Shoulder torques resulting from luggage handling tasks in non-inertial frames

Shippen, J & May, B

Original citation & hyperlink:
Shippen, J & May, B 2018, 'Shoulder torques resulting from luggage handling tasks in non-inertial frames' *Technology and Health Care*, vol 26, no. S2, pp. S565-S569.
https://dx.doi.org/10.3233/THC-182503

DOI 10.3233/THC-182503
ISSN 0928-7329
ESSN 1878-7401
Publisher: IOS Press

Shoulder torques resulting from luggage handling tasks in non-inertial frames

James Shippen[1*], Barbara May[1]
[1]Coventry University, Coventry, CV1 5FB, United Kingdom
+44 – 24 – 7688 7072, email: j.shippen@coventry.ac.uk

**corresponding author*

ABSTRACT:

BACKGROUND: This paper reports on the torques developed in the shoulder joint experienced by occupants of moving vehicles during manual handling tasks. Handling heavy weights can cause musculoskeletal injuries, especially if handling is done with arms extended or at high levels.

OBJECTIVE: The aim of the study was to measure the longitudinal and lateral accelerations in a variety of passenger vehicles together with the postures of subjects lifting luggage onto storage shelves. This data enabled the application of inverse dynamics methods in a non-inertial reference frame to calculate the shoulder joint torques.

METHODS: The subjects lifted 3 pieces of luggage of masses of 5kg, 10kg and 14kg onto shelving which were at heights of 1.2m, 1.6m and 1.8m. The movement of subjects was measured using a 12 camera, 3-dimensional optical tracking system. The subjects stood on forceplates to measure the ground reaction forces.

RESULTS: 63 trials were completed, although 9 trials were aborted due to the subjects feeling unable to complete the task. It was found that the shoulder torques exceeded the levels recommend by the UK Health and Safety Executive for manual handling. A lift assistance device is suggestedto reduce the shoulder torques required for luggage handling.

KEYWORDS**:** biomechanics, manual handling, non-inertial reference frames

1.0 INTRODUCTION

Large torques developed at a joint have been shown to have a detrimental affect on the prevalence of injury at the joint[1,2] and the forces in the muscles surrounding the joint which generate the torque also act to increase the contact loads at the joint. Therefore it could be hypothesized that there exists a correlation between measureable, quantifiable biomechanical features (joint torques, joint contact forces) and the injury risk associated with various body locations (e.g. spine, knees, shoulders) and various pathologies (e.g. joint, neurological or muscle damage) during lifting.

The Health and Safety Executive Manual Handling Operations Regulations[3] estimates that 12.3 million working days are lost in Great Britain each year due to musculoskeletal disorders. The HSE provides useful and practical advice on how to reduce the risk of injury which apply to a wide range of manual handling activities including lifting, lowering, pushing, pulling or carrying. It suggests that ways to reduce the risk of manual handling injuries include reducing the amount of twisting and stooping, avoiding lifting heavy loads from floor level or to above shoulder height and reducing carrying distances.

Manual handling is frequently studied but rarely in a non-inertial reference frame where the linear accelerations and rotational velocities and accelerations cause pseudo-forces to act on masses within the reference frame. These pseudo-forces may be significant for manual handling tasks performed within accelerating vehicles. An example of such a task is luggage handling on a passenger vehicle which is accelerating from stationary, emergency braking or cornering with small radius of curvature at high speeds. This paper investigates the torques which occur at the shoulders during luggage handling in the presence of pseudo-forces and compares the torques with those recommended by the UK Health and Safety Executive.

2.0 METHODS

The pseudo-forces acting on a mass in a non-inertial reference is:

$$\mathbf{F} = -2m\mathbf{\Omega} \times \mathbf{V_B} - m\,\mathbf{\Omega} \times (\mathbf{\Omega} \times \mathbf{x_B}) - m\,\frac{d\,\mathbf{\Omega}}{dt} \times \mathbf{x_B} - m\,\ddot{\boldsymbol{r}} \qquad (1)$$

where $\mathbf{F}$ is the pseudo force vector

m is the mass of the particle

$\mathbf{\Omega}$ is the angular velocity vector of the non-inertial reference frame

$\ddot{\boldsymbol{r}}$ is the linear acceleration vector of the non-inertial reference frame

$\mathbf{x_B}$ is the position vector of the particle in the non-inertial reference frame

$\mathbf{V_B}$ is the velocity vector of the particle in the non-inertial reference frame

Therefore to calculate the pseudo forces it is necessary to measure the linear acceleration and the angular velocity and angular acceleration of the reference frame attached to the vehicle.

To measure these variables, a Sony Xperion mobile ‘phone was mounted onto the internal structure of main line rail carriages, light rail carriages, buses, underground metro systems and airport shuttle buses. The above time histories of these vehicles were measured with the ‘phone’s MEMS tri-axial accelerometer and gyroscopes at a rate of 200 samples per sensor per second. The accelerometer saturates at 2g which is substantially less than the accelerations encountered on any mode of transport (maximum acceleration = 1.33g) Also, the route of the vehicle was also recorded using the ‘phone’s GPS receiver and this was synchronised to the accelerometers and the gyroscopes.

It is also necessary to measure the movement of the mass within the non-inertial reference frame. For practical reasons this study measured the movement of the subjects, and hence the luggage mass, in an inertial reference frame and the pseudo-forces were subsequently calculated from equation (1). However, using this approach the subjects undertaking the manual handling task in the inertial frame will not experience pseudo-forces. It is acknowledged that on-board an accelerating vehicle actual pseudo-forces will cause a modification of the motion performed by the operative, however these changes in movement are considered second order and are ignored in the current study.

The movement of the 7 subjects (mean height = 1.70m, standard deviation height = 0.08m, mean mass = 76kg, standard deviation mass = 19kg) was measured using a 12 camera, 3-dimensional optical motion capture system. Thirty eight retro-reflective markers were attached to the subjects at anatomical locations specified by the Plug-In-Gait marker set[4]. The movement of the subjects was measured at a rate of 100 frames per second. During the trials the subjects stood on forceplates to measure the ground reaction forces; the forceplates were sample at a rate of 1000Hz

The subjects were instructed to lift 3 pieces of luggage onto the shelving; the shelf heights were 1.2m, 1.6m and 1.8m and typical of the heights of shelving on public transport. The 3 pieces of luggage had masses of 5kg, 10kg and 14kg. One trial consisted of lifting the luggage from the ground onto the shelf, returning to a resting posture and then lowering the luggage from the shelf back to the floor. The task was to be completed at a self-selected rate. The subjects were instructed to abort the trial if they felt unable to complete the lift. In total 63 trials were recorded; 9 trials were aborted due to the subject feeling unable to complete the task. The testing protocol was granted ethical approval by the University's Ethics Board and each subject gave informed consent to participate in the trials.

The Biomechanics of Bodies (BoB) software[5] was used to calculate the time histories of the major joints of the body from the optical tracking data. An example of a posture measured using the optical tracking system and illustrated in BoB is shown in figure 1. BoB also calculated the actual (inertial and gravitational) forces acting on the human body due to self weight, from a mass distribution model[6]. Bespoke code was written to additionally incorporate pseudo-forces from equation (1). BoB was also used to calculate the torques at the shoulders using inverse dynamics.

3.0 RESULTS

The peak lateral and longitudinal accelerations and jerks recorded for each mode of transport is listed in Table 1.

The maximum shoulder torque occurring for each subject for each luggage mass and shelf height combination was calculated using inverse dynamics techniques; the results are illustrated in figure 2. Also shown in figure 2 are the maximum shoulder torques for males and females lifting masses onto low and high shelves recommended for a single lift by the Health and Safety Executive and by the Liberty Mutual Insurance Group[7].

4.0 CONCLUSIONS

It has been found that shoulder torques experience during activities of daily life can exceed those recommend for industrial activities. Whereas the torques generated within the body will be rigorously monitored and regulated in an industrial context, this level of mediation will probably not be present outside the working environment and could result in injuries and over-use strains. As it will be unacceptable and impractical to apply the same level of regulation outside the working environment as to that currently found within an industrial setting it should be the responsibility of the designer of the internal features of passenger vehicles ensure hazardous loads are infrequently encountered. An assistive lifting device can be retrofitted onto passenger services vehicles to assist people with reduced load carrying capabilities such as the older person, pathological weakness and for exceptionally heavy loads. Figure 3 illustrates an example of such an assistive device

References

[1] Grund T., Reihl I., Krosshaug T., Senner V., Gruber K. (2010) Calculation of ankle and knee joint moments during ACL-injury situations in soccer. Procedia Engineering (2)2, 3255-3261

[2] Anz A.W., Bushnell B.D., Griffin L.P., Noonan T.J., Torry M.R., Hawkins R.J. (2010) Correlation of Torque and Elbow Injury in Professional Baseball Pitchers. American Journal of Sports Medicine. 38 (7), 1368-1374

[3] Manual handling. Manual Handling Operations Regulations
Guidance on Regulations L23 HSE Books 2004
ISBN 0 7176 2823 X

[4] Vicon (2017) https://docs.vicon.com/download

[5] Shippen J.M., May B.J. (2010) Calculation of Muscle Loading and Joint Contact Forces in Irish Dance. Journal of Dance Science and Medicine (14) 1, 11-18

[6] Shippen JM
The calculation of a human lumped mass model from acceleration and force plate data
Proceedings of the Institution of Mechanical Engineers Vol 216 Part H pp 333–340 2002

[7] Manual Materials Handling Guidelines, Liberty Mutual Insurance Group

Table

Mode	Lateral acceleration	Longitudinal acceleration	Lateral jerk	Longitudinal jerk
	g	g	gs^{-1}	gs^{-1}
Airport shuttle	0.29	0.18	0.32	1.13
Light rail	0.13	0.12	0.15	0.08
Underground metro	0.07	0.15	0.05	0.10
Main line rail	0.08	0.01	0.04	0.01
Passenger bus	0.33	0.19	0.23	0.17

Table 1: Peak lateral and longitudinal accelerations for each mode of transport

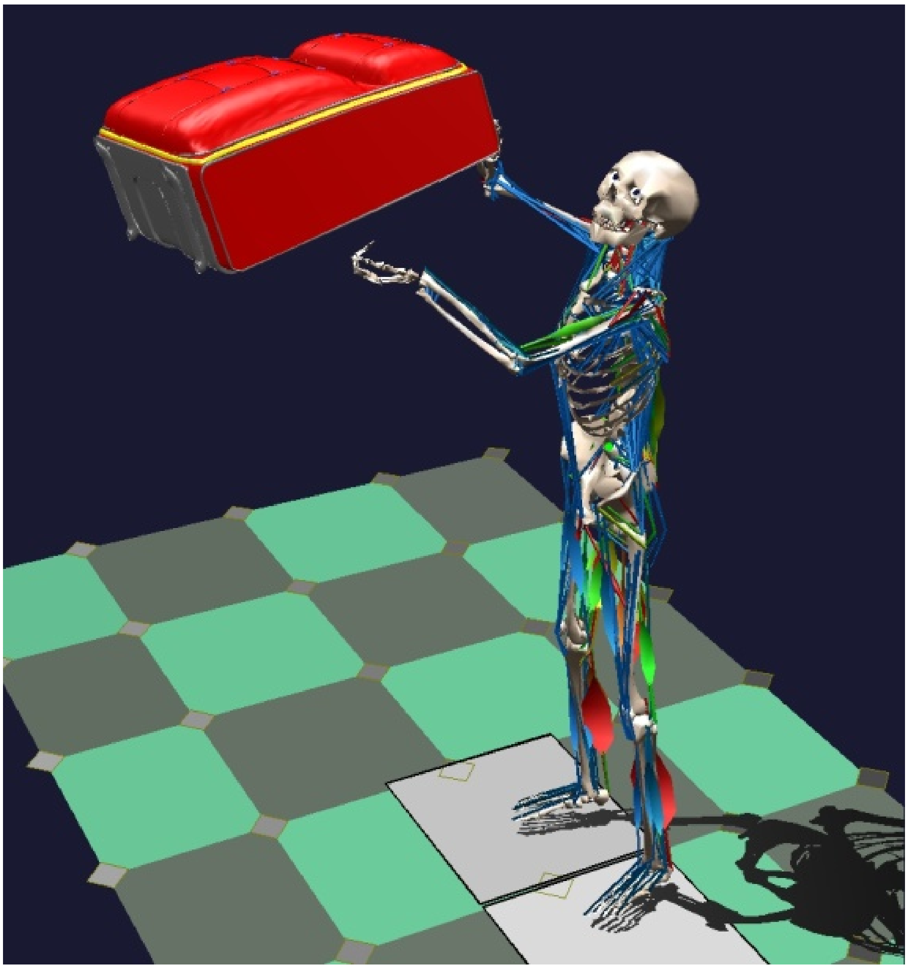
Figures captions

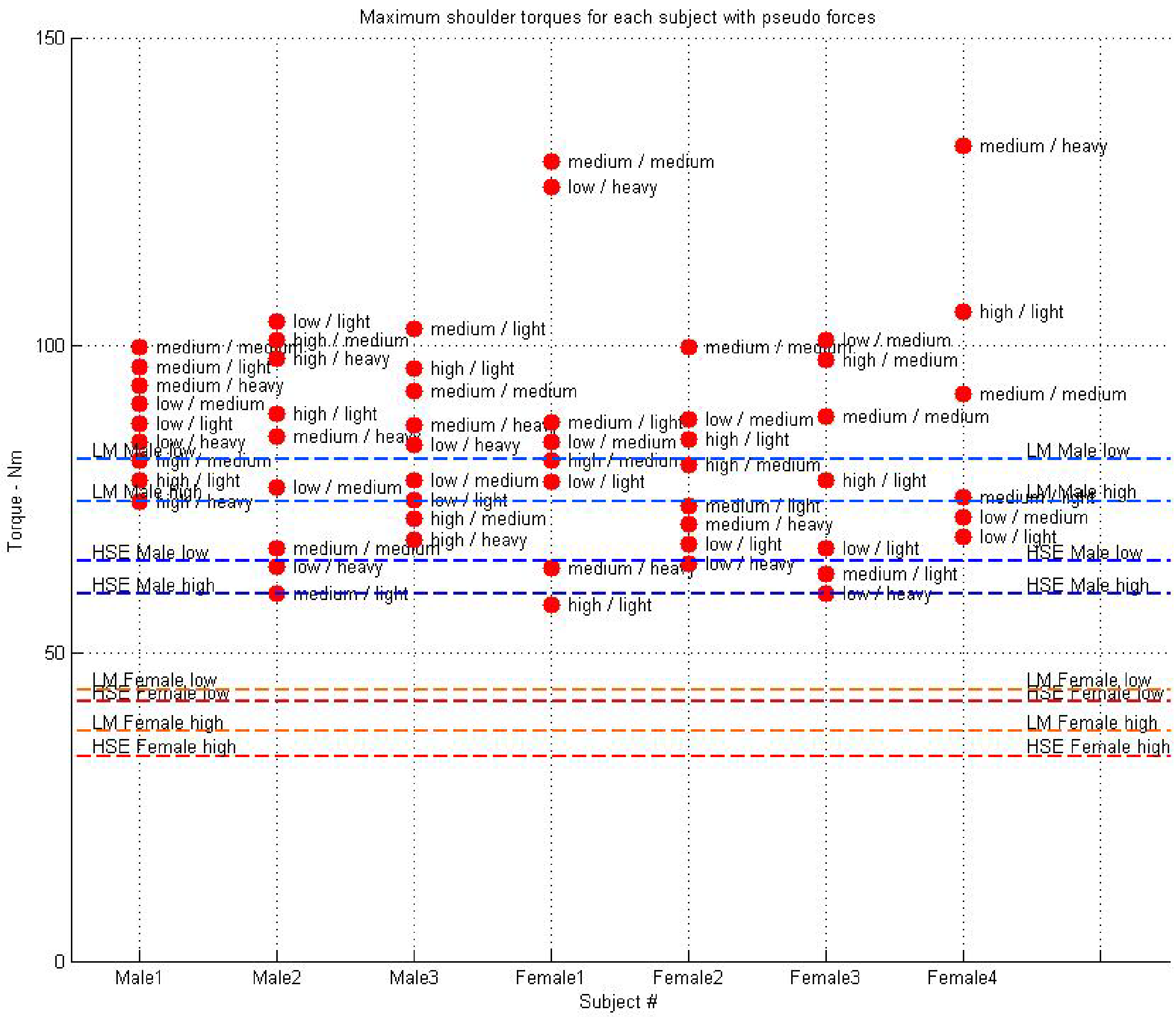
Figure 1: An example of a posture during the luggage lifting task.

Figure 2: Maximum shoulder torques of each subject for each luggage mass / shelf height combination

Figure 3: Luggage lifting device suitable for retro-fitting into existing commercial passenger vehicles showing the control panel and hoist

Figures




Maximum shoulder torques for each subject with pseudo forces
150
100
50
0
Torque - Nm
Male1
Male2
Male3
Female1
Female2
Female3
Female4
Subject #
medium / medium
medium / light
medium / heavy
low / medium
low / light
low / heavy
high / medium
high / light
high / heavy
low / light
high / medium
high / heavy
high / light
medium / heavy
low / medium
medium / medium
low / heavy
medium / light
medium / light
high / light
medium / medium
medium / heavy
low / heavy
low / medium
low / light
high / medium
high / heavy
medium / medium
low / heavy
medium / light
low / medium
high / medium
low / light
medium / heavy
high / light
medium / medium
low / medium
high / light
high / medium
medium / light
medium / heavy
low / light
low / heavy
low / medium
high / medium
medium / medium
high / light
low / light
medium / light
low / heavy
medium / heavy
high / light
medium / medium
medium / light
low / medium
low / light
LM Male low
LM Male high
HSE Male low
HSE Male high
LM Female low
HSE Female low
LM Female high
HSE Female high
LM Male low
LM Male high
HSE Male low
HSE Male high
LM Female low
HSE Female low
LM Female high
HSE Female high