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UPPER LIMB KINEMATICS AND INERTIAL SENSORS: WHICH CALIBRATION FOR THE BEST ACCURACY?

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Introduction and Objectives: Magneto-Inertial Measurement Unit sensors (MIMU) are increasingly used in motion analysis as they allow monitoring ambulatory measurements. Sensor 3D orientation can be estimated by combining information from a 3D accelerometer, a 3D gyroscope and a 3D magnetometer. When focusing on joint kinematics, the definition of segment coordinate systems must be associated with MIMU [1]. International standards [2] do not provide a usable method due to the absence of position information delivered by MIMU. In the literature, three main classes of MIMU calibrations can be distinguished: segment axes equal to technical MIMU axes (TECH), and segment axes generated during a static pose (STATIC) or during functional movements (FUNCT). Despite much interest from the scientific community in this topic, two aspects of research deserve more investigation regarding MIMU-based upper limb kinematics. First, few studies have investigated the comparison of MIMU calibrations, being either focused on segment axes and not joint angles [1] or performed on an artificial arm [3]. Second, evaluations of the performance of MIMU-based upper limb kinematics often appear incomplete and disparate in terms of the protocol and validity criteria used [1,4,5]. The present study compares TECH, STATIC and FUNCT classes of calibration in terms of accuracy for the generation of wrist, elbow and shoulder (humero-thoracic) joint angles during maximal amplitude movements.

Methods: Ten subjects were equipped with four wireless MIMUs (MTw, Xsens, Netherlands) on the thorax, and right upper arm, right forearm and right hand segments. The three classes of MIMU calibration, TECH, STATIC and FUNCT were compared. STATIC consists in maintaining a standing pose with the upper arm along the body, elbow flexed at 90°, in neutral forearm pronation-supination (PS). FUNCT uses the combination of STATIC and functional movements of wrist extension, elbow flexion/extension (FE) and shoulder internal/external rotation (IER). An optoelectronic system (Eagle 4, Motion Analysis C., USA) was used as the reference measurement system for the kinematics (REF), according to the ISB standard [2]. Joint angles were compared during six separate movements of maximal amplitude (max): wrist FE, wrist abduction/adduction (AA), elbow FE, forearm PS, shoulder FE and shoulder AA (in the scapular plane). In addition, a seventh test movement consisted of a circular movement in the transverse plane (wheel) that mainly relied on elbow and shoulder DoFs. The experiment was repeated five times per subject, involving a total of fifty experimental sessions (N=50). For the seven test movements, the accuracy of the three MIMU calibrations was assessed using the mean Coefficient of Multiple Correlation inter-protocol (CMCip) [6] and the mean RMSE values calculated over the whole experiment (N=50) and compared with the REF data. Four mean CMCip thresholds were considered: very good (≥0.85), good (0.75-0.85), moderate (0.65-0.75) and bad (<0.55).

Results: The accuracy of the three MIMU calibrations was very good and equivalent (0.85≤CMCip≤0.99) for all the principal FE angles during max wrist FE, elbow FE, shoulder FE and AA, and wheel movements. The same observation was made for the coupled PS during max forearm PS (0.93≤CMCip≤0.97) (figure 1). Lower accuracy and disparities between calibrations could be observed for the principal AA angle during max wrist AA (0.66≤CMCip≤0.86) and for the
coupled AA and IER shoulder angles during max shoulder FE and AA, and wheel movements (0.53≤CMCip≤0.86), without any constant predominance of a particular calibration. Regarding RMSE values, no significant difference could be observed between MIMU calibrations for any of the movements performed (8.0°≤RMSE≤26.2°).

**Figure:**

**Caption:** Figure 1. Elbow joint angles over time from REF (black-dotted), TECH (blue), STATIC (red), FUNCT (green) during max forearm PS

**Conclusion:** This study highlights that the three classes of calibration (TECH, STATIC, FUNCT) provide good level of accuracy considering CMCip, without any significant difference between them. However, it should be mentioned that the accuracy is only one aspect of the MIMU calibration performance. Indeed, differences between MIMU-based and REF joint angle always exist due to the different definition of the segment axes and the dissimilar effect of soft tissue artifact [1]. RMSE values are comparable to previous results of 20° and 10°-20° reported in the literature [1,7]. For a complete evaluation of MIMU-based upper limb kinematics, reproducibility [1] and interpretation [5,8] of joint angle should also be considered key criteria.

**References:**

**Disclosure of Interest:** None Declared