A FRAME ORIENTATION OPTIMISATION METHOD TO ENABLE VALID KINEMATIC COMPARISONS: ASSESSING IMU-BASED KNEE KINEMATICS

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Introduction

In the field of movement biomechanics, validation of new motion analysis tools requires gauging accuracy against a gold standard. To achieve this, kinematic signals obtained from innovative systems are frequently compared to those stemming from previously validated setups. These comparisons often assume that, as long as the underlying movement is the same, the kinematics resulting from different sources or analysis techniques should lead to a consistent outcome. However, the exact orientation of local segment frames has demonstrated to substantially influence the magnitude and characteristics of the resulting kinematic signals [1-3], although this effect is often overlooked or misunderstood by validation studies. Here, we present a Frame Orientation Optimisation Method (FOOM) [3] that makes it possible to establish whether two datasets differ through frame alignment errors or whether the underlying joint kinematics are indeed fundamentally different.

Methods

Previously, the rotational knee kinematics of six subjects during level walking, stair descent and sit-to-stand-to-sit trials were assessed using inertial measurement units (IMUs), and subsequently compared to a reference simulator signal to determine accuracy [4]. To better understand the source of the observed differences between the IMU- and simulator-based signals, a Frame Orientation Optimisation Method was implemented. FOOM minimised cross-talk parameters in each dataset independently using least squares optimisation, allowing the standardisation of the kinematic signals ensuing from each measurement system by transforming local segment frames towards a common unspecified relative orientation.

Results

The presented FOOM framework led to an average 3.32° ± 1.24° rotation of local segment frames around the corresponding screw axis to achieve a decrease in root-mean-square error between IMU-based estimates and simulator reference signals from 0.79° ± 0.30° in out-of-sagittal-plane rotations to 0.29° ± 0.30°. Importantly, frame reorientation altered signal characteristics enough to allow for convergence on a consistent kinematic waveform around all three axes, while still retaining fundamental differences between individual subjects (Figure 1).

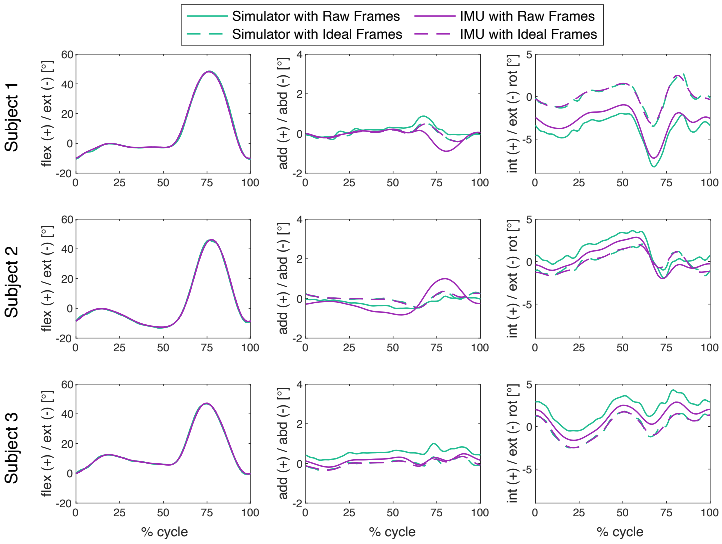

Figure 1: Knee kinematics [°] (tibia relative to femur) during level walking for three sample subjects before (solid: "raw") and after (dashed: "ideal") frame reorientation.

Discussion

Optimised kinematic signals point towards different interpretations of the evaluated movement patterns. While the converged signals differ from both original datasets, they become consistent with one another after reorientation of local segment frames. Results highlight the importance of accounting for differences in segment frame orientation when drawing conclusions from the comparison of kinematic data. Furthermore, the proposed FOOM protocol demonstrates the ability to independently realign segment frames to a common (even if initially unknown) optimal relative orientation that can allow the consistent interpretation of joint kinematics.

References

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