Influence of Carrying Unstable Load on Thoracic Kinematics While Walking on a Curved Path

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Abstract. This study investigated the effect of carrying unstable load on thoracic kinematics while walking on a curved path. Three-dimensional spinal kinematics were defined as the rotations between thoracic and the Virtual laboratory coordinate system (Tho/Virtual lab) which consisted of lateral bending (LB), flexion/extension (FE) and axial rotation (AR) in the frontal plane, sagittal plane and transverse plane, respectively. Eight healthy young adults (4 males and 4 females) performed loads carrying and walking on one meter radius curved path. Spinal kinematics was determined at the left leg heel strike and just before the right toe off during the curved path walking. As a result, a significant main effect of load intensity was found only on FE of (Tho/Virtual lab) at both left leg heel strike and right toe off. The study concluded that an increase in the load intensity of unstable load from 10% of body weight likely to generate more thorax extension.

1. Introduction
Manual handling is one of the most common activities in the workplace as well as in our daily life including lifting, carrying, placing, pushing and pulling the loads [1]. Back pains and injuries were the most common kind of musculoskeletal disorders caused by manual handling [2]. In 2017/18, 40% of musculoskeletal disorders reported to the Health and Safety Executive in United Kingdom, were back injuries [3]. Therefore, having good ergonomics on manual handling is always essential to enhance safety and minimize risk of injuries in the workplace.

There were numbers of studies carried out to investigate different aspects of manual handling load and its effect on the spine [4, 5, 6, 7]. Fowler et al. [4] showed that there was association between load and forward flexion or side flexion of spine during asymmetric load carriage which was considered as a risk factor for postural problem. Conducting a study with increasing on posterior carriage (0% - 5% - 10% - 15% of body weight), Devroey et al. [6] reported there was a significant effect of load intensities.
(from 10% of body weight and above) on thorax flexion, thus backpack loads from 10% of bodyweight onwards should be avoided. Moreover, Alamoudi et al. [7] stated that posterior carriage generated the largest trunk flexion while frontal carriage produced largest trunk extension. This effect increased with the weight of the load carriage. Performing another facet of load handling (lifting), Norasi et al. [5] concluded that there was no significant impact of load magnitude on spinal kinematics during lifting load from the same height.

The previous studies mainly focused on stable loads, which have the center of mass (COM) remains the same in the whole process. However, there are also work conditions where the workers must lift and carry loads with moving content such as in the chemical industry, soft drink beverage delivery industry, food industry, etc. This type of load is known as unstable load. Because of their instability, the workers need to handle sudden additional weight at specific areas while carrying these loads. However, studies on unstable load were minimal and its effect on spinal kinematics remains unclear. Furthermore, carrying a load while walking on a curved path often performed during activities of daily life which was more challenging than straight walking even for a healthy subject. Therefore, this study is proposed to investigate the effect of carrying unstable load on spinal kinematics while walking along a curved path. This knowledge is essential and can be used to design safer and more reliable manual handling guidelines. Hypothetically, there is a main effect of load intensity of unstable load on spinal kinematics.

2. Methodology

2.1. Subject

Eight healthy subjects (four males and four females) with normal BMI (18.5 – 24.9) aged from 22 to 23 years old, mean height was 162.33 cm (SD = 8.69 cm), and mean weight was 58.93kg (SD = 8.58 kg) participated in the experiments. All participants reported to no neurological history, musculoskeletal disease, and gait disorders. The participants were informed of the procedure and had given written informed consent before the experiment.

2.2. Experimental equipment

The kinematics data were captured using five Oqus-camera motion capture system (100 Hz; Qualisys AB, Goteborg, Sweden) and Ground Reaction Force (GRF) was detected using two rectangular Bertec force plates with dimensions of 400 x 600 mm. Data were collected using Qualysis Track Manager (QTM) version 2.6. The five cameras were arranged in such a way that the force plates were in the centre of data collection volume to collect the highest percentage of marker signal when the subject was walking on the force places, Figure 1. The static trials were captured in 3 seconds and dynamic trials were captured based on preferred walking speed at 100 Hz. The walking paths with turning radii of 1 meter was marked using colour tape. Two unstable loads were designed using two bottles with a size of 9.5 liters of water, Figure 2. The bottles were filled with water with the volume of water being 10% and 12.5% of the subject’s body weight (BW). The bottles were then closed tightly to ensure there was no water dripped when being carried and tied together with tape.

Marker placement was based on Modeling the Thorax and Plug in Gait Lower Limb Model introduced in C-motion, Visual 3D [8,9]. Twenty - six reflective markers were attached to the head, trunk, pelvis, legs, feet to estimate the body center of mass (COM). Three markers were placed on the head i.e., at the top of the head (HEAD), left ear (L_EAR) and right ear (R_EAR). For the lower limbs, there were six markers placed laterally for each side i.e., left/right thigh (L/R_THI), left/right knee (L/R_KNE), left/right tibia (L/R_TIB), left/right ankle (L/R_ANK), left/right 2nd metatarsal head (L/R_TOE) and left/right heel (L/R_HEE). The remaining eleven markers were attached to the pelvis and trunk for spinal kinematics [10]. These markers were placed on the right and left acromion (RA, and LA), deepest point of incisura jugularis (IJ), xiphoid process (most caudal point of the sternum) (PX), seventh cervical vertebra (CV7), second and seventh thoracic vertebrae (T2, T7), the right and left anterior superior iliac spines (RASIS, and LASIS), the right and left posterior superior iliac spines.
(RPSIS, and LPSIS). The markers were placed on those positions by palpating the surface landmarks on the human body and also following the technique introduced by Ernst et al. [11].

![Figure 1](image1.png)

**Figure 1.** Layout of motion capture system, unit:mm

![Figure 2](image2.png)

**Figure 2.** Illustration of two unstable loads designed using two bottles with a size of 9.5 liters of water.
2.3 Experiment procedure
Prior to performing the experiment, a preliminary calibration procedure was performed on both camera and force plate system. All subjects were explained about the tasks and given time for familiarization. Subjects performed walking on a one-meter radius curved path while carrying an unstable load. The unstable load conditions were set as no load, 10% and 12.5% of subject’s bodyweight. The subjects were instructed to turn to the left with the left foot and at self-preferred speed. The bottle was held in front, where its bottom surface was oriented parallel to the sagittal plane of the subjects. In addition, the subjects were walking in the opposite directions to the mediolateral (ML) and anteroposterior (AP) directions of the global coordinate system.

The data were low passed filtered using a 4th order Butterworth filter with a cut off frequency of 6 Hz in Visual 3D [12][13]. Spinal kinematics referred to three–dimensional rotations between thoracic and the Virtual laboratory coordinate system Tho/ Virtual lab which consisted of: lateral bending (LB), flexion/extension (FE) and axial rotation (AR) in the frontal plane, sagittal plane, and transverse plane, respectively. The thoracic coordinate system Tho was defined by four markers: CV7, T7, IJ and PX. The origin of Tho coincided with the mid-point between CV7 and PX (as described in Visual 3D, Modeling The Thorax [8]). The vertical axis, was the line connecting the midpoint between PX and T7 and the midpoint between IJ and CV7, pointing upward. The ML axis was perpendicular with the planned formed by IJ, CV7 and midpoint between PX and T7, pointing to the right. The AP axis, was the common line perpendicular to the vertical axis and ML axis, pointing forward.

As the subject was walking toward the negative X axis of the coordinate system (represented AP direction, direction is indicated by the dash line and the arrow in Figure 1) and turning to the left which was the negative Y axis (represented ML direction) of the global laboratory coordinate system, the Virtual laboratory coordinate system (Virtual lab) was defined to facilitate the calculation of spinal kinematics (as described in Visual 3D [14]). The origin of Virtual lab coincided with the origin of the global laboratory coordinate system. The positive of X axis and Y axis of the Virtual lab coordinate system were in the opposite direction to the positive of X axis and Y axis of the global coordinate system [14]. The Tho and Virtual lab were used to calculate three-dimensional joint angles. The calculation of FE, LB and AR angles were performed using Compute Model Based Data in Visual 3D [15]. The output was displayed in X, Y and Z components. As explained in Visual 3D, the X component of joint angle refers to the rotation about the X axis, similarly for Y and Z [15]. Therefore, the theta in X, Y and Z component were the angle of lateral bending, flexion/extension, and axial rotation, respectively. The positive direction was determined using the right-hand rule. The positive and negative value in X component indicated right and left bending, respectively. The flexion and extension which was indicated by positive and negative value in Y component, respectively. The positive value in Z component indicated left axial rotation while the negative value directed right axial rotation.

2.4 Statistical analysis
One–way repeated measure analysis of variance (ANOVA) was performed to determine the effects of load intensity on spinal kinematics at the left heel strike and right toe off. The significance level was set at α=0.05 for all the statistical tests. All statistical analyses were performed using Microsoft Excel 2010.

3. Results and Discussion
All participants completed all trials without falling or slipping while carrying and walking with unstable loads. A significant main effect of load intensity was found on FE of Tho/Virtual lab at the left heel strike (ρ = 0.0028) and at the right toe off (ρ = 0.0157). The statistical results at the left heel strike and right toe off were summarized and shown in Table 1.
Table 1. Statistical results at left heel strike and right toe off

| Load condition          | No Load | 10% of BW | 12.5% of BW | p-value |
|-------------------------|---------|-----------|-------------|---------|
| Lateral bending (deg)   | -1.22 ± 2.39 | -1.67 ± 1.80 | -2.78 ± 3.63 | 0.8246  |
| Flexion /extension (deg)| 0.65 ± 5.81 | -4.47 ± 6.26 | -5.47 ± 4.27 | 0.0028  |
| Axial rotation (deg)    | 18.56 ± 13.28 | 19.20 ± 10.01 | 22.90 ± 10.52 | 0.7163  |

| Load condition          | No Load | 10% of BW | 12.5% of BW | p-value |
|-------------------------|---------|-----------|-------------|---------|
| Lateral bending (deg)   | -2.46 ± 3.32 | -1.76 ± 2.51 | -2.75 ± 4.05 | 0.9370  |
| Flexion /extension (deg)| -0.91 ± 5.68 | -5.68 ± 6.36 | -6.38 ± 5.03 | 0.0157  |
| Axial rotation (deg)    | 25.21 ± 14.99 | 23.75 ± 11.12 | 29.20 ± 11.19 | 0.6816  |

From the results, it was found that there was only a main effect of load intensities on FE of Tho/Virtual lab while no effects on other spinal kinematics. This is in line with previous studies [6][7]. Alamoudi et al. [7] stated that the magnitude of load carriage affected trunk flexion and extension significantly but not trunk lateral bending. Furthermore, Dervoey et al. [6] reported a significant increase in thorax flexion with increased load from 10% of BW and above for backpack. This was believed due to adaption of the body to bring COM forward to maintain the balance. In the current study, unstable load was carried in front of the body which caused the COM of the upper body to be shifted anteriorly [16]. Therefore, thorax extension would occur to bring COM of body and unstable load backward thereby the body is maintained to be stable. The heavier the load intensities, the more thorax extension to compensate displacement of COM of upper body in anterior direction.

The unstable load has no significant effect in lateral bending and axial rotation. The bottle was not fully filled, depending on the subjects BW, 50-80% of the volume were occupied with water. Perhaps, the intensity of the unstable load up to 15% of the BW did not give significant changes to the shift of overall centre of mass in the transverse (axial rotation) and frontal plane (lateral bending) during the double support phase of the curved walking. Thus, this created very minimal postural adjustment to counteract the effect of load in the two planes.

4. Conclusion
Based on the limited sample size, the following conclusion could be made. A significant change on the thorax flexion/extension were observed when participant walk on the one-meter curved path while carrying the unstable load of more than 10% bodyweight. Increasing load intensities likely to generate more thorax extension at the double support phase of the curved path walking.
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