Ergonomic Analysis on Musculoskeletal Disorders of Slate Pickers in Coal Preparation Plant

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Abstract: Objective: the risk of the musculoskeletal disorders that the slate pickers of the coal preparation plant under a coal group suffer is evaluated and analyzed to bring forth an improvement solution by various means such as labor intensity measurement, questionnaire survey and posture analysis. Methods: the MetaMax 3B pulmonary ventilation volume gauge was adopted to measure the expiratory volume of the workers at working and breaking time to figure out the daily energy metabolic rate at work; then, a survey was conducted on the severity of workers' cumulative musculoskeletal disorders by means of Standardised Nordic Questionnaires for the Analysis of Musculoskeletal Symptoms (NMQ) and the Newly Developed Questionnaire for Work Related Fatigue Feeling (WRFFQ); afterwards, in combination with the Ovako Working Posture Analysis System (OWAS), a video survey was implemented on the workers, and besides, the freeze-frame was extracted from the video to observe the postures that appeared most frequently and then to work out the repeatability proportion of the working postures of every key body part. Results: there was a huge difference between the maximum and minimum daily average energy metabolic rates at work, with the former arriving at 6.0570 (kJ/min.m²) and the latter at 3.9682 (kJ/min.m²). The aching parts included waist, back and knee, and the waist achieved the highest score (31%), which manifested that the picking work in coal preparation plant had a greatest impact on the waist of workers. Of all work-related fatigue symptoms, waist pain had the largest weighted average value (4.89), which was higher than the overall average (4.34). According to observation, the postures that appeared most frequently consisted of forward bending, and standing, which fell into the category of grade AC3. Due to the high repeatability, these two postures have resulted in obvious damage to workers. Conclusions: because of the problems such as the high labor intensity and the uneven labor distribution of slate pickers, the hazardous operation, and the high repeatability, the physical and psychological health and production efficiency of the workers are severely influenced. For this reason, there is a need to take improvement measures as soon as possible. In view of this, two schemes including job rotation and seat installation are adopted and put into practice. The adjustment of job rotation scheme and the facility improvement during coal preparation and rock picking have balanced labor intensity, reduced working fatigue, upgraded working efficiency and provided practical guidance for the improvement in the occupational health and working environment of slate pickers in coal preparation plant.

Keywords: coal preparation plant, slate picker, musculoskeletal disorders, ergonomic analysis, working posture analysis

1. Introduction

Muscular Skeleton Disorders (MSDs) refer to damages or functional disorders that impact muscle, skeleton and nerve, etc. Workers are easy to generate symptoms of Muscular Skeleton Disorders in manual labor process. In the beginning, workers with lighter symptoms will have uncomfortable or mildly painful feeling. With the time accumulation, workers with serious symptoms often can't work and need medicines or special devices to treat. MSDs are a kind of general occupational diseases in industrialized countries and have larger frequency of occurrence, so it causes huge economic losses. Data display that disease proportion of MSDs occupies 31% of all occupational diseases in Finland. In America, growth rate of MSDs
has been raised to 61% of 1991 from 18% of 1981. Yearly insurance compensation costs are up to ten billions of dollars. In Canada, direct and indirect economic losses caused by MSDs every year nearly reach up to hundreds of billions of dollars. With the industrialization process of China, the tendency of Muscular Skeleton Disorders (MSDs) is aggravated constantly. Moreover, prevalence rate of all industries distributes unevenly. For example, workers who work in automobile assembly line are 42.4%, video workers are 42.6%, machining workers are 30.7%, and textile workers are 97%.

In China, coalmine production operation has characteristics of simple equipment, bad environment and shortage of safeguard procedures universally, resulting in higher morbidity of coal miners’ Muscular Skeleton Disorders. Here morbidity of lumbago and backache is 62.9%. Research report also displays that lumbago and backache are primary type of Muscular Skeleton Disorders for coal miners. Coal preparation plant is an important department in coalmine production chain. Workers choose waste rock (for short “rock picking”) by hand. There is bad working environment and very large labor intensity. According to field research, it can find that there are many occupational factors and non-occupational factors relate to MSDs in this work. Workers of rock picking often appear antverted and bending posture in operation process. Moreover, they need to bend forward and turn body to move and lift bulk waste rock. Workers work 8 hours per shift. During the period, belt conveyor operates all the time. Workers need to pick rock constantly and seldom have time to have a rest, resulting in fatigue body and work decrement. At present, general cultural quality of workers of rock picking in coal preparation plant is comparatively lower. They have insufficient self-protection awareness and don't care about body abnormality brought by excessive workload. However, when they realize it, it has already been developed into serious physical diseases. The occurrence of MSDs in workers of rock picking mainly focuses on repeated mechanical operation, transfer of heavy things and long-term operation with bad posture, etc., while long-term operation with bad posture is the most important factor that causes Muscular Skeleton Disorders (MSDs). It is necessary to adopt positive measures to evaluate and reduce bad posture of operation as soon as possible and avoid from impacting physical and mental health of workers continuously.

2. Objects and Methods

2.1 Respondents

This paper selects 56 workers of rock picking who work in coal washing workshop of certain coal mine in state-owned coal industry group of Gansu, China as respondents to be studied. 49 of them are females with average age of 36.8 years old. These workers work in assembly line of rock picking for a long time. This has bad work environment and has large workload. They often take a sick leave, because they feel mean. In survey process, a total of 54 questionnaires are granted. 51 effective questionnaires are recycled.

2.2 Research Methods and Tools

This paper applies questionnaire (NMQ) of Northern Europe standardized musculoskeletal symptoms, fatigued subjective symptom questionnaire, operation labor intensity determination, Ovako Working Posture Analysis System (OWAS), etc., to assess and analyze risk of sickening muscular skeleton disorders for workers of rock picking in coal preparation plant. According to evaluation data and analysis results, the paper puts forward improvement plan and put it into effect.

3. Human Engineering Analysis and Discussion

3.1 Survey of Musculoskeletal Symptoms

By applying questionnaire (NMQ) of Northern Europe standardized musculoskeletal symptoms, Through the questionnaire survey, it can be observed that common painful parts of workers mainly focus on waist, back, knee and neck. The waist is the highest (31%), and ankle is the lowest (2%). The findings indicate that workers of rock picking in coal preparation plant have the larger risk of sickening muscular skeleton disorders. Moreover, percent differences of appearing painful symptoms in each part are great.
3.2 Fatigued Subjective Symptom Survey

By applying Fatigued Subjective Symptom Survey proposed by society of Japanese industrial hygiene, the paper conducts a survey on feeling of fatigue for workers. According to results, it calculated score and weighted mean. The findings are shown in Table 1. Weighted mean in the Table expresses feeling intensity of workers’ fatigue, so as to show workload’s influence of strong and weak degree on operators.

Table 1. Fatigued Subjective Symptom Survey

<table>
<thead>
<tr>
<th>Fatigued Symptoms</th>
<th>Weighted Mean</th>
<th>Fatigued Symptoms</th>
<th>Weighted Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atony and sore</td>
<td>4.22</td>
<td>Shoulder ache</td>
<td>4.64</td>
</tr>
<tr>
<td>Backache</td>
<td>4.89</td>
<td>Legs’ pain</td>
<td>4.41</td>
</tr>
<tr>
<td>Pain of hands and fingers</td>
<td>3.85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Through data in the Table 1, it can be observed that the highest score is backache. The weighted mean is 4.89 scores, showing that operation rock picking has a greater influence on waist of workers. Secondly, Atony and sore of workers are also serious, because most of waste rocks in this working environment are heavy. In addition, shoulders and legs also bear larger fatigue damage. Degree of coincidence of 5 kinds of fatigued symptoms is higher. Mean of degree of coincidence is 4.34. The single comparison is backache > shoulder ache > legs’ pain > atony and sore > pain of hands and fingers.

3.3 Labor Intensity Measure

Labor intensity refers to the operators’ physical output and tension degree in the production process. Different labor intensity brings diverse energy consumed by human body in unit interval. From the perspective of labor physiology, it is relatively reasonable to rank by regarding energy metabolism as standard in line with the method stipulated in Manual Labor Ranking GB3869-83 of Chinese National Standards. The number of respondents in each station is 2-3 for tracing 3 days continuously, recording time of engaging in all kinds of labor and rest on workdays, selecting average value of three days and determining average labor time of workdays. It adopts MetaMax 3B pulmonary ventilation volume to measure expiratory air volume of various labor and rest. Corresponding energy metabolic rate, workdays and average energy metabolic rate are solved.

3.3.1 Calculation of Average Energy Metabolic Rate

According to field research, it knows about specific working process in workshop of rock picking. Raw coal is transferred to coal bunker through conveyor from coal outlet. Arrows in the figure point to moving direction of conveyor. Workers stand at both sides of conveyor with 7 people in each side. The station is divided into P1-P7 in line with direction of conveyor. Both sides at workers’ station are white waste rock groove and black waste rock groove. White waste rock is pure stone, while black waste rock contains a small quantity of flammable materials in its stone. Black waste rock has repeated value in use, so it should be divided from white waste rock. Raw coal is mingled with lots of black and white waste rocks. With the operation of belt conveyor, workers need to turn over raw coal constantly, pick out waste rock and put it into two grooves. It can be observed that when raw coal comes out from coal outlet, there is obvious bulk waste rock. Workers at P1 station need to bend to a large extent, put up bulk waste rock, turn around and throw it into waste rock grooves. In this process, it is easy to cause waist pain. Moreover, differences of workers’ pulmonary ventilation are obvious. There is unequal distribution of labor intensity. It can calculate average energy metabolic rate of work at each station, as shown in Table 2:
Table 2. Average Daily Energy Metabolic Rate Form of Single Action (kJ/min.m$^2$)

<table>
<thead>
<tr>
<th>Measured station</th>
<th>Energy metabolic rate of preparation time</th>
<th>Preparatory working time</th>
<th>Energy metabolic rate of rock picking</th>
<th>Rock picking operating time</th>
<th>Energy metabolic rate of rest</th>
<th>Rest time</th>
<th>Average energy metabolic rate on workdays</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>3.2035</td>
<td>27.9</td>
<td>6.9663</td>
<td>394.3</td>
<td>1.2315</td>
<td>57.8</td>
<td>6.0570</td>
</tr>
<tr>
<td>P2</td>
<td>3.2124</td>
<td>27.1</td>
<td>6.8973</td>
<td>395.4</td>
<td>1.2396</td>
<td>57.5</td>
<td>6.0115</td>
</tr>
<tr>
<td>P3</td>
<td>3.3089</td>
<td>26.7</td>
<td>6.0342</td>
<td>396.9</td>
<td>1.1021</td>
<td>56.4</td>
<td>5.3030</td>
</tr>
<tr>
<td>P4</td>
<td>3.1298</td>
<td>26.6</td>
<td>5.8365</td>
<td>397.1</td>
<td>0.9539</td>
<td>56.3</td>
<td>5.1138</td>
</tr>
<tr>
<td>P5</td>
<td>2.8573</td>
<td>26.2</td>
<td>5.5706</td>
<td>397.9</td>
<td>0.9987</td>
<td>55.9</td>
<td>4.8900</td>
</tr>
<tr>
<td>P6</td>
<td>2.9632</td>
<td>26.5</td>
<td>4.7853</td>
<td>397.9</td>
<td>1.4567</td>
<td>55.6</td>
<td>4.2991</td>
</tr>
<tr>
<td>P7</td>
<td>3.0386</td>
<td>26.6</td>
<td>4.4452</td>
<td>398.1</td>
<td>0.9823</td>
<td>55.3</td>
<td>3.9682</td>
</tr>
<tr>
<td>Average value</td>
<td>3.1019</td>
<td>26.8</td>
<td>5.7907</td>
<td>396.8</td>
<td>1.1378</td>
<td>56.4</td>
<td>5.0939</td>
</tr>
</tbody>
</table>

It can be observed from data in Table 4 that in the situation of less rock picking operating time by comparing with average value, energy metabolic rate of rock picking has large difference. Workers at P1 station have the biggest average energy metabolic rate on workdays. It reaches 6.0570 kJ/min.m$^2$, which is greatly larger than average value 5.0939 kJ/min.m$^2$. Workers at P7 station have the minimum average energy metabolic rate on workdays. It only is 3.9682 kJ/min.m$^2$. Daily energy metabolic rate of 7 operating stations still have large differences. Workers at P1 station have the biggest labor intensity, while workers at P7 station have the minimum labor intensity.

3.4 Analysis on Operation Posture

3.4.1 Introduction to Methods of Posture Analysis

Some overload postures of workers will increase the risk of sickening muscular skeleton disorders. Ovako Working Posture Analysis System (OWAS) was proposed by Finnish Ovako Oy Iron and Steel Company in 1973. This system videos working process of workers, extracts some typical work posture from video, confirms a code with 5 figures for every working posture in line with movement range of four parts, including head and neck, arm, back and leg, as well as weight factors supported by these postures, and determines corresponding action ranking of each working posture in line the code. At present, many scholars apply OWAS to research and discuss working posture of workers in different industries, such as operators in vegetable greenhouse, bus drivers, metal processing operation and workers in a male building. From their result, we can find that OWAS can analyze various postures of workers in different industries and evaluate hazard. This paper refers to criterion provided by Graham et al to inquire work posture code and corresponding action ranking of works of rock picking in coal preparation plant. Action ranking of workers’ working postures can be divided into four grades, including AC1, AC2, AC3 and AC4.

3.4.2 Posture Analysis on Workers of Rock Picking

This group shoots 2 times of working postures for workers of rock picking. Video recording is about 3 hours every time. By observing video recording, repeated postures are observed and summarized. The highest frequency of occurrence is anteverted, bending, standing (see Figure 1) and bending and turning postures.
Through posture statistics and code pattern analysis, it should judge corresponding action ranking of single postures, obtain repeated proportions of bad working postures for body parts, and select the most obvious difference of labor intensity between P1 station and P7 station to judge working posture ranking, as shown in Table 3.

Table 3. Repeated Proportions of Bad Working Postures for Body Parts of Workers

<table>
<thead>
<tr>
<th>Part</th>
<th>Part posture</th>
<th>Workers at P1 station</th>
<th>Workers at P7 station</th>
<th>1st shooting</th>
<th>2nd shooting</th>
<th>Average percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st shooting</td>
<td>AC value</td>
<td>2nd shooting</td>
<td>AC value</td>
<td>1st shooting</td>
<td>AC value</td>
</tr>
<tr>
<td>Head and neck</td>
<td>Free Side bend</td>
<td>23</td>
<td>1</td>
<td>21.2</td>
<td>1</td>
<td>22.10</td>
</tr>
<tr>
<td></td>
<td>Anteverted</td>
<td>6.5</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>5.25</td>
</tr>
<tr>
<td></td>
<td>Straight Backward bending</td>
<td>64.4</td>
<td>2</td>
<td>74.7</td>
<td>2</td>
<td>69.55</td>
</tr>
<tr>
<td></td>
<td>Bend and twist</td>
<td>1.5</td>
<td>1</td>
<td>1.6</td>
<td>1</td>
<td>1.55</td>
</tr>
<tr>
<td></td>
<td>Hands under shoulders</td>
<td>65.2</td>
<td>3</td>
<td>66.4</td>
<td>3</td>
<td>65.80</td>
</tr>
<tr>
<td></td>
<td>Bend and twist</td>
<td>30.1</td>
<td>2-3</td>
<td>30</td>
<td>2-3</td>
<td>30.05</td>
</tr>
<tr>
<td></td>
<td>Hands under shoulders</td>
<td>100</td>
<td>1</td>
<td>100</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Arm</td>
<td>Single under shoulder</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sitting posture</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Standing posture</td>
<td>100</td>
<td>3</td>
<td>100</td>
<td>3</td>
<td>100</td>
</tr>
</tbody>
</table>

Posture for workers’ body parts. Action grade of backward bending and leg standing postures is AC3, showing higher repetition of forward bending and standing, having obvious damage to human body and needing soon improvement measures. Anteverted action grade is AC2.
Through observation, workers of rock picking often lower their head and turn over raw coal in the entire working process. It causes slight damage to human body and needs recent improvement measures. Action grade of backward bending and rotation belongs to AC2 or AC3. Workers often bend and move bulk waste rock, and throw it into groove by side bending. It has already produced obvious damage to human body and needs soon improvement measures.

4. Improvement Plan and Implementation Effect

4.1 Station Rotation

Through the above-mentioned several methods, it can find that coal dressing and rock picking will produce muscular skeleton disorders with different degrees on workers at different stations, so it needs soon improvement measures. First of all, aiming at imbalance labor intensity of different station workers and different repeated proportions of bad postures for body parts, it improves existing station rotation for rock picking workshop, changes original head and tail rotation into sequent rotation, and uses improved rotation to measure labor intensity. It can be observed that workers at each station have the smallest difference of pulmonary ventilation in rock picking operation process. Distribution of labor intensity may be comparatively balanced.

4.2 Increase of Seats

It can increase seats at stations, as shown in Figure 6. Original standing operation of workers turns into alternative operation of standing and seating to reduce bad and single working posture for long time remaining. Through posture statistics and code pattern analysis, it judges corresponding action grade of postures, obtains repeated proportions of bad working postures for body parts, and selects P1 station and P7 station to judge working posture grade. Compared with AC grade before improvement, it declines slightly, indicating repetition, reduction degree of forward bending posture, and reduction of hazard for human body. Anteverted action grade is AC2. Though action grade has no change by comparing before improvement, average percent of this posture is reduced obviously. Action grade of back bending and rotation working postures is AC2. It is reduced slightly by comparing with AC2-3 before improvement, indicating repetition and reduction degree of sitting posture and back bending.

4.3 Implementation Effect

Through common implementation of multiple improvement methods and data calculation analysis, it summarizes repeated proportions of bad postures for individual parts of workers at P1 and P7 stations in working process. Through the analysis on repeated average percent of bad postures for individual parts of workers at each station, improvement methods can be obtained. By combining with implementation, posture repetition difference of workers at each station is small. Moreover, compared with before implementation, repeated percent of various bad postures is declined slightly.

5. Conclusions

This paper uses workers of rock picking in coal preparation plant as research objects, determines average energy metabolic rate on workdays by measuring expiratory volume at various labor and rest for workers by using pulmonary ventilation meter, and combines with questionnaires and OWAS posture analytic system to research muscular skeleton disorders of workers of rock picking in coal preparation plant and the entire working process. By analyzing measured data, questionnaire results and posture research, the following conclusions can be obtained: most of workers of rock packing in coal preparation plant have pain symptoms on individual parts with different degrees. Here, backache, pain of shoulder and back, legs' pain and neck ache are the most serious. Labor intensity of workers at each station is large and distributes unevenly. Repetition of bad working postures with harms also has higher proportion. Moreover, posture repetition of workers at each station also has great differences and impact physical and mental health of workers and their production efficiency, so it needs soon improvement measures. Therefore, we put forward rotation of station order,
increase of seats and labor protection, etc., improvement schemes and implement them. By adjusting rotation scheme of station for coal dressing and rock picking and improving operation equipment, it balances labor intensity, reduces the repeated proportions of bad working postures and differences between stations, declines operation fatigue, enhances work efficiency and provides references for how to avoid from these damages and design improvement. Research results can help to improve working environments of workers in coal preparation plant, and play certain guidance significance on promoting occupational health of workers of rock picking in coal preparation plant and improvement of working environment.

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References

Lu Xirong, Occupational Chronic Muscular Skeleton Disorders [J], Hygiene branch of foreign medical science, 1990, 4: 197.
Badley EM. The economic burden of musculoskeletal disorders in Canada is similar to that for cancer and may be higher [J]. J heumatol, 1995, 22 (2):204-206.
Zhang Zhenxiang, Japanese Fatigued Symptom Checklist (2002[J], Human Engineering, 2003, 9(3): 60-


