DYNAMIC RESPONSE OF THE TRUNK TO POSITION PERTURBATIONS - EFFECTS OF GENDER, PRELOAD, AND TRUNK ANGLE

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INTRODUCTION

Females are more likely to experience low back pain (LBP) and injury than males.[1] The reasons for this gender difference may relate to factors contributing to the control of spinal stability such as intrinsic muscle stiffness and paraspinal reflexes, i.e. effective trunk stiffness.[2] While no gender differences in effective trunk stiffness have been found following sudden force perturbations[3], this could be due to higher trunk flexion velocity, and thus larger reflexes, observed in females who had smaller trunk mass. In addition, other factors such as trunk extension preload and trunk flexion angle may influence effective trunk stiffness, and therefore spinal stability. In an effort to help understand gender differences in LBP, the goal of this study was to investigate the effects of gender, preload, and trunk angle on the dynamic response of the trunk to small position perturbations.

METHODS

Eight males (21.3±1.4 years, 73.4±6.7 kg) and eight females (23.6±7.3 years, 59.3±5.6 kg) were exposed to sudden anteriorly-directed trunk position perturbations. Participants stood in a custom metal frame (Fig. 1) restraining the pelvis and lower limbs, and were instructed to remain relaxed with their hands at their side and head facing forward. Three force preloads (0, 15, and 30 %effort) based on a maximum extension in upright posture were held, and legs were raised to three angles (0, 20, and 40 degrees) of trunk flexion. During all random conditions, twelve position perturbations were generated by a servomotor (Kollmorgen AKM53K, Radford, VA, USA) and transmitted to the trunk at the T8 level via a rigid harness-rod system (Fig 1). Each perturbation had a target amplitude of 10 mm and a peak velocity of 0.357 m/s.

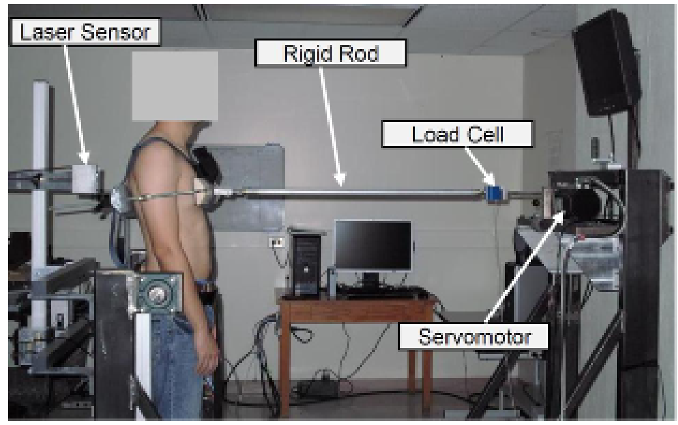

Figure 1. Experimental set-up.

Input motor displacement was measured with a high-accuracy encoder attached to the servomotor shaft, and trunk displacement was measured with a high-accuracy CCD laser displacement sensor (Keyence LK-G 150, Osaka, Japan) aimed at the midline of the dorsal trunk above the harness. Forces during the perturbations were measured using an in-line load cell (Interface SM2000, Scottsdale, AZ, USA) connecting the motor shaft to the harness-rod system. All data were sampled at 1000 Hz and similarly processed with 10 Hz low-pass Butterworth filters to avoid relative phase shifts.

The dynamic response of the trunk that we used as our dependent variable is the measured force when applying a position perturbation to the trunk. It is due to the combined effects of trunk stiffness, damping, and mass. To isolate the intrinsic response that contributes to the stability of the spine, the portion of the response due to accelerating trunk mass was removed, leaving only the measured force response due to stiffness and damping. Trunk stiffness, damping, and mass were estimated with a two degree-of-freedom (2-DOF) linear dynamic model (Fig. 2) representing the trunk and the harness-rod connecting device and using a system of second-order linear differential equations.

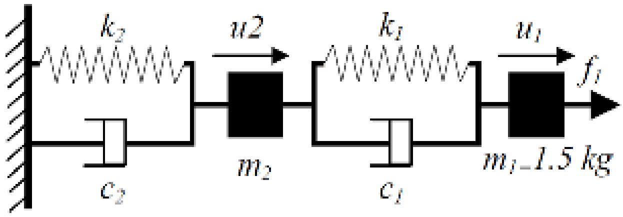

Figure 2. 2-DOF linear dynamic model. Mass (m), damping (c), and stiffness (k) of the harness-rod system and the trunk are represented by systems 1 and 2, respectively, and u and its derivatives represent displacement, velocity, and acceleration. Kinematics from both the motor encoder and laser sensor were model inputs.

Analyses involved the first ~50ms following perturbation onset so any force due to reflexes was not included. Parameter estimation was performed using a least-squares curve fit in MATLAB™ that varied the model parameters to minimize the differences between predicted and experimentally measured forces (MathWorks, Natick, MA, USA).

A 3-way ANOVA was conducted to determine the effects of gender, preload, and trunk angle on the estimated peak dynamic force response.

RESULTS

The model predicted experimentally measured forces with an average correlation of $r = 0.996$. Main effects indicated that the peak dynamic force response to trunk position perturbations (Figs. 3 and 4) was smaller ($p=0.008$) in females (64.2±5.8 N) than males (91.8±6.3 N), increased with preload ($p<0.001$), and increased with trunk angle ($p<0.001$).

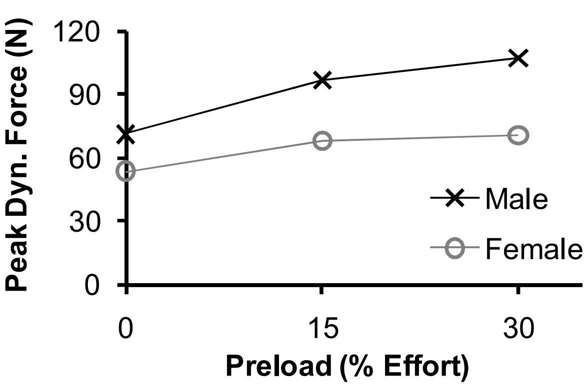

Figure 3. Peak dynamic force response vs. preload.

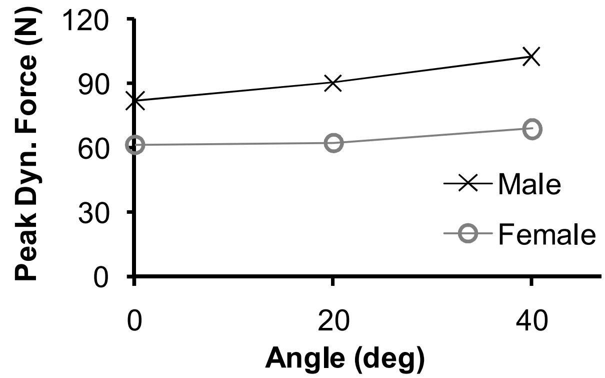

Figure 4. Peak dynamic force response vs. angle.

Interactions indicated that peak dynamic force increased more in males with increasing preload ($p<0.001$) and increasing trunk angle ($p=0.001$), and increased preloads eliminated any effect of trunk angle ($p=0.002$).

DISCUSSION AND CONCLUSIONS

Females exhibited a smaller dynamic force response than males following sudden trunk flexion position perturbations. This smaller response resulting from trunk stiffness and damping may be related to the increased rate of LBP and injury in females.[1] The dynamic response was also seen to increase with preload and trunk angle, and even more so in males than females. This gender difference could be because males have decreased joint laxity, as is seen in the knee,[4] or because they can achieve greater stiffness with their ability for active muscle contribution (strength). Therefore, the gender risk of LBP in females could be further pronounced in the workplace where tasks involve various carrying loads and postures.

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