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COMPARISON BETWEEN CALCULATED AND MEASURED EFFECTIVE PROPULSIVE FORCES DURING A SUPPORT SCULLING MOTION

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INTRODUCTION

Propulsive force generated during sculling motion results from drag and lift forces. These forces may be calculated using a quasi-static approach, which involves the following three steps [1,2]: (1) measuring the propulsive forces acting on model hands for a range of orientations and then calculating lift and drag coefficients for each orientation of the hand; (2) analysis of 3D kinematic data from underwater video to calculate the hand's path, speed and orientation; and (3) combining the first two steps, that is, from the hand orientation it is possible to determine the force coefficients and then calculate the forces using hydrodynamic equations. However, the effects of flow acceleration and the unsteady nature of the propulsive forces are not included in this approach [3]. Therefore, Sanders [3] developed a model that takes into account the effects of acceleration in the direction of the flow.

This last model has been applied [4], but no one has verified if the propulsive force values obtained from this model are close to the real force values. Thus, the purpose of this study was to compare the calculated effective propulsive force using the model developed by Sanders [3] and the measured effective propulsive force during a support sculling motion.

METHODS

The sample consisted of one synchronised swimmer (13 years; 1.53 m; 48.3 kg) who had 3 years and 10 months of training. Her guardian signed the informed consent forms. The Ethics Committee of the university where the study was undertaken approved this study.

The experiment took place in an indoor 25 m swimming pool. The participant was asked to perform 15 seconds of sculling motion at maximum intensity while trying to keep the force constant and a stationary vertical position with her head above the water surface while she was tethered.

Four digital video cameras (Dual Camera Waterproof VPC-WH1; 60 Hz; 640x480 pixels) were used. The cameras were used to capture the right and left hand movement, thus one pair of cameras was positioned to the right sagittal plane of the participant, while the other was positioned to the left sagittal plane. All cameras were positioned underwater, 3.69 m from the centre of the calibration frame, while the distance between the cameras on the same side was 0.88 m. A calibration frame (0.80 m x 0.80 m x 1.60 m), with 10 control object points, was used for each side.

In each hand, landmarks were placed on the distal end of the third finger, on the metacarpophalangeal joints of the second and fifth fingers and on the centre of the wrist joint.

In order to measure the effective propulsive force, a load cell (ZX Alfa Instrumentos, up to 2500 N, 2000 Hz) was used with the aid of a data acquisition system (Miotec Equipamentos Biomédicos Ltda), which also allowed synchronisation of the cameras and the force data. The load cell was fixed to the bottom of the poll. The elastic tube was attached to the load cell and to the participant's waist. The hydrostatic weighing of the participant was measured with the aid of the same load cell attached to a platform.

In order to analyse the data, the landmarks were manually digitized by an experienced digitizer using Dvideow software. Most of the studies found in the literature analysed only one cycle of sculling motion. In contrast, in the present study, it was decided to analyse thirteen consecutive cycles to minimise the influence of any random error that may occur during the digitalizing procedure.

Three-dimensional coordinates were obtained applying the DLT method. The accuracy of the measurements was calculated and was equal to 5.3 mm, 4.5 mm and 5.0 mm in x, y and z-axis respectively. All three-dimensional coordinates were smoothed using a seventh order low-pass Butterworth digital filter with cut-offs according to residual analysis [5].

Using Matlab software, all variables were calculated for each instant throughout all thirteen cycles. The hand orientation (attack and sweepback angles) was defined according to Schleihauf [1], and then all the force coefficients were estimated based on Sanders' research [3]. Using the smoothed data from the midpoint between the second and fifth metacarpophalangeal joint, resultant speed and acceleration of the hand in the direction of the hand motion were calculated. It was also estimated the hands' area normal to the direction of the forces. Then, it was possible to calculate the propulsive forces (drag force and the two components of lift force) for each hand by considering the effects of acceleration of the hand in the direction of hand motion [3]. The next step was to estimate each force direction [6] and the angle between each force and a vertical vector, after which the calculated effective propulsive force was estimated considering both hands.

The raw force measured by the load cell was smoothed using a seventh order low-pass Butterworth digital filter with cut-off according to residual analysis [5]. Then, the hydrostatic weighing was added to the measured force to obtain the measured effective propulsive force.

In order to analyse the forces, the time of each cycle of sculling motion was normalised (from 1 to 100%). The degree of agreement between the calculated and measured effective propulsive forces was established based on graphical techniques developed by Bland and Altman [7], in which the data were presented graphically by plotting the difference between the calculated and measured forces versus their average. The mean difference (bias) and standard deviation (SD) of the differences between the calculated and measured forces were calculated. The limits of agreement were set at bias ± 2SD.

RESULTS AND DISCUSSION

According to Figures 1 and 2, the calculated and measured effective propulsive forces do not agree.

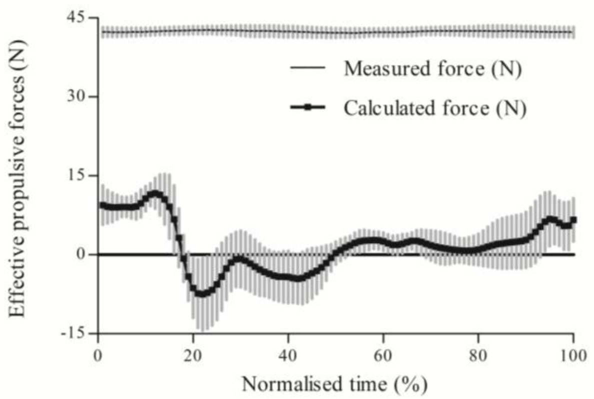

Figure 1: Average and SD of the measured and calculated effective propulsive forces from thirteen consecutive cycles in relation to the normalised time.

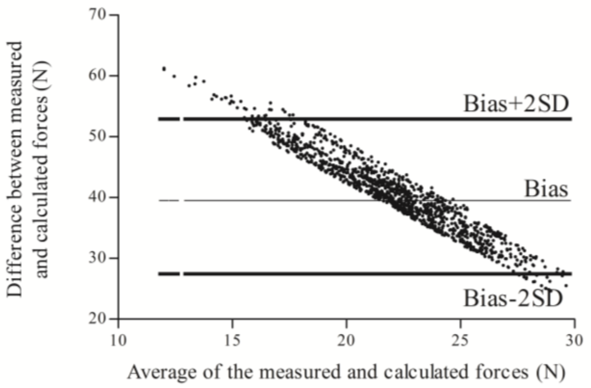

Figure 2: Difference between measured and calculated effective propulsive forces in relation to the average of the measured and calculated effective propulsive forces.

The present study corroborates previous findings which determined the quasi-static approach underestimates the coefficients and the propulsive forces [8, 9] even when the model used takes into account the effects of acceleration of the hand in the direction of hand motion. To our knowledge, this was the first study that verified the model developed by Sanders [3] who pointed out that his model should be improved. He suggested (1) verifying whether the acceleration coefficients are independent of the hand speed and (2) adding the effects of acceleration of the hand that are not in the direction of hand motion. However, to our knowledge, although this model was already applied [4], no one has implemented his suggestions.

The highest average of calculated effective propulsive force was 11.68 N, while in the same period of time the average of measured effective propulsive force was 42.44 N. This difference is an example of the unsteady effects' contribution to propulsive forces, such as vortex shedding and the added-mass effect, which are associated with the body's acceleration [3,9].

CONCLUSIONS

The measured effective propulsive force was greater than the calculated effective propulsive force even when using a model that takes into account the effects of acceleration of the hand in the direction of hand motion. Thus, the result of this study highlights (1) the importance of the unsteady mechanisms for propulsion during sculling motion and (2) the need to improve the approach used to estimate propulsive forces.

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