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Front crawl swimming analysis using accelerometers: A preliminary comparison between pool and flume

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Abstract

Biomechanical characteristics such as stroke rate and stroke length can be used to determine the velocity of a swimmer and can be analysed in both a swimming pool and a flume. The aim of the present preliminary study was to investigate the differences between the acceleration data collected from a swimming pool with that collected from a flume, as a function of the swimmer's stroke rate and stroke count, with the objective of identifying the impact on the swimmer's performance. The differences were determined by the analysis of the stroke's features, comparing several strokes normalized to one stroke count from an elite swimmer. Triaxial accelerometer logging using a sensor located in an arm band positioned immediately in the wrist was used to record the swimmer's stroke. There is statistical evidence that show that there are small differences between the pool and flume on medio-lateral wrist movements ($0.64 \leq r \leq 0.75$). The correlation coefficients are ($0.75 \leq r \leq 0.83$) and ($0.82 \leq r \leq 0.89$) for the other two axes.

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Keywords: Accelerometer; swimming, pool; flume; stroke rate; stroke length; correlation.

1. Introduction

Swimming performance is achieved by a series of factors that impact on an athlete's competitive success. Those factors include physiological, psychological and biomechanical characteristics [1]. Among the important biomechanical characteristics are stroke rate (number of stroke cycles per minute) and stroke length (distance in

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metres per stroke cycle), which are used to determine the velocity of a swimmer and can be analysed in both a swimming pool and a flume.

In a flume, a face mask can be used to record the breath-by-breath oxygen consumption [2], also, the velocity of the water can be controlled and recorded using a calibrated propeller driven sensor, so the swimmer is forced to maintain speed from the first to the last second of each exercise bout, allowing a high intensity workout. In a regular swimming pool, fatigue results in speed reduction and thus lowers the absolute training intensity and affects the metabolic systems trained. A flume can also help to focus on technique by supplying the swimmer with instantaneous feedback about his or her stroke.

However, the high cost of the swimming flume means that it is virtually inaccessible except to specialist research teams. Many athletes, trainers and scientists need to work with other methods in which stroke rates, counts and times can be manually recorded, extracted from video data in a manual review process or automatically extracted from sensor platforms [3,4].

Acceleration data collected from sensor platforms have been used for some years, to monitor human movement and relate this to the energy expenditure of athletes and the tasks associated with every-day living. Recent work has shown that limb and torso accelerations measured during swimming can be related to the energy expenditure determined by direct measurement of oxygen uptake in swimmers of different skill levels [5].

In addition to the high cost, the water flow in a flume is not uniform, and differs from pool swimming. For example, the alignment of the swimmer's body (particularly the head), the pressure on the hands, the differential velocity across the flume, etc., have implications for biomechanical studies and training. Thus, the aim of the present study is to investigate the differences between the acceleration data collected from a swimming pool with that collected from a flume, as a function of the swimmer's stroke rate and stroke count, with the objective of identifying the impact on the swimmer's performance.

2. Methods

2.1. Technology

In-house sensor platforms were used for this experiment [3,4]. The sensors consisted of a 3-axis accelerometer with dimensions 52mm × 34mm × 12mm (L×W×H) and a weight of approximately 22g, capable of measuring acceleration forces of ±10g in three perpendicular directions (g being the gravitational force). When oriented vertically, the sensor shows a static 1g response due to gravity [3].

2.2. Swim details and sensor calibration

This preliminary study shows the flume's and pool's stroke rate feature comparison of self-ranked swimmer's ability in a 100m and 400m test. The swimmers were informed of the reasons for the study and signed a consent form to participate in the study. The study was approved by the Ethics Committee.

The sensor units were taped to the swimmer's sacrum, left wrist and left ankle using medical tape. The swimmer was asked to both stand vertically and then lie in the horizontal glide position for five seconds to calibrate the accelerometers. In the flume, swimmers wore a face mask and a nose plug to ensure the gas analyser recorded the oxygen intake and exhaled breath [2]. The velocity of the water in the flume was controlled and recorded using a calibrated propeller driven sensor. The swimmer was asked to swim three six minute swims with two to five minute rest periods. In the pool, swimmers were asked to swim two laps in a 25mts length pool. More details about the sensor placement and the orientation of the sensor axes with respect to the human body are discussed in [5].

3. Results

A comparison of the swimmer's stroke features between flume and pool is presented in this section. The first study shows a comparison of 100 strokes from an elite swimmer in both pool and flume environments. Although the sensors were placed in the swimmer's wrist, sacrum and ankle, this preliminary study shows an analysis in the swimmer's wrist (Figure 1), being the most significant and feasible for comparison. The stroke analysis was

performed for each axis in the tri-axial accelerometer. Figure 2 shows the acceleration as function of time for each axis in both pool and flume.

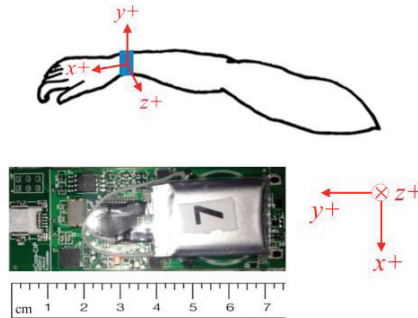


Figure 1. Sensor unit placed on the outside of the wrist, and snapshot of the tri-axial accelerometer used in this study.

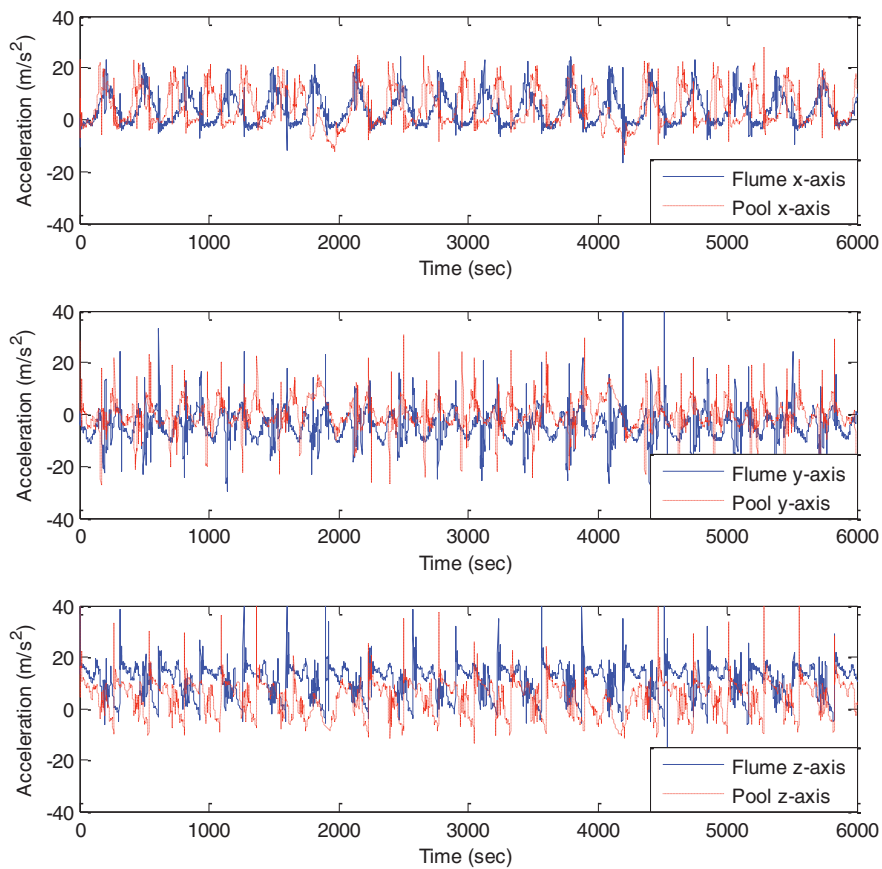


Figure 2. Tri-axial acceleration in m/s^2 as function of time for an elite swimmer in the pool and flume.

There is significant difference between individual strokes in all three axes, as evident in Fig. 2. For that reason, 100 strokes on each axis were considered. The strokes were time-normalized to 1 stroke unit and a cubic extrapolation was used to adjust the number of samples for all strokes (up sample). Figure 3 shows the mean value

of the 100 strokes for both pool and flume in a normalized scale. The pool curves show oscillations at the beginning of the stroke in all three axes. This may be related to the fact that in the pool the elite swimmer breaths every five or six strokes, changing slightly the orientation of the wrist. Although the strokes were normalized to one stroke count, the raw data showed a bigger stroke length in the flume due to the fact that in the flume the arm is driven by the water flow from the propeller, while in the pool the movement is only due to the swimmer’s strength. The mean curves for all three axes show a good agreement between flume and pool.

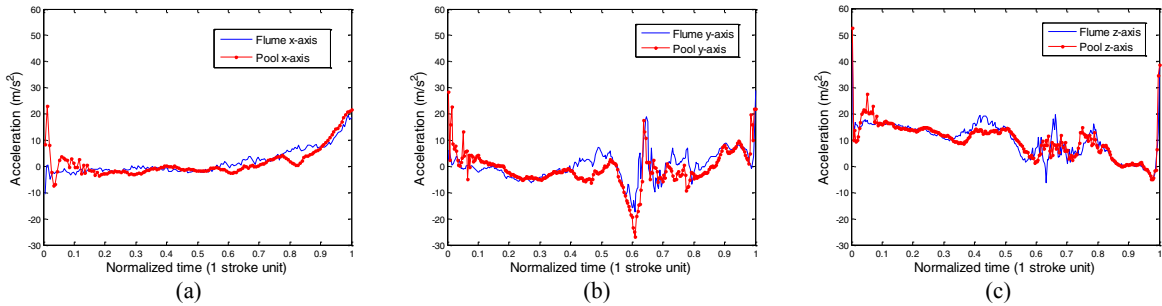


Figure 3. Mean value of 100 strokes normalized to 1 stroke unit. Comparison between pool (red data) and flume (blue data) on (a) x-axis (b) y-axis and (c) z-axis.

In the second preliminary study, a correlation analysis of 100 strokes from 3 self-ranked elite swimmers was determined. Figure 4 shows the correlation between pool and flume for each axis, the fitted straight lines are: $y = 0.89x + 1.2$ for the x-axis, $y = 0.69x - 1.1$ for the y-axis, and $y = 0.97x + 0.95$ for the z-axis. A slope of unity indicates the same acceleration amplitude between the pool and flume. A slope of less than one indicates more movement in the flume compared to the pool.

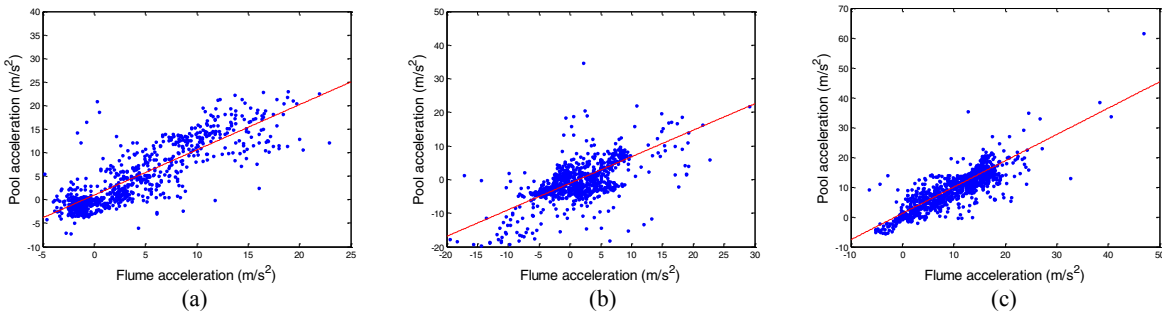


Figure 4. Slope and correlation analysis between pool and flume of 100 strokes from 3 swimmers for (a) x-axis (b) y-axis and (c) z-axis.

Figure 5 shows the correlation coefficients between the pool and flume for the 100 strokes of each swimmer on each axis. Both Figures 4 and 5 show a strong correlation for the three axis, being more evident in the z-axis ($0.82 \leq r \leq 0.89$) since it is less affected by the flume water flow and the swimmer’s breath between some strokes. The weakest correlation occurs in the y-axis analysis ($0.65 \leq r \leq 0.75$). This is most likely due to the velocity profile across the flume causing an increase in lateral movement compared to swimming in still water. Figure 4(b) shows that the y-axis acceleration variation in the flume is much higher than in the pool. It is anticipated that the oscillations (buffeting) of the arm and hand in the y direction are far more difficult for the swimmer to control compared to the main thrust plane formed by the x and z axes.

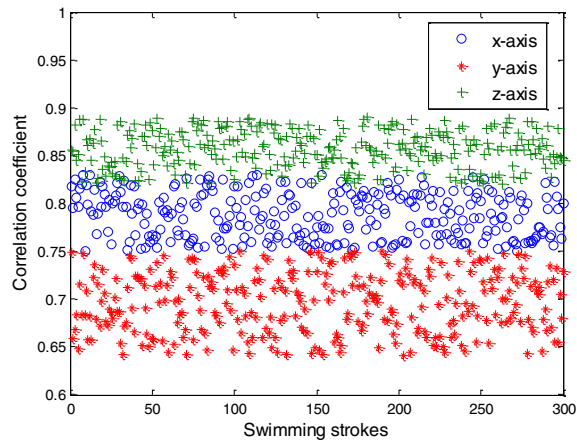


Figure 5. Correlation coefficients between pool and flume for 100 strokes of 3 swimmers for each axis.

4. Conclusions

A front crawl's swimming comparison between a swimmer's performance in the pool and in the flume was presented in this paper. Tri-axial accelerometers were placed on the swimmer's wrist, sacrum and ankle. This preliminary study presented an analysis of stroke's features on the swimmer's wrist. 100 strokes of 3 self-ranked elite swimmers were analysed. A strong positive correlation coefficient was determined on all axes. Training in the flume is restricted to few athletes and teams with high resources. The comparison presented in this paper suggests that swimmers training in the pool will obtain the same results as those obtained in the flume, since small differences in the stroke's mean and strong positive correlations were found. The medio-lateral wrist acceleration indicates more movement in the flume, probably due to water velocity profile. This is not the case in stationary water. This work also demonstrates the effectiveness of an arm-band mounted sensor in recording and categorising swimming strokes. An ongoing full comprehensive comparison between pool and flume includes more participants of different skill levels and a data comparison of sensors placed at the sacrum and ankle.

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