QUANTIFYING CRITICAL FEATURES OF UNDERWATER STROKE TECHNIQUE IN FREESTYLE SWIMMING

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The purpose of this study was to establish methods for accurately quantifying the time of entry, catch and release in freestyle swimming. The methods allow ready data collection, digitising and analysis without recourse to expensive cameras and diglising equipment thereby enabling analysis by coaches as well as biomechanists. Interpolation procedures to improve the accuracy of estimating the time of occurrence of the events were developed.

KEY WORDS: Freestyle, front crawl, swimming, interpolation, accuracy, reliability, technique.

INTRODUCTION: Based on a new approach to identifying important kinematic variables in swimming (Sanders, 1999) several 'critical features' should be quantified during the pull phase in freestyle swimming. In this new approach these critical features emerge logically from biomechanical principles. To maximise the speed that can be sustained over the race distance, the swimmer attempts to optimise technique by minimising resistive impulse and maximising propulsive impulse using techniques that are physiologically economical. Critical features to maximise propulsive impulse emerge from the application of Newton's Second Law expressed as the biomechanical principle 'the change in motion depends on the magnitude of the net force and the time over which it acts'. In this paper we focus on the critical features that arise from the second part of that principle, that is, the time over which propulsive forces are applied (Figure 1). To maximise the period of producing propulsive force relative to total stroke cycle time, the swimmer needs to start applying propulsive forces, that is 'make the catch', soon after entry. The time of the propulsive part of the pull is from the instant of catch to the time that the force ceases to be propulsive. The latter is termed 'release'. Thus, the critical features to be measured are the time of catch with respect to entry, and the time from catch to release.

It must be recognised at the outset that these times are not necessarily statistically related to performance because of the confounding effects of other variables. For example, the magnitude of propulsive force is related to the speed of limb movement with respect to the water. Therefore, by moving the limbs rapidly to maximise propulsive force, a swimmer may reduce the time of applying that propulsive force. However, this does not mean that the swimmer is not applying the principle. The intention to maximise the period of applying propulsive force may be better reflected by limb displacement, particularly the hand, between the instants of catch and release. Further, it may be informative to express the times relative to the total cycle time. All of these measures are dependent on accurate quantification of the instants of entry, catch, and release.

Although it seems logical to quantify critical features that arise from mechanical principles, quantification of those critical features described above has been rare for the following reasons.

1. There are many difficulties involved with capturing data for underwater phases of the stroke, particularly during competition.
2. It is difficult to identify accurately the instants when the forces produced by the limbs become propulsive (the catch) and when they cease to be propulsive (release).
3. Quantifying the variables involves digitising from video. This task is somewhat onerous and time consuming thereby discouraging analysts from including these variables in routine competition analysis.

The purpose of this study was to establish methods for accurately quantifying the time of entry, catch, and release in freestyle swimming.

METHOD: Desirable criteria for the methods to be developed were identified. These were:

1. The methods should allow ready data collection, digitising and analysis without recourse to expensive cameras and digitising equipment. This enables analysis by coaches as well as biomechanists.
2. The method should not involve time consuming and elaborate calibration procedures and subject preparation.
3. The methods should allow precise identification of the instants of catch and release.

Equipment: In keeping with the first criterion, standard VHS, SVHS or Super 8mm video cameras may be used. For freestyle swimming it is sufficient to use one camera, mounted such that the frame is aligned with the earth reference system, that is, not tilted. The video camera may be set as an underwater camera with appropriate waterproof housing, outside an underwater window, or set on the pool deck to view through a periscope. The axis of the camera should be at right angles to the plane of motion of the swimmer and fixed rather than panned. The camera should be zoomed so that the closest arm segment is in view for one complete cycle. The use of only two-dimensional data collection and analysis methods is deemed adequate for identifying catch and release in freestyle swimming and is in keeping with criterion 2. There is a growing body of evidence that propulsive forces in freestyle swimming are due mostly to drag rather than lift (Rushall et al, 1998; Sanders, 1998) and that the catch is made with predominantly backward movement of the hand rather than lateral movement. Therefore, the catch may be estimated as the instant of first backward movement of the hand with respect to the water. Similarly, release may be estimated as the instant of last backward movement of the hand with respect to the water.

Inexpensive two-dimensional digitising systems are now available and are adequate for this particular analysis. Examples include the 'Human Movement Analysis System (HMA Technology Inc.) and 'Video Expert' (Motion Analysis Corporation). These software packages run on standard IBM compatible PCs. An appropriate video capture card and video capture software must be installed on the computer.

Analysis Procedure: Each trial should be captured and imported into the digitising program. The analyst can qualitatively identify frames surrounding the events of interest. These are the instant of entry, the instant of catch, and the instant of release. The actual instant of breaking the water surface has limited value as a temporal variable. Previously it has been used somewhat erroneously to indicate the end of recovery and the start of the pull phases. Some swimmers continue to recover the arm forward afler breaking the water with the hand, that is the hand continues to reach forward with respect to the moving body due to elbow extension and shoulder action. Other swimmers recover the hand almost entirely over the water and the water is broken at a time when the elbow and shoulder joints are near the limits of their actions that contribute to forward reach. Therefore, in this study 'entry' was defined as the instant that the hand achieves its greatest horizontal displacement with respect to a fixed reference point on the swimmer's body such as the hip. 'Catch' was defined as the instant that the hand started moving backwards with respect to the external reference frame while 'release' was defined as the instant that the hand started moving forward with respect to the external reference frame or the instant when the hand lefl the water.

To obtain these critical features three landmarks should be digitised. These are an external reference point in the field of view, 3rd metacarpophalangeal joint (MP), and an internal reference point on the near side of the body, such as the midpoint of the swimming costume line. The external reference point allows correction for camera movements. All coordinates are subsequently expressed with respect to the external reference point.

It is necessary to digitise only those frames surrounding the estimated events of interest. These are entry, catch and release. Five frames either side of a frame estimated to be near the event of interest is sufficient. These frames provide data for subsequent curve fitting to yield accurate estimates of the time of occurrence of the event. To improve the accuracy and reliability of digitising, steps should ensure water clarity. Also, results are improved considerably when the subjects the internal reference point and the MP joint are marked with high contrast markers (black is usually best).

Data Analysis: The horizontal coordinates of the digitised data of each landmark should not be smoothed because there are insufficient points for adequate smoothing and the points will be fitted with a polynomial function using a least squares criterion. The x (horizontal) coordinates for each landmark are then exported to an Excel spreadsheet (Microsoft Office). The coordinates for the reference point are then subtracted from the coordinates for all other landmarks to yield a set of data that is expressed with respect to the reference point. The internal reference marker coordinates are subtracted from the corresponding MP coordinates to yield displacement of the hand with respect to the fixed internal reference point. This will be used to determine the instant of entry as defined above.
An Excel column representing the time with respect to an **arbitrary** reference frame is established by multiplying the frame number by the inverse of the sampling rate. The sampling rate for standard video with the PAL system is 25 frames per second. If the data capture and digitising software allow digitising of fields (2 fields per frame) then this would be 50 fields per **second**.
Curve Fitting: Using the Excel graphics software a 'scatterplot' is produced for each variable around the event of interest. Horizontal displacement should be the ordinate and time the abscissa. A polynomial function is then fitted to each plot using approximately ten points. Figure 1 is an example plot with the polynomial formula displayed on the graph.

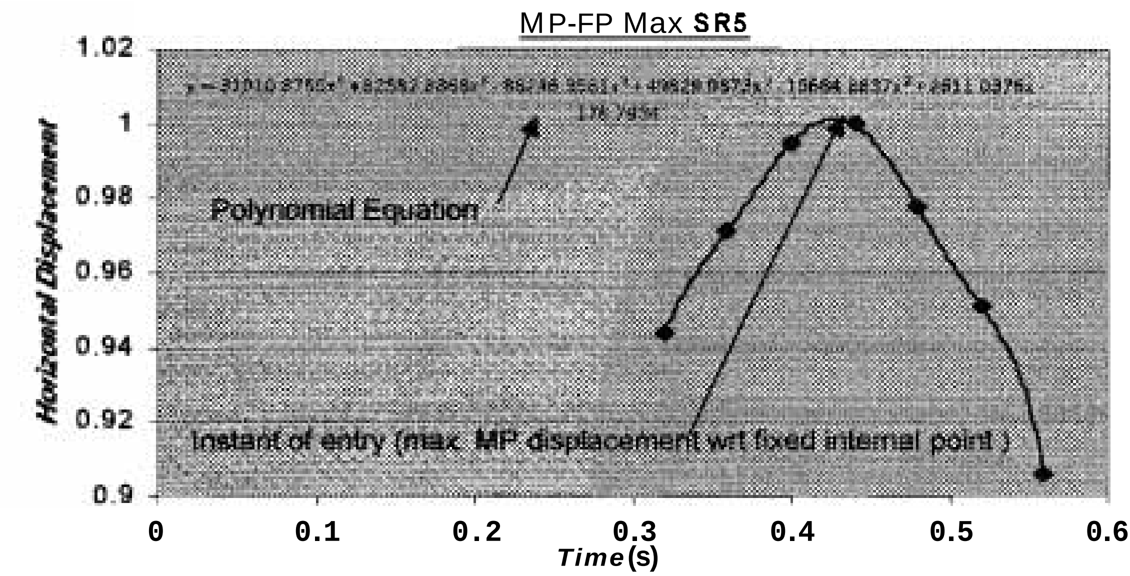

Figure 1 - Example of a polynomial fitted to digitised horizontal displacement data.

The formula for the polynomial function is copied to the spreadsheet and entered in a new column. Modifications must be made so that the formula uses symbols that Excel recognises. The basic formula and the formula to be entered in the Excel worksheet are shown below:

Output Formula: $-31910.8755x^6 + 82582.8868x^5 - 88246.3581x^4 + 49829.9873x^3 - 15684.8837x^2 + 2611.0376x - 178.7934$

The X's in the formula represent time. In the worksheet formula the x is a reference to a cell in the column that contains time values with very small increments, for example 0.001s around the approximate time of the event of interest.
We seek the times at which the following values occur.

1. maximum horizontal displacement of the hand with respect to the fixed internal reference point (the time of entry)

2. the time of maximum horizontal displacement of the hand with respect to the external reference frame (time of catch)
3. the time of minimum horizontal displacement of the hand with respect to the external reference frame (time of release)

For each value above the appropriate formula is applied to the time column. The Excel spreadsheet command 'MAX(column references)' for entry and catch, or 'MIN(column references)' for release, are applied to the appropriate column to identify the value and its corresponding time of occurrence.

RESULTS: The reliability of the procedure for each of the events of interest was estimated by digitising the same trial five times and determining the time from entry to catch, the time from catch to release. The subject had contrasting markers on the MP and hip joints. Reliability was calculated as the standard deviation of the five calculations for each measure. The results are presented in Table I.

Table I Reliability of Estimates

Item	Reliability (SD)
Entry to catch time (s)	0.0064
Time of Catch (s)	0.0133
Time of Release (s)	0.0086

CONCLUSION: The time of entry, catch, release, being critical features in freestyle swimming, may be calculated with reasonable accuracy, reliability, and expediency using readily available hardware and software. These methods may be applied routinely to provide useful information to swimmers to assist in improving performance.

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