Influence of fatigue in swimmers suffering from *swimmer shoulder* pain

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Abstract. The shoulder joint is susceptible to be damaged in sports with overhead actions, often leading to *swimmer shoulder* pathology. Fatigue can also worsen and increase the risk of overuse injuries. Evaluating shoulder kinematics during swimming is crucial to identify injury-related movement patterns and to provide a correct physiotherapy treatment. To measure kinematics, inertial and magnetic measurement systems (IMMSs) offer a very versatile approach with respect to traditional video-based systems. This preliminary study focuses on the effects of fatigue on shoulder joint kinematics in swimmer with *swimmer shoulder* compared to healthy swimmers, by using IMMS. 11 young swimmers (5 pathological, 7 male) took part in the study. Each participant executed 40 seconds of dry front crawl followed by a fatiguing protocol and by other 40 seconds of dry front crawl. We analyze the arm movement relative to the thorax examining the differences of the movement amplitudes between healthy and pathological subjects and before and after fatigue exercise according to the three rotations: Flexion/Extension, Abduction/Adduction, and Internal/External rotation. Some slight non-significant differences were found after exercise compared to before in all the three rotations while a significant difference between healthy and pathological subjects was found in Flexion/Extension rotation both before and after fatigue exercise. The use of IMMS allowed to verify the repeatability of the kinematic movement and to quantify the rotation angles identifying which component of the movement is most affected by the *swimmer shoulder* pathology. However, a larger number of subjects is necessary in order to confirm the results.

Keywords: Inertial Sensors, Shoulder Kinematic, Swimmer.

1 Introduction

Shoulder joint is a complex joint often subject to damage in sports that require overhead actions. Kennedy and Hawkins introduced the term *swimmer shoulder* indicating the shoulder pain in swimmers caused by several different aetiologies, and it stands as the predominant disability among elite swimmers [1, 2]. Fatigue can also negatively affect shoulder's strength, proprioception and range of motion and could lead to overuse shoulder injury [3].

The evaluation and the characterization of the shoulder kinematic during swimming is important for both sport improvements and clinical aspects as it allows to optimize the performance and to identify altered movement patterns that can generate injury or could be associated with previous lesion [4]. The main method to study shoulder kinematic is through a 2D or 3D video-based system and it is considered the gold standard in this field [5]. Nevertheless, this technique presents limitations in the measurement systems: high costs, time-consuming data processing procedures, a confined place with no possibility to repeat the acquisitions in different location, and the video analysis can only be conducted offline.

However, more recently, inertial and magnetic measurement systems (IMMSs) are increasingly used to study and evaluate kinematic parameters also in swimming. Generally, the IMMS consists of one 3D accelerometer, one 3D gyroscope and a 3D magnetometer [6] able to measure linear and angular accelerations along three orthogonal directions of the IMMS system of reference, in relation to a global, earth-based system of reference. Some researchers have used IMMSs to explore the kinematics of the homerus, the homerothoracic and the elbow [7, 8], while Cutti et al. [6] validated a protocol based on the use of the inertial sensors to analyse the scapulothoracic, humerothoracic, and elbow kinematics in ambulatory settings for simple and slow movements. Moreover, Magalhaes et al. [9] extended the protocol [6] to the swimming context as there was no protocol specifically developed for this type of sport setting.

The aim of our work is to study the effects of fatigue on the kinematic of the shoulder joint between thorax and arm in swimmers suffering from *swimmer shoulder* compared to healthy swimmers by using an IMMS.

2 Materials and Methods

2.1 Participants

11 young swimmers (7 male), aged between 15 and 27 (mean 20.18 ± 3.5 years), recruited from local swimming clubs, took part in the study. Inclusion criteria required participants to have a minimum of 3 years of swimming training and maintain a training volume of at least 4.5 hours per week, with the front crawl being their primary swimming style. Six subjects were identified as healthy as they did not present a history of chronic or acute muscular or joint diseases affecting the tested shoulder or upper limb and five individuals were considered affected by *swimmer shoulder* pathology by an expert physiotherapist team.

Participants and their legal guardians were properly informed about the protocol and signed informed consent before being enrolled in the study that received approval from the local university ethics committee (122/2022) and adhered to the principles outlined in the Declaration of Helsinki.

2.2 Study protocol

The protocol used for the movement acquisitions is part of a more extended protocol within which tensiomiography and shoulder strength measurements were also carried out and not considered for this study [10].

The testing session took place in a local swimming pool and consisted of three parts: during the first and the third part concerning the execution of the exercise, the movement was measured through inertial sensors, while during the second part the fatiguing protocol was carried out. In the first and third part, the participants were asked to perform 40 seconds of dry front crawl exercise using only one arm, lying prone on a physiotherapist's bed, with a metronome set at a reasonable frequency of beats per minute (70) to synchronize the movements. At each beat the arm had to be over the head or along the body. Thus, each subject performed 23 full strokes (one every two beats). Before the start and after the end of the exercise, the subject kept resting position with arm along the body for 10 seconds. The fatiguing procedure consisted of 30 minutes front crawl swimming in water at different incremental intensities as the protocol described in [10].

2.3 Acquisition and analysis

Since the aim of the study was to characterize the movement of the shoulder, a reduced version of the protocol proposed by Magalhaes et al. [9] was adopted. Two wireless magneto inertial sensors were used to acquire data from MTw Awinda Development Kit (Xsens Technology) able to detect 3D Euler angles: one sensor was placed on the subject's chest (on the flat portion of the sternum), while another sensor on the subject's arm (above the centre of the homerus and posteriorly) by means of Velcro body strap. This setup allowed for the study of the arm movement relative to the thorax.

For the calibration phase, the subject was asked to keep the tested arm along the body for some seconds. The devices are linked to the host through the dedicated software (MT Manager) which allows the operator to collect data at a sample frequency of 100 Hz during the first and the third phase of the protocol. For each stroke and for each Euler angle, maximum and minimum values were identified, and the peak-to-peak amplitude of the stroke was calculated, excluding the first and the last stroke. As the stroke duration was strictly linked to the metronome synchronization, the analysis focused only on the amplitude of the movement according to the three angle rotations. In order to estimate the mean shape of stroke movement of each subject, for each Euler angle, all the strokes were synchronized at the times in which the minimum amplitude peaks were reached and then averaged. To highlight the existence of significant differences in stroke amplitude either in healthy and pathological group, in this preliminary analysis, we compared the amplitude values of the three angular rotations before and after the fatiguing session in healthy and pathological subject. The significance of the differences was assessed with the sign rank test for paired group in the comparison before/after fatiguing exercise and with the rank sum Wilcoxon test in other comparison. The analysis was performed using a program written in MATLAB®.

3 Results

Figure 1 reports the average trends of stroke amplitude for each movement rotation in healthy and pathological subjects before and after the fatiguing protocol. Internal/External rotation and Adduction/Abduction rotation present a similar behavior with slight difference between healthy and pathological group and before and after the exercise, while the Flexion/Extension rotation presents a marked difference between healthy and pathological group both before and after the fatiguing exercise. Noticeably, the movement trends are similar both between the two groups and before and after exercise separately in each of the three Euler angles (Fig.1).

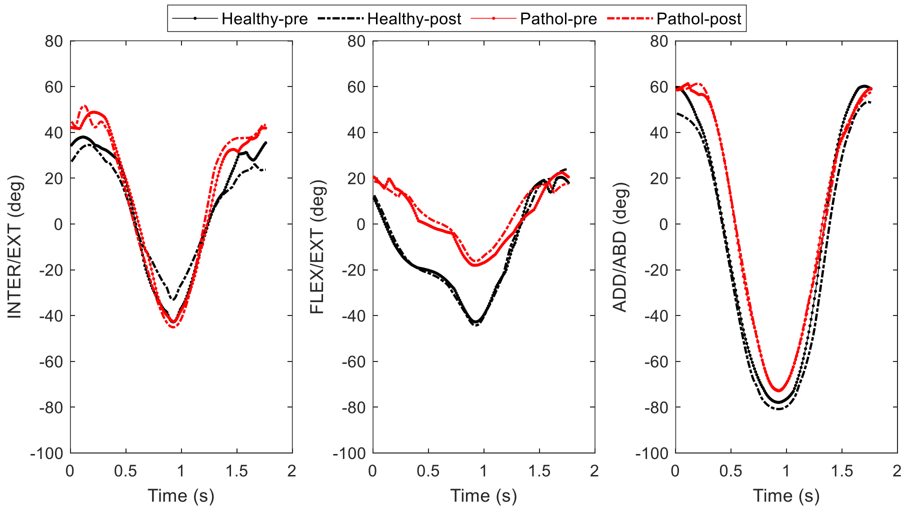

Fig. 1. Mean amplitude trend of the three movement rotation in healthy (black) and pathological (red) subjects before (solid line) and after (dashed line) the fatiguing protocol.

Table 1 shows mean values (± 1SD) of stroke amplitude calculated on subjects belonging to the two groups before and after the fatiguing protocol for the three movement rotations. The results correspond to what shown in the graph of Figure 1 highlighting a large variability (SD greater than 10 degs) among the subjects in most of all the situations.

Because of the low number of subjects, we report in Figure 2 the boxplot presenting median values, 75^{th} and 25^{th} percentile of the three rotation angles in the two groups before and after exercise. As expected, only Flexion/Extension shows (Table 1) a large difference before and after the fatigue in both healthy and pathological group while the Adduction/Abduction rotations present a reduction of the amplitude after the fatiguing task both in healthy and pathological subjects. Finally, the Internal/External rotations show an increase only in pathological subjects after exercise. However, due to the large variability among the responses of the subjects and the low number of participants, only the Flexion/Extension rotations showed significant (p=0.0043) differences between healthy and pathological group both before and after the fatigue exercise.

Table 1. Mean values (± 1SD) of stroke amplitude (deg) before ('pre') and after ('post') fatiguing exercise for each of the three rotation angles (Internal/External, Flexion/Extension, Adduction/Abduction) in healthy and pathological subjects.

	Inter/Ext [°]	Flex/Ext [°]	Add/Abd [°]
Healthy-pre	87±11	77±13	144±10
Healthy-post	85±18	80±16	138±7
Pathol-pre	91±12	46±6	142±15
Pathol-post	96±12	40±6	141±16

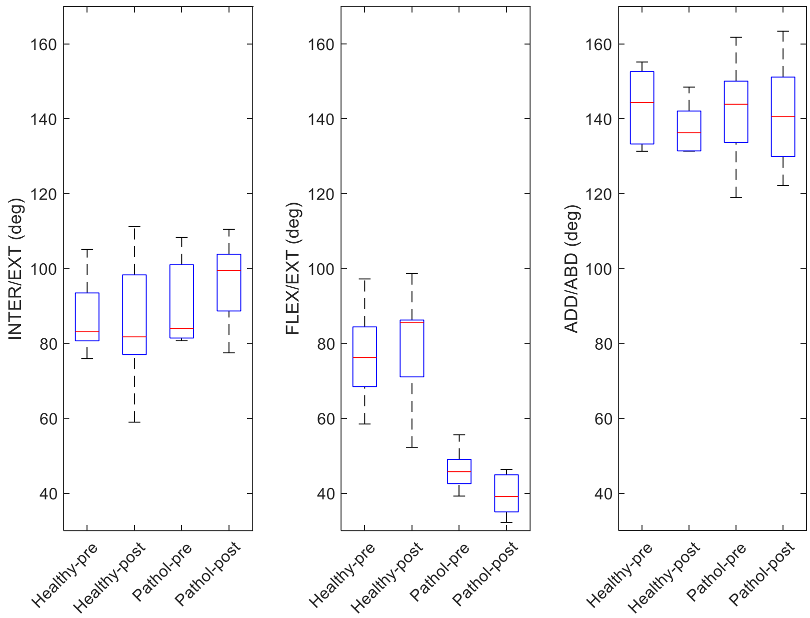

Fig. 2. Box plots of the amplitude values. In red the median values with the box delimiting the 25° and 75°percentiles. The results are displayed separately for each movement rotations in the two different conditions (before and after fatigue exercise) for healthy and pathological subjects.

4 Discussion

Swimmer shoulder represents one of the main disabilities in elite swimmer and some researchers demonstrated that fatigue could negatively effect on strength, range of motion and proprioception thus highlighting a connection between fatigue and potential mechanisms leading to shoulder pathology in swimmers [3]. The aim of our work was to study the effects of fatigue on the kinematic of the shoulder joint in swimmers suffering from *swimmer shoulder* compared to healthy subjects.

The used of magneto inertial sensors allowed to verify the repeatability of the kinematic movement and to quantify the rotation angles. The results showed some differences after fatiguing exercise in Internal/External rotation with an increase of the amplitude in pathological subject and a slightly decrease of the amplitude after the fatigue in Adduction/Abduction in both healthy and pathological groups. However, despite these differences were not significant mainly due to the low number of subjects and a large standard deviation (see Table 1 and Fig.2), the results found confirm that fatigue has an influence on the kinematic of the shoulder as reported in [3], but we cannot directly compare the results because of the different methodology used.

Finally, the only significant difference we found is between healthy and pathological groups in the Flexion/Extension rotation both before and after the fatigue exercise with greater values in healthy subjects. These differences are ascribable to the pathology and our methodology allowed us to highlight which component of the movement is affected enabling a more targeted treatment in order to recover the incorrect motor response due to the pathological condition.

5 Conclusion

Our study allowed to verify that the IMMS is a technology able to quantify the rotation angles in a non-invasive and easy way also in swimmers. This instrumentation highlights what is the influence of fatigue due to physical exercise and what movement differences are due to the pathology, precisely identifying which of the three rotation angles is affected by the pathology. The low number of subjects limited the statistical significance of the results but the increase in the number of subjects could confirm the results found in this preliminary work.

Declaration of conflicts of interest
The authors declare that they have no conflict of interest.

References

1. Martino ID, Rodeo SA (2018) The Swimmer's Shoulder: Multi-directional Instability. Current Reviews in Musculoskeletal Medicine 11:167. https://doi.org/10.1007/s12178-018-9485-0
2. Hidalgo-Lozano A, Calderón-Soto C, Domingo-Camara A, Fernández-de-Las-Peñas C, Madeleine P, Arroyo-Morales M (2012) Elite swimmers with unilateral shoulder pain demonstrate altered pattern of cervical muscle activation during a functional upper-limb task. J Orthop Sports Phys Ther 42:552–558. https://doi.org/10.2519/jospt.2012.3875
3. Matthews MJ, Green D, Matthews H, Swanwick E (2017) The effects of swimming fatigue on shoulder strength, range of motion, joint control, and performance in swimmers. Phys Ther Sport 23:118–122. https://doi.org/10.1016/j.ptsp.2016.08.011
4. Fantozzi S, Giovanardi A, Magalhães FA, Di Michele R, Cortesi M, Gatta G (2016) Assessment of three-dimensional joint kinematics of the upper limb during simulated swimming using

wearable inertial-magnetic measurement units. J Sports Sci 34:1073–1080. https://doi.org/10.1080/02640414.2015.1088659

5. A Novel Macro-Micro Approach for Swimming Analysis in Main Swimming Techniques Using IMU Sensors - PMC. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7841373/. Accessed 25 Jan 2024

6. Ambulatory measurement of shoulder and elbow kinematics through inertial and magnetic sensors | Medical & Biological Engineering & Computing. https://link.springer.com/article/10.1007/s11517-007-0296-5. Accessed 25 Jan 2024

7. Luinge HJ, Veltink PH, Baten CTM (2007) Ambulatory measurement of arm orientation. J Biomech 40:78–85. https://doi.org/10.1016/j.jbiomech.2005.11.011

8. Zhou H, Stone T, Hu H, Harris N (2008) Use of multiple wearable inertial sensors in upper limb motion tracking. Medical Engineering & Physics 30:123–133. https://doi.org/10.1016/j.medengphy.2006.11.010

9. Magalhães F, Giovanardi A, Di Michele R, Cortesi M, Gatta G, Fantozzi S (2014) Swimming motion analysis: 3D joints kinematics of the upper limb using wearable inertial and magnetic sensors

10. Buoite Stella A, Cargnel A, Raffini A, Mazzari L, Martini M, Ajcevic M, Accardo A, Deodato M, Murena L (2023) Shoulder tensiomyography and isometric strength in swimmers before and after a fatiguing protocol. Journal of Athletic Training. https://doi.org/10.4085/1062-6050-0265.23