Reproducibility of kinematical variables describing head and neck movement – A 3D movement analysis using the Finite Helical Axis Method

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INTRODUCTION

The finite helical axis method (Spoor and Veldpaus, 1980) is an illustrative way to describe the combined rotation and translation of composite joint segments, such as the cervical spine. The head rotation relative the upper body is described with the helical rotation angle; θ, around the moving helical axis (described by position vector **c** and direction vector **n**). The helical axis ("axis of motion") visualize on which level the rotation occurs. It relates to the composite movement of all cervical vertebrae and migrates during head movement (Winters, 1993). The helical rotation angle is well defined for small rotations, while error in axis direction and position are inversely proportional to the rotation magnitude (Woltring, 1985). This may affect the reliability of finite helical axis variables.

The aim of this pilot study was to investigate the reproducibility of head movement variables derived with the finite helical axis method (Grip, 2007) in a group of healthy volunteers.

METHODS

A task, including fast head rotations, was performed by 6 healthy young adults. The movement task was performed twice by each subject, with one week between each performance. The subject sat on a chair and a board with arrows was placed one meter in front of the subject. Fast maximal movements of flexion, extension and side rotations (left and right), were performed immediately after an arrow on the board (showing the direction) was illuminated. The movement was performed as fast as possible to a comfortable extent.

Movements were registered at 120 Hz with an optical movement capture system that included five cameras (Qualisys Medical AB®, Gothenburg, Sweden). In total, 10 retro-reflective markers were placed on the head and upper torso: four in a rigid cluster configuration on the head, one on the suprasternal notch, three on a rigid plate on the back, and one on each shoulder. The subject was seated relative to the lab coordinate frame, the X axis was transverse (along the shoulders), Y axis was anterior-posterior and Z-axis was vertical.

Data analysis was performed off-line using MATLAB® (The MathWorks Inc., Natick, MA, USA) and SPSS (version 11.0.1). The coordinate data were filtered with a 2nd order low-pass Butterworth filter, cut-off frequency 6 Hz. Head rotation was calculated relative initial head position. The maximal range of movement (ROM) and mean velocity were then calculated. The direction vector at 80% of ROM, $\mathbf{n}_{ref}$, was derived. The finite helical axis variables (**c** and **n**) were estimated for each time frame using a dynamic moving window ($\Delta\theta = 4°$) and were filtered with the same filter as above The 3D angle between finite position of **n** and $\mathbf{n}_{ref}$; called ω, described the change in axis direction. The center of rotation; **CR**, was defined as the intersection of the different finite axes; and was calculated for combined flexion/ extension and combined right/left side rotations. The trajectory of **c**, **CR** and ω was averaged over consecutive rotation levels (0-15°, 15-30°, 30-45°, 45-60°).

All variables described above were averaged from 5 repetitions on the day of measurement, and the test-retest reliability was estimated as follows: The effect from day (n=2) on ROM, mean head velocity, **CR**, mean ω and mean **c** was studied using a 2×1 repeated-measures ANOVA design. The effect from day (n=2) and rotation level (m=4; 0-15°, 15-30°, 30-45°, 45-60°) was studied for **CR**, ω and **c** using a 2×3 repeated-measures ANOVA design.

RESULTS AND DISCUSSION

Head movement curves were repeatable, as illustrated in Figure 1.

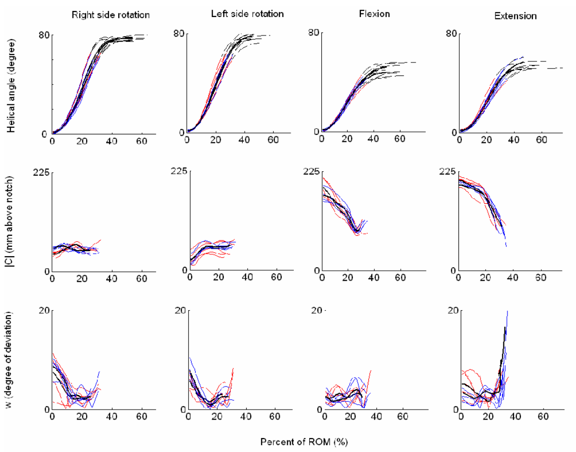

Figure 1: Repeated measurements for one subject from day 1 (red lines), and day 2 (blue lines) together with mean curves for each day (thick black lines). Angle of rotation (θ, on the top), axis position (**c,** in the middle) and 3D angle of **n** (ω, on the bottom); are illustrated for four movement directions; right, left, flexion and extension.

Repeated-measures ANOVA showed no significant effects from day of measurement on any of the derived variables (p = 0.11 to p = 0.99). A downward migration of **c** and **CR** was significant during flexion and extension, as well as lateral migration of **CR** during side rotation and extension (no interactions with day of measurement). A significant increase of ω towards the end of the movements was also observed.

SUMMARY/CONCLUSIONS

Estimates of ROM, head velocity, **CR**, ω and **c** were repeatable. The use of a moving window of 4° and a low-pass filtering when calculating finite positions of **n** and **c** may have increased the reliability.

The downward migration of the axis (Figure 1, middle row) was probably related to an increased curvature of the neck during flexion and extension as well as greater contributions from the lower cervical spine vertebrae towards the end of the side rotations. The change of ω for all movement directions (Figure 1, bottom row) was probably related to an increased amount of lateral bending towards the end of the movement.

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