GROUPING OF WORKING POSTURES IN AN AUTOMOBILE ASSEMBLY LINE CONSIDERING WORKING AREAS AND THE SIMILARITY OF WORKING POSTURES

SungHyuk Kwon¹, Byungkee Chae², Seokhee Na¹, Min K. Chung¹, Young W. Song³

¹Department of Industrial and Management Engineering, Pohang University of Science and Technology, San 31, Hyoja-dong, Nam gu, Pohang, Gyeongbuk, Korea
Corresponding author’s e-mail: na@postech.ac.kr

²Mobile communications division, LG electronics, Seoul, Korea

³Department of Occupational Health, Catholic University of Daegu, Hayang-eup, Gyeongsan-si, Gyeongbuk, Korea

Abstract: Identifying the risk factors of work-related musculoskeletal disorders (WMSDs) requires much time and cost for an automobile assembly line which may include hundreds of unit tasks. We characterized and grouped unit tasks for an automobile assembly line to solve these problems. 751 unit tasks were classified into three categories (interior, exterior and underbody) and 36 subcategories, considering the similarity of working postures. For each subcategory, a representative posture was chosen and identified by analyzing the postures of the five body parts (neck, shoulder, elbow, trunk and leg). For 36 subgroups, 20 representative postures were definitely selected for the corresponding subgroup. In addition, WMSD risk factors for each subgroup were assessed by evaluating the postural load of each representative posture. Most interior tasks showed high postural loads on the trunk, and most exterior and underbody tasks showed high postural loads on the neck and shoulder.

1. INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) are a group of painful disorders of muscles, tendons and tendon sheaths. They also comprise nerve entrapment syndromes, joint disorders, and neurovascular disorders (Erdil & Dickerson, 1997). There are three risk factors causing WMSDs - individual factors, psychosocial factors and physical factors (Winkel & Mathiassen, 1994; NIOSH, 1997). Physical factors including repetitive/prolonged activities, awkward and/or static posture, vibration, force exertion, localized stress, and cold temperatures are the main factors of WMSDs (Hagberg et al., 1995; Bernard, 1997). Among physical factors, awkward posture with external load is one main factor of WMSDs (Armstrong, 1986; NISOH, 1997).

Awkward postures are often observed in automobile assembly lines. This is because many components must be assembled inside or on the bottom of an automobile which has very limited space (Engstrom et al., 1999; Kim et al., 1998). The symptom reporting rate of musculoskeletal disorders exceeds 50% in automobile assembly lines because of awkward postures and other related risk factors (Kim 2001; Hussain, 2004; Zetterberg et al., 1997). Therefore, research effort should be addressed to working postures in automobile assembly lines to reduce WMSDs and to assure a safe work environment. Kim et al. (1998) categorized the working area as the interior, exterior, and bottom of an automobile. They determined possible working postures corresponding to each category of the working area by brainstorming.

The objective of this study was to identify WMSDs-related problems for automobile assembly lines. First, working postures for each category of the working area were identified by observing pictures from actual workplaces. Second, working postures were classified into groups. Then, by identifying the representative posture for each group, WMSDs-related problems of each working area were identified.
2. METHODS

This study is composed of the following four stages: (1) selecting tasks to be analyzed, (2) clustering analysis, (3) identifying representative postures, and (4) identifying WMSDs-related problems for each working area.

2.1 Target unit tasks

751 unit tasks of two SUV assembly lines for a Korean automobile manufacturing company were selected for this study. The symptom reporting rate of WMSDs was higher in assembly tasks than any other task in the automobile industry (Hyun et al., 2002). Kim et al. (2001) found that the symptom reporting rate of musculoskeletal disorders for SUV assembly lines were higher than that of passenger car assembly lines.

2.2 Clustering analysis

2.2.1 Variables

In this study, the working area and the posture were selected as the variables for classifying unit tasks. We define working area as the location where the assembly tasks are conducted. Working area was categorized into interior, exterior, and underbody (Kim et al., 1998). Then, considering the specific location of the working area, each category was divided further into detailed subcategories. When the working area is the interior of a car, the position of the worker must also be considered because the worker’s position can be either inside or outside of the car, as shown in Figure 1. The categorization results of the working area are shown in Table 1 and Figure 2.

![Figure 1. Examples of different working postures for the same detailed working areas](image)

Table 1. Categorization of working areas

<table>
<thead>
<tr>
<th>working area</th>
<th>worker position</th>
<th>codes</th>
<th>detailed working area</th>
<th>codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>interior</td>
<td>interior</td>
<td>1</td>
<td>ceiling</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>floor</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>side (+ dashborad)</td>
<td>3</td>
</tr>
<tr>
<td>exterior</td>
<td>ceiling</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>floor</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>side (+ dashborad)</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>exterior</td>
<td>side, interior</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ceiling, exterior</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>side, exterior</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>bonnet</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>exterior</td>
<td>1st box</td>
<td></td>
<td>side</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>ceiling</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>side</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>hatch back</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>underbody</td>
<td>underbody</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>side</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Neck, shoulders, elbows, back, and legs were selected as body parts for posture categorization. Then, for each body part, the postural classification scheme was provided in terms of the angle that each body joint makes. Table 2 shows the classification result. In general, neck, shoulders, elbow, wrist, back, and legs are considered in a postural classification scheme. Among these, the posture of wrists varies a lot for the same task, and is more heavily influenced by external load than by body posture (Na, 2006). Therefore, in our study, we excluded wrists. Table 2 shows the classification results.

The posture classification scheme of Chung et al. (2005) was used for neck, shoulder, back, and legs. For elbows, the posture classification scheme of Kee & Karwowski (2001) was used because Chung et al. (2005) did not consider elbows. The posture classification scheme of Chung et al. (2005) considered rotation and lateral bending of the neck and back. However, we excluded this motion from the body posture classification scheme for simplicity because the incidence of these body postures was very low on automobile assembly lines. For the same reason, unbalanced or awkward leg motions were also excluded.

<table>
<thead>
<tr>
<th>body segment</th>
<th>body posture classification</th>
<th>codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>neck</td>
<td>0<del>20° (F), 0</del>25° (E)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>20~45° (F)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>&gt; 45° (F)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>&gt; 25° (E)</td>
<td>4</td>
</tr>
<tr>
<td>shoulders</td>
<td>0<del>45° (F), 0</del>20° (E)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>45~90° (F)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>90~135° (F)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>&gt; 135° (F)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>&gt; 20° (E)</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0~45° (F)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>45~120° (F)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>&gt; 120° (F)</td>
<td>3</td>
</tr>
<tr>
<td>elbows</td>
<td>0<del>30° (F), 0</del>10° (E)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>30~60° (F)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>60~90° (F)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>&gt; 10° (E)</td>
<td>4</td>
</tr>
<tr>
<td>back</td>
<td>0~30° (F)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>30~60° (F)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>60~90° (F)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Sitting</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Squatting</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Kneeling</td>
<td>6</td>
</tr>
</tbody>
</table>
2.2.2 Clustering Methods

Clustering analysis was conducted for unit tasks of each working area (270 unit tasks for interior, 309 unit tasks for exterior and 172 unit tasks for underbody). For all working areas, the variables for the clustering analysis were posture of five body segments and detailed working area. As was described in the previous section, for the interior working area, one more variable, worker position, was used because the worker’s position can be either inside or outside of the car for this working area. First, the main working posture is selected for each unit task based on the time fraction in that unit task. Then, by analyzing a picture, relative variables were arranged. Table 3 shows an example of the data for a unit task whose working area is the interior of a car.

Table 3. An example of data arrangement for a unit task

<table>
<thead>
<tr>
<th>no</th>
<th>picture</th>
<th>neck</th>
<th>shoulders</th>
<th>elbows</th>
<th>back</th>
<th>legs</th>
<th>worker position</th>
<th>Detailed Working area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

The code related to each variable in this study has a nominal scale. Nominal scale data do not have magnitude or order. Therefore, by using degree of similarity (Bratchell, 1989), the number of clusters was decided by observing the increase in the following objective function

\[
\text{Objective function} = \frac{\sum_{j=1}^{m} \sum_{k=1}^{n_j} \sum_{j'=1}^{n_{k_j}} \text{sim}(X_j, X_{j'})}{\sum_{j=1}^{m} n_j C_2},
\]

where \( m \) is the number of clusters, \( n \) is the number of unit tasks for each cluster, \( \text{sim} \) is the similarity, \( X_j \) is the \( j_{th} \) unit task and \( X_k \) is the \( k_{th} \) unit task.

2.3 Identification of characteristics of each group

After clustering unit tasks into groups, the characteristics of each group (representative posture and representative working area) were identified using the mode of data. Because the scale used in this study is a nominal scale, the mode was used among other representative values.

2.4 Identification of WMSDs-related problems for each working area

Groups resulting from the clustering analysis were categorized by representative working area. From this categorization, characteristics of detailed working area in terms of the working posture and worker position could be identified. Each group, including a high portion of unit tasks having working postures and working areas different from the representative working postures and representative working areas of the group, was divided into subgroups by hierarchical clustering analysis. WMSDs-related problems are identified for each categorization based on the result of Chung et al. (2005) and Kee & Karwowski (2001) are shown in Table 4.

Table 4. Range of angle for each body joint causing high postural load

<table>
<thead>
<tr>
<th>neck</th>
<th>shoulders</th>
<th>elbows</th>
<th>back</th>
<th>legs</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 45° (SF)</td>
<td>&gt; 90° (SF)</td>
<td>&gt; 120° (SF)</td>
<td>&gt; 60° (SF)</td>
<td>&gt; 60° (SF)</td>
</tr>
<tr>
<td>&gt; 25° (SE)</td>
<td>&gt; 20° (SE)</td>
<td>&gt; 10° (SE)</td>
<td>Squatting posture</td>
<td></td>
</tr>
</tbody>
</table>

*: SF: severe flexion, SE: severe extension
3. CLUSTERING RESULTS

In this section, clustering results are represented for each working area (interior, exterior, and underbody). Then, representative postures and body parts under the risk of WMSDs are identified for resulting clusters.

3.1 Interior of a car

In the case that the working area is the interior of a car, initially, eight clusters were obtained as shown in table 5. Cluster 3 and 5 were classified further into two and three clusters respectively, because the modes of the detailed working area for those clusters were only 75% and 50% of the number of unit tasks for each cluster. For further classification, a hierarchical divisive clustering approach was used (Sneath & Sokal, 1973; King 1967; Sokal & Michener, 1958). As a result, tasks whose working area is interior of a car were classified into eleven clusters. Each cluster was differentiated from other clusters in terms of representative postures or detailed working areas.

Table 5. Initial clustering result (working area is interior of a car)

<table>
<thead>
<tr>
<th>Cluster</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of unit tasks</td>
<td>29</td>
<td>29</td>
<td>51</td>
<td>43</td>
<td>24</td>
<td>29</td>
<td>13</td>
<td>52</td>
<td>270</td>
</tr>
</tbody>
</table>

Table 6 illustrates the final result of K-means clustering and further classification considering worker positions and detailed working areas. For each cluster, the representative posture is provided in the form of a table. For example, if the worker position is in the interior of a car and the detailed working area is ceiling, then the representative working posture has severe extension of neck, moderate and severe flexion of shoulder, moderate flexion of elbow, neutral back, and sitting leg. Body parts under the risk of WMSDs are indicated by shading. Eight clusters out of eleven clusters included at least one shaded body part.

Table 6. Clustering result and representative posture (interior of a car)

<table>
<thead>
<tr>
<th>Worker position</th>
<th>Detailed Working area</th>
<th>Neck</th>
<th>Shoulder</th>
<th>Elbow</th>
<th>Back</th>
<th>Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior</td>
<td>Ceiling</td>
<td>N</td>
<td>MF</td>
<td>SF</td>
<td>SE</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Side (a)</td>
<td>MF</td>
<td>SF</td>
<td>SE</td>
<td>SE</td>
<td>SF</td>
</tr>
<tr>
<td></td>
<td>Side (b)</td>
<td>SF</td>
<td>SE</td>
<td>SE</td>
<td>SE</td>
<td>SF</td>
</tr>
<tr>
<td></td>
<td>Floor</td>
<td>SF</td>
<td>SE</td>
<td>SF</td>
<td>SE</td>
<td>SF</td>
</tr>
<tr>
<td>Exterior</td>
<td>Ceiling</td>
<td>MF</td>
<td>SF</td>
<td>SE</td>
<td>SE</td>
<td>SF</td>
</tr>
<tr>
<td></td>
<td>Side (a)</td>
<td>MF</td>
<td>SF</td>
<td>SE</td>
<td>SE</td>
<td>SF</td>
</tr>
<tr>
<td></td>
<td>Side (b)</td>
<td>SF</td>
<td>SE</td>
<td>SE</td>
<td>SE</td>
<td>SF</td>
</tr>
<tr>
<td></td>
<td>Side (c)</td>
<td>SF</td>
<td>SE</td>
<td>SE</td>
<td>SE</td>
<td>SF</td>
</tr>
<tr>
<td></td>
<td>Side (d)</td>
<td>SF</td>
<td>SE</td>
<td>SE</td>
<td>SE</td>
<td>SF</td>
</tr>
<tr>
<td></td>
<td>Floor (a)</td>
<td>MF</td>
<td>SF</td>
<td>SE</td>
<td>SE</td>
<td>SF</td>
</tr>
<tr>
<td></td>
<td>Floor (b)</td>
<td>SF</td>
<td>SE</td>
<td>SE</td>
<td>SE</td>
<td>SF</td>
</tr>
</tbody>
</table>

3.2 Exterior of a car

In the case of the working area being the exterior of the car, initially, eleven clusters were obtained as shown in table 7. Cluster 2 was classified further into three clusters based on the working posture and each of clusters 1, 3, 4, and 5 was classified further into two clusters based on the detailed working area. For further classification, a hierarchical divisive clustering approach was used. As a result, tasks whose working area is the interior of a car were classified into eighteen clusters. Each cluster was differentiated from other clusters in terms of representative postures or detailed working areas.

Table 7. Initial clustering result (working area is exterior of a car)

<table>
<thead>
<tr>
<th>Cluster</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of unit tasks</td>
<td>35</td>
<td>32</td>
<td>48</td>
<td>33</td>
<td>12</td>
<td>14</td>
<td>32</td>
<td>33</td>
<td>20</td>
<td>12</td>
<td>38</td>
<td>309</td>
</tr>
</tbody>
</table>

Table 8 illustrates the final result of K-means clustering and further classification considering detailed working areas. For each cluster, the representative posture is provided in the form of a table and body parts under the risk of WMSDs are indicated by shading. Fourteen clusters out of eighteen clusters included at least one shaded body part.

Table 8. Clustering result and representative posture (exterior of a car)

<table>
<thead>
<tr>
<th>Box</th>
<th>Detailed working area</th>
<th>Neck</th>
<th>Shoulder</th>
<th>Elbow</th>
<th>Back</th>
<th>Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>MF</td>
<td>SF</td>
<td>SE</td>
<td>NE</td>
</tr>
<tr>
<td>1st</td>
<td>Interior side (a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interior side (b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interior side (c)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>Top (a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Top (b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Top (c)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Top (d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exterior side (a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exterior side (b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exterior side (c)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bonnet (a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bonnet (b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd</td>
<td>Top</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Side (a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Side (b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Side (c)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Side (d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hatch-back</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.3 Underbody of a car

If working area is the underbody of the car, initially, five clusters were obtained as shown in table 9. Cluster 1 and 4 were classified further into two clusters based on the detailed working area. For further classification, a hierarchical divisive clustering approach was used. As a result, tasks whose working area is the underbody of a car were classified into seven clusters. Each cluster was differentiated from other clusters in terms of representative postures or detailed working areas.

Table 9. Initial clustering result (working area is underbody of a car)

<table>
<thead>
<tr>
<th>Cluster</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of unit tasks</td>
<td>33</td>
<td>39</td>
<td>53</td>
<td>30</td>
<td>17</td>
<td>172</td>
</tr>
</tbody>
</table>

Table 10 illustrates the final result of K-means clustering and further classification considering detailed working areas. For each cluster, representative posture is provided in the form of a table and body parts under the risk of WMSDs are indicated by shading. Four clusters out of seven clusters included at least one shaded body part.

Table 10. Clustering result and representative posture (underbody of a car)

<table>
<thead>
<tr>
<th>Detailed working area</th>
<th>Neck</th>
<th>Shoulder</th>
<th>Elbow</th>
<th>Back</th>
<th>Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>MF</td>
<td>SF</td>
<td>SE</td>
<td>N</td>
</tr>
<tr>
<td>Underbody</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underbody</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underbody</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underbody</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


4. DISCUSSION

In this study, body parts under the risk of WMSDs are identified from the representative working posture of each task group in the automobile assembly lines. Table 11 shows the proportion of body parts under the risk of WMSDs for different working areas.

Table 11. Proportion of risky body parts for different working areas

<table>
<thead>
<tr>
<th></th>
<th>Neck</th>
<th>Shoulder</th>
<th>Elbow</th>
<th>Back</th>
<th>Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior of a car (11 groups)</td>
<td>27%</td>
<td>27%</td>
<td>0%</td>
<td>36%</td>
<td>9%</td>
</tr>
<tr>
<td>Exterior of a car (18 groups)</td>
<td>33%</td>
<td>33%</td>
<td>0%</td>
<td>28%</td>
<td>11%</td>
</tr>
<tr>
<td>Underbody of a car (7 groups)</td>
<td>43%</td>
<td>71%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Total (36 groups)</td>
<td>33%</td>
<td>39%</td>
<td>0%</td>
<td>25%</td>
<td>8%</td>
</tr>
</tbody>
</table>
When the working area is the interior of a car and exterior of a car, the neck, shoulder, and back were under high risk of WMSDs. When the working area is the underbody of a car, the neck and shoulder were under high risk of WMSDs. Generally, neck and shoulder were more exposed to the risk of WMSDs than other body parts for SUV assembly lines.

For grouping similar unit tasks in terms of working postures and detailed working areas, clustering method, which is a kind of statistical approach, was used. Therefore, there are some groups where further discussion is needed when identifying representative working postures. Table 12 shows the proportion of each representative working posture for a total of 36 task groups. For 20 groups, the proportion of the representative working posture for each group was over 50%, which means that the identification of representative working postures is reasonable. However, for three groups, the proportion was below 20%. In this case, those groups can be divided further to obtain representative postures having a higher proportion or can be merged into other groups which have relatively higher similarity.

Table 12. Proportion of the representative working posture of each group

<table>
<thead>
<tr>
<th>Interior of a car</th>
<th>Exterior of a car</th>
<th>Underbody of a car</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling</td>
<td>55%</td>
<td>1st box Interior side (a) 59%</td>
</tr>
<tr>
<td>Side (a)</td>
<td>38%</td>
<td>1st box Interior side (b) 25%</td>
</tr>
<tr>
<td>Side (b)</td>
<td>37%</td>
<td>1st box Interior side (c) 42%</td>
</tr>
<tr>
<td>Floor</td>
<td>31%</td>
<td>1st box Top (a) 44%</td>
</tr>
<tr>
<td>Ceiling</td>
<td>50%</td>
<td>1st box Top (b) 74%</td>
</tr>
<tr>
<td>Side (a)</td>
<td>40%</td>
<td>1st box Top (c) 31%</td>
</tr>
<tr>
<td>Side (b)</td>
<td>50%</td>
<td>1st box Top (d) 42%</td>
</tr>
<tr>
<td>Side (c)</td>
<td>69%</td>
<td>1st box Exterior side (a) 100%</td>
</tr>
<tr>
<td>Side (d)</td>
<td>54%</td>
<td>1st box Exterior side (b) 18%</td>
</tr>
<tr>
<td>Floor (a)</td>
<td>40%</td>
<td>1st box Exterior side (c) 50%</td>
</tr>
<tr>
<td>Floor (b)</td>
<td>52%</td>
<td>1st box Bonnet (a) 63%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1st box Bonnet (b) 29%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2nd box Top 57%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2nd box Side (a) 56%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2nd box Side (b) 15%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2nd box Side (c) 39%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2nd box Side (d) 17%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2nd box Hatch-back 34%</td>
</tr>
</tbody>
</table>

In Figure 3, due to the different horizontal and vertical assembly locations for the same detailed working area, examples of different working postures for the same detailed working area (1st box top and 2nd box side) are illustrated. Therefore, further categorization of detailed working area should be taken into consideration based on the vertical and horizontal distance. For some groups, more than two groups should be unified because the working postures for those groups are much the same. Figure 4 shows an example of similar working postures for the two different detailed working areas.

Figure 3. Examples of different working postures for the same detailed working area
Despite some limitations, this study was done systematically using statistical methods. Therefore, the process and the result of this study will give some insights when the personnel in charge of identifying WMSDs related problems in a certain working areas. The results can be practically applied to the redesigning of current automobile assembly lines.

5. CONCLUSION

In this study, 751 unit tasks of two SUV assembly lines for a Korean automobile manufacturing company were classified into 36 groups using a clustering method based on the working postures and detailed working area. For each group, a representative working posture and body parts at risk were identified. 751 unit tasks were divided based on the working area (interior of a car, exterior of a car and underbody of a car). For each working area, clustering analysis was conducted based on the working postures and detailed working area. As a result, a total of 36 task groups were extracted (11 groups for interior of a car, 18 groups for exterior of a car and 7 groups for underbody of a car). For each group, a representative working posture was identified based on the mode of the working postures in the group. Finally, by analyzing the representative working postures, body parts at risk of WMSDs were identified for each detailed working area.

The contribution of this study is that body parts at risk for each detailed working area are systematically identified using a statistical method to check awkward posture related problems in the automobile assembly lines. The process and results of this study will be useful to personnel in charge of identifying the WMSDs related problems caused by awkward working postures as well as redesigning current automobile assembly lines.

There are some limitations to the practical implementation and wide use of these results. First, further subdivision of detailed working area, considering horizontal and vertical location, is needed to make sure that there aren’t too many working postures different from the representative working postures in the same detailed working area. Second, some groups have the same detailed working area and body parts at risk as well as slightly different representative working postures. Those groups can be combined into one group to simplify the analysis.

6. REFERENCES


