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Functional Determination of a Cervical Spine Joint Coordinate System via an Optimization Approach

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Determination of a subject-specific fixed cervical spine joint coordinate system (JCS) is challenging due to several anatomical constraints. Cervical spine motion (flexion/extension, axial rotation, and lateral bending) is the combined contribution from the occipito-atlanto-axial complex and 2nd cervical vertebra through the 1st thoracic vertebra. Additionally, there is a lack of accessible bony landmarks aligning with rotation axes. Several methods of quantifying total cervical spine motion from three-dimensional kinematic data have been previously reported, however, none of the JCS determination methods have utilized an optimization approach. **PURPOSE:** The purpose of this study was to determine the feasibility and accuracy of a numerical optimization approach in determining subject-specific cervical spine JCS through a series of coordinated movements. **METHODS:** Twenty-eight participants (15F; 21.4 ± 5.4 yo; 71.0 ± 14.9 kg), free from any musculoskeletal limitations in the cervical spine, granted informed consent and participated in this IRB approved study. While in a seated position, all participants performed the following sequence of ordered head movements representing their full active neck range of motion (ROM): (1) flexion-extension, (2) axial rotation left-right, (3) lateral flexion left-right. Five reflective markers (dia.=12.5mm) were rigidly fixated to the head via a tight fitting elastic band and a 4-marker reflective marker cluster was rigidly fixated to the upper thoracic region. Marker coordinates were measured with an 8-camera three-dimensional motion capture system (Qualisys OQUS 100; Gothenburg, SWE; 120 Hz) with a residual accuracy < 0.30 mm. All three-dimensional coordinates were filtered with a 4th order Butterworth lowpass filter with cutoff frequency of 25 Hz. A custom-written MATLAB (MathWorks; Natick, MA) program utilized a Nelder-Mead simplex optimization routine to determine axes parameters that minimized the difference between the measured joint motion and the actual joint motion. Off-axis angle deviations were computed over the entire ordered movement sequence and for each joint rotation direction respectively. Computed ROMs were compared against published norms from healthy participants [1]. **RESULTS:** Averaged across all participants and over all rotations, off-axis angle deviations were 8.1±2.5°. Off-axis deviations were smallest for flexion-extension rotations (3.5±2.3°) and largest for lateral bending rotations (14.0±5.1°). Aggregate active ROMs compared favorably to previous reports (Flexion 67.7±12.3°, Extension 68.4±12.3°, Rotation Left 74.7±8.7°, Rotation Right 73.5±6.6°, Lat. Bending Left 47.6±7.8°, Lat. Bending Right 46.4±6.2°) **DISCUSSION**: Despite anatomical limitations that prevent traditional joint axes determination, the reported methodology adequately fit a set of ordered head motions with an optimized fixed cervical spine joint coordinate system. An advantage of the current methodology is that body fixed reflective markers do not need to align with either the lab-based coordinate system or a segment coordinate system (e.g. head, thoracic).

REFERENCE: 1. Houck et al. Title. *Gait & Posture*. 1997;5(2):184.

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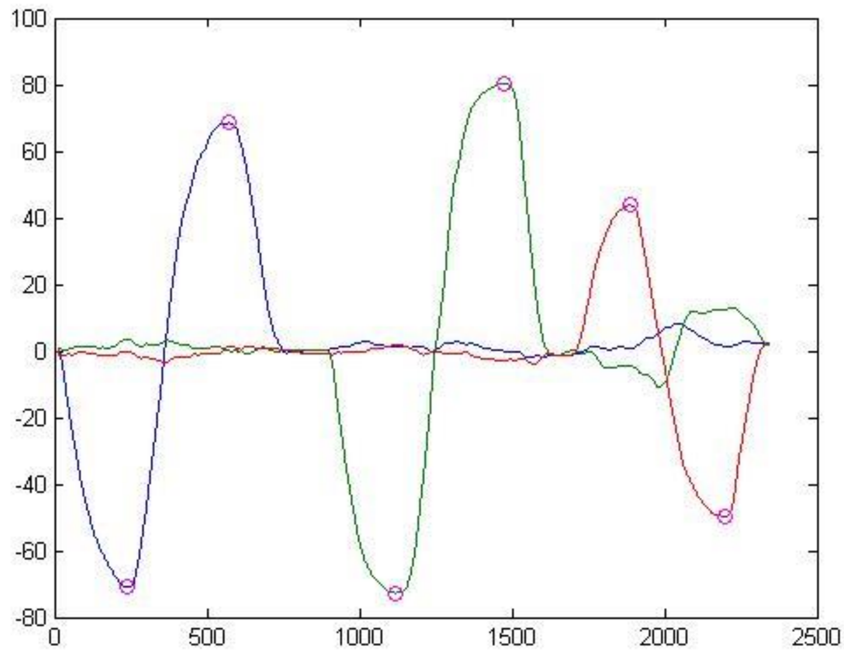

Figure 1 - Neck motions (flexion-extension - Blue, axial rotation – Green, and lateral bending - Red) during an ordered movement calibration trial.