Variation in lifting kinematics related to individual intrinsic lumbar curvature: an investigation in healthy adults

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Supplementary Information

Marker placement

Retro-reflective markers were affixed to each participant's skin according to previously developed marker-sets and models for the lower limbs and pelvis (1) and the lower back (2, 3) Single markers were placed bilaterally on the heads of the first and fifth metatarsals, calcaneus, anterior superior iliac spines (ASIS) and posterior superior iliac spines (PSIS). Three-marker clusters, on a semi-rigid T-bar base plate, were affixed bilaterally on the thigh and tibia. Static calibration trials included additional markers on the medial and lateral femoral condyles and the medial and lateral malleoli to set segment coordinate systems and locate joint centres. The lumbar segment consisted of single markers placed on the spinous processes of the first, third and fifth lumbar vertebrae (L1, L3 and L5 respectively). The upper lumbar (UL) and lower lumbar (LL) spine segments were marked by markers approximately 5 cm to left and right of the second spinous process (LUL, RUL) and to either side of the fourth (LLL, RLL) spinous processes (Figure S1).

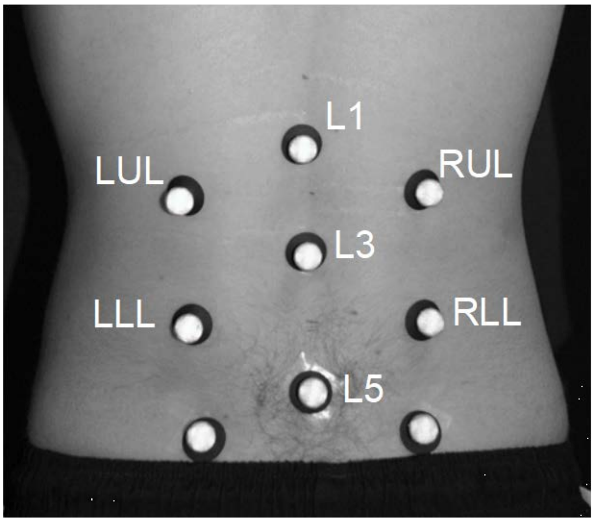

Figure S1. Low back marker set (labelled) and posterior superior iliac spine markers (unlabelled). L1, L3, L5= spinous processes of the 1st, 3rd and 5th lumbar vertebrae; LUL= left upper lumbar; RUL= right upper lumbar; LLL=left lower lumbar; RLL=right lower lumbar.

Kinematic modelling

Following kinematic recording, minor gaps in marker position data were filled using cubic spline interpolation in Vicon Nexus 1.7 (Vicon Motion Systems Ltd., Oxford Metrics, UK) and trajectories were filtered using a fourth-order low-pass Butterworth filter with a cut off frequency of 12 Hz, determined following a residual analysis (4) and visual inspection of the data. A combination of lower body and low back models developed at the University of Western Australia (1-3) were adapted and used for kinematic modelling of the data. Lower limb anatomical and segment coordinate systems were defined according to the International Society of Biomechanics standards (5). As previously described (2), L5 defined the origin of the lumbar segment coordinate system. The y-axis was defined by a vector from L5 to L1 and the x-axis by the cross product of the y-axis and a line between the LLL and RLL markers. The cross product of the y- and x-axes defined the z-axis. An upper lumbar segment was created with an origin located midway between the L1 and L3 markers and a lower lumbar segment was defined with an origin located half-way between L5 and L3. Kinematics were calculated using a z-x-y (flexion-extension, abduction-adduction, internal-external rotation) Euler angle decomposition (6). Lumbar and pelvis angles were represented relative to a global laboratory coordinate system while the upper lumbar and lower lumbar angles were defined as the orientation of the segment relative to the pelvis. Kinematic data were time-normalised to 101 points using cubic spline interpolation and averaged over three trials for each individual.

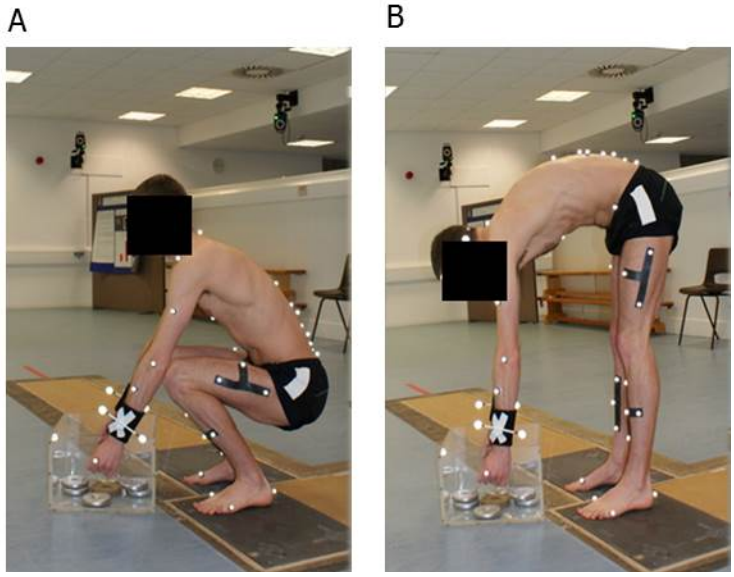

Figure S2. Lifting trial set up including an example of a squat (A) and stoop (B) lifting style.

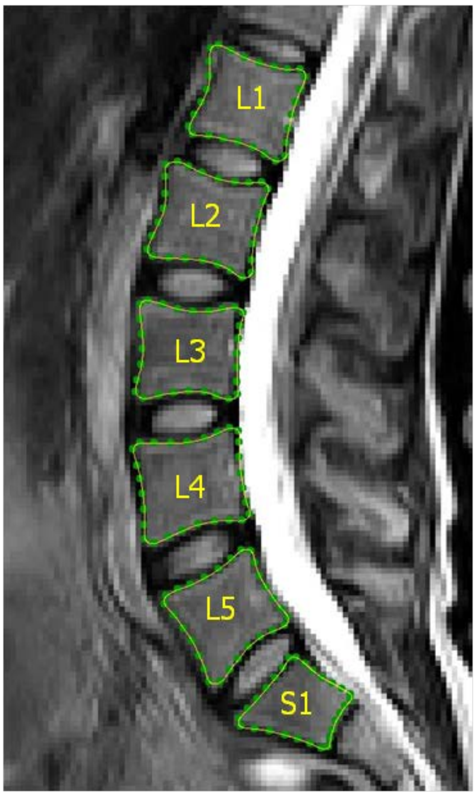

Figure S3. Sagittal MR image of the lumbar spine (L1-S1) annotated with a 168-point template for statistical shape modelling.

References

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