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The Effect of Sitting Posture on Lumbar Spinal Loading

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Abstract:

Lower back pain inflicts millions of people worldwide, resulting in huge costs and loss of quality of life. Today, in the COVID19 pandemic, work is increasingly defined as sitting by a desk, often on non-ergonomic chairs. Research has shown a combination of sitting and non-typical posture to be a risk factor for lower back pain. This project aims to understand if that is because of different loading of the lumbar spinal vertebrae for different sitting postures. A static force analysis is done on three different sitting postures: habitual, neutral lumbo-pelvic angle, and a slump sitting case. The simplified model consists of three forces: joint contact force, erector spinae muscle force and the weights of body parts. Results show a clear relationship between the muscle force direction and the magnitude and direction of the joint contact force. The joint contact force was approx. 5% lower for the habitual case compared to the other two. The shear component of the joint contact force was found to be lowest for the habitual case, supporting the hypothesis that awkward postures lead to lower back pain by increasing transverse loading.

Introduction

Lower back pain is one of the most costly disorders among people and is the cause of massive discomfort to millions of people. Despite immense and thorough research in the area, a consensus on lower back pain cause is far from present [4]. Studies show that upper body form and spinal curvature changes while sitting and that prolonged sitting could be associated with increased risk of getting lower back pain, especially if the sitting is combined with awkward posture [3]. Before and increasingly during the COVID19 pandemic, people are finding themselves working from home using phones and laptops. The work is predominantly done by sitting on an office chair and by a desk for multiple hours daily. This project aims to understand the effect of bad sitting posture on the loading of the lumbar spine. Three different sitting postures are considered in the analysis to determine wether bad posture has an effect on magnitude and direction of the joint contact force (JCF) on the L4 vertebrae.

Methods

This project performed static force analysis on three different sitting postures. The data used is from measurements from Edmondston et al. shown in Figure 1. The three postures represent (a) an habitual case, (b) lumbo-pelvic neutral posture case and (c) slouched posture, often termed as 'slumped sitting'. The lumbo-pelvic neutral posture is where the pelvis is rotated so the thorax is positioned more naturally above it, similar to habitual standing posture.

The images of Figure 1 are used for setup of a simplified statics problem of the thorax, head, upper arm and forearm. Force and moment equilibrium is enforced:

$$\sum F_x = 0 \text{ , horizontal forces; } \sum F_y = 0 \text{ , vertical forces;} \quad (1)$$

$$\sum M_o = 0 \text{ , moments about point o} \quad (2)$$

The free body diagram is cut at L4/L5 and along the lower part of the thorax, above the belt on Figure 1. Origin of coordinate system is the L4/5 lumbar spine joint, from where moments are calculated, assuming it freely rotates in the sagittal plane. Figure 2 shows the resulting free body diagram. The system consists of three kinds of forces: the spinal joint contact force, the erector spinae back muscle force and the weights of the different body parts. We assume abdominal muscles are not active, which is consistent with research [2]. The unknown variables in this analysis are the magnitudes and directions of the joint contact force and the erector spinae muscle force. Since this static system is indeterminate, another assumption has to be made for it to be solved. The direction of the erector spinae muscle force is therefore added as an assumed quantity, measured positive from horizontal in clockwise direction based on Figure 1 and approximated by measurement of Figure 1 (a)-(c).

The mass properties of the body parts are assumed the same for all cases, numerical values can be seen in Table 1. The locations of center of mass for the force diagram in Figure 1 are retrieved by image processing using ImageJ. A body part is drawn and outlined by threshold, filled in with black and its center of mass is calculated. The thorax and abdomen mass distribution is assumed uniform. A pixel to length scale is approximated using the subjects ear, where a male human's ear is on average 6.5 cm in length. The distance from L4/5 to the erector spinae muscle is assumed 5 cm, and the distance vector is assumed to always be perpendicular to the force vector [5].

The resulting data about mass and their respective locations is loaded into MATLAB where the system of equations is solved.

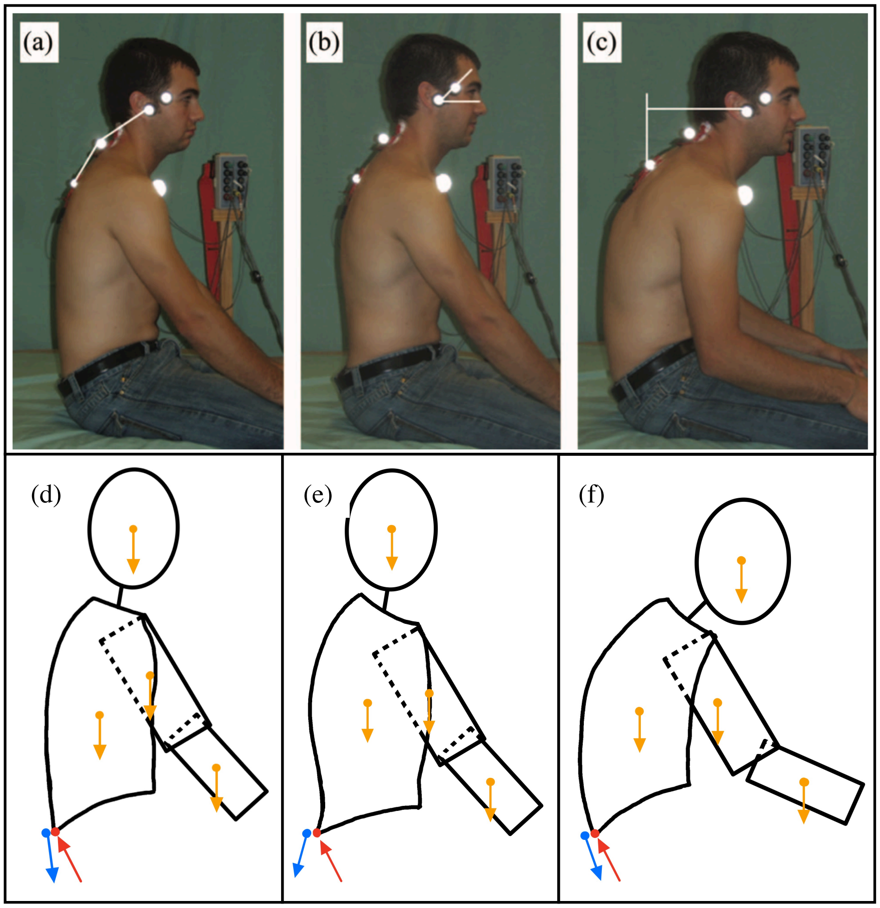

Figure 1. Posture data copied from Edmondston et al. [1] for habitual posture (a), neutral lumbo-pelvic angle (b), and slump sitting (c), and the free body diagram models for each case respectively (d), (e) and (f). The forces shown are joint contact forces (red), erector spinae muscle forces (blue) and the weights of body parts (orange).

Table 1. Mass data for body parts used for static analysis. Retrieved from Bastel et. al [5].

Body Part	Mass (% of total body mass)
Thorax and Abdomen	35.5
Upper Arms	2.8 x 2 = 5.6
Forearms and Hands	2.2 x 2 = 4.4
Head	8.1

Results

For the cases shown in Figure 1, the results are shown in Table 2. Same joint contact force was attained for cases (b) and (c). Figure 2 shows the effect of different muscle force directions on the magnitude and direction of the JCF. Note that the direction of the JCF is linearly dependent on the muscle direction and is independent of posture case. The erector spinae force magnitude was found to be constant for all directions.

Joint contact force magnitude increases linearly with the total body mass. Figure 3 shows the the effect of muscle force direction on the magnitude of the transverse, often termed shear, component of the joint contact force.

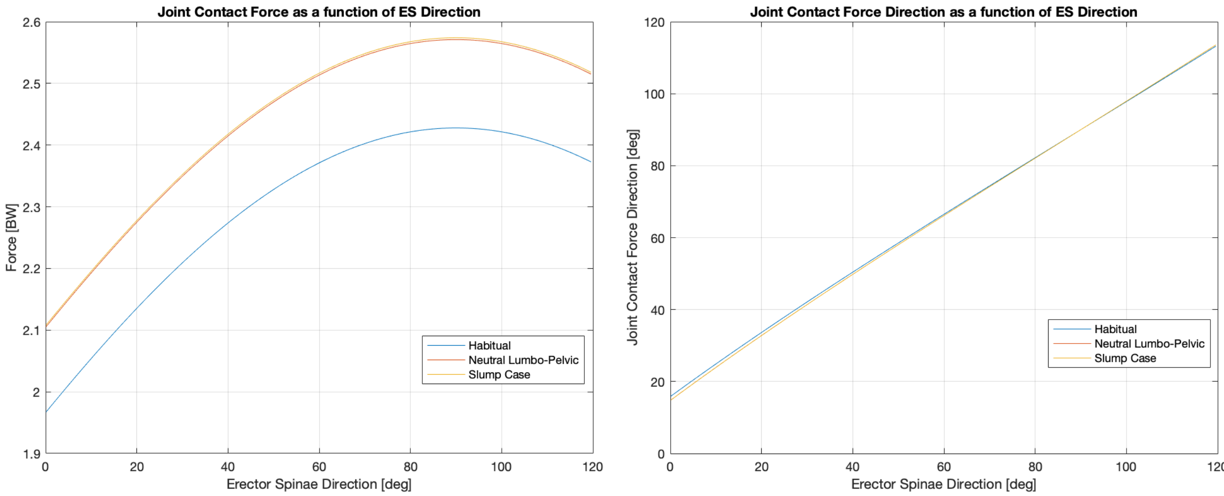

Figure 2. The resulting joint contact force magnitude (left) and direction (right) as a function of erector spinae muscle force direction.

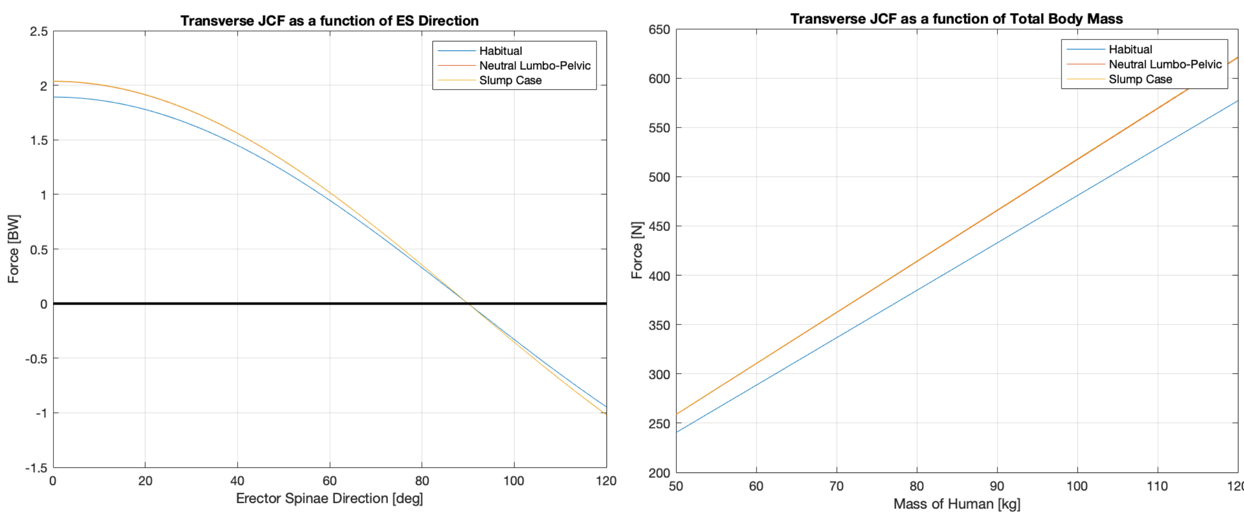

Figure 3. The transverse joint contact force magnitude as a function of erector spinae muscle force direction (left) and total body mass (right).

Discussion

Analysis of the three different postures shows the joint contact force does not differ considerably between them. The habitual case has about 5% lower JCF, see Table 2. The analysis reveals the direction of the erector spinae force highly impacts the size and direction of the joint contact force. Figure 2 show up to a 25% increase in force based on muscle force direction. Figure 2 additionally shows that for this model, the direction of JCF is independent of posture.

Table 2. Results for JCF and ES force from static analysis.

Parameter Value	(a) Habitual Case	(b) Neutral L-P Case	(c) Slump Case
Joint Contact Force Magnitude [%BW]	2.42	2.55	2.55
Joint Contact Force Direction [deg]	82.2	105.9	74.1
Erector Spinae Force Magnitude [% BW]	1.89	2.04	2.04
Erector Spinae Force Direction [deg]	80	110	70

Literature is inconsistent on the relationship between sitting and lower back pain, however, there is evidence that sitting combined with awkward posture may be a risk factor [3]. That would be consistent with this analysis, showing a relationship between the lumbar spine angle and the size of JCF. A possible explanation of causality between awkward postures and lower back pain is increased transverse loading of lumbar spinal joints, more specifically the intervertebral disc. By response to transverse load, the disc could, over time, pressure nerves in the spinal cord and thus cause back pain. Figure 3 shows how the habitual position, with muscle force angle close to 90 degrees, results in the lowest transverse loading, which is consistent with that hypothesis. This analysis is also in agreement with other studies relating body weight and increased spinal loading, Figure 3 showing specifically increased transverse component of the JCF for increased body mass.

This analysis is highly simplified, ignoring the complex structure of the lumbar spine vertebrae or the effects of abdominal muscles for back extension, which are areas of interest for future work. Next steps could include constricting the muscle force magnitude based on muscle stress, especially since EMG studies show similar muscle activity for all sitting postures [2], while adding other stabilizing forces into the model from ligaments and facet joints.

Despite simplifications, this analysis has given insight into the JCF, revealing it may not be its size that matters, but rather its direction, and that it's highly dependent on the directions of other acting forces.

References

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