IN VIVO LOAD-RELAXATION OF THE TRUNK WITH PROLONGED FLEXION

Nima Toosizadeh, Babak Bazrgari, Brad Hendershot, Khoirul Muslim and Maury A. Nussbaum

Industrial & Systems Engineering, Virginia Tech, Blacksburg, VA, USA
email: nussbaum@vt.edu

INTRODUCTION

Many occupational tasks require prolonged trunk flexion, and such exposures are associated with an increased risk of low back disorders (LBDs). Understanding the mechanical and physiological consequences of flexion is complicated by time-dependent responses to sustained trunk postures. As such, an accurate assessment of load partitioning among passive and active components of the human trunk, such as in biomechanical models, requires a realistic representation of rate-dependent passive properties. While creep and load-relaxation responses of the spine under axial loading have been extensively investigated [1-3], viscoelastic responses to prolonged trunk flexion, in particular load-relaxation behaviors, have not been sufficiently described.

Hence, the main purpose of this study was to quantify the load-relaxation response of the human trunk during prolonged flexed postures. Load-relaxation responses of the trunk were measured *in vivo* at different trunk flexion angles and exposure durations. Measured trunk responses were then fit using a viscoelastic model. We hypothesized that the trunk would exhibit nonlinear viscoelastic responses to prolonged flexion and that these would depend on the trunk flexion angle.

METHODS

Twelve participants, gender balanced, with mean (SD) age of 22.7 (3.7) years and body mass of 67.8 (11.3) kg, participated in the study. Trunk postures were monitored using electromagnetic sensors (Xsens, Los Angeles, CA, USA) on the T10 and S1 spinous processes, and bipolar surface electrodes were used to monitor activity of the bilateral erector spinae, internal obliques, external obliques and rectus abdominis muscles. Using these, initial measurements were obtained of flexion-relaxation (FR) angles. Participants then stood in a metal frame that restrained pelvic and lower limb motions. Participants' trunks were constrained at the T8 level using a harness-rod assembly (Fig. 1) and their legs were raised to achieve trunk flexions of 33, 66, and 100% of their FR angle; this was held (with minimal muscle activity) for durations of 2 and 16 min. Temporal variation of passive trunk resistance (i.e., trunk load-relaxation) to the induced flexion was measured using an in-line load cell (Interface SM2000, Scottsdale, AZ, USA) located on the rod-harness assembly.

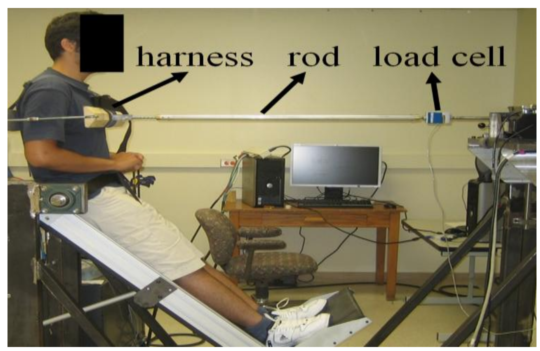

Figure 1: Experiment setup (33% of FR angle)

Load-relaxation responses of the trunk were modeled using a three-parameter model, based on Ponyting-Thomson's approach:

$$M(t) = \frac{\theta_0 k_2}{k_1 + k_2}\left(k_2 e^{-\left(\frac{k_1+k_2}{C}\right)t} + k_1\right)$$

where θ_0 is the initial angle, k_1 and c are torsional spring and damper components in parallel, and k_2 is an in-series torsional spring (Fig. 2). Passive moments, M(t), were calculated from measured forces and the vertical distance between the harness and S1. Model parameters were estimated for each trial (angle and duration) by minimizing least-squared errors in predicted moments. Mixed-factor analyses of variance (ANOVA) were used to assess the effects of gender, flexion angle, and duration on model parameters ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Measured load-relaxation behaviors (i.e., decreases in moments) were significantly affected by exposure duration (p=0.037) and flexion angle (p<0.01), but did not differ between genders (p=0.25). Mean (SD) trunk moments decreased following 2 min. of exposure at 33, 66, and 100% of FR by 2.2 (3.6), 2.6 (4.5), and 21.6 (21.9) Nm, respectively. Following 16 min. of exposure, the respective decreases were 6.8 (5.9), 11.6 (11), and 26.1 (16.3) Nm. For each participant and condition, the Ponyting-Thomson models fit the measured load-relaxation behaviors closely (average relative error = < 3%).

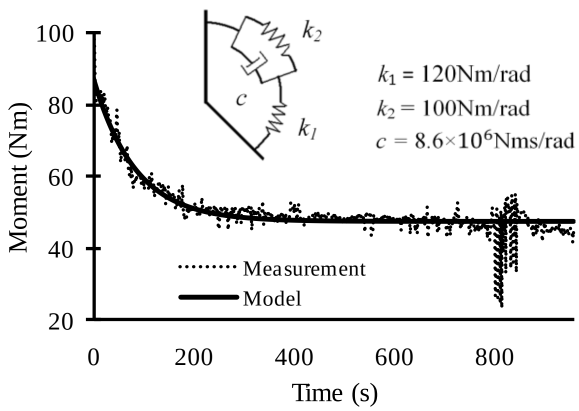

Figure 2: Sample results for measured and predicted passive trunk moment (angle = 100% of FR, duration = 16 min.).

Fitted model parameters indicated nonlinear viscoelastic behaviors during the sustained flexed postures. All three parameters were significantly (p<0.01) affected by flexion angle, with particularly large effects evident when flexion angle increased from 66 to 100% of FR (Fig. 3). Here, k_1 and c represent the time-dependent and k_2 the instantaneous responses to deformation. The larger values of k_1 and c at 100% of FR thus indicate a more pronounced load-relaxation response at this extreme flexion angle. No model parameters were affected by exposure duration (p>0.089), and these did not differ between genders (p>0.22). These findings suggest that a simple linear viscoelastic model can reasonably simulate trunk responses to prolonged flexion, but (as was anticipated) passive tissue responses are specific to flexion angle. The current experimental setup isolated the effects of trunk flexion angle and exposure duration independent of variation in gravitational loads and trunk muscle activity. Specified flexion angles were achieved by raising participants' legs, rather than by having them maintain forward flexion of the trunk. Any variability or potential confounding induced by muscle activity, inaccurate posture maintenance, or fatigue was thereby avoided.

CONCLUSIONS

Exposure to prolonged static trunk flexion is an important risk factor for occupational LBDs. The current work can facilitate a better understanding of how the load distribution among passive and active trunk components is altered during such exposures. Here, the angle-dependent, nonlinear, load-relaxation behavior of the human trunk was quantified. Future applications of these results to biomechanical models of the human trunk may provide better estimates of spinal loadings and stability under diverse occupational demands.

REFERENCES

1.Marta K, et al. *J Biomech* **39,** 1180-1190, 2005.
2.Holmes AD,et al. *Med Eng Phys* **18**,99-104, 1996.
3.Burns ML, et al. *J Biomech* **17**, 113-130, 1984.

ACKNOWLEDGEMENTS

This publication was supported by Cooperative Agreement Number R01-OH004089 from CDC-NIOSH. Its contents are solely the responsibility of authors and do not necessarily represent the official views of the CDC.

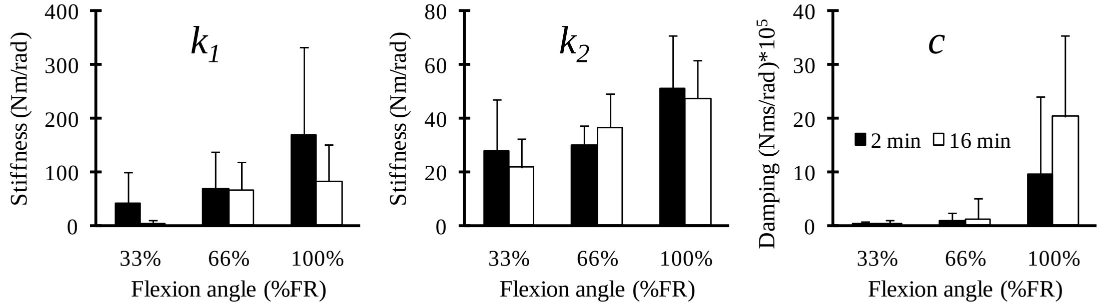

Figure 3: Summary of effects of flexion angle and duration on model parameters. Error bars are SD.