Influence of different modes of load carriage on lower limb biomechanics of industrial workers

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ABSTRACT

Study was conducted with an aim to i) study the lower limb biomechanics of healthy workers, ii) determine changes of human biomechanics with different modes of load carriage and iii) suggest biomechanically efficient mode of load carriage. Study was conducted on 20 workers in the age range 20 to 55 years. Qualisys Motion Capture System (Sweden), Kistler Force Plate (Switzerland) and Polar S810i HR monitor, Finland were used. Heart rate was recorded at rest and during different modes of load carriage with 40% of body weight i.e. loads on head, shoulder and hand. Movement of lumbar spine while carrying loads was recorded by using Industrial Lumbar Motion Monitor (iLMM), USA. Walking speed for head load, shoulder load and hand load were 4.19±0.55 km.hr⁻¹, 4.09± 0.82 km.hr⁻¹ and 3.94± 0.84 km.hr⁻¹ respectively. Stride length was longer in case of head mode (1.20±0.45 meter) followed by hand (1.19±0.01 meter) and shoulder mode (1.12±0.04 meter) of load carriage. Average Twisting Velocity of lumbar spine was found lowest in case of head mode of load carriage followed by shoulder and hand mode. Heart Rate cost of carrying loads on head, shoulder and hand were 50±10.54 beats/min, 52.95±10.88 beats/min and 57.45±10.04 beats/min respectively. Energy cost of carrying loads on head, shoulder and hand were 294±61.99 jule/min, 311.346±63.97 jule/min and 337.81±59.03 jule/min respectively. Results demonstrated a significant relationship between kinetic and kinematic parameters of workers at different load conditions. Findings would provide substantial input for designing work and work rest cycle for industrial workforce.
Keywords: Load carriage, biomechanics, stride length, double limb support, energy cost, heart rate.

1. INTRODUCTION

Biomechanics of human movement is the process to stand upright and move about on two legs. The main three functions of lower limbs of human are to bear weight, maintain balance and advancement of limbs. The rhythmic alternating movements of the two lower limbs helps in the forward movement of the body and the manner in which it occurs i.e. how a person walks is what is known as gait.

There are three main phases of gait i) Stance phase (support) - begins when the heel of the forward limb makes contact with the ground and ends when the toe of the same limb leaves the ground. ii) Swing phase (no support) - begins when the foot is no longer in contact with the ground. The limb is free to move. iii) Double support - both limbs are in contact with the ground simultaneously. The activity that occurs between heel strike of one limb (reference limb) and the subsequent heel strike of that same limb is known as gait cycle.

It is evident that biomechanics of human movement changes with modes of load carriage in an industrial situation. Further, biomechanical load coupled with energy cost of work provides a significant input for design of a work system. Heart rate response has been found an easy assessment technique in industrial situation, since heart rate can be easily measured without using any
sophisticated equipment. There have been various studies using the Energy Expenditure Index to measure energy cost \([1,5,6,8]\). It is evident along with biomechanics of human movement, that there is change in EEI pattern with different modes of load carriage in industrial workers. Various modes of load carriage are adopted in industrial situations, which has its own advantages and limitations and affects the efficiency and productivity of the workers.

2. AIMS AND OBJECTIVES

Present study was carried out with following aims and objectives:

1) To capture and study the lower limb biomechanics of healthy industrial workers
2) To investigate the changes of human lower limb biomechanics with different modes of load carriage
3) To investigate the Physiological response of carrying load at different modes
4) To suggest biomechanically efficient mode of load carriage.

3. MATERIALS AND METHODS

3.1 Participants

Participants in this study were workers from unorganized sectors located around Mumbai, the western region of India. Purposive sampling technique was used to select the volunteers in this study. Physical profile of the volunteers were was checked and care was taken that none of them had musculoskeletal problems or restriction on normal walking. The sample size of the study was 20 in the age range 20 to 55 years.

3.2 Instrumentation

Qualisys Motion Capture System (Sweden) was used to study the lower limb biomechanics. For tracing the subject’s movements, an array of six high speed cameras (type: ‘Oqus’) by the company ‘Qualisys’ was used. Kistler (Switzerland) force plates (2 Nos) were used along with the Qualisys system. This system altogether captures motion data along with the force data. In the study, it was used to collect kinematic data of gait. Polar S810i Heart Rate Monitor, Finland was used to measure heart rate after exertion of activity. Written consent was obtained and then a screening examination was conducted to ensure each volunteer was free of lower extremity musculoskeletal problems.

3.3 Data collection procedure

Thirty six reflective markers were placed on specific locations of each volunteer’s legs and pelvic region. The defining markers, which enabled Visual 3D to reconstruct the digital skeleton of the volunteers, included the following anatomical positions: ASIS (Anterior Superior Iliac Spine), PSIS (Posterior Superior Iliac Spine), greater trochanters, thigh, shanks, lateral, and medial side of knee joint line, lateral and medial malleolus, heel marker was placed on the posterior side of the calcaneus of both the legs and two markers were placed on the first and fifth metatarsal bone of both the legs. After the static trial, heel, knee and hip markers were not needed so were removed during the motion trial.

The OQUS cameras and the Qualisys Motion Capture System, Sweden were used to film the volunteers walking along a 50 meter rectangular walkway. Each volunteer first walked along the walkway at their self-selected speed without any load. This was used to establish a baseline and then, in random order, they walked along the walkway while carrying 40% of body mass of individual volunteers [3] load on head, across one shoulder and hand (frontal plane). Each volunteer followed the same protocol for the testing conditions. The volunteers were allowed to walk on both the force plates (Kistler, Switzerland). Force plate-1 and force plate-2 were stepped by left foot and right foot respectively. The volunteers were asked to walk for 15 minutes during which the activity was recorded by the OQUS infrared digital cameras and was considered for
analysis. Resting and peak heart rates were also noted for each activity. Three modes of walking were selected i.e. carrying (40% of body mass in Kg) load on head, shoulder and hand load on frontal plane.

3.4 Data-Processing
To record the motion and force plate data the software Qualisys Track Manager was used and was analyzed by Qualisys Visual 3D software (professional version). The gait parameters and Energy Expenditure Index were generated for each of the volunteers and comparison was made between young and aged workers with different modes of load carriage.

4. RESULTS AND DISCUSSIONS
The volunteers were comprised of 20 healthy industrial workers in the age range of 20–55 years (38.1±12.99 years). None of the volunteers had any history of neurological or orthopedic disorders likely to affect their mobility. Volunteers were excluded from the study if they had any health problem like arthritis, diabetic feet or Parkinson’s disease.

Table 1. Demographic parameters of the subjects

<table>
<thead>
<tr>
<th>Variables</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>BMI (Kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ±SD</td>
<td>38.1 ±12.99</td>
<td>167.4 ±7.45</td>
<td>63.9 ±7.02</td>
<td>22.85 ±2.42</td>
</tr>
<tr>
<td>Range</td>
<td>20–55</td>
<td>157 -182</td>
<td>54 -77</td>
<td>17.17 -26.80</td>
</tr>
</tbody>
</table>

Walking speed was maximum while carrying load on head (4.19±0.55 km/hr) and minimum while carrying load in hand (3.94± 0.84 km/hr). Comparison of stride width shows that it increases from head load (1.20±0.45 m) to hand load (1.19±0.01 m) to shoulder load (1.12±0.04 m). Since, load on hand creates a moment arm anterior to spine and shifts the Centre of Gravity outside the body, hence, to counteract shifting of Centre of Gravity, there is increase of Base of Support (stride width) with hand load (0.46±0.04 m). Decrease in speed and increase in stride width is a sustained effort to maintain the stability while carrying load [4]. Wide-based gait is considered indicative of imbalance [2]. So, hand load caused maximum imbalance as speed decreased and stride width increased which indicated as adaptability for the workers to carry on their work and it had more adverse impact on elderly workers.

Study of Guha Thakurta et al, 2016 [10] conducted on young and aged workers shows that stride length of young groups found to be maximum while carrying load on hand. The minimum stride length was found while carrying load on head for both the groups. The stride length was found maximum for aged workers while carrying load on head and it was found minimum for them while carrying load.
on hand. Overall stride length was found to be greater among younger workers compared to aged workers. Rose et al [7] shows similar result, in which young adults showed a greater increase than did the aged subjects. While the changes in gait characteristics were relatively small for the young subjects, the older population was affected to a greater extent thereby demonstrating a greater sensitivity to load magnitude in a load carriage task.

**Table 3. Biomechanical parameters with modes of load carriage**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average Twisting Velocity (deg/sec)</th>
<th>Probability of LBD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Load</td>
<td>0.98 ± 0.41</td>
<td>16.0 ± 6.63</td>
</tr>
<tr>
<td>Shoulder Load</td>
<td>1.12 ±0.63</td>
<td>16.9 ± 5.90</td>
</tr>
<tr>
<td>Hand Load</td>
<td>1.31 ±0.64</td>
<td>19.1 ± 6.31</td>
</tr>
</tbody>
</table>

Modes of load carriage has an impact on spinal movement and probability of low back disorder. In the present study Low Back Disorder (LBD) was predicted by the Ballet 2.0 software. It was observed that Average Twisting Velocity was least in case of head load (0.98±0.41 deg/sec) followed by shoulder load (1.12±0.63 deg/sec) and hand load (1.31±0.64 deg/sec). Accordingly, LBD was least in case of head load (16.0 ±6.63 %) followed by shoulder load (16.9±5.90 %) and hand load (19.1±6.31 %).

In Table-4, the heart rate (pre-work and post-work), heart rate cost in different load conditions have been presented. Table-5 shows oxygen consumption (VO₂) and the energy cost of work in different load conditions.

**Table 4. Heart rate responses with modes of load carriage**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre-load heart rate (beats/ min)</th>
<th>Post-load (beats/ min)</th>
<th>HR Cost (beats/ min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Load</td>
<td>74 ±12.45</td>
<td>124 ±15.78</td>
<td>50 ±10.54</td>
</tr>
<tr>
<td>Shoulder Load</td>
<td>79.1 ±10.17</td>
<td>132 ±10.96</td>
<td>52.95 ±10.88</td>
</tr>
<tr>
<td>Hand Load</td>
<td>80.2 ±9.11</td>
<td>137.6 ±11.39</td>
<td>57.45 ±10.04</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VO₂ (ml/kg/ min)</th>
<th>Oxygen cost of work (ml/kg/ min)</th>
<th>Energy cost of work (Jule/ min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Load</td>
<td>22.32 ±4.42</td>
<td>14.0 ±2.95</td>
<td>294.0 ±61.99</td>
</tr>
<tr>
<td>Shoulder Load</td>
<td>24.56 ±3.07</td>
<td>14.83 ±3.05</td>
<td>311.4 ±63.97</td>
</tr>
<tr>
<td>Hand Load</td>
<td>26.13 ±3.19</td>
<td>16.09 ±2.81</td>
<td>337.8 ±59.03</td>
</tr>
</tbody>
</table>

| M±SD          |                   |                                  |                                  |

There is a gradual increase in heart rate cost from head load (50±10.54 b/min) to shoulder load (52.95±10.88 b/min) and hand load (57.45±10.04) among the workers (Table 4). Also, response of energy cost shows that values are higher in hand load (337.8±59.03 Jule/min) and shoulder load (311.4±63.97 Jule/min) in comparison to head load (294.0±61.99 Jule/min) (Table 5).

**Table 5. Oxygen consumption and energy cost with modes of load carriage**

The results of the study demonstrated that workers displayed significantly different gait patterns under experimental conditions. Carrying methods had an effect on all the gait
parameters like stride length and walking speed. Based on the results of this study, it is needed to consider gait parameters to understand the workload on carrying tasks. Workers could not sustain large stride length, normal walking speed because of load that was placed in the front in the hands of the workers. Such load placement restricted walking pattern of the workers. The study revealed that comparing the three modes of load carriage the gait deviation were found to be less during head mode of load carriage compared to the hand mode and shoulder mode of load carriage among the workers.

5. CONCLUSIONS

This study examined the effect of three modes of load carrying method on the walking patterns of the industrial workers. Present study indicated that head loading has certain important advantages over hand loading and shoulder loading considering the effect on workers gait. Most particularly it is possible to carry greater loads on the head for longer duration and it is generally considered to be more comfortable for the manual workers. Minimizing all those biomechanical changes seems a rational design goal for the industrial workers doing manual handling of load.

6. REFERENCES


[10] Arundhati Guha Thakurta, Rauf Iqbal and Amitabha De: The Influence of Three Different Load Carrying Methods on Gait Parameters of Indian Construction Workers. MOJ Anatomy & Physiology, 3(4), 00098, 2017