The Effects of Sex and Handedness on Lumbar Kinetics During Asymmetric Lifting Tasks: A Pilot Study

Jazmin Cruz, Ivan Aguilar, and James Yang*

Human-Centric Design Research Lab, Department of Mechanical Engineering, Texas Tech University, Lubbock, TX 79409, USA, *Corresponding author: james.yang@ttu.edu

Abstract

Manual material handling such as box lifting is a very common task that is used in the industrial and medical fields. It is widely accepted that manual lifting can potentially lead to low back injury. Asymmetric lifting, which involves twisting of the trunk, shifts trunk muscle activation and can increase the lower back loading on the spine thus further increasing the likelihood of injury. Other researchers have explored asymmetric lifting but have not considered the effects of handedness. Sex has also been considered as a factor related to low back injury, but majority of research work include only male subjects in literature. This work aims to examine the effects of sex, handedness, box load, and box origin on the maximum lumbar flexion/extension L5-S1 joint moments generated during two-handed box lifting so that safer lifting recommendations can be made for those tasks. Eight participants (sex: 4 women, 4 men; age: 28.62 ± 4.53 years; height: 170.00 ± 7.45 cm; body mass: 72.36 ± 8.97 kg; handedness: 4 left-dominant, 4 right-dominant) performed two-handed box lifts with five different box origins (two left lifts, one sagittally symmetric lift, and two right lifts) and three different box weights (1.20 kg, 5.74 kg, 10.27 kg). Motion data was collected using a motion capture system and force plates. There were no clear trends for the effect of sex, but our results suggest that individuals should lift from their dominant-hand side when performing asymmetric two-handed lifting tasks. Future work which will incorporate the use multiscale modeling (musculoskeletal modeling and finite element modeling) to perform a deeper analysis of spine biomechanics during these lifts at the muscle and tissue levels, respectively.

Keywords: Manual Material Handling; Lumber Spine; Low Back Pain; Asymmetric Lifting.

Introduction

Low back pain is a common symptom experienced by all age groups. It is the leading cause of disability across the globe and accounts for more lost workdays than any other occupational musculoskeletal condition (Hartvigsen et al., 2018). In addition to physical cost of low back pain, the USA spends more than $100 billion on low back pain management (Katz et al., 2006). A better understanding of low back pain is needed so that prevention may be possible.

It is believed that manual material handling may have some direct relationship with low back pain as it is the most common musculoskeletal disorder experienced by workers performing heavy physical work and lifting tasks (Marras, 2000). For example, it has been shown that individuals triggered an episode of low back pain shortly after performing awkwardly positioned manual tasks, heavy load manual tasks, or a combination of the two (Steffens et al., 2015). This connection has prompted further exploration of the causality of low back pain by other researchers who have looked at factors such as foot placement (Delise et al., 1996), box weight (Potvin et al., 2021; Song & Qu, 2014; Weston et al., 2020), and more.

Differences in lifting biomechanics between the sexes have been identified with regards to coordination (Lindbeck & Kjellberg, 2001) and lumbar spinal loading (Firouzabadi et al., 2021). Furthermore, the peak risk of low back pain for men and women occurs at different ages such as 40 and 60 years old, respectively (Marras, 2000). Over the years, researchers have taken sex into account but majority of these works include only male participants (Beaucage-Gauvreau et al., 2019; Delise et al., 1996; Ghofrani et al., 2021). It is critically important to include women in low back pain research studies as low back pain is more common in women than in men (Hartvigsen et al., 2018).

In addition to sex, handedness has yet to be thoroughly explored in lifting research. One study identified that spine compression and lateral shear increased at double the rate during asymmetric lifts beginning from the left side than the same lift from the right side (Marras & Davis, 1998). Intuition leads us to believe that humans naturally favor one side over the other, but little research has considered handedness during lifting (Butler et al., 2009; Weston et al., 2020).

The objective of this work is to examine the effects of sex, handedness, box load, and box origin on the maximum lumbar flexion/extension L5-S1 joint moments generated during box lifting as producing a higher low back joint moment is known to indicate low back pain risk (Hoozemans et al., 2008; Kingma et al., 2010). We hypothesize that women will experience higher maximum lumbar joint moment across all loading conditions. Additionally, we expect that individuals will experience higher maximum lumbar joint moment when lifting from their dominant side.

Methods

OpenSim Lifting Model

The previously validated lifting full-body (LFB) OpenSim model was used in this work (Beaucage-Gauvreau et al., 2019). It contains 30 rigid body segments, 29 degrees-of-freedom, and 238 musculotendon actuators as shown in Figure 1. The model treats the trunk and head as a rigid body, but contains spherical joints at the T12/L1, L1/L2, L2/L3, L4/L5, and L5/S1 intervertebral joints within the spine.

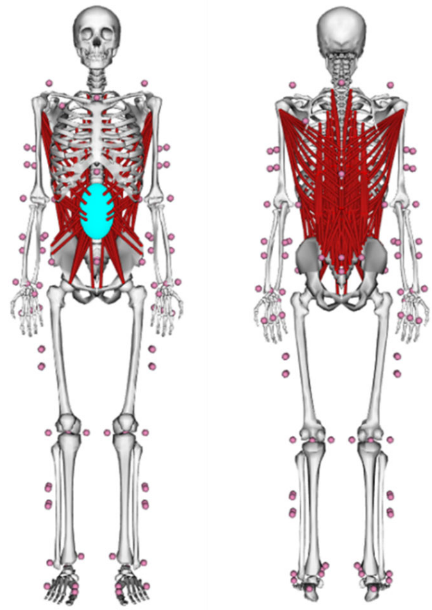

Figure 1: Lifting full-body (LFB) OpenSim Model

Lifting Protocol

The lifting protocol consisted of five box origins as shown in Figure 2. The milk crate was lifted with three loading conditions: unloaded (1.20 kg), 10 lbs (5.74 kg), and 20 lbs (10.27 kg). Each trial began in T-Pose and ended the lift with the milk crate at hip level while facing forward. Participants performed 30 lifts that included two repetitions of all box origins under all loading conditions in a randomized order. Subjects were allowed to lift in whatever way felt most natural to them but were instructed to keep one foot on each force plate throughout each trial. Figure 3 shows a subject mid-lift where they are turning to their right-hand side to pick up the box from the P5 box origin.

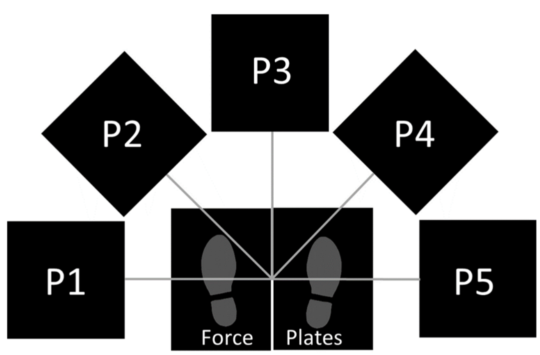

Figure 2: Box Origins

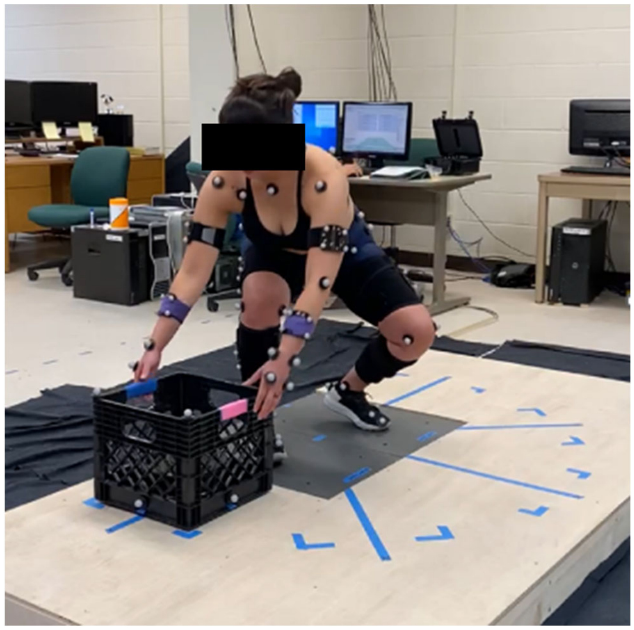

Figure 3: Subject Lifting Box from P5

Experimental Data Collection and Processing

Eight subjects participated in this study (sex: 4 women, 4 men; age: 28.62 ± 4.53 years; height: 170.00 ± 7.45 cm; body mass: 72.36 ± 8.97 kg; handedness: 4 left-dominant, 4 right-dominant). This study was approved by the Institutional Review Board of Texas Tech University (IRB2017-406) and participants signed informed consent forms. Participants had reflective markers and marker clusters placed throughout the whole body as shown on the LFB OpenSim model and Figure 3. Motion data was collected using an 8-camera motion analysis system (Motion Analysis Corp., Santa Rosa, California, USA) and two force plates (Bertec Corporation, Columbus, OH, USA) at 100 Hz and 2000 Hz, respectively. Kinematic and kinetic data were filtered using a Butterworth filter with a cutoff frequency of 6 Hz.

OpenSim Simulation Workflow

This study closely follows the workflow methodology described in a recent publication (Akhavanfar et al., 2022). First the LFB model is scaled to match each participant by using their static T-Pose motion file. Inverse kinematics is performed using the motion files of the tasks with the newly scaled model. Lastly, inverse dynamics is performed using the inverse kinematic results and filtered force plate data. The box load was applied as a downwards external force to the mid-point between the second and fifth metacarpal bones, i.e., half of the box load was applied to each hand. Maximum joint moments at the L5-S1 intervertebral level were extracted for flexion/extension for all lifting scenarios and were normalized by participant mass.

Results

The results for the overall group, left-handed/right-handed groups, and male/female groups can be seen in Figures 4, 5, and 6. Tabular versions of these groups can be seen in Tables 1, 2, and 3.

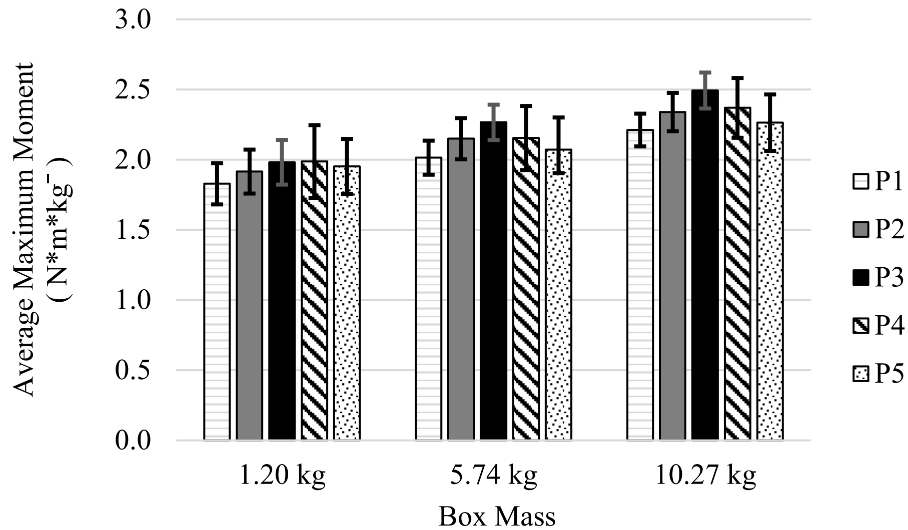

Figure 4: Average Maximum Flexion/Extension Moment at L5-S1

Table 1. Average Maximum Flexion/Extension Moment at L5-S1 Tabular Results (Average ± 1 SD in N*m*kg⁻)

	1.20 kg	5.74 kg	10.27 kg
P1	1.83 ± 0.15	2.01 ± 0.12	2.21 ± 0.12
P2	1.92 ± 0.16	2.15 ± 0.15	2.34 ± 0.14
P3	1.98 ± 0.16	2.27 ± 0.13	2.49 ± 0.13
P4	1.99 ± 0.26	2.15 ± 0.23	2.37 ± 0.21
P5	1.95 ± 0.20	2.07 ± 0.17	2.26 ± 0.20

Table 2. Left-Handed and Right-Handed Average Maximum Flexion/Extension Moment at L5-S1 Tabular Results (Average ± 1 SD in N*m*kg⁻)

	Left-Handed			Right-Handed		
	1.20 kg	5.74 kg	10.27 kg	1.20 kg	5.74 kg	10.27 kg
P1	1.82 ± 0.16	2.05 ± 0.12	2.15 ± 0.09	1.84 ± 0.15	1.98 ± 0.12	2.28 ± 0.11
P2	1.95 ± 0.17	2.16 ± 0.13	2.36 ± 0.15	1.88 ± 0.14	2.14 ± 0.17	2.32 ± 0.13
P3	2.01 ± 0.15	2.34 ± 0.05	2.48 ± 0.17	1.95 ± 0.17	2.19 ± 0.13	2.51 ± 0.08
P4	2.08 ± 0.22	2.33 ± 0.13	2.44 ± 0.15	1.89 ± 0.27	1.98 ± 0.16	2.30 ± 0.26
P5	2.05 ± 0.17	2.15 ± 0.20	2.30 ± 0.23	1.85 ± 0.17	2.00 ± 0.09	2.23 ± 0.17

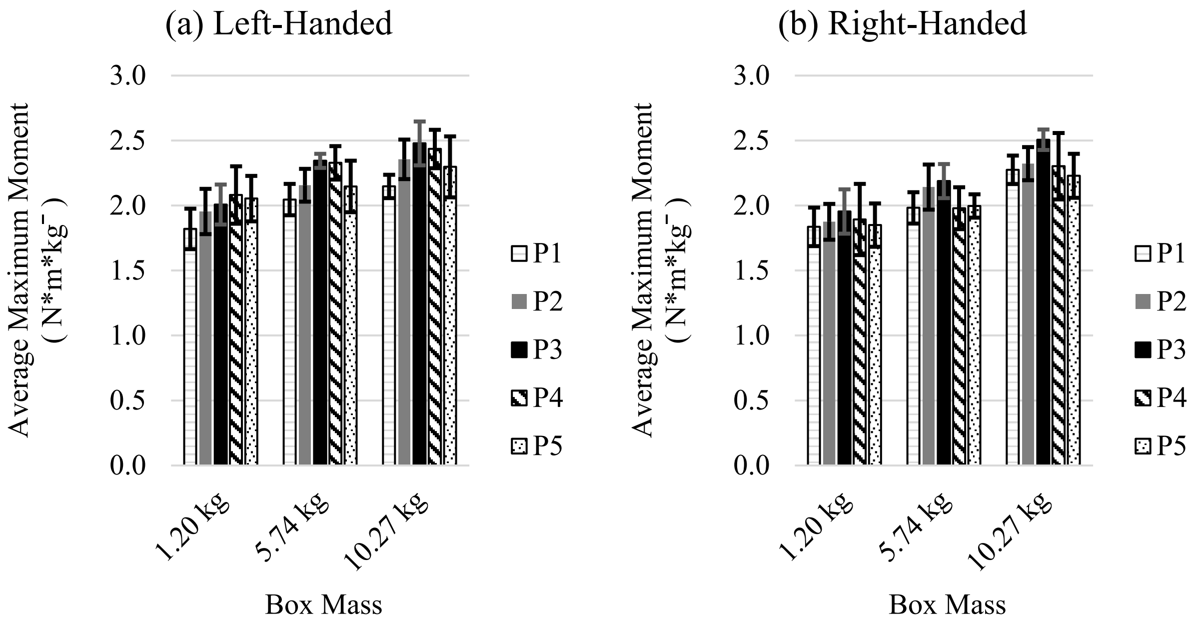

Figure 5: Average Maximum Flexion/Extension Moment at L5-S1 for (a) Left-Handed and (b) Right-Handed Groups

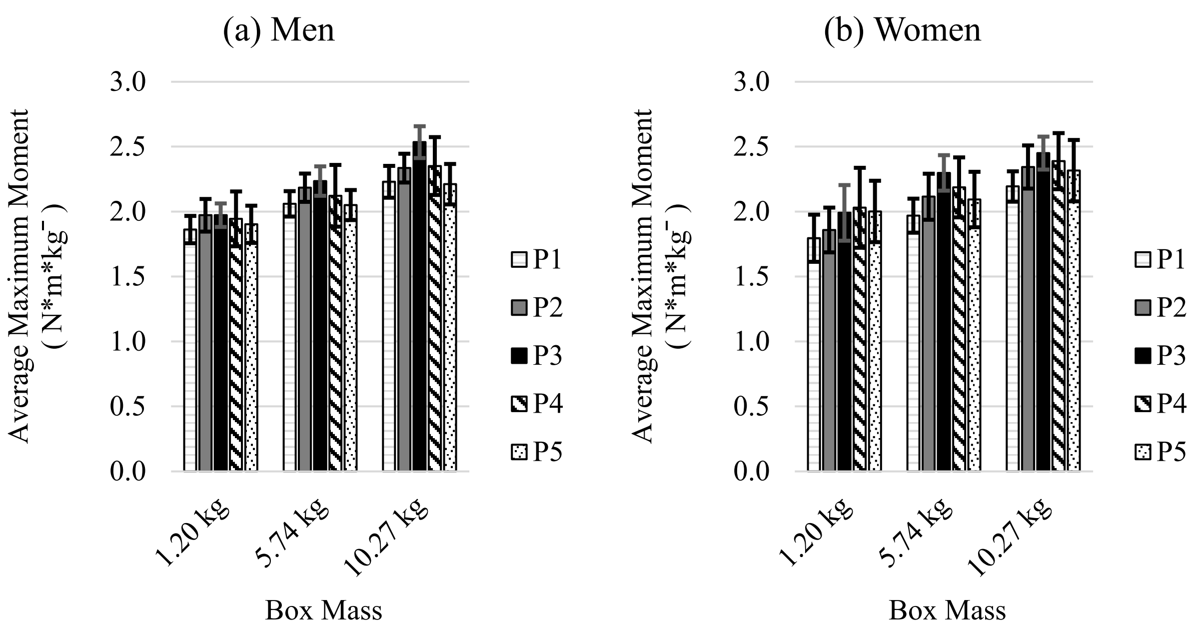

Figure 6: Average Maximum Flexion/Extension Moment at L5-S1 for (a) Male and (b) Female Groups

Table 3. Male and Female Average Maximum Flexion/Extension Moment at L5-S1 Tabular Results (Average ± 1 SD in N*m*kg^{-})

	Male			Female		
	1.20 kg	5.74 kg	10.27 kg	1.20 kg	5.74 kg	10.27 kg
P1	1.86 ± 0.11	2.06 ± 0.10	2.23 ± 0.12	1.80 ± 0.18	1.97 ± 0.13	2.19 ± 0.12
P2	1.97 ± 0.13	2.18 ± 0.11	2.34 ± 0.11	1.86 ± 0.17	2.11 ± 0.18	2.34 ± 0.17
P3	1.97 ± 0.09	2.23 ± 0.11	2.53 ± 0.12	1.99 ± 0.21	2.30 ± 0.14	2.45 ± 0.13
P4	1.94 ± 0.21	2.12 ± 0.24	2.35 ± 0.22	2.03 ± 0.31	2.19 ± 0.23	2.39 ± 0.22
P5	1.90 ± 0.14	2.05 ± 0.12	2.21 ± 0.16	2.00 ± 0.24	2.09 ± 0.21	2.32 ± 0.24

Discussion and Conclusions

Box Mass

The effect of box mass on lumbar moment across each lifting scenario can be seen in

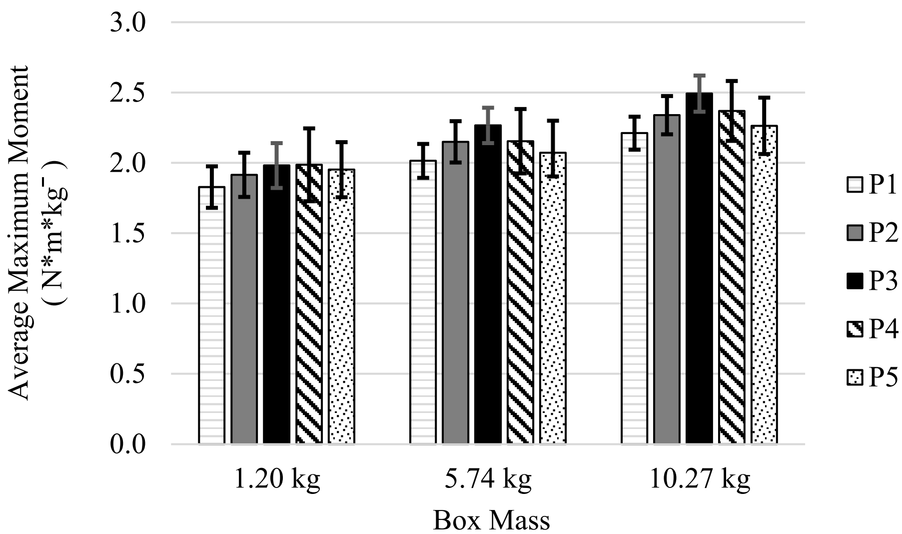

Figure 4. In general, the lumbar moment increases as the box mass increases, which is consistent with what has been found in the literature (Song & Qu, 2014).

Box Origin

The box origin of the lift had an influence on the lumbar moment. Figure 4 shows that the greatest flexion moment occurred when lifting from P3, while the lower flexion moments occurred when lifting from P1 and P5. This is an interesting result as it was expected that asymmetric lifts should be the most dangerous. This work did not take lateral bending or rotational moments into account, which have been known to increase during heavy asymmetric lifting tasks (Kim & Zhang, 2017). It is possible that the combination of increased lateral bending and rotational moment could result in higher risk of low back pain and should be explored in future work to assess low back pain risk.

Handedness

Our original hypothesis was that individuals will experience higher maximum lumbar joint moment when lifting from their dominant side, however, Figure 5 shows the opposite trend. Across all mass conditions, left-handed individuals experienced higher lumbar moments during right side lifts than they did during the reflected left side lifts, i.e. P1 vs P5 and P2 vs P4. Similarly, right-handed individuals experienced higher lumbar moments during left side lifts than right sided lifts, except for the 1.20 kg condition. This finding suggests that individuals should lift from their dominant-hand side if they want to reduce their lumbar flexion moment and, in turn, reduce their risk for low back pain.

Sex

We expected women to experience higher lumbar moments than their male counterparts. However, as shown in Figure 6, there does not appear to be any large differences in moments between the sexes. This suggests that men and women can be treated equally when lifting under the conditions tested in this work.

Limitations

This study is not without limitations. First, only eight participants were analyzed which prevented a robust statistical analysis to be performed. This small sample size provides preliminary trends, but a thorough statistical analysis with a larger sample set would further support the current conclusions. Our future work includes the data processing of 12 additional subjects. With a larger data set, an analysis of variance (ANOVA) can be calculated to identify the statistical significance of sex, handedness, box mass, and box origin on the average maximum flexion/extension moment. Second, the study only explored the flexion/extension moment and has not yet investigated the lateral bending or rotational moments at the L5-S1 level. Future work will include these moments.

Conclusions

This work aimed to assess the effects of sex, handedness, box mass, and box origin on the maximum lumbar flexion/extension joint moments during two-handed lifting tasks. There were no clear trends for the effect of sex, but our results suggest that individuals should lift from their dominant-hand side when performing asymmetric two-handed lifting tasks. This preliminary work serves as a starting point in identifying how sex and handedness affect underlying biomechanics of lifting. A better understanding of these tasks can lead to safer lifting recommendations to individuals that work in manual material handling occupations. Besides including a larger sample set, future work will incorporate the use of musculoskeletal modeling and finite element modeling to perform a deeper analysis of spine biomechanics during these lifts at the muscle and tissue levels, respectively.

Acknowledgments

We would like to thank Brandon Cruz and Juan Baus for their help with data collection for this work. This work was partially funded by National Science Foundation CBET #2014278.

References

1. Akhavanfar, M., Uchida, T. K., Clouthier, A. L., & Graham, R. B. (2022). Sharing the load: modeling loads in OpenSim to simulate two-handed lifting. *Multibody System Dynamics*, 213–234. https://doi.org/10.1007/s11044-021-09808-7
2. Beaucage-Gauvreau, E., Robertson, W. S. P., Brandon, S. C. E., Fraser, R., Freeman, B. J. C., Graham, R. B., Thewlis, D., & Jones, C. F. (2019). Validation of an OpenSim full-body model with detailed lumbar spine for estimating lower lumbar spine loads during symmetric and asymmetric lifting tasks. *Computer Methods in Biomechanics and Biomedical Engineering*, *22*(5), 451–464. https://doi.org/10.1080/10255842.2018.1564819
3. Butler, H. L., Hubley-Kozey, C. L., & Kozey, J. W. (2009). Activation amplitude patterns do not change for back muscles but are altered for abdominal muscles between dominant and non-dominant hands during one-handed lifts. *European Journal of Applied Physiology*, *106*(1), 95–104. https://doi.org/10.1007/S00421-009-0994-9
4. Delise, A., Gagnon, M., & Desjardins, P. (1996). Load Acceleration and Footstep Strategies in Asymmetrical Lifting and Lowering. *International Journal of Occupational Safety and Ergonomics*, *2*(3), 185–195. https://doi.org/10.1080/10803548.1996.11076347
5. Firouzabadi, A., Arjmand, N., Pan, F., Zander, T., & Schmidt, H. (2021). Sex-Dependent Estimation of Spinal Loads During Static Manual Material Handling Activities—Combined in vivo and in silico Analyses. *Frontiers in Bioengineering and Biotechnology*, *9*, 1030. https://doi.org/10.3389/fbioe.2021.750862
6. Ghofrani, M., Soleimanifar, M., & Talebian, S. (2021). Control of trunk muscles activity while manual material handling symmetrically and asymmetrically, Based on Motor control strategy. *Pakistan Journal of Medical and Health Sciences*, *15*(6), 1736–1740. https://doi.org/10.53350/pjmhs211561736
7. Hartvigsen, J., Hancock, M. J., Kongsted, A., Louw, Q., Ferreira, M. L., Genevay, S., Hoy, D., Karppinen, J., Pransky, G., Sieper, J., Smeets, R. J., Underwood, M., Buchbinder, R., Cherkin, D., Foster, N. E., Maher, C. G., van Tulder, M., Anema, J. R., Chou, R., … Woolf, A. (2018). What low back pain is and why we need to pay attention. In *The Lancet* (Vol. 391, Issue 10137, pp. 2356–2367). https://doi.org/10.1016/S0140-6736(18)30480-X
8. Hoozemans, M. J. M., Kingma, I., de Vries, W., & van Dieën, J. (2008). Effect of lifting height and load mass on low back loading. *Ergonomics*, *51*(7), 1053–1063. https://doi.org/10.1080/00140130801958642
9. Katz, J. N., Disorders, L. D., Pain, L., & Factors, S. (2006). Lumbar disc disorders and low-back pain: socioeconomic factors and consequences. *The Journal of Bone and Joint Surgery. American Volume*, *88 Suppl 2*, 21–24. https://doi.org/10.2106/JBJS.E.01273
10. Kim, H. K., & Zhang, Y. (2017). Estimation of lumbar spinal loading and trunk muscle forces during asymmetric lifting tasks: application of whole-body musculoskeletal modelling in OpenSim. *Ergonomics*, *60*(4), 563–576. https://doi.org/10.1080/00140139.2016.1191679
11. Kingma, I., Faber, G. S., & van Dieën, J. H. (2010). How to lift a box that is too large to fit between the knees. *Ergonomics*, *53*(10), 1228–1238. https://doi.org/10.1080/00140139.2010.512983

12. Lindbeck, L., & Kjellberg, K. (2001). Gender differences in lifting technique. *Ergonomics*, *44*(2), 202–214. https://doi.org/10.1080/00140130120142
13. Marras, W. S. (2000). Occupational low back disorder causation and control. *Ergonomics*, *43*(7), 880–902. https://doi.org/10.1080/001401300409080
14. Marras, W. S., & Davis, K. G. (1998). Spine loading during asymmetric lifting using one versus two hands. *Ergonomics*, *41*(6), 817–834. https://doi.org/10.1080/001401398186667
15. Potvin, J. R., Ciriello, V. M., Snook, S. H., Maynard, W. S., & Brogmus, G. E. (2021). The Liberty Mutual manual materials handling (LM-MMH) equations. *Ergonomics*, *0*(0), 1–17. https://doi.org/10.1080/00140139.2021.1891297
16. Song, J., & Qu, X. (2014). Effects of age and its interaction with task parameters on lifting biomechanics. *Ergonomics*, *57*(5), 653–668. https://doi.org/10.1080/00140139.2014.897376
17. Steffens, D., Ferreira, M. L., Latimer, J., Ferreira, P. H., Koes, B. W., Blyth, F., Li, Q., & Maher, C. G. (2015). What triggers an episode of acute low back pain? A case-crossover study. *Arthritis Care and Research*, *67*(3), 403–410. https://doi.org/10.1002/ACR.22533/ABSTRACT
18. Weston, E. B., Aurand, A. M., Dufour, J. S., Knapik, G. G., & Marras, W. S. (2020). One versus two-handed lifting and lowering: lumbar spine loads and recommended one-handed limits protecting the lower back. *Ergonomics*, *63*(4), 505–521. https://doi.org/10.1080/00140139.2020.1727023