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THREE-DIMENSIONAL KINEMATIC ANALYSIS OF SHOULDER THROUGH WEARABLE INERTIAL AND MAGNETIC SENSORS DURING SWIMMING STROKES SIMULATION

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SUMMARY

Wearable inertial and magnetic measurement units (IMMUs) have recently gained much attention in investigations approaching human kinematic analysis in sports scenario. Running, tennis, baseball, snowboarding, rowing, and swimming are some examples of sports already approached. In swimming, many studies proposed several methods to identify the temporal phases of a single swimming stroke or the swimming style. However, this temporal information alone does not provide any joint kinematic data like joint angles. Therefore, the present study aimed to verify the accuracy of a protocol, previously developed for ambulatory joint kinematic analysis through IMMUs, in measure the shoulder kinematics during swimming strokes simulation. A stereo-photogrammetric system was considered the gold standard. Three trained swimmers realized 3 trials of breaststrokes simulation and 3 trials of front-crawl strokes simulation in dry condition. As first verification, the relative motion of both the segments thorax and arm with respect to the first-synchronized frame (automatically detected by an ad-hoc algorithm) was compared by means of root mean square error (RMSE) and correlation coefficient (*r*) between the two systems. The RMSE was 5° and 7°, and the *r* was 0.85 and 0.91 for breaststroke and front-crawl stroke, respectively, indicating a good relationship between both methods in measuring the body segments' orientation. As second verification, the shoulder flexion/extension, abduction/adduction and internal/external rotation angles were computed, and no significant difference was found ($p<0.05$) between both systems. In conclusion, a protocol previously implemented for joint measurement in ambulatory settings is also suitable and accurate to estimate the shoulder kinematics during swimming strokes simulation when using wearable inertial and magnetic measurement units.

INTRODUCTION

The use of technology in swimming played an important role in acquiring reliable performance data to provide greater understanding of the swimming biomechanics and enable swimmers to perform to their highest potential.

Recently, several authors examined the difference of movement patterns and the evaluation of the athlete's technique using sensors composed by accelerometers, gyroscopes and magnetometers, also known as IMMUs, covering a large range of disciplines, including: ambulatory measurements, physical activity, gait analysis, and improvement of the athlete's performance [1]. Thus, the use of IMMUs has been presented as a useful tool for monitoring human movement kinematics.

In swimming, wearable IMMUs were used to measure several variables regarding athletes' performance including lap time, stroke identification, stroke count, stroke rate, stroke length, wall push off, forward speed, swimmer's proficiency, energy expenditure, and swimming velocity [2, 3]. However, to the knowledge of the present authors, no previous investigation performed a three-dimensional kinematic analysis of the shoulder joint, that is, by far, the most demanded joint during swimming [4]. As a consequence, investigations approaching the shoulder kinematics analysis can aid coaches and therapists in identifying risk factors for injuries as well as in planning injuries prevention programs. Therefore, the aim of this study was to verify the suitability and accuracy of a protocol previously developed for the shoulder joint kinematic analysis through IMMUs in ambulatory settings in measure the shoulder joint kinematics during swimming.

METHODS

The protocol implemented was described and validated by Cutti and co-workers [5]. Whereas the protocol was developed to measure the upper-limbs kinematics in ambulatory settings, the present work proposes to verify its applicability also in swimming.

From a biomechanical point of view, the shoulder joint was modeled as an open kinematic chain composed by 2 rigid segments (thorax and arm), with 3 degrees of freedom. Two clusters composed of one IMMU and four retro-reflexive passive markers fixed on a wooden plate (15x15x1cm) were used, one placed on the right arm and the other on the thorax. Basically the protocol consisted in positioning the clusters on the body segments and in calculating joint angles according to the appropriate Euler's convections.

The evaluation of the IMMUs' estimation of the orientation was performed during swimming strokes simulation on a bench in dry condition. A wireless IMMUs system (APDM, Opal, USA, 2 nodes, 128Hz) and a stereo-photogrammetric system (BTS Smart DX, Italy, 8 cameras, 200Hz) recorded the trials. Data from both systems were posteriorly synchronized and resampled at the IMMUs' frequency rate. Three trained swimmers were laid facing down on a bench and their lower-limbs were hold tight by a person. Each subject performed 2 trials (one breaststroke and one front-crawl stroke) during 10s, trying to simulate the movements in the swimming pool. The relative motion of the segments thorax and arm with respect to the first-synchronized frame was compared by means of root mean square error (RMSE) and correlation coefficient (*r*) between the two methods.

RESULTS AND DISCUSSION

The goal of the present study was to verify the accuracy of a protocol previously developed for ambulatory joint kinematic analysis through IMMUs in measure the shoulder kinematics during swimming strokes simulation in comparison with a gold standard system. The results of the first verification are presented in table 1.

Table 1: Root mean square error and correlation coefficient for both measurement systems.

	Breaststroke		**Front-Crawl**	
	RMSE (°)	r	RMSE (°)	r
Mean	5	0,85	7	0.91
Minimum	3	0.76	5	0.82
Maximum	8	0,97	10	0.97

The mean RMSE was 5° and 7° for the breaststroke trials and for the front-crawl stroke trials, respectively, in accordance with other investigations that performed human joint angle measurement. In addition, the mean *r* was 0.85 for the breaststroke trials and 0.91 for the front-crawl stroke trials indicating a good relationship between both systems in estimating the body segments' orientation with respect to the first frame.

Figure 1 shows the three shoulder angles for one subject's trial representative of all trials. Five strokes normalized by its percentage of the duration were plotted overlapped. No significant difference was found ($p<0.05$) between both systems in the estimation of the shoulder flexion/extension, abduction/adduction and internal/external rotation angles. Nonetheless, these values are comparable to the three-dimensional joint kinematics estimated using underwater kinematics video analysis [6].

For our analysis, only the shoulder was considered because it is the most demanded joint during swimming. Further investigations in other joints such as elbow, wrist, hip, knee and ankle can be addressed in order to get a full body kinematic analysis during swimming.

In this work we intended to perform shoulder kinematic analysis in dry condition because the protocol proposed by Cutti and co-workers [5] was implemented in an ambulatory environment. The dry condition has two main advantages: 1) the stereo-photogrammetric system is more accurate with respect to the underwater one, and 2) the whole swimming stroke cycle can be analyzed: the aerial phase (recovery) as well as the "underwater" phases. Finally, the joint kinematic analysis in real condition (i.e. underwater) during swimming will be aimed in the next future.

CONCLUSIONS

The protocol implemented previously for joint measurement in ambulatory settings is also suitable and accurate to estimate the shoulder kinematics during swimming strokes simulation using wearable inertial and magnetic measurement units.

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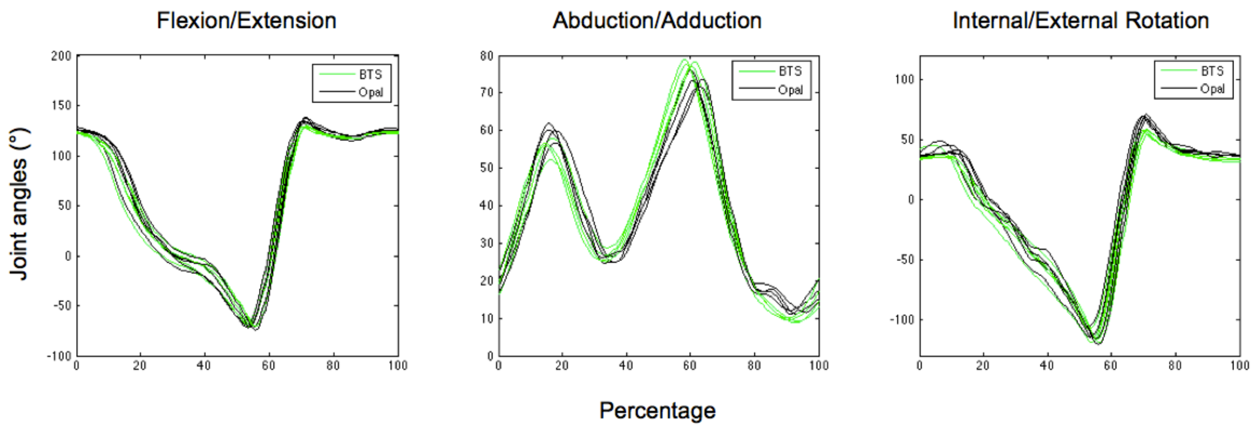

Figure 1: Shoulder flexion/extension, abduction/adduction and internal/external rotation. Lines green for the stereo-photogrammetric system (BTS) and lines black for the inertial and magnetic measurement units (Opal).