Effect of neck posture on cervicothoracic loads in overhead crane operators

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Effect of neck posture on cervicothoracic loads in overhead crane operators

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Awkward neck postures are commonly documented to be associated with an increased risk of neck disorders. This study intended to continuously monitor and evaluate neck postures and to estimate the cervicothoracic loads among overhead crane operators during work time. Neck postures were measured among 40 randomly selected operators by an inclinometer during 2 h of work time. To determine the tasks and adapt the posture recordings to each of their corresponding tasks, direct observation was conducted concurrently. The median neck flexion and lateral bend angles were 28.23° and 11.30°, respectively. The mean compression and shear loads on the neck ranged from 75.22 to 113.14 N and from 9.50 to 41.11 N, respectively. The results indicated substantial levels of exposure to awkward and extreme neck postures among the operators. The nature of the operators’ work and the visual requirements of some tasks will increase the mechanical loads on the neck.

Keywords: cervicothoracic loads; musculoskeletal disorders; overhead crane operator; neck posture

1. Introduction

Neck pain and musculoskeletal disorders (MSDs) are believed to have a complex and multifactorial nature. Physical risk factors such as awkward neck postures (neck flexion and rotation (and repetitive movement as well as work-related psychological risk factors are involved in neck pain and MSDs. Concerning physical risk factors, a significant correlation has been found between neck pain and risk factors such as workstation design, prolonged awkward posture in the neck and shoulder regions, sitting duration and hand-arm vibration [1–3].

MSDs in the neck region have often been reported to be due to the nature of the work and its associated risk factors. Based on epidemiological studies, MSDs are prevalent among crane operators. In these cases, almost 90% of crane operators constantly suffer from some MSDs mainly in the upper back, neck, lower back and shoulders [4]. Gustafson-Söderman [5] indicated that almost 70% of crane operators have experienced discomfort in their back and neck due to prolonged sitting with forward-flexed postures.

Overhead crane operators are a group of crane operators who perform various tasks mostly in an awkward posture in the neck, shoulder and back regions. The neck posture of overhead crane operators is influenced by several factors including the cabin design, load position and anthropometric characteristics of operators during the operation. In effect, during the operation, awkward postures are the most important risk factors causing MSDs in the neck of overhead crane operators. Since the line of sight of overhead crane operators is below the horizontal line, operators need a wide field of view with flexed postures of the neck and lower back while performing tasks, particularly in loading and unloading tasks. In general, awkward postures of the neck, shoulders, wrists and lower back are observed while performing tasks throughout the day. Accordingly, postures with neck and trunk flexion and arm diversion are common among overhead crane operators. Similarly, Burgess-Limerick et al. [6] have shown that neck flexion increases lever arm and biomechanical loads on the cervical spine. The increase of compression, shear load and muscle fatigue in the neck are important risk factors which can lead to neck pain and disorders. Therefore, risk factors such as the angle, duration and variation of postures in the neck during the full workshift can be considered the main risk factors from the biomechanical view of point, particularly in overhead crane operators in a full-shift exposure.

To date, several qualitative studies have been conducted about musculoskeletal problems in overhead crane operators based on self-reports and observational techniques. However, there are few quantitative and biomechanical studies on the musculoskeletal system of operators while performing their tasks during a full workshift. As an example, Munro [7] examined the postural demands of overhead crane operators using a video-based method. In this study, trunk angles were estimated from video
recordings using markers on the far wall of crane cabins. Another study conducted by Ray and Tewari [8] evaluated the ergonomic design of the crane cabin. To that end, postures of crane operators were analyzed by a real-time observational method. This way, the main postures and their duration were identified only by observation. Epidemiological studies have recommended the use of direct measurement as a suitable device for an accurate assessment of postures. The primary advantages of direct measurement techniques over observational methods are their higher rates of accuracy, lower costs and higher levels of reliability. Similarly, some recent studies have proven that some direct measurement techniques are more affordable than observational methods [9,10].

Regarding the high prevalence of MSDs, in particular, in the neck regions of the crane operators, we performed a biomechanical study on crane operators’ necks to identify ergonomic risk factors during their work time and provide a practical guideline to improve their ergonomic conditions. In effect, this study intended to provide a kinematic analysis of their neck postures during a workshift based on a direct method using long-term inclinometry. Therefore, the main objectives of this study were: (a) to continuously monitor and evaluate neck postures; (b) to estimate the cervicothoracic loads among overhead crane operators during work times. The results from this study are expected to provide useful information for the development of a cost-effective injury prevention strategy.

2. Materials and methods
The present study was conducted in four steel industries manufacturing steel plates, black plates and reinforcing bars. The structural specifications of most overhead cranes used in these industries to carry steel, hot slabs, hot rolled coils, cold rolled coils, etc., were the same, including a movable cabin design, chair, air conditioner, visibility and the capacity of the cabin. However, the cranes were static in some of these industries, although there were fewer static cranes than movable ones. Approximately 85% of the cabins were at a height of 12 m from the ground.

2.1. Participants
In this study, 10 operators from each industry and a total of 40 operators from the four steel industries were randomly selected to take part in the study. Table 1 presents the demographic characteristics of the participants. Their mean age was 35.24 years; their mean work experience was 10.42 years. As regards the inclusion criteria, we included those operators who were right-handed, older than 25 years, weighed less than 85 kg and were shorter than 180 cm, with experience of more than 5 years. People with spinal surgery and significant vertebral deformity resulting from any etiology were excluded from participating in this study. Before making observations, all participants were briefed on the study’s objectives and they were required to complete an informed consent, which was approved by the Ethics Review Committee of Tehran University of Medical Sciences.

<table>
<thead>
<tr>
<th>Demographic variable</th>
<th>M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>35.24 (5.1)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.21 (4.6)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74.81 (5.7)</td>
</tr>
<tr>
<td>Work experience (years)</td>
<td>10.42 (3)</td>
</tr>
</tbody>
</table>

Table 1. Mean (SD) demographic characteristics of the overhead crane operators (N = 40).

2.2. Describing tasks
Overhead crane operators spend most of their work time in a sitting posture in a crane cabin during the workshift. To determine the tasks of overhead crane operators and adapt the posture recordings to each of their corresponding tasks, direct observation was conducted concurrently with recording posture data for 2 h and postures and mechanical loads on the cervical region were estimated, based on the observed tasks.

The working process and the tasks of the overhead crane operators were recorded using a video compact digital camera (Canon, Japan). After observing the work process and tasks performed, it was found that the operators perform four main tasks to complete a work process. This process lasts almost 35 min and is repeated during an 8-h shift. The tasks performed in this process include: (a) the operator transfers the cabin to the storage site of the bundles of metal rods using the control panel and levers; (b) the operator performs the necessary adjustments to place the electromagnet on the bundles of metal rods with respect to its field of view at a height of 12 m above the ground; (c) after the safety conditions and loading confirmation are provided, the operators transfer the loads to the discharge hall in a short distance (between 50 and 80 m); (d) finally, loads are discharged in a certain location (unloading). This step, like the second task, requires the operator’s precision and field of view.

2.3. Study equipment
Neck inclination angles including flexion–extension and lateral bending of the neck in relation to the vertical were recorded using inclinometers, with a triaxial accelerometer geometry modeled virtual corset (VC) (Microstrain, USA). The inclinometer is a light, wireless, battery-powered, pager-sized (72 g, 6.8 cm × 4.8 cm × 1.8 cm) portable logger with 2 MB of onboard memory and a sample rate of 7.5 Hz. The validity of this instrument has been previously confirmed in the study of trunk and neck posture analysis [10,11].
2.4. Procedure, data collection and processing

Neck inclinations in the sagittal and transverse planes were recorded, using the inclinometer with triaxial accelerometer geometry modeled VC, continuously over a 2-h period while the operators were performing their normal assigned tasks.

The inclinometer was placed on the operators’ foreheads using tape. Prior to data collection, the reference posture was recorded when the operator was standing upright, looking at a mark at eye level. Upon completion of the observation, the raw signals were downloaded to a personal computer for analysis. Prior to signal analysis, the inclinometer’s signals were filtered with a low pass of 3 Hz and a fourth-order Butterworth filter. Amplitude probability distribution functions (APDF) were also calculated for the inclinometer data [12]. The 10th, 50th and 90th percentiles of the APDF referred to low, median and peak angles. The limits for neutral, non-neutral and extreme flexion and lateral bend postures were defined based on Standard No. EN 10054:1996 [13]. All intended parameters were calculated using custom programs developed in MATLAB version R2007B.

2.5. Estimation of cervicothoracic loads

Compression and shear loads on the neck (C7/T1) for each task were calculated based on the following equations [14,15]:

\[
FC_{C7/T1} = \frac{9.81 \times (TBW) \times (HW\%) \times \cos \theta}{5} + \frac{9.81 \times [(TBW) \times (HW\%) \times (HCL\%)] \times \sin \theta}{5} 
\]

and

\[
FS_{C7/T1} = 9.81 \times [(TBW) \times (HW\%)] \times \sin \theta, 
\]

where \( FC_{C7/T1} \) = compression force; \( FS_{C7/T1} \) = shear force; \( HCL\% \) = length from head center of gravity to C7/T1 as the percentage of total body height; \( HL\% \) = neck length as the percentage of total body height; \( HW\% \) = head weight as the percentage of total body weight; \( TBH \) = total body height; \( TBW \) = total body weight; \( \theta \) = neck angle.

Neck angles (\( \theta \)) were determined for each subtask based on the task analysis during work time. For each task, median (50th percentile) neck angles were calculated using the start and stop times from the observation data. To estimate the median cervical spine loads, median neck angles resulting from the tasks along with the anthropometric data were entered into the biomechanical model.

2.6. Statistical analysis

All statistical analyses were performed using SPSS version 16.0. The Kolmogorov–Smirnov test was used to examine the normality of the distribution of data. All data were tested to be normally distributed. A repeated-measure analysis of variance was applied considering the percentiles of neck posture and the mechanical loads data as dependent variables and tasks differently as independent variables. As the sphericity assumption was not met for some variables (\( p < 0.05 \) in Mauchly’s test) the results obtained by Greenhouse–Geisser adjustment were considered.

3. Results

3.1. Neck posture

Table 2 presents APDF analysis of the neck angles and angular velocity during the work process for each task. As shown in Table 2, the median neck flexion and lateral bend angles were 28.23° and 11.30° during work time, respectively.

The results of task analysis showed that the maximum and minimum median neck flexion angles belonged to loading and transferring the cabin, respectively. Generally, significant differences were found in the neck flexion angles between transferring the cabinet and doing other tasks at the 50th and 90th percentile APDF (\( p < 0.05 \)), while no significant difference was found between the loading and unloading tasks. On average, crane operators spent 53.41% of their work time with their neck flexed in non-neutral and extreme postures (Figure 1). Besides, the angular velocity was low in all tasks for the neck region. Significant differences were also found for neck angular velocity in tasks at the 90th percentile APDF (\( p < 0.05 \)).

3.2. Cervicothoracic load

Compression loads on the neck ranged from 75.22 to 113.14 N, while shear loads ranged from 9.50 to 41.11 N (Figure 2). Statistically, a significant difference was identified between loads of the four targeted tasks. The maximum and minimum mechanical loads were related to loading and transferring the cabin, respectively.

4. Discussion

In the present study, neck posture and angular velocity of the overhead crane operators were measured through continuous monitoring by long-term inclinometry. The biomechanical load on the neck of overhead crane operators while they were performing various tasks was calculated based on the obtained kinematic and anthropometric data. Generally, the results of kinematics analysis showed that overhead crane operators spent 26.72% of their work time with their neck flexed in extreme postures (>45° ) during the workshift. Moreover, a significant difference was found between the mechanical loads on the C7/T1 joint during the tasks requiring more accuracy and visual ability on the operators’ part than other tasks performed by them.
Table 2. Head postures and movements during work and each task among 40 crane operators.

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Task</th>
<th>Work</th>
<th>Transferring the cab</th>
<th>Unloading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck flexion (°)</td>
<td>APDF 10th</td>
<td>7.13</td>
<td>3.18&lt;sup&gt;B&lt;/sup&gt;</td>
<td>8.41&lt;sup&gt;D&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>APDF 50th</td>
<td>28.23</td>
<td>13.00&lt;sup&gt;A,B,C&lt;/sup&gt;</td>
<td>31.31&lt;sup&gt;D&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>APDF 90th</td>
<td>38.51</td>
<td>17.32&lt;sup&gt;A,B,C&lt;/sup&gt;</td>
<td>41.13&lt;sup&gt;D,E&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>APDF(10th–90th)</td>
<td>31.53</td>
<td>14.14</td>
<td>32.72</td>
</tr>
<tr>
<td>Neck lateral bend (°)</td>
<td>APDF 10th</td>
<td>4.82</td>
<td>4.82&lt;sup&gt;A&lt;/sup&gt;</td>
<td>6.33&lt;sup&gt;D&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>APDF 50th</td>
<td>11.30</td>
<td>2.82&lt;sup&gt;A,B&lt;/sup&gt;</td>
<td>12.56&lt;sup&gt;D&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>APDF 90th</td>
<td>13.33</td>
<td>5.55&lt;sup&gt;A,C&lt;/sup&gt;</td>
<td>14.52&lt;sup&gt;D,E&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>APDF(10th–90th)</td>
<td>17.82</td>
<td>4.55</td>
<td>8.19</td>
</tr>
<tr>
<td>Movement velocity (°/s)</td>
<td>APDF 10th</td>
<td>1.51</td>
<td>1.51&lt;sup&gt;B&lt;/sup&gt;</td>
<td>1.63</td>
</tr>
<tr>
<td></td>
<td>APDF 50th</td>
<td>13.81</td>
<td>1.34&lt;sup&gt;A&lt;/sup&gt;</td>
<td>17.25&lt;sup&gt;D&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>APDF 90th</td>
<td>35.73</td>
<td>15.51&lt;sup&gt;A,C&lt;/sup&gt;</td>
<td>38.73&lt;sup&gt;D&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Note: APDF = amplitude probability distribution functions; for flexion/extension, positive angles denote flexion and negative angles extension; for lateral bending, positive angles denote right and negative angles left. Superscript letters indicate significant differences \((p < 0.05)\): ^1transferring the cab vs loading; ^2transferring the cab vs transferring the load; ^3transferring the load vs unloading; ^4loading vs transferring the load; ^5loading vs unloading; ^6transferring the load vs unloading.

![Figure 1. Percentage of time spent in neck flexion and lateral bend postures.](image)

Note: Error bars denote SD. The full color version of this figure is available online.

### 4.1. Neck posture

Overhead crane operators are commonly working in a sitting position, more often with their neck and back bent forward and their arms below shoulder level for prolonged time periods.

According to the results, the median neck flexion among operators was 28.23° during 2 h of work time. Such a long-term neck flexion angle of more than 20° is believed to be a contributing risk factor for neck and shoulder pain due to static contraction of neck muscles [3,16]. In this concern, Weon et al. [17] concluded that sitting activities with long-term forward head posture may lead to pain in the neck and shoulders during work time compared with a neutral head posture.
Some tasks of the overhead crane operators, such as continuous monitoring of the transport and loading and unloading processes, require high visibility and attention on their part. Likewise, the results of kinematic analysis of the neck postures during their typical daily activities showed that the maximum neck flexion angle mostly belonged to such tasks. Studies have shown that high demands of concentration and visibility while performing tasks can be an important factor in creating more neck flexion for the operators. Courtney and Chan [18] conducted a study on grab unloader operators and found that while performing some tasks, particularly loading below the horizon line, the operators had to work with forward flexed postures of the neck almost 50% of their work time. They believed that this could lead to a static load and fatigue on the neck regions. In fact, neck posture is deemed to have a significant effect on the activity level of the neck muscles and the neck flexion can lead to greater muscle activity in the neck muscles as compared with the neutral and extension postures [19].

Considering the percentage of time spent with awkward neck postures, the results showed that operators were exposed to neck posture of 20° and 45° for 25.72 and 26.75% of their work time, respectively. The results of different jobs showed a positive trend in the relationship between neck flexion and neck pain. The risk of neck pain increases in those operators who perform more than 70% of their work with a flexed neck at a minimum flexion angle of 20° [20]. To explain this point, it is believed that the crane operators usually have a non-neutral head posture 80% of their work time, and compared with other sitting jobs such as office workers and straddle carrier drivers, the head posture of crane operators is almost static [21].

Compared to other sitting jobs, our results suggest that overhead crane operators may experience higher proportions of neck flexion angle at the 50th percentile neck postures than dentists [22], dental hygienists [23], air-traffic controllers [24] and office workers [25]. This difference may be due to the nature of their work and task demands compared with other sitting jobs. In the current study, the median neck posture variation (difference between the 90th and 10th percentiles) was 31.52°. This narrow variation indicates high static loads in the neck during long-term activities. The lack of postural variation and constrained posture of the neck for a prolonged period may be one of the main risk factors in the development of fatigue and pain in the neck–shoulder region among overhead crane operators [23,24].

Low angular velocity and lack of postural variation for the neck in each task showed that the postures are constrained during work. Physical risk factors, such as constrained postures as well as repetitive movements, have been suggested as risk factors for the neck and arms [20,24]. Thus, as constrained postures are likely characterized by a combination of low velocities and continuous muscular activity, it is important to describe both aspects.

4.2. Cervicothoracic loads

The increased loading on the C7/T1 joint and muscles of the cervical spine as a result of the forward head flexion may contribute to work-related neck and upper limb disorders by increasing loads on the disc and tissues. The results of task analysis showed that the amount of loads on the C7/T1 joint increased as the head flexion angles increased for visual requirements of the tasks. Many experimental
studies have demonstrated that looking down to a visual display unit will increase lower cervical flexion, causing increased demands on the neck extensor muscles to support the weight of the head [26,27]. In effect, the greater neck forward flexion will significantly lengthen the lever arm. In these situations, the weight of the head acts to create a moment in the cervical spine. Thus, the moment which the muscles controlling the flexion of the cervical spine develop will be intensified extremely. Based on this statement and neck flexion angles measured in the overhead crane operators, it can be concluded that the mechanical load on the C7/T1 joint is high and long-term exposure may be dangerous.

In another study, Newell and Kumar [14] used a video-based method and reported mean instantaneous loads on the C7/T1 joint for sitting tasks in orthodontists. The findings showed that the mechanical loads on the C7/T1 joint of the dentists were greater than the loads in overhead crane operators. The neck flexion angle was estimated to be 55° in some dentistry tasks, while the critical task that had led to an excessive increase in the neck angle of overhead crane operators was determined to be 31.53°. This difference may be related to the job nature and the task demands of these two jobs. In addition, data recording and analysis of neck posture is one of the important factors in estimating mechanical loads, which may lead to the difference in estimating loads [28]. This study recorded neck postures using an inclinometer as its sampling rate (7.5 Hz) was more than twice the acceptable sampling rate through video, as has been recommended by Andrews and Callaghan [29].

It was found that prolonged exposure to awkward neck posture and the frequency of adopting a flexed neck posture in each task could increase the risk of neck injury among overhead crane operators. In turn, cumulative biomechanical loads represent a combination of the intensity, duration and frequency of the exposure combined into a single daily dose. Cumulative loads have been shown to be an important independent predictor of MSDs [14,30,31].

Although the present study only estimated instantaneous loads, the results indicated that the operators spent more than 50% of their work time with an angle greater than 20°. This finding shows that the crane operators may be exposed to high cumulative loads on their neck. Thus, further study is recommended to assess the cumulative loads on their neck for an entire workshift.

In general, according to the findings, it seems that with the implementation of administrative and engineering controls, the risk factors contributing to the development of neck disorders can be controlled. For instance, engineering controls including the use of video surveillance in the cabins has been recommended to reduce the posture load on the operators’ neck [7]. Management controls increase the occupational variation through developing jobs to provide a variety of postures for dynamic situations. In turn, organizational management measures such as reducing the work time and determining an appropriate work–rest regime may prevent the operators from developing chronic lower back pains. Likewise, Nordander et al. [32] concluded that in industrial, office and non-industrial occupations, repetitive/constrained conditions increase the risk of MSDs in the neck and shoulders as compared with varied/mobile work. In this condition, programs for the prevention of MSDs in the neck must focus on reducing work time in sitting postures and increasing dynamic postures [20].

4.3. Limitations

In the present study, we evaluated the neck postures of operators at a height of 12 m above the ground; however, cranes that are either higher or lower will have different visibility and, therefore, we recommend assessing the effect of different crane heights on head postures.

The second limitation of the study was that the inclinometer was not able to measure axial twisting. However, axial twisting at the neck has been associated with neck discomfort and injuries [16]. Thus, considering this point in a future study would be worthwhile.

5. Conclusion

Based on the kinematic evaluation of their neck, due to the nature of their work and cabin design, the crane operators were exposed to awkward postures in the neck region long term, which was associated with the development of MSDs and injuries. Furthermore, it was found that there was a significant difference between the mechanical loads exerted on the neck during some tasks requiring excessive head flexion and the tasks with lower flexion. Besides, compared to other high-risk jobs involving neck-intensive work, crane operators are likely to have higher exposure rates. Since the visual field appears to be the main cause for these awkward postures, engineering controls that address visibility will be important. In addition, administrative measures addressing work schedules and the work–rest regime may be required.

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