Title: Trunk posture for the manual material handling of beer kegs

The paper presents a quantitative assessment of trunk postures in workers lifting kegs at a craft brewery, using an inertial measurement unit (IMU)-based kinematic measurement system. Further, the paper presents the results obtained from a LiFFT cumulative damage tool which was used to evaluate the task.

I appreciate that the authors conducted the study in a real working environment, and that they offer recommendations on how to improve that environment. However, there are several issues I think should be addressed in order for the paper to reach its full potential.

I apologize to the authors that I was not a reviewer on the first draft of the paper, so my comments are new to you. In my comments I will try both to address ideas for directions that the paper could take, and to provide some clarifications. I also suggest some references that I think could help you in both respects; please choose what you think is relevant.

**Main issues:**

1. When a worker is also lifting a load estimating load on the back just form trunk posture is very difficult to do. A comment on this subject in the first review led you to adapt your method, adding LiFFT cumulative damage tool analysis to your research. Yet, it seems that you have not changed your paper’s title, introduction or abstract, in order to account for this.

2. Furthermore, it seems that you are still focusing mainly on the trunk postures aspect, and not on the evaluation of injury risks for the workers - I think the latter is the more important issue.

You could use tools like those recommended by the first reviewer. However, if you want to make it more specific, you could try using the IMU to do inverse dynamics (exemplified by the following two papers):

G.S. Faber, C.C. Chang, I. Kingma, J.T. Dennerlein, J.H. van Dieën, Estimating 3D L5/S1 moments and ground reaction forces during trunk bending using a full-body ambulatory inertial motion capture system. *Journal of Biomechanics* 49 (2016)

Validation of a wearable system for 3D ambulatory L5/S1 moment assessment

during manual lifting using instrumented shoes and an inertial sensor

suit, G.S. Faber, I. Kingma, C.C. Chang, J.T. Dennerlein, J.H. van Dieën, *Journal of Biomechanics 2020*

**Specific Comments**

* To make it easier for you to find what my comment refers to, I have added line numbers to your document (starting from 1 on every new page).

1. P3, line 28: What is the height of the pallet and was this taken into account?

2. P3, line 29: “The vertical rail height of the roller conveyor was 169 cm from the floor.” This seems to be very high. Your pictures indicate that that the roller conveyor is at +/- 90 cm - please mark where this measurement is on the picture.

2. P3, lines 8 and 33: I am not sure that the numbers add up. How many people are working at this work station at any one time? If “[A]t peak efficiency, the kegging line throughput (clean and fill) varied from 144 to 160 half-barrel kegs per hour”, this means an 8-hour shift = 1,280. So, for 600 there should be a minimum of two people working together. Please explain this in the manuscript.

3. P5, line 12: If I understand correctly, each worker did 32 high and 32 low lifts. It would be nice to also see this in the figures for the trunk angle during the tack (adding standard deviation, not just the average).

4. P5, lines 31-33: It is not clear how you define these angles. What are they relative to: a global reference frame, or maybe the hips? More written explanation, and possibly figures, would help here - maybe in an appendix? How and why do you define ‘awkward postures’ (add a reference)?

5. P5, Table 1: Min. mass is 88.9 and max. mass is 78.8 - is this right?

6. P6, Table 1: Is ankle height measured with or without shoes?

7. P6, Table 2: The table name is not correct, because the table shows more than mean angles. Also, in many cases the larger number is in the minimum column, and the smaller value is in the maximum column. What is the mean angle, and how do you calculate it (what is the interval)? Please explain further why this is important (if I have understood correctly, I do not think it is that important, as it is a proxy for the average load, whereas the bigger factor is the peak force during the cycle).

8. P7: Are these figures for a single lift, or are they a mean of all the lifts? How different are data for one worker from data for another? What is the accuracy of your system in angles (this should be in the method section)?

9. P8, line 8: From your pictures, it seems that when a keg is hard to reach the worker pulls and tips it toward him before lifting. How did you model the force applied by the worker in such a case? Or, did you always assume the keg mass\* gravity (mg)?

9. P8, line 12-13: “The present study observed 64 lifts, which equates to 324 lifts per shift” - how did you get to this number? How long did it take each of the workers to perform these tasks?

(64\*8=512)

10. P8: “For example, according to LiFFT, a worker who lifts an empty keg 324 times with a peak moment of 60 ft lbs (81.3 Nm)…” - the torque value is reasonable, according to recently published studies of similar tasks.

*For moments*

Yaar Harari, Avital Bechar, Raziel Riemer 2020 Workers’ biomechanical loads and kinematics during multiple-task manual material handling, applied ergonomics

*For moments and lever arm*

Yaar Harari, Raziel Riemer, Avital Bechar 2019 Differences in spinal moments, kinematics and pace during single-task and combined manual material handling jobs. Applied ergonomics

It would be helpful to know how you calculated these numbers. How did you obtain the lever arm and the load, and what was the variability of these between different workers? You should be able to obtain the above from the Xsens system, or via the forward kinematics method (i.e. using angles from the Xsens system and the segment lengths as measured).

P9, line 15: Again, I would like to know how you calculated these numbers. Please write 126ft.lb in Nm also.

P10, lines 11-22: I like this recommendation.

Here are a few papers that recommend changing workers’ stations, while also looking into the productivity/financial aspects (this is relvent to page 12, lines 12-18):

Das, B.; Sengupta, A. K. (1996). Industrial workstation design: a systematic ergonomics approach, *Applied Ergonomics*,

Battini, D.; Faccio, M.; Persona, A.; Sgarbossa, F. (2011). New methodological framework to improve productivity and ergonomics in assembly system design, *International Journal of Industrial Ergonomics*,

Cimino, A.; Longo, F.; Mirabelli, G. (2009). A multimeasure-based methodology for the ergonomic effective design of manufacturing system workstations, *International Journal of Industrial Ergonomics*

Longo, F.; Mirabelli, G. (2009). Effective design of an assembly line using modelling and simulation, *Journal of Simulation*, Vol. 3, No. 2, 50-60.

Del Rio Vilas, D.; Longo, F.; Monteil, N. R. (2013). A general framework for the manufacturing workstation design optimization: a combined ergonomic and operational approach, *Simulation*, Vol. 89, No. 3, 306-329,

Harari, Y., Bechar,A., and Riemer, R**.** 2019. Simulation-based optimization methodology for human-machine system design that maximizes productivity while considering ergonomic constraints. IEEE Transactions on Human-Machine Systems

Ben-Gal, I.; Bukchin, J. (2002). The ergonomic design of workstations using virtual manufacturing and response surface methodology, *IIE Transactions*,

Harari, Y., Bechar, A., Raschke, U., and Riemer, R. 2017. Automated simulation – based workplace design that considers ergonomics and productivity. *International Journal of Simulation Modelling*