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Inertial sensor, 3D and 2D assessment of stroke phases in freestyle swimming

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Abstract

Assessment of human movement kinetics and kinematics use various methods of capture. Typical systems used are 2D or 3D camera systems. These laboratory-based simulations have accurately estimated movement variables. While these systems have shown accuracy in assessment, there are inherent problems with capture capabilities including: simulation of actions, and limitation of the camera system's capture range. Therefore data capture in a realistic environment is usually quite inhibitory. Microtechnology has been shown to address these restrictive issues of assessing human movement. The use of inertial sensors for land and water based biomechanical applications has been steadily gaining popularity. Traditional systems are severely hampered in aquatic environments, due to problems imposed by liquids that are not present in gaseous surroundings. These limitations do not intrude on inertial sensor captured data. Prior to a water based research, inertial sensor technology would require validation. The aim of this study was to validate an inertial system to measure temporal kinematics of a freestyle armstroke on a swimming bench. Six participants simulated freestyle swimming action. Variables measured were components of the stroke phase. A triaxial inertial sensor was positioned on the dorsal side and at the distal end of the forearm. Validation was carried out with comparisons against 2D video capture and a 3D infrared camera system. For statistical analysis, a Pearson's correlation, typical error of estimate, and mean bias were applied. Very large correlations, along with minimal error and mean bias indicate that inertial sensors as a viable option for swimming armstroke assessment.

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1. Introduction

Assessment of human movement has examined the kinetics and kinematics through various methods of capture. This includes force platforms, magnetic motion analysis, 2D video, and 3D camera systems. The 3D data captured by an infrared camera system needs to be processed for analysis. The major limitations to any of these systems are limited capture periods, the number of actions e.g. walking strides or swimming strokes that can be taken within the field of view. Data capture with these systems in a realistic environment is usually quite inhibitory, if not impossible. Microtechnology has been shown to address these restrictive issues of assessing human movement.

Even with limitations of laboratory based technology of measure, at times it is necessary to utilise these systems. One reason being to validate novel methods. Validation provides a means to compare a new design an existing technology or method of capture, typically a gold standard or commonly used system. Optoelectronic data capture, specifically infrared cameras, has been extensively used for human movement assessment. By using associated software, multi segmented models determine kinematic measures such as joint angles, temporal-spatial parameters [1]. In freestyle swimming, there are many kinematic components that make up a full armstroke. Coordination and movement of armstroke is an important component in freestyle swimming [2]. Up to 90% of a freestyle swimmer's velocity has been attributed to the effect of armstroke [3, 4].

Definition of armstroke phases for freestyle swimming are: propulsive, and recovery. Generally, the propulsive phase can be further broken down into the following: the point at which the hand enters the water; *entry* (i). This is followed by small lateral movement away from the body; *outsweep* (ii). Simultaneously, there is a downward movement; *downsweep,* to where the hand is below the elbow: *catch* (iii) and is where propulsion of the armstroke is considered to begin [3, 5]. After the catch, hand movement tends to be inwards, towards the midline of the body; *insweep* (iv). The final portion of propulsion; *upsweep* (v), takes the hand to the point of leaving the water; *exit* (vi). Exit of the hand from the water is typically at the waist/hip region. Recovery is any movement of the hand back to in front of the swimmer for the next hand entry. The usual recovery pattern is a high elbow over the hand whose return path is close to the body where the mid point of recovery is approximately when the hand is in line with the armpit (vii). The breaking down of armstroke components into stages is important for assessment. This indicates that the identification of events is required. Therefore the primary purpose of this study was for a comparative validation between inertial sensor measures and an infrared camera, when measuring hand entry and exit of a simulated swimming freestyle armstroke. A secondary aim was to determine via video data confirmation whether other elements of the simulated armstroke could be identified.

2. Methods

Six athletes (3 male, 3 female), mean age 24 ± 5.3 yrs, participated in this study. Participant's swimming experience ranged between a swimmer for health and fitness through to sub elite triathletes. Everyone participates, or, had previously participated in swim squad training. Volunteers were screened for injuries and debilitating issues that may negatively affect their wellbeing or the study's outcome. All were informed of the study's purpose and freely agreed to participate. Each participant signed a university ethics committee approved consent form (ENG/05/10/HREC). Prior to testing participants were instructed to warm up similar to what they would during a training session. During testing, participants were asked to complete five, 30 second (s), simulated freestyle swims. This was to be at a rhythm that reflected their stroke rate during swimming that would not be considered a sprint race pace. Rest intervals were approximately one minute. Three modes of data capture were employed: inertial sensors, an infra red camera system, and a digital camera. The inertial sensors (previously described elsewhere [6] measured accelerations and angular velocities in the three orthogonal planes at the wrist of each participant (200 Hz capture rate). A sensor was positioned on the dorsal side and at the distal end of the forearm (Figure 1).

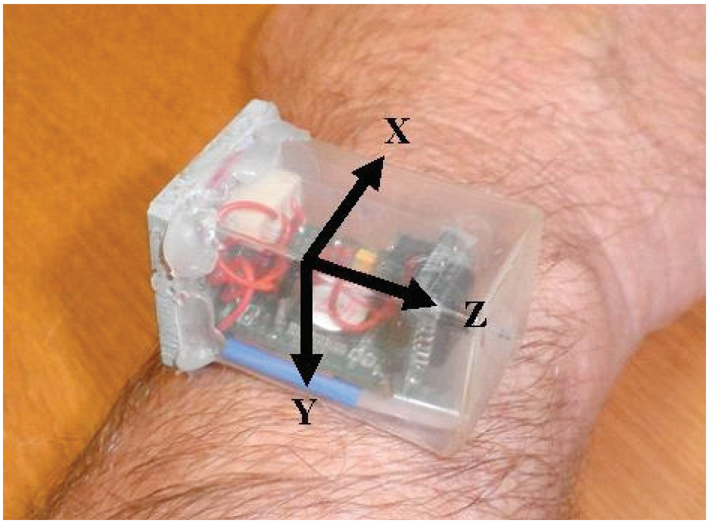

Fig. 1. Inertial sensor placement and orientation. The view is looking towards the hand

The infrared system (Oqus 300 series, Qualisys Medical AB, Gothenburg, Sweden) incorporated seven cameras (200 Hz capture rate). This system was primarily used to compare kinematic timing data of the phases for the armstroke against data from the inertial sensors. A half body marker model was applied. However data from the lateral and medial markers positioned at the styloid processes of the radius and ulnar respectively have only been reported in this study. A 25 Hz digital video camera (NVGS180, Panasonic 3CCD. Panasonic Corporation, Osaka, Japan) data was used to identify armstroke events.

For comparisons to be carried out, the inertial sensors were synchronised to the other two systems. This was achieved by placing a clapper-board on both sensors. In order for synchronisation with the infrared system, two reflective markers were placed on both halves of the clapper. The impact strike of the clappers resulted in a spike in the inertial data, a spike in the infrared data was also recorded, and visual feedback identified video synchronisation. An automated method for synchronising data was developed in MATLAB (The MathWorks, Massachusetts USA version 7.11.0.584 (R2010b)).

The primary components of the armstroke that were identified as important to measure were: entry and exit. These two variables were the focus of analysis. Other elements of the stroke were anticipated to be found as identifiable. All were deemed as measurable when the components coincided with an event in the plotted traces of one of the inertial channels e.g. at a positive or negative spike in the data, or when the trace crossed the zero point in the acceleration or angular velocity. Synchronisation of the video and inertial sensor data found that events of entry, exit, mid-stroke (immediately following the catch), upsweep, and mid arm recovery were detectable in at least two of the six data channels available.

To compare between the infrared camera system and inertial sensor data a Pearson's correlation, typical error of estimate, and mean bias were applied. Typical error of estimate (TEE) and bias data were standardised where the typical error was divided by the standard deviation and the mean bias was also divided by the standard deviation. Interpretation of the standardised data was carried out using a modified Cohen scale where: < 0.20 = trivial, 0.20 – 0.60 = small, 0.6 – 1.2 = moderate, 1.2 – 2.0 = large, > 2.0 = very large [7].

3. Results

Timing comparisons between the infrared camera and inertial sensor data for entry point to entry point, exit to exit, and propulsive phase (entry-to-exit) found minimal error (Table 1). Correlations between the measured entries as well as the exits were both near perfect. Correlation for the temporal measure for the comparison of entry-to-exit was found to be very strong. Raw TEE data implies a predictive error of approximately 0.1 s for all three variables. When standardised, the entry-to-entry, exit-to-exit, and propulsive phase found that the raw TEE data were small (0.22), trivial (0.19), and small (0.53) respectively. There was no bias found in the entry-to-entry data. Bias was in favour of the inertial sensor in the exit to exit data. The bias found in the propulsive phase data favoured the infrared cameras. All bias was statistically trivial. Bias favouring one method of data capture over the other indicates an error towards that method. For example, the propulsive phase data points to a bias towards the infrared camera capture.

Table 1. Validative comparisons of correlation, typical estimate of error, and mean bias. Excluding correlation data, all measures are in seconds.

		Mean	Pearson	TEE (raw)	Mean bias
Entry to entry	Camera	1.97 ± 0.4	0.97	0.10	0.00
	Inertial sensor	1.96 ± 0.5			
Exit to exit	Camera	1.94 ± 0.4	0.98	0.09	-0.01
	Inertial sensor	1.94 ± 0.4			
Entry to exit	Camera	0.78 ± 0.2	0.85	0.11	0.10
	Inertial sensor	0.80 ± 0.2			

Video comparison (Figure 2) through synchronisation enabled primary events to be identified in the inertial sensor data (Figure 3). Primary identification for entry-to-entry (i) was found to occur approximately at the zero crossing of the data traces in the X acceleration and the Z gyroscope. Efficient hand exit (vi) identification was found in the Y gyroscope data with secondary confirmation in the X gyroscope and Y acceleration data. The catch (iii) was found in the Y and X gyroscope data. Upsweep (v) coincided around the positive peaks in the X acceleration and Z gyroscope data. Mid- recovery was clearest in the Z gyroscope and Y acceleration traces at the negative peaks when a full stroke was performed.

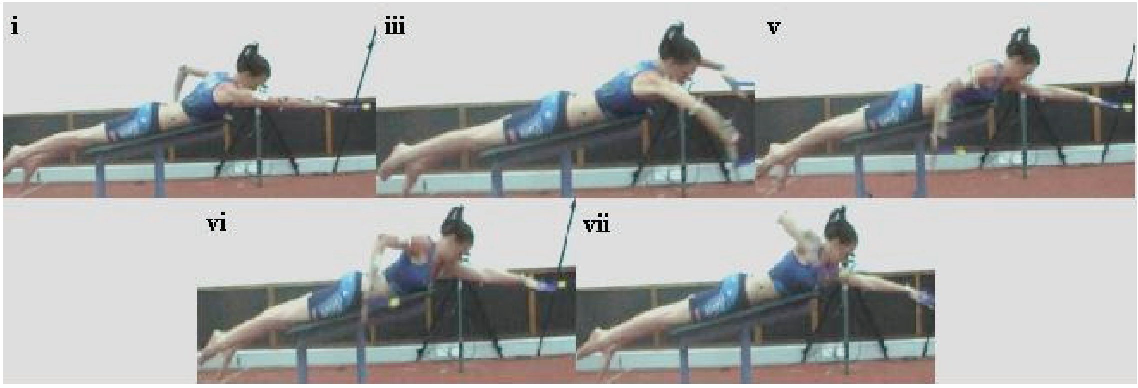

Fig. 2. Lateral video image of primary events in a freestyle armstroke. The sequence commences at the top left and completes at the bottom right. The order of events as defined in the introduction that can be observed from this view are: i: entry, iii: catch, v: upsweep, vi exit, vii: mid-recovery. The missing events are: ii: outsweep, iv: insweep.

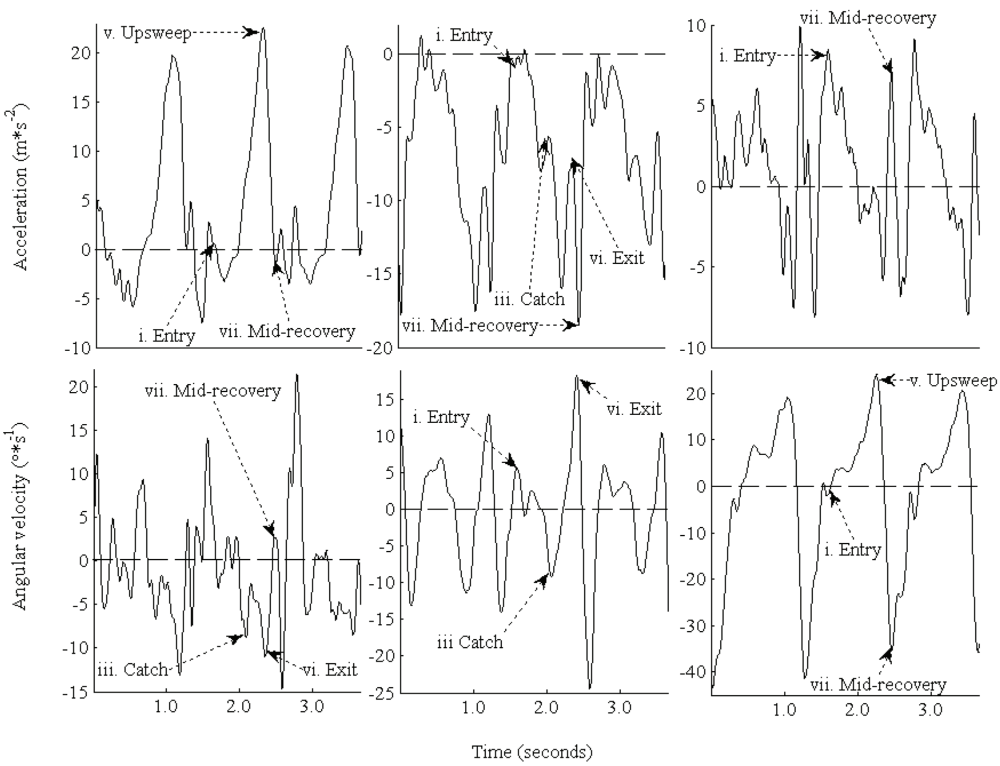

Fig. 3. Typical representation of three acceleration channels (top) and three angular velocity channels (bottom). Channel identification are, from left to right: X, Y, and Z for both modes of inertial measure. Events are recorded as found during analysis. Therefore not always aligning with a spike or zero point crossover. NOTE: For figure clarity, Y axis scales vary and are not necessarily centred around zero.

4. Discussion and Conclusion

The aim of this study was to determine the effectiveness of an inertial sensor to measure temporal kinematics of the entry and exit events in a simulated swimming freestyle armstroke. This was carried out by comparing the technology against an infrared camera system. A secondary aim was to confirm via video footage that inertial sensors can identify other elements of a simulated swimming stroke.

The very strong to near perfect correlations found, along with the small and trivial TEE and bias measures validate inertial sensor technology for measuring simulated swimming armstroke kinematics. This adds to the knowledge base that already exists showing inertial sensors as an effective means for various human movement activities [6, 8]. By this study determining that armstroke events are identifiable and measurable with inertial sensors, kinematic swimming parameters can be assessed. Future work may involve in-water swimming analysis. To measure these variables without the inherent problems of optical distortion due to water properties may provide another opportunity in the direction of microtechnology for swimming assessment. Comments in a study from the 1930s state that freestyle swimming is not constant where periods of acceleration and deceleration occur, which has an effect on swimming speed [9]. Swimming velocities have increased since that time. However, if a comparison was made on a swimmer's velocity today, it would most likely still show acceleration and deceleration components. It is these variables that this technology reads to measure a swimmer's technique. Ongoing research can further develop inertial sensors to provide a useful alternative to what is currently available.

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