Chapter 16
Assessment of Ergonomic Risk for Work-Related Musculoskeletal Disorders Among Foundry Workers

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1 Introduction

Work-related musculoskeletal disorders (WMSDs) occur when the physical capabilities of the worker do not match the physical requirements of the job (Tayyari and Smith 1997). Prolonged exposures to ergonomic risk factors can cause damage to a worker's body and lead to MSDs. Awkward postures, repetitive motions and load handling are significant causes of MSDs at the workplace (Basahel 2015; Fernandes et al. 2011; Nejad et al. 2013; Nimbarte 2014; Parida and Ray 2015).

Ergonomists focus on the identification, quantification and estimation of ergonomic risk through assessment tools using the direct, semi-direct and indirect methods. Direct methods include the application of sophisticated electronic devices and sensors on a human body to measure work postures. The real-time application of these devices in the working condition and higher operating cost generally impede the application of direct methods. Alternatively, semi-direct and indirect methods are applied to quantify the ergonomic risks. Semi-direct methods include the computer programs enabling human posture evaluations through video recording and photographs. Semi-direct methods are broadly classified based on MSD into three classes, viz.: (a) repetitive movements, (b) strained postures and (c) handling of loads. The popular techniques of repetitive movements are RULA, Job strain index, IBV, OCRA, while REBA, OWAS, Vira, PATH methods are applied to evaluate MSDs due to strained postures. The techniques such as NIOH, KIM and MAC are used to assess the ergonomic risks due to load handling (Buckle 2005; Crawford et al. 2008; Gómez-Galán et al. 2017; Valero et al. 2016).

Indirect methods use the subjective assessment of operators through standardized questionnaires. Some of the popular questionnaires are Nordic, Keyserling, Quick

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Exposure Check (QEC). These methods sometimes need to be validated statistically and limited to the views of a sample population only (Gómez-Galán et al. 2017; Valero et al. 2016).

The classical ergonomics research presents the tussle between semi-direct and indirect methods. Factors related to WMSD are complex and therefore researchers argue that there are no specific guidelines for the selection of method. Chiasson et al. compared eight methods used to evaluate risk factors associated with MSD and concluded that no two methods are in perfect agreement (Chiasson et al. 2012). Roman-Liu compared the methods for assessing external load causing MSD and concluded that it is necessary to develop a comprehensive method appropriate to all body parts and all work tasks (Roman-Liu 2014). Waters et al. highlight the complexity in the evaluation of risks of MSD and suggest step by step procedure to select suitable tools for risk assessment (Waters et al. 2016). Kee et al. compared the results of OWAS, RULA and REBA and did not find any correlation between them. OWAS and REBA underestimated the results than RULA (Kee et al. 2016). Jones et al. compared five postural methods and found moderate agreement between the methods and the results varied with jobs (Jones et al. 2016).

The proponents of semi-direct methods argue that semi-direct methods are precise and capture real-time workspace issues, while indirect methods are quick, comprehensive and researchers' bias-free. The risk output of each method depends on exposures (exertion, posture, repetition, load etc.) and their magnitude considered. As the weightages assigned are different for each method, agreement between methods changes with the job profile. Thus, the reliance on the single paradigm either semi-direct or indirect is inadequate to explain the ergonomics risks causing WMSDs.

The aim of this paper is to assess the ergonomic risk for WMSDs in foundry worksystems using both semi-direct (REBA) and indirect (QEC) methods. Further, we compare the results of these two techniques and comment on the effective comprehension of techniques in ergonomic risk assessment.

We specifically choose the foundry worksystem as the context for this study due to the following reasons: (i) Foundry worksystems are typically characterized by forceful exertions, repetitive work cycles, awkward postures and whole-body vibrations which are the risk factors associated with MSDs (Armstrong et al. 2002; Ilangkumaran et al. 2014). (ii) Foundry worksystem involves a significant amount of MMH activities, leading to further aggregation of MSD prevalence. (iii) Dearth of foundry-specific studies considering posture analysis.

2 Methodology

In this study, we compare semi-direct (REBA) and indirect (QEC) methods to assess the prevalence of WMSDs in the foundry worksystems. Specifically, REBA is selected for this purpose as foundry worksystems are characterized by awkward work postures and excessive manual material handling. Thus, REBA as an effective strained posture analysis is applied to quantify the risk of MSD. Additionally, we

use QEC that allows physical work activities to be assessed in collaboration with the worker. We further compare the results of both REBA and QEC with the correlation analysis.

2.1 Subjects

We included 105 workers as subjects from nine foundries in Western India. These foundries are small-scale units with manual material handling. All the subjects are male, ranging from 20 to 52 years of age. The consent of management and workers was obtained before the study. The subjects selected belong to the worker and helper category from four major departments: fettling, melting, molding and pattern making. The study was carried out during working hours of the day shift (i.e. between 8 a.m. and 5 p.m.).

2.2 Data Collection

For REBA analysis, photographs of 105 workers in selected working postures were taken from different angles. Care was taken to obtain angles of body parts accurately.

The standard analysis procedure for sections A and B of REBA was adopted for examining respective body parts (neck, trunk, leg, arm and wrist). The angles were measured by marking lines along the relevant body segments on the photographs (Fig. 1). REBA scores were calculated and risk levels evaluated for each activity department-wise (pattern making, molding, melting-pouring and fettling).

QEC analysis is a combination of observer's assessment and worker's assessment. The interviews of the same 105 workers were taken as per standard QEC protocol. Observations were made to complete the observer's assessment.

We use data inputs from REBA and QEC to derive scores and action levels based on the ergonomic risk involved. Further, we use correlation analysis to present the comparative of REBA and QEC for both scores and action levels using Minitab®-16.

3 Results

A total of 105 workers were assessed for risk of WSMD from four departments of foundries, viz., fettling, molding, melting and pouring, and pattern making. Table 1 summarizes the demographic details of the total study population. The mean age of the study population is 31.48 (8.45) years with a mean height of 163.29 cm.

The REBA score varies from low (2) to very high risk level (11) among the total sample. As no subject has a REBA score of 1, which is a negligible risk level, this level is not considered for analysis. 30.47% of the sample is exposed to high risk

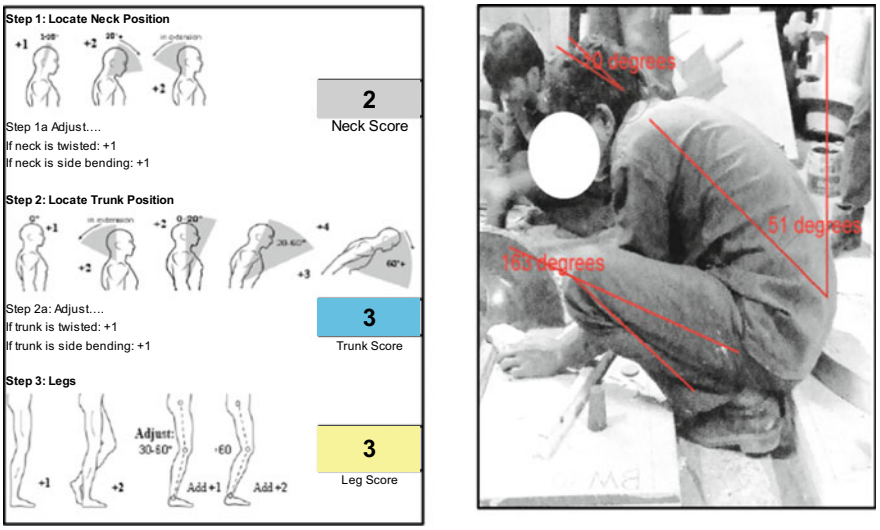


Fig. 1 Illustration of REBA score calculation using photograph

Table 1 Demographic details of a sample population

No	Particulars	Mean (SD)	Minimum	Maximum
1	Age (years)	31.48(8.45)	19	61
2	Weight (kg)	57.63(7.04)	40	82
3	Height (cm)	163.29(6.47)	136	188
4	Foundry experience (years)	7.25(4.90)	1	25

level and 16.19% to very high risk level (Table 2 and Fig. 2). Thus, activities carried out by the above said 46.66% of the workers are risky and need immediate action. Population exposed to medium risk level is also considerable (44.76%) and action is necessary for those.

Department-wise risk analysis reveals that workers from the melting and pouring departments are prone to very high risk levels (44%), followed by workers from the fettling department (13.33%) (Table 2 and Fig. 3).

According to the QEC score, four standard action levels—low, moderate, high and very high—are decided. Out of the total study population, 75.23% fall under high risk level, whereas 11.42% study population falls under very high risk level (Table 2 and Fig. 4). Department-wise analysis indicates that the melting department has the highest percent (20%) of very high risk level and the fettling department has the highest percentage of high risk level (Table 2 and Fig. 5).

The body part wise QEC analysis reveals that from the total population, the mean score of risk for the back (moving) is 30.76 (high), for shoulder/arm is 32.11(high), for wrist/hand is 28.97 (moderate) and for the neck is 14.10 (very high).

Table 2 Action levels for both REBA and QEC

Department(n)	ACTION LEVEL							
	Low n (%)		Moderate n (%)		High n (%)		Very high n (%)	
	REBA	QEC	REBA	QEC	REBA	QEC	REBA	QEC
Fettling (30)	1(3.33)	0	16(53.33)	0	9(30)	29(96.66)	4 (13.33)	1(3.33)
Melting and pouring (25)	1(4)	2(8)	7(28)	2(8)	6(24)	16(64)	**11(44)**	**5(20)**
Molding (41)	5(12.2)	1(2.22)	21(51.21)	7(17.07)	14(34.14)	28(68.29)	1(2.22)	5(12.2)
Pattern making (09)	2(22.22)	0	3(33.33)	2(22.22)	3(33.33)	6(66.66)	1(11.11)	1(11.11)
Total (105)	9(8.57)	3(2.85)	47(44.76)	11(10.47)	32(30.47)	79(75.23)	17(16.19)	12(11.42)

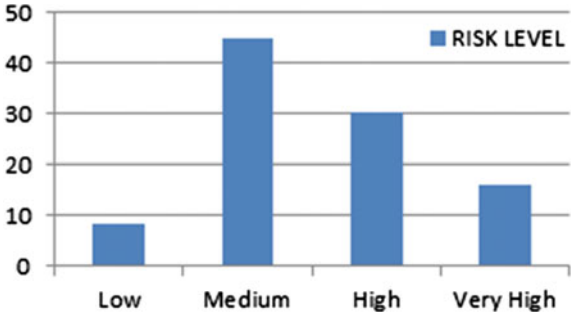


Fig. 2 Percentage risk levels by REBA of the study population (n = 105)

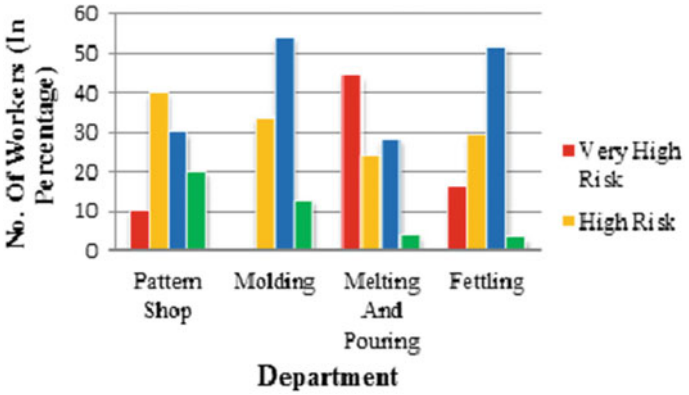
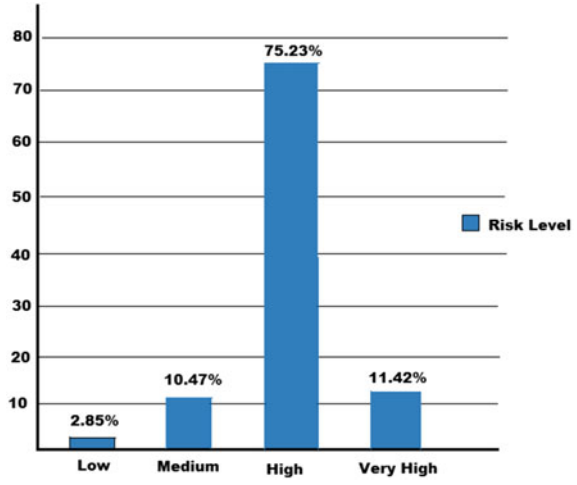


Fig. 3 Department-wise REBA risk analysis

Fig. 4 Percentage risk levels by QEC of the study population (n = 105)



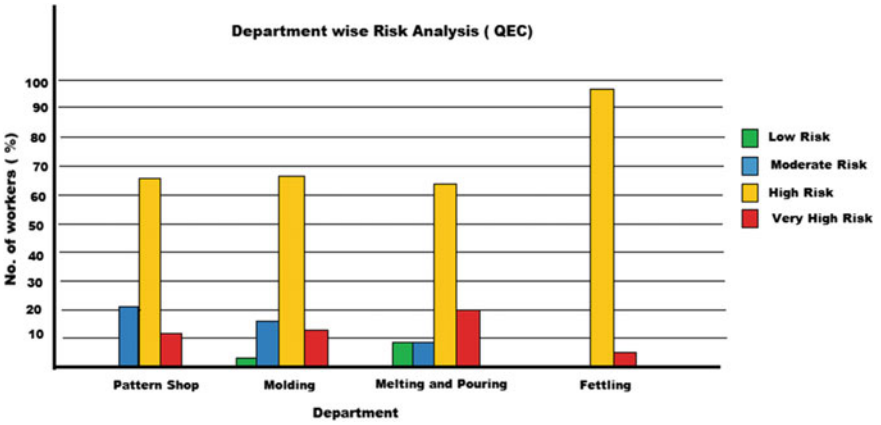


Fig. 5 Department-wise QEC risk analysis

Department-wise QEC analysis for body part was carried and the back and shoulder mean score is highest for the melting department (36.16—high and 34.48—high, respectively). The Wrist score is maximum for the fettling department (30.8—high) and the neck score is maximum for pattern making (16.66—high) (Table 3).

In QEC analysis other factors considered are driving, vibration, working pace and stress. For the study population considered, driving is not applicable and neglected in this analysis. Table 4 gives the department-wise mean score of these factors. QEC score for vibration parameter is maximum (7.16) for the fettling department. For the melting department, both working pace score as well as stress score are maximum (4.84 and 4.44, respectively).

A comparison of REBA and QEC analysis is given in Table 5. From both analyses, the mean risk score for the melting department is the highest followed by the fettling department.

Statistical analysis was done to check the correlation between REBA and QEC outcomes. The Pearson's correlation coefficient for REBA and QEC score is 0.219

Table 3 Body part wise QEC scores

Department (n)	Back mean (SD)	Shoulder/Arm mean (SD)	Wrist/Hand mean (SD)	Neck mean (SD)	QEC score mean (SD)
Fettling (30)	29.2(3.91)	31.2(5.47)	30.8(3.26)	15.73(1.01)	60.75(6.04)
Melting and pouring (25)	36.16(8.50)	34.48(4.25)	29.04(3.00)	12.24(2.18)	63.59(6.04)
Molding (41)	29.26(6.14)	31.80(5.41)	27.80(5.24)	13.58(3.00)	58.21(8.77)
Pattern making (09)	27.77(4.84)	30(5.65)	27.55(4.66)	16.66(2.00)	57.95(7.64)
Total (105)	30.76(6.82)	32.11(5.31)	28.97(4.33)	14.10(2.75)	60.2(7.95)

Table 4 QEC scores for other factors

Department (n)	Vibration	Working pace	Stress
Fettling (30)	7.16(3.18)	4.03(1.62)	3.66(2.91)
Melting and pouring (25)	1(0)	4.84(2.57)	4.44(2.25)
Molding (41)	4.73(3.49)	3.12(1.38)	3.73(2.39)
Pattern making (09)	1(0)	1.66(1.32)	1(0)
Total (105)	4.21(3.67)	3.66(1.99)	3.64(2.55)

Table 5 Comparison of REBA and QEC scores

Department (n)	REBA score mean (SD)	QEC score mean(SD)
Fettling(30)	7(2.43)	60.75(6.04)
Melting and pouring (25)	**8.56(3.4)**	**63.59(7.84)**
Molding (41)	6.65(2.52)	58.21(8.77)
Pattern making (09)	6.55(3.28)	57.95(7.64)
Total (105)	7.2(2.86)	60.89(7.95)

with $p = 0.025$ (<0.05). The probability curve was plotted to insight the relation between action levels of the two methods.

4 Discussions

The major outcome of this study is the presence of a high risk of WMSD in foundry workers. REBA analysis indicates that out of the total population 30.47% is under high risk and 16.19% is under very high risk. However, QEC output reveals that 75.23% is under high risk and 11.42% is under very high risk. Due to higher percentage of very high and high risk categories in both REBA and QEC analysis, immediate interventions are necessary. Administrative and engineering controls are a must in the majority of activities.

The department-wise analysis indicates that the highest percentage of very high risk activities are from the melting and pouring department for both REBA and QEC, followed by the fettling and molding departments. Activities like pouring molten metal, fettling and preparing mold are found to be more prone to MSDs due to excessive load handled, awkward posture or a combination of both.

QEC analysis specifies body part wise risk which is not possible in REBA. The result of QEC analysis of the total population indicates a high score of risk exposures for shoulder (32.11), back (30.76) and neck (14.10). For the melting and pouring department both back and shoulder scores are highest, 36.16 and 34.48, respectively. This is due to the fact that the melting and pouring department has more manual material handling activities with awkward postures than any other department which may

lead to risk of WMSD. The fettling department has the highest score for wrist/hand (30.8) which is because fettling activity involves awkward wrist and hand postures with load. The pattern making department has the highest score of neck (16.66) because this department involves the majority of activities with a bent neck.

The QEC score for vibration parameter is maximum (7.16) for the fettling department because workers from this department are mainly working with grinders, pneumatic hammers, etc. In the melting department, workers need to pour the molten metal before it cools down below a specific temperature in a particular number of molds. Due to this both working pace score as well as stress score are maximum (4.84 and 4.44, respectively) for the melting and pouring department.

Both REBA and QEC outcomes are similar and reveal that the melting and pouring department activities are at very high risk. For QEC and REBA scores, Pearson's correlation coefficient is 0.219 with $p = 0.025$ (<0.05). This indicates there is a moderate correlation between the scores of the two methods. This result is similar to a study in different sectors by Chiasson et al. (coefficient 0.35) (Chiasson et al. 2012).

Even though there is a moderate correlation between REBA and QEC scores, in this study, there is no strong relationship between action levels. QEC overestimates the risk than REBA. The overall percentage of high risk by QEC is 75.23%, whereas by REBA is 30.47%. This is due to the fact that in QEC percentage of moderate risk level is shifted to high risk due to manual material handling in foundry activities. The overall percentage of medium risk by QEC is only 10.47%, whereas by REBA is 44.76%. Therefore the probability curve for the QEC action level is steeper than the REBA action level (Fig. 6).

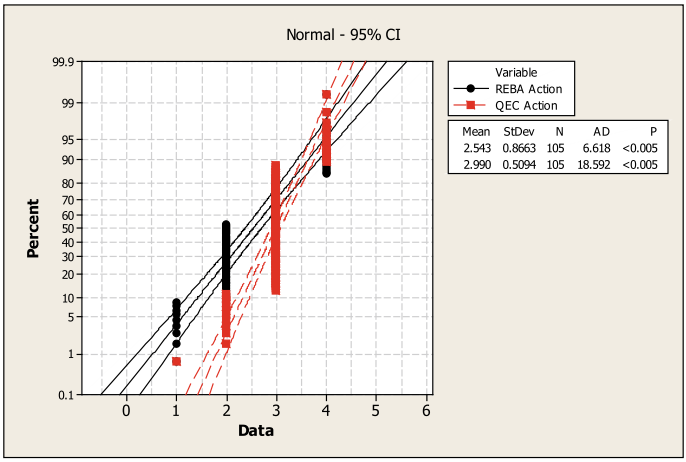


Fig. 6 Probability distribution of REBA and QEC action levels

Indirect methods (QEC in this research) are quick and easy but a subjective response of indirect method may lead to overestimation of risk. To get comprehensive realistic insights, the combined use of the semi-direct method (REBA in this research) and indirect method as used in this study is preferable.

Majid Motamedzade et al. compared the results of REBA and QEC in Engine Oil Company and found a strong relationship between both scores and action levels (Motamedzade et al. 2011). This result differs from the present study due to the changed context. Small-scale foundry worksystem involves more material handling than Engine Oil Company.

5 Conclusion

There is a dearth of studies related to the risk of WMSD in the foundry context, particularly using postural analysis tools. This study reveals that workers from small-scale foundries are at high risk of WMSDs and need immediate attention. Melting and pouring activities have a higher risk of WMSDs compared to other departments. Thus, designing and developing the interventions for the melting and pouring section is an apt extension to this work. Molten metal pouring ladle as an engineering intervention is under development focusing on the reduction of WMSDs risks.

Secondly, the study results show back and shoulder are more susceptible body parts to the risk of MSD in small-scale foundries due to higher manual material handling. These observations can be used to prioritize engineering, educational and enforcement interventions in small-scale foundries considering the WMSDs injury data. Increment in mold heights, ergonomic stands for the ladle and standard operating procedures (SOPs) are taken as the action tasks to address WMSDs risks in concerned departments of small-scale foundries.

The results also reveal that both semi-direct (REBA) and indirect (QEC) methods are suitable for quantification of the risk of WMSDs in the foundry context and reveal a similar outcome. But indirect method (QEC) overestimates risk than the direct method (REBA), so care should be taken in the application of a mix of the indirect and direct methods.

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