THE USE OF ATTITUDE SENSORS TO MEASURE CERVICAL SPINE ROM

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INTRODUCTION
Evaluation of the cervical spine range of motion (ROM) is important when investigating the cause of both neck and back pain [1]. Subsequently, the increased number of such cases over the past few decades has given rise to an increased interest in accurately quantifying cervical spine (c-spine) ROM.

Like most of Man’s joints, a range of techniques have been used in an attempt to quantify the c-spine ROM. The cervical range of motion (CROM) device, like other series of inclinometers and goniometers, measures tri-planar motion but requires a static posture to manually record data [2, 3]. Equally, the use of the various motion analysis techniques is susceptible to typical issues such as line-of-sight requirements and spatial restrictions.

Attitude sensors comprise 3 integrated elements (i.e. a gyroscope, an accelerometer and a magnetometer) in each orthogonal axis, thereby enabling the recording of dynamic, tri-planar movements. The independent streaming of data directly from each sensor to a dedicated PC means that none of the above limitations hinder the use of such a system. Attitude sensors have demonstrable accuracy and validity in quantifying motion of rigid joints [4, 5]; however, their use in reliably measuring the c-spine ROM has yet to be reported.

Subsequently, this study aims to determine whether attitude sensors can be used to reliably quantify the range, and pattern, of c-spine motion. The acquisition of reliable data will be dependant on minimising artefacts, such as skin slippage and hence a series of anatomical landmarks will be used as attachment sites, to establish the optimal sensor positioning.

METHODS
Two wired attitude sensors (model 3DM-GX3-25; Microstrain, VT, USA) were used to measure the cervical spine range of motion of 12 participants (6 males, 6 females; mean age: 23 years ± 1.60 SD; range: 21 – 26 years). Data was collected at 100Hz, using custom-built software and a datalogger (H-Scientific, Portsmouth, UK), and reported as Euler angles in the three orthogonal planes (i.e. yaw, pitch & roll).

Four anatomical landmarks were then located and marked on each participant (Figure 1): thoracic vertebrae 4 (T4); the manubriosternal joint line (MJL); the anterior prominence of the forehead (FH); the external occipital protuberance (EOP; the presence of hair meant that a preliminary trial was conducted to identify the most rigid sensor attachment method, which was identified as using adhesive tape against a latex hat). Hence, 4 combinations of sensor locations were investigated:

- Setup A: T4 – EOP
- Setup B: T4 – FH
- Setup C: MJL – FH
- Setup D: MJL – EOP

Participants were seated in a lumbar supporting chair, before the sensors were attached as per Setup A. Three continuous flexion-extension (FE) cycles were then performed through a range that was both comfortable and repeatable (but not necessarily their maximum range of motion). Cycles in rotation and then lateral bending were performed, before the series of movements were repeated for Setups B – D.

The data enabled calculation of the relative angles between the trunk and head sensor, from the direction cosine matrices. Subsequently, this process ensured that the calculated c-spine motion was independent both of inconsistent sensor orientation at the attachment site, and any inadvertent trunk rotation.

The movement-time curves for each primary movement were then time-normalised, to account for the differing movement velocity of each participant. The maximum range of this motion was measured from the normalised movement curves. The reliability of the movement pattern was assessed by comparing the similarity of the movement-time curves, using the coefficient of multiple correlation (CMC) and root mean square error (RMSE). A CMC value approaching 1 is indicative of a highly repeatable movement pattern. The reliability of using a single point of comparison (i.e. the data-point describing
the greatest change in joint angle per movement cycle) was determined using the intra-class correlation coefficient and absolute mean difference between peak measurements. The reliability of the four sensor locations was then compared using the respective CMC and ICC values across each movement.

RESULTS AND DISCUSSION
Whilst high CMC values and relatively small root mean square errors demonstrated excellent reliability in measuring the movement patterns of each participant with each sensor setup, a one-way ANOVA and subsequent t-test identified a statistical difference between the flexion-extension CMC data acquired by Setups A and B. Considering the higher RMS error and lower mean CMC of setup A compared to B, setup A was deemed inferior in acquiring reliable flexion-extension movement patterns, probably due to slippage at the latex hat-skin interface.

Excellent reliability (i.e. CMC > 0.95) and consistent RMSE were reported across all attitude sensor setups when considering rotation; however, relatively poor correlation is reported between the 3 peak rotations recorded per movement using setup D (ICC = 0.89). Slippage at the hat-skin interface was again the predicted source of error.

All sensor positions provided excellent reliability (i.e. CMC > 0.95) when assessing the movement-time curves for lateral bending. When considering the reliability of recording peak lateral bending however, setup C performed inferiorly when compared to other sensor locations (i.e. ICC = 0.80). Whilst this setup (i.e. MJL and forehead) does not have an obvious source of error, the concaved surface anatomy of some participants did hinder achieving secure MJL attachment. Hence, it is hypothesised that a compounding of minor movements at both attachment sites influenced the reliability of the recorded data.

Having identified Setups A, D and C as the poorest for measuring the c-spine angle during flexion – extension, rotation and lateral bending respectively, it becomes apparent that positioning attitude sensors with reference to Setup B, will ensure recording of the most reliable movement pattern, and peak measurement, c-spine data. Setup B did not involve either the MJL or EOP, both of which presented significant challenges to achieving secure sensor attachment.

CONCLUSION
This study presents a systematic approach to evaluating the use of attitude sensors, and recommends the use of such systems in future work investigating c-spine ROM. This study also recommends that, based on the clinical landmarks reported here, that optimal data will be obtained by attaching one sensor over T4 and the other sensor to the forehead.

REFERENCES