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Original Article

Risks of low back pain in four different lumbopelvic movement patterns during two person-lifting in freestyle and recommended lifting methods

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Abstract

Loads on the spine (LOS) play an important role in back injuries. Numerous studies have focused only on one lifter who carried a single object. This current study aimed to classify lifting strategies using the pelvic angle at the beginning of the lift and compare LOS between the freestyle and recommended lifting methods to lift a patient off the floor (50 kg) using a stretcher with two lifters. Each pair of 88 participants were asked to lift a stretcher off the floor with the freestyle and recommended lifting methods. The results showed that the pelvic angle can be divided into four types and LOS was high in types III and IV. This study suggests that LOS of the lifter would decrease by performing at least a semi-squat posture and an anterior pelvic tilt of 10–20 degrees.

Keywords: lifting, loads on the spine, low back pain, lumbopelvic movement

1. Introduction

In emergency responses, manual lifting and handling of patients are very important procedures (Khorram-Manesh *et al.*, 2014) and may cause back injuries among healthcare personnel (Gentzler & Stader, 2010). LOS and posture are important factors that greatly impact back injury among the lifters.

In 2011, Arjmand *et al.* published predictive equations to estimate spinal loads in symmetric lifting tasks. The inputs of these predictive equations were sagittal trunk flexion, pelvic and lumbar spine rotations, the horizontal distance from hand to shoulder, and loads in hands. These predictive equations have high R^2 values (99.36%) and low root mean square errors (RMSEs) (88 N) in predicting spinal

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loads at the L5-S1 level compared to the kinematics-driven model. Predicted compressive force can be compared with *in vivo* measurements of intradiscal pressure (IDP) values (Wilke, Neef, Hinz, Seidel, & Claes, 2001) under identical tasks. The measured and computed IDP values at the L4-L5 disc are in close agreement under similar loadings and postures.

Lifting strategies are observed and defined in many methods (Burgess-Limerick & Abernethy, 1997; Li & Zhang, 2009; van Dieën, Hoozemans, & Toussaint, 1999). A squat technique is characterized by a start position of deep knee flexion with the trunk close to erect. However, the typical stoop technique might be trunk flexion with nearly extended knees. The semi-squat technique uses a posture between the squat and stoop lifts. The risk of back injuries was higher in stoop technique, while the squat technique might decrease LOS to a maximum of one-third (10–34%) (van Dieën *et al.,* 1999). The compressive force on the lumbar intervertebral disc in the squat technique was reduced by shifting the stresses on the lumbar region to the legs (Toussaint, Van Baar, Van Langen, De Looze, & Van Dieën, 1992).

Lumbopelvic rhythm was used to explain the lifting techniques. While lifting, the lifter performed trunk extension during which the coordinated movement of the lumbar spine and pelvis during lift occurred and could not be deserted (Nelson, Walmsley, & Stevenson, 1995). The lumbopelvic rhythm can be classified into two groups: simultaneous and sequential (Hu & Ning, 2015).

In simultaneous lumbopelvic coordination, in the trunk flexion phase, the back and hip extensor muscles (erector spinae and biceps femoris) are activated concurrently followed by the activation of the gluteus maximus muscle and finishing with the lumbar paraspinal muscle and biceps femoris muscle activity. On the other hand, sequential lumbopelvic coordination is initiated with the biceps femoris followed by activation of the gluteus maximus, lumbar paraspinal muscle and ends with the biceps femoris relaxing first and the lumbar paraspinal last (Leinonen, Kankaanpää, Airaksinen, & Hänninen, 2000).

Understanding freestyle lifting of a trainee might be of benefit to communicate the risk of a back injury and to perceive the impact of musculoskeletal disorders (MSDs) on their health and job security (Abedini, Morowatisharifabad, Enjezab, Barkhordari, & Fallahzadeh, 2014). Furthermore, previous studies showed the kinematic data of lifting strategies during the lift of low-lying objects (Davis, Splittstoesser, & Marras, 2002; de Looze, Toussaint, van Dieen, & Kemper, 1993; Straker, 2003), but all of the previous studies were done using one lifter who carried a single object and little kinematic data of lifting strategies were reported. Unsynchronized lifting from two lifters might lead to abnormal posture, different postures of the lifters, and be a risk factor for MSD.

From previous studies that focused on the lifting strategies, some ergonomic interventions were proposed that included some education and training to reduce the risk of MSDs in healthcare personnel (Hignett, 2003). The conclusion from a meta-analysis reported that manual material handling advice and training with or without assistive devices did not prevent back pain or back pain-related disability compared to no intervention or alternatives (Verbeek *et al.,* 2012). However, several interventions were recommended such as safety meetings, education and training in a workshop, and peer coach education plus education in practice (Hartvigsen, Lauritzen, Lings, & Lauritzen, 2005; Kraus, Schaffer, Rice, Maroosis, & Harper, 2002; Lavender, Lorenz, & Andersson, 2007; Warming *et al.,* 2008; Yassi *et al.*, 2001; Zadvinskis & Salsbury, 2010). Some guidelines suggest that the lifter should start the lift with moderate flexion of the back, hips, and knees. However, there is no mention of specific guidance concerning the pelvic angle (the Health and Safety Executive, 2016) which is another important parameter in Arjmand's predictive equations to estimate the spinal loads. There is limited evidence to support how the pelvic angle is importantly related to LOS and how it could be included in an intervention to diminish the risk of MSDs. The aims of this study were to classify the type of lifting strategies using the pelvic angle at the beginning of the lift and compare LOS between the freestyle and recommended lifting methods using a total weight of 50 kg to lift a person off the floor using a stretcher and two lifters.

2. Materials and Methods

This study was approved by the Thammasat University Research Ethical Committee and the Institutional Review Board, Faculty of Medicine, Prince of Songkla University.

2.1 Experimental procedure

The study participants were 88 healthy males who were firefighters or municipal officials between 20 and 60 years old with no recent back pain. Each pair of participants were asked to lift the stretcher which carried a 20-kg dummy and add-on dumbbells off the floor three times with a total weight of 50 kg with freestyle lifting at a comfortable speed. After a 5-minute rest, each pair of participants was asked to lift the stretcher three times with a total weight of 75 kg with freestyle lifting at a comfortable speed. After a 5-minute rest, each pair of participants attended a 10-minute safety material handling session which was conducted by an occupational medicine physician and physiotherapists. The instructions were "*Please perform the squat lifting technique. When you are ready, please start lifting at a comfortable speed and keep the back and arms straight. Also, keep the hands not far from your body*". After a 5-minute rest, each pair of participants was asked to lift the stretcher three times for each of the total weights of 75 and 50 kg using the recommended lifting technique at a comfortable speed with a 5-minute rest in the same fashion as in freestyle lifting.

2.2 Calculation of loads on the spine and joint angle measurements

For joint angle measurements, markers were placed according to the methods of the full body plug-in-gait model with add-on markers at T1, T12, left and right iliac crests, left and right greater trochanters of the femur, and at the backs of the hands (Abedini *et al.,* 2014; Arjmand *et al.,* 2011) (Figure 1).

The handles of the stretcher were about 8 cm from the floor. The lumbar, knee, and ankle joint motions were captured using a ten-camera Vicon motion analysis system.

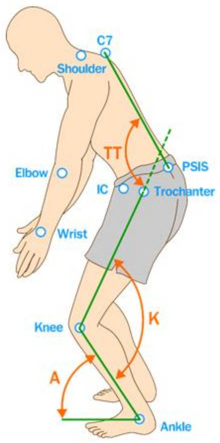

Figure 1. Definitions of the knee angle (*K*), the ankle angle (*A*), and the angle between the trunk and thigh (*TT*) in relation to the markers.

The three-dimensional positions of the anatomical markers on the subject were collected at a sampling frequency of 100 Hz. The predicted loads on the intervertebral discs were calculated using Arjmand's methods in each time frame (Arjmand *et al.*, 2011).

2.3 Statistical methods

The joint angles, horizontal distance from hand to shoulder, and predicted LOS were calculated into 100% of lifting using a "spline" function. The demographic data of the participants are presented as mean and standard deviation or number and percentage. The classification of lifting using the pelvic angles and a comparison LOS between freestyle and recommended lifting were analyzed with generalized additive models (GAMs) with spline smoothers in the 'mgcv' package (Wood, 2011) and 'voxel' package. In general, the GAMs model has the following structure.

$$g(\mu) = \alpha_0 + \sum_{i=1}^{p} f_i\,(X_i) \qquad (1)$$

where $\mu = E\ (Y)$ for Y, a response variable with some exponential family distribution, g g is the link function, and the f_i are some smooth functions of the covariates X_i for each i=1, ..., p. All analyses were performed using R version 3.2.2 (R Core Team, 2017). The statistical significance was considered to be a 2-sided P<0.05.

3. Results and Discussion

The general characteristics of the 88 healthy male firefighters or municipal officials are presented in Table 1.

3.1 Four types of lifting strategies from GAMs

The classification of lifting strategies was analyzed using GAMs with spline smoothers to determine the relationship between the pelvic angles and LOS at the beginning of the lift. The relationship between the pelvic angles and LOS was not linear (Figure 2). This meant that the relationship was not constant. When quantitative covariates have a non-linear association with the outcome, GAMs might be the

Table 1. General characteristics of the participants.

General characteristics (N = 88)	Mean±SD
Age (years)	43.00±9.39
Weight (kg)	70.85±9.96
Height (cm)	167.67±6.47
Body mass index (kg/m^2)	25.17±2.96
Waist circumference (cm)	88.01±8.49
Hip circumference (cm)	95.12±7.05
Thigh circumference (cm)	51.81±4.61
Waist-to-hip ratio	0.53±0.05
Work experience (years)	15.57±9.48

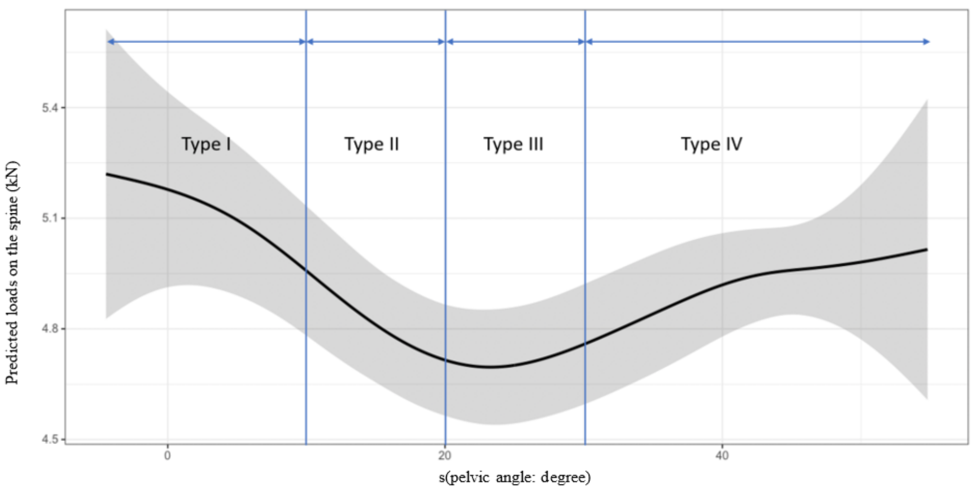

Figure 2. Smoothed curves from generalized additive models in predicted loads on the spine varied for different pelvic angles at the beginning of the lift.

appropriate method for the analysis (Barrio, Arostegui, & Quintana, 2013; Moore, Hanley, Turgeon, & Lavoie, 2011).

From the GAMs analysis, the pelvic angles varied at the beginning of the freestyle lifting and could be classified into four types of pelvic movement depending on the pattern of the smoothed curves (Table 2). The association between the pelvic angles and the predicted LOS at the beginning of a lift were significant (P<0.001).

At the beginning of lifting, the pelvis of the participants in type I pelvic movement pattern was in a neutral position, while the pelvis of types II through IV had a more anterior tilt than in type I.

The early extension phase of lifting was initiated by knee extension followed by pelvic posterior tilt while the lumbar and thorax segment remained still. The lumbar and thorax segment started to extend at about one-third of the lifting cycle and lasted until the experiment was finished in the upright position. The motion started mainly from the pelvis and finished by the lumbar spine which was in agreement with previous studies (Davis, Troup, & Burnard, 1965; Granata & Sanford, 2000; Tafazzol, Arjmand, Shirazi-Adl, & Parnianpour, 2014).

3.2 Loads on the spine between the four types of lifting strategies

The estimated LOS in this study was calculated from predictive equations which were developed using the kinematics-driven model with high precision (Arjmand & Shirazi-Adl, 2006a, 2006b). The advantage of this method resulted from the estimation of muscle forces and spinal loads based on the balance of net moments at a multiple level with consideration for the equilibrium at the remaining levels (Arjmand, Plamondon, Shirazi-Adl, Lariviere, & Parnianpour, 2011) which was different from the classic methods. For example, Chaffin's model uses only the thorax and the knee angle to estimate LOS (Chaffin, Andersson, & Martin, 2006).

From the GAMs analysis of freestyle lifting of 50 kg, the results showed that type I had the smallest LOS (Table 3). These outcomes resulted from the lower thorax flexion angle in the type I lifter than in the other types.

In the case of lifting 50 kg, LOS of type 1 were higher in the early phase (0–30% of lifting) (Figure 3) than the recommendation which is not more than 3.4 kN (Waters, 2006). The averages of LOS in types I & II were 3.29 kN and 3.03 kN, respectively.

3.3 Differences of loads on the spine between the types of pelvic angle

LOS were significantly different between the four types of pelvic angle and between the freestyle and recommended lifting methods (R^2=85.52) using the total weight of 50 kg (Table 3).

From the GAMs analysis, the differences of LOS in the four types of pelvic movement patterns during the 50 kg freestyle lifting possibly occurred due to lumbopelvic rhythm while lifting. In this study, the two types of lumbopelvic coordination were observed, i.e., simultaneous and sequential. In freestyle lifting, the simultaneous type was found in types I and II in which the lumbar segment was moving along with the pelvis during the entire extension phase of the experiment. On the other hand, the sequential type was found in types III and IV.

On the other hand, in the recommended lifting method, the participants in type I performed sequential lifting which was initiated with the thorax which was continuously extended while the knee and pelvis were fixed. In type II, simultaneous lifting was found and the participants in this group extended the knees with thorax extension. It can be noted that the motion of the thorax in type II seemed to be stable because this was total movement but when the knees were extended, the thorax had to perform more extension to get the same degree of flexion-relative thorax angle.

The differences between LOS in the recommended lifting were affected by the pelvic angle in types I & II with

Table 2. Four types of pelvic movement patterns classified by the pelvic angle at the beginning of freestyle lifting from GAMs analysis.

Types of pelvic movement pattern (N = 88)	Pelvic angle (degree)	n (%)
I	≤10.00	11 (12.50%)
II	10.01-20.00	16 (18.20%)
III	20.01-30.00	15 (17.00%)
IV	>30.00	46 (52.30%)

Table 3. Differences in loads on the spine by 100% lifting between four types of pelvic movement patterns during freestyle and recommended lifting of 50 kg total weight (GAMs analysis).

Parametric coefficients:	Estimate	Std. error	t value	Pr(>|t|)
(Intercept)	3.625	0.032	112.98	<0.001
Recommended lifting (ref: freestyle lifting)	-0.331	0.016	-20.648	<0.001
Type II (ref: type I)	0.294	0.019	15.252	<0.001
Type III (ref: type I)	0.345	0.02	17.624	<0.001
Type IV (ref: type I)	0.372	0.017	22.208	<0.001
Recommended lifting: Type II	-0.505	0.022	-23.257	<0.001
Recommended lifting: Type III	0.112	0.058	1.942	0.052
Recommended lifting: Type IV	0.551	0.037	14.731	<0.001

* Model: LOS ~ s(time, by=type) + s(time, ID, bs="fs") + lifting*type + s(ID, bs="re") + s(ID, time, bs="re"): where LOS is loads on the spine (kN), time is 1-100 % of lifting, type is pelvic movement pattern I-IV, lifting is freestyle or recommended lifting, and ID is identical number of participants; Where s(time, by=type) is smooth curve of loads on the spine by time in each pelvic movement pattern, s(time, ID, bs="fs") is smooth curve of loads on the spine by time in each ID with smooth factor interactions technique, s(ID, bs="re") is smooth curve of loads on the spine by random effect from ID, and s(ID, time, bs="re") is smooth curve of loads on the spine by random effect from time in each ID.

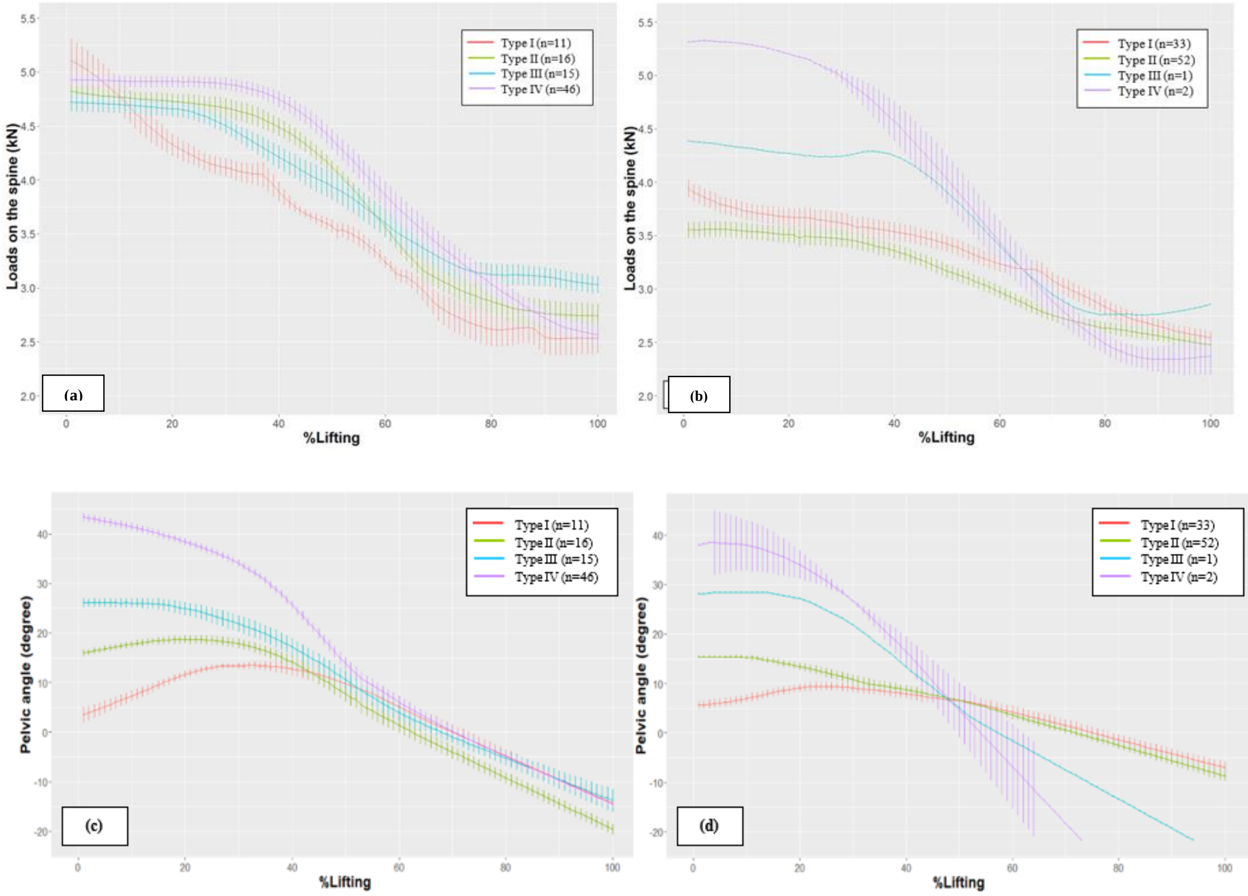

Figure 3. Spine in freestyle (a) and recommended lifting (b); Pelvic angle in freestyle (c) and recommended lifting (d).

the same degree of thorax flexion angle. The results from this study confirmed that LOS would decrease if the lifter performed the squat posture with increased pelvic tilt (Hayashi, Katsuhira, Matsudaira, & Maruyama, 2016).

From the observations, the lifting in types I & II were the semi-squat technique because at the beginning of the recommended lifting method, the lifter performed the identical angle of the deep knee and trunk flexion but there were statistical differences in LOS between type I and II (Table 3). These differences resulted from the divergence in pelvic angle in which type II had a more anterior tilt than type I. The results implied that LOS would decrease if the lifter started the lifting with semi-squat technique and little anterior pelvic tilt (10–20 degrees) which meant that the add-on suggestion about the anterior pelvic tilt would diminish the risk more than the classical technique.

There were differences in the measurements of pelvic angles between Hayashi *et al.* (2016) and this study. Hayashi *et al.* (2016) measured the pelvic angle using coordinate systems determined by markers on the anterior and posterior superior iliac spine and iliac crest (Katsuhira *et al.*, 2013), but in this study the pelvic angle was calculated from markers on the iliac crest and two markers at the posterior superior iliac spine. LOS in the current study were lower than the results of Hayashi *et al.* (2016) in which the average of LOS was 3.82 kN (SD 0.49). In type II of lifting strategies, the pelvis would increase the pelvic anterior tilt which moved the L4/5 joint forward which resulted in a decrease in the lever arm and thus decreased the compression force on the lumbar intervertebral disc (Katsuhira *et al.*, 2013).

From a focus group discussion, some participants reported that the previous workshops focused mainly on the squat technique and in keeping the spine straight without mentioning the pelvic and lumbopelvic rhythm. According to the results from type II, in order to decrease the risk of lifting on the lumbar intervertebral disc, the pelvic angle and lumbopelvic coordination should be considered. Furthermore, the core body muscles should be trained and strengthened to decrease back pain or back pain-related disability.

3.4 Limitations

Although the participants were firefighters and municipal officers who were assigned to rescue victims from disasters, such as lifting and lowering patients from a flood or fire, the functional performance test of half of the participants in the sit and reach test, leg dynamometer test, back endurance test and push-up test were lower than the Thai male population with the same average age. These tests are important because tightness in this area is implicated in lumbar lordosis, forward pelvic tilt, and lower back pain (Wells & Dillon, 1952), and might cause poor posture.

Furthermore, the number of years of experience was entered into the GAMs but this variable was not in the final model because the variable did not make a significant contribution.

4. Conclusions

The lifting strategies could be classified into four types and the classification was confirmed with the different parameters of the lifting and LOS. This study suggests that LOS would decrease if the lifter performs at least the semi-squat posture, anterior pelvic tilt of 10–20 degrees, maintains straight back and arms, and the hands are kept not far from the body with simultaneous lumbopelvic rhythm.

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