computed as the first derivation of the COG's horizontal displacement with respect to time. The acceleration of the swimmer was computed as the second derivative of the COG's horizontal displacement with respect to time. Digital smoothing techniques were applied after each derivative computation. To investigate whether hip movement could be successfully substituted for the COG, similar computations were performed on the horizontal displacement data obtained from the hip joint to compute velocity and acceleration parameters of the hip. The velocity and acceleration profiles for each swimmer were plotted. Animated stick figures, drawn from the smoothed digitised data by computer on a coloured monitor, were displayed simultaneously with the velocity and acceleration COG profiles. This was then stored for viewing by the coach on video tape.

ANALYSIS

In all, a total of nine elite breaststroke swimmers were analysed. To identify whether the system developed in this research could be effectively used to evaluate stroke technique and identify weaknesses in particular swimmer's style, the following procedures were adopted. The evaluation consisted of observing the velocity and acceleration profiles of the swimmers in conjunction with the stick figure animations representing the actions in the swimming stroke. A subjective evaluation of both the velocity and acceleration profiles was performed to identify their relevance to technique analysis. Coaches were asked to comment on information presented.

To build up a complete picture of breaststroke propulsion, velocity and acceleration-COG parameters from all swimmers in the study were reviewed to develop a general velocity and acceleration profile which was representative of elite breaststroke swimming. The analysis to evaluate whether the parameters associated with hip movement could adequately represent COG movements was assessed as follows. Intra stroke velocity and acceleration curves of the hip and COG were graphed and compared by visual inspection. A correlation coefficient to determine the degree of relationship between hip and COG velocity, and hip and COG acceleration profiles was performed for each swimmer tested. the Pearson product moment correlation coefficient was computed using the paired values on each curve. These represented the velocity or acceleration values at corresponding points in time. The number of pairs of values used in the correlation calculation corresponded with the number of film frames from which the information was derived.

RESULTS

The general acceleration profile developed from all the breaststroke swimmers revealed that three major propulsive phases in breaststroke swimming existed. The first of these was biphasic and of moderate magnitude, the second was single peaked and in most cases quite small, and the thud was single peaked and largest in magnitude. The animated stick figures revealed the first biphasic peak was associated with the arm pull and the third large single peak was associated with the leg kick. Aninspection of the individual swimmer acceleration profiles revealed that thc magnitude and duration of each phase varied considerably between swimmers. However, each of the three phascs was present in the acceleration profile of every swimmer tested. The second single peak was greater in magnitude for the more clitc swimmers and in the case of the D.D.R. swimmer was equal in magnitude to the biphasic arm pull peak.

It was difficult to disclose inefficiencies in stroke technique on the basis of fluctuations in the velocity profiles for each swimmer. The acceleration profiles of each of the swimmers, on the other hand, were very informative. The information gained from the acceleration profiles disclosed the degree to which each propulsive action in the stroke was successful in achieving its aim. Not only was the magnitude of the effective propulsive force demonstrated but the duration of the force was also displayed. The worth of the velocity profile became apparent at this point as it provided an indication of the effect in both magnitude and duration of the acceleration peak in each propulsive action. The interaction between the magnitude and duration of the acceleration peaks, associated with each propulsive movement, could be assessed on the basis of change in the velocity of the swimmer's COG, obtained from the velocity profile. A similar situation existed with regard to assessing the effectiveness of streamlining the body. This was obtained from the magnitude and duration of deceleration troughs associated with the non propulsive phases of the stroke.

A visual inspection of the hip versus COG graphs revealed that they were out of phase with one another. The maximum and minimum values on the hip curve were also greater in absolutevalues than those of the COG curve in both acceleration and velocity for all swimmers. A mean of 143 paired points was used in the correlation coefficient calculation for each swimmer. The range was 116 to 199. The mean correlation coefficient calculated for hip velocity against COG velocity was 0.67. The range of correlation coefficient values was 0.42 which had a significance value ($p=0.000$) to 0.86 ($p=0.000$). The mean correlation coefficient for hip against the COG acceleration was 0.40. The range was 0.71 ($p=0.064$) to 0.68 ($p=0.000$).

CONCLUSIONS

The analysis revealed that three distinctive propulsive stages occurred in breaststroke swimming. The first of these following the 'catch' was associated with the hand pull and was biphasic. The first and larger part of the peak was a consequence of the downsweep and following this was a less pronounced part of the peak which was attributed to the insweep of the arms and hands. In some swimmers this second aspect of the first propulsion stage was almost non existent and this disclosed an inefficiency in the technique of the swimmers concerned. The third propulsive stage was the largest and this was attributed to the leg kick. The second propulsive stage, in which the magnitude of the toleration peak approached that of the hand propulsion stage for the more elite swimmers, was not associated with any particular propulsive action of the swimmers. The researchers and coaches hypothesised this acceleration stage to be the swimmer catching the wave produced by the swimming action itself. During the arm propulsive stage the swimmer moves a large volume of water forward with the trunk. The main cause of this phenomenon is the relatively large surface of the trunk moving forward against a still, incompressible volume of water. When the swimmer decelerated following the completion of the arm pull the volume of water or wave tended to surge passed the swimmer and was used as a source of propulsion. This may be explained in terms of a transfer of momentum from the swimmer to the water, during the arm pull phase, and then back to the swimmer, during the second propulsive phase. A subjective evaluation of the acceleration profiles for the different swimmers revealed that the more elite breaststroke swimmers had a larger second propulsive stage than the not as highly ranked breaststroke swimmers.

Intra stroke velocity and acceleration profiles proved to be a useful biomechanical tool in the analysis of stroke technique in breaststroke swimming. Coaches found that the animated stick figures along with theprofile graphs, which were presented on video tape for the coach to view at a later stage, were an invaluable aid for identifying problems in stroke mechanics.

The acceleration profile for a particular swimmer was the most important diagnostic tool to establish an inefficiency in the swimmer's style. Due to the discrepancies which existed between the acceleration of the hip and that of the COG, the researchers believe that hip movement could not be used as a satisfactory substitute for the acceleration profile of the COG. The correlation coefficients were reasonably high for the relationship between the hip acceleration parameters and that of the COG for most of' the swimmers. This could be expected because the movement of the hip was related to the movement of the entire body. However, because there was not a consistent relationship between the hip and COG movement for all swimmers, it would be unwise to assess inefficiency in stroke technique on the basis of the hip acceleration profile or that of a single point on the body.

DISCUSSION

It is very difficult for a swim coach to detect subtle technique errors which may detract from a swimmer's performance. Such difficulties arise as a consequence of the actions of the swimmer which occur primarily under the water and in many cases hidden by the swimmer's body from the coaches view on pool deck. Most of the actions occur very rapidly and are difficult to analyse because of the speed of movement. The biomechanical system of swimming analysis described in this article provided the coach with objective and quantitative information about parameters which were used to analyse stroke technique. This information was presented simultaneously with pictorial information displaying the swimmer's exact movements so that technique inefficiencies could be readily detected. The greatest drawback with the analysis system was the time taken to process the information and prepare the video report. At the present time a research grant from Australian Sports commission is being used to develop an immediate feedback analysis system. This will dramatically reduce the time between the swimming performance and the availability of the biomechanical assessment.

An important outcome of this research was a greater understanding of the propulsive mechanisms in breaststroke swimming. The discovery of a previously unidentified propulsive phase of the stroke, which the researchers attributed to the catching of the wave, is particularly significant. The importance of the swimmer utilising propulsion from the wave, produced by the breaststroke action itself, and the relative value of propulsion and retardation produced by the various other phases of the stroke made the information which emerged from the investigation quite substantial.

The other important finding from the study was that the movement parameters of the hip should not be used for technique evaluation due to a shift in phase of the hip from the true movement pattern of the entire body. The shift was found to be inconsistent from one swimmer to the next. Other studies which have used a single point on the swimmer's trunk to represent the entire body should be reviewed with caution because of the finding of this research.

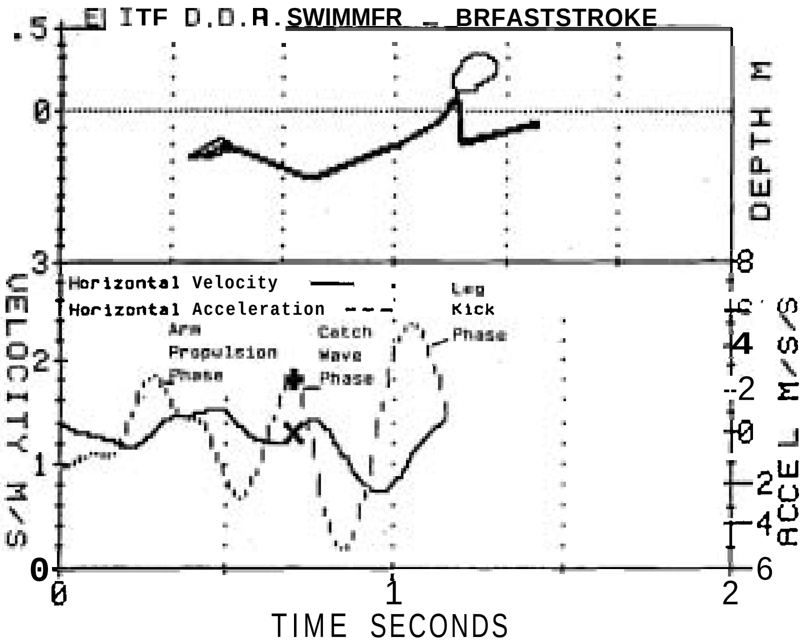


Figure 1: Elite D.D.R. swimmer during the wave catching phase. Top aspect illustrates the position of the swimmer. Bottom aspect graphs the velocity and acceleration profiles of the swimmer's centre of gravity. The cross sign on the velocity profile and the plus sign on the acceleration profile indicates the location on the profiles which is represented by the stick figure. Note that the magnitude of the wave catching phase, as demonstrated in the acceleration profile, is as great as that of the arm propulsion phase but shorter in duration.

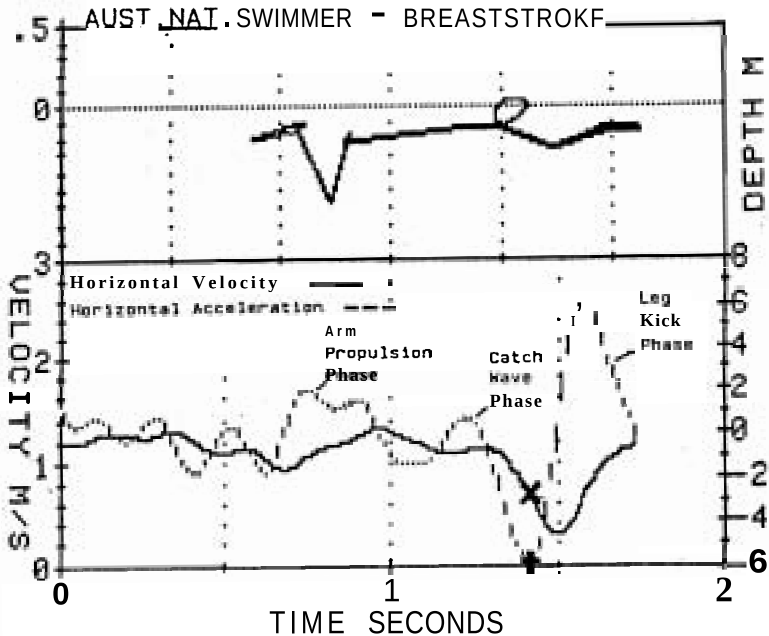


Figure 2: Australian national breaststroke swimmer. Top aspect illustrates the position of the swimmer. Bottom aspect graphs the velocity and acceleration profiles of the swimmer's centre of gravity. The cross sign on the velocity profile and the plus sign on the acceleration profile indicates the location on the profiles which is represented by the stick figure. Note that this particular figure demonstrates in the swimmer's style an inefficiency in technique. The inefficiency is caused by bringing the knees to a position which is almost at right angles to the oncoming water. This results in excessive drag which is highlighted by the minimum value in the acceleration profile.

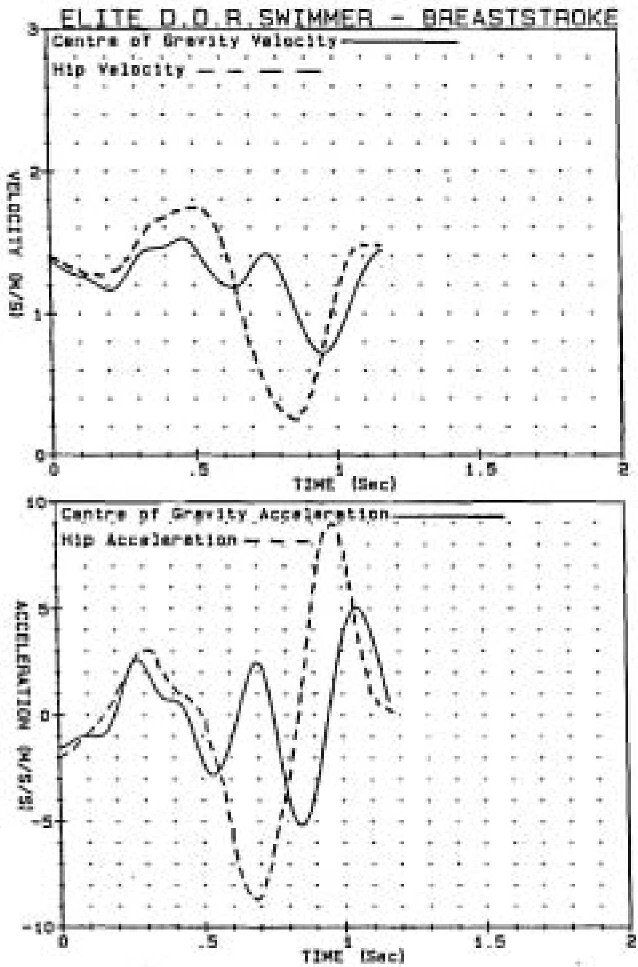
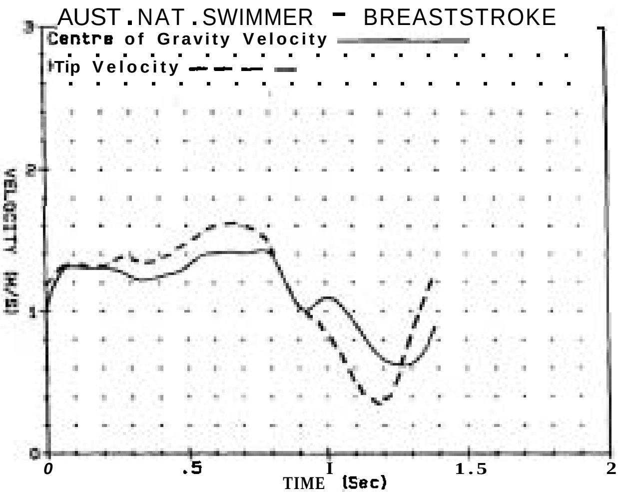


Figure 3: Elite D.D.R. swimmer. Variation between hip and centre of gravity intrastroke velocity and acceleration profiles. Demonstrates one of the worst cases of discrepancy between hip and centre of gravity movement.



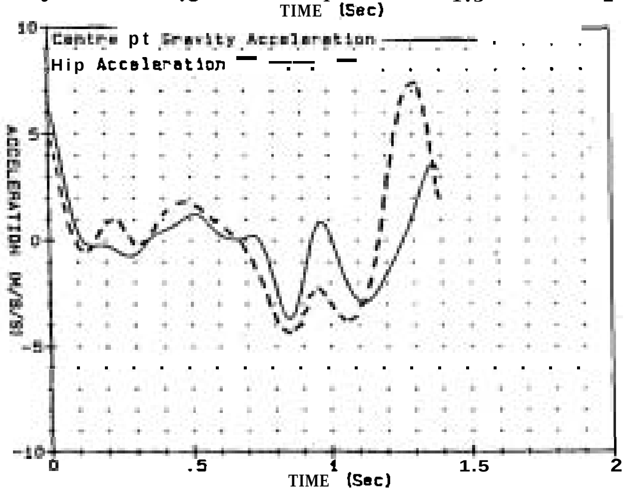


Figure 4: Australian National swimmer. Variation between hip and centre of gravity intrastroke and acceleration profiles. Demonstrates one of the cases of least discrepancy between hip and centre of gravity movement.